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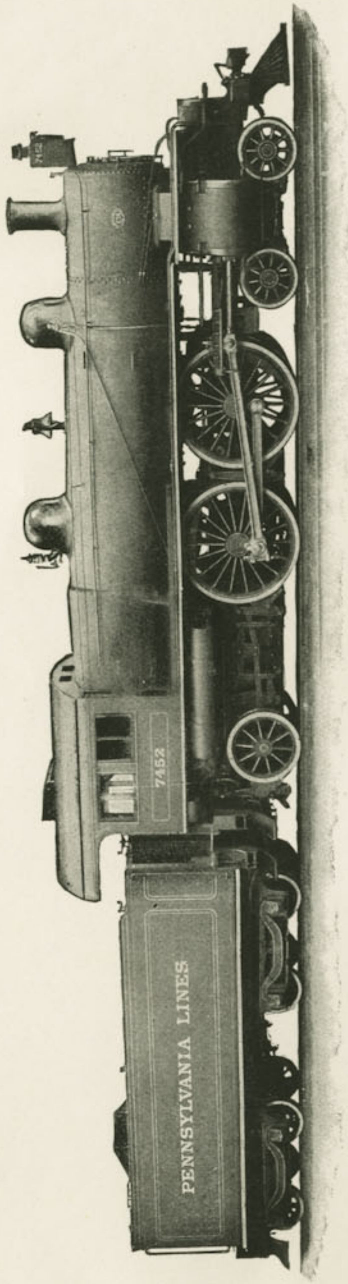


COLE FOUR-CYLINDER BALANCED COMPOUND PASSENGER LOCOMOTIVE USED ON THE PENNSYLVANIA RAILROAD AND PENNSYLVANIA LINES WEST OF PITTSBURG
(American Locomotive Co.)

PRACTICAL RAILROADING

A NEW, COMPLETE AND PRACTICAL TREATISE ON STEAM, ELECTRIC AND MOTOR CAR OPERATION

INCLUDING

DESCRIPTION OF ALL THE VARIOUS PARTS OF THE DIFFERENT TYPES OF LOCOMOTIVES, THEIR PRINCIPLES OF OPERATION, MANAGEMENT, REPAIR AND MAINTENANCE; ALSO THE AIR BRAKE, MECHANICAL STOKERS, FEED WATER HEATERS, SUPERHEATERS, AND THE LATEST DEVELOPMENTS IN THE RAILWAY FIELD

WRITTEN EXPRESSLY FOR THE

MASTER MECHANIC, TRAVELING ENGINEER
LOCOMOTIVE ENGINEER AND FIREMAN

OSCAR C. SCHMIDT
Consulting Editor

PROFUSELY ILLUSTRATED WITH HALF-TONES, DIAGRAMS AND LINE CUTS

1913 EDITION

STANLEY INSTITUTE
PHILADELPHIA

PREFACE.

There has been no time in the history of Locomotive Engineering when the problems confronting the men who manage and operate the railroads of this country have been so important as they are at the present. It is true, in looking back over the constructive period of the past, that great problems were met with and enormous difficulties removed, but in those days the objects to be attained, while equally as important as those met with to-day, did not have the same reference to constructive details, concentration of service, or diminished cost of operation, as they have now. The principles of construction and operation were such that many of the finer details were lost sight of, in the effort to build a road and operate it so as to meet satisfactorily the public demands for continuity of service; but the increased sustained speed of passenger trains, and the increased weight of both passenger and freight trains, together with the comparative scarcity of fuel and the increased safety demanded, have led to the lowering of grades, the elimination of curves, the introduction of newer forms of propulsion, the use of various types of fuel-saving devices, and the installation of elaborate signal systems.

At no time have the different types of locomotive construction and the methods of repair and operation had the search-light of investigation turned upon them as to-day, when every new piece of apparatus which has the least indication of reducing the total operating and maintenance expenses is welcomed, and accordingly tried out in practice. The costs of fuel, water, labor, material for locomotive repairs, wiping, hostlering, washing boilers, inspecting and dispatching, and lubrication, are all factors which enter into the problem of economical railroad management, so that it is to be expected that water-softening plants, increased facilities for weighing and handling the fuel, new types of valve gears, the use of mechanical stokers, feed water heaters and superheaters are attracting world wide attention. While many of these newer features of locomotive construction are still in their infancy, they have had the sanction of many of the head men of the largest railroad systems; and while, perhaps, some of these newer features may not stand the sustained test of time, yet they are steps which indicate the path which locomotive engineering will take in the future.

Among the various problems which are before the railroad world to-day, none are more important than the construction of the kinds of motive power to be used on each individual road. While the steam locomotive of course is, and will no doubt continue to be, the standard form of motive power on all railroads, yet there are conditions of service which give the electric locomotive many advantages over its steam rival; and no greater proof of this is evident than that many roads are adapting it for various kinds of service. Steam and gasoline motor cars are also attracting considerable attention, and are being used more extensively on the branch lines of many roads where the service is of a light character.

The newer types of balanced compound and Mallet locomotives have given fresh impetus to the construction of very heavy locomotives for both passenger and freight service. With the balanced compound engines, experience has shown that they not only give a greater economy, due to the

long expansion of the steam, but that destructive influence of the unbalanced reciprocating parts on the track and on the engine itself is avoided. Results of several years service of the Mallet Compound Articulated Locomotives have shown them to be of considerable value in heavy slow freight service, and that in them the high power heavy electric locomotive has a rival in the number of tons of freight which can be handled and in the economy of operation and repairs.

In the following pages all of the above subjects have been considered with the idea of bringing to the attention of every locomotive engineer the various problems of steam, electric and motor car propulsion. There are various chapters on the duties of the fireman, the management of engines, different types of locomotives, boilers and valve gears, with instruction as to their repair and maintenance. Mechanical stokers, feed water heaters and superheaters are described, and there are several chapters on locomotive accessories, electric railroading, and block signal systems. The subject of the air brake is one of the most important chapters in the book, in which will be found a description of the latest types of air brakes in actual use, together with air brake and train air signal instructions as adopted by the latest convention of the American Railway Master Mechanic's Association. Methods of handling coal and ashes, and methods of handling and softening the feed water, are two subjects of very present importance in the operation of all large railroads, and each is made a chapter of individual study.

All the subjects in the book have been handled directly from the practical standpoint, and all historical matter and description of old and useless types of apparatus and methods have been eliminated, as it has been considered that while we must all bow our heads to the many inventors and inventions which have made our twentieth century progress attain-able, yet at the same time the scope of the field of engineering is so great that the importance of understanding the various types of apparatus and methods in use far overshadows what has been done in the past; consequently, all reference to history and antiquated types of apparatus has been avoided, except in several cases where it has been found advisable to mention briefly the development of a given subject. This will be found to be true in the chapter on valve gears, where some of the older types of valve gears which were used on older locomotives are briefly described.

To the railroad man whose interest lies in the shops, there are chapters on sheet metal work, forge practice, construction and designs of boilers, the boiler shop and the lay out of plates, machine shop work, measuring instruments, the milling machine and its uses, tool making, etc.

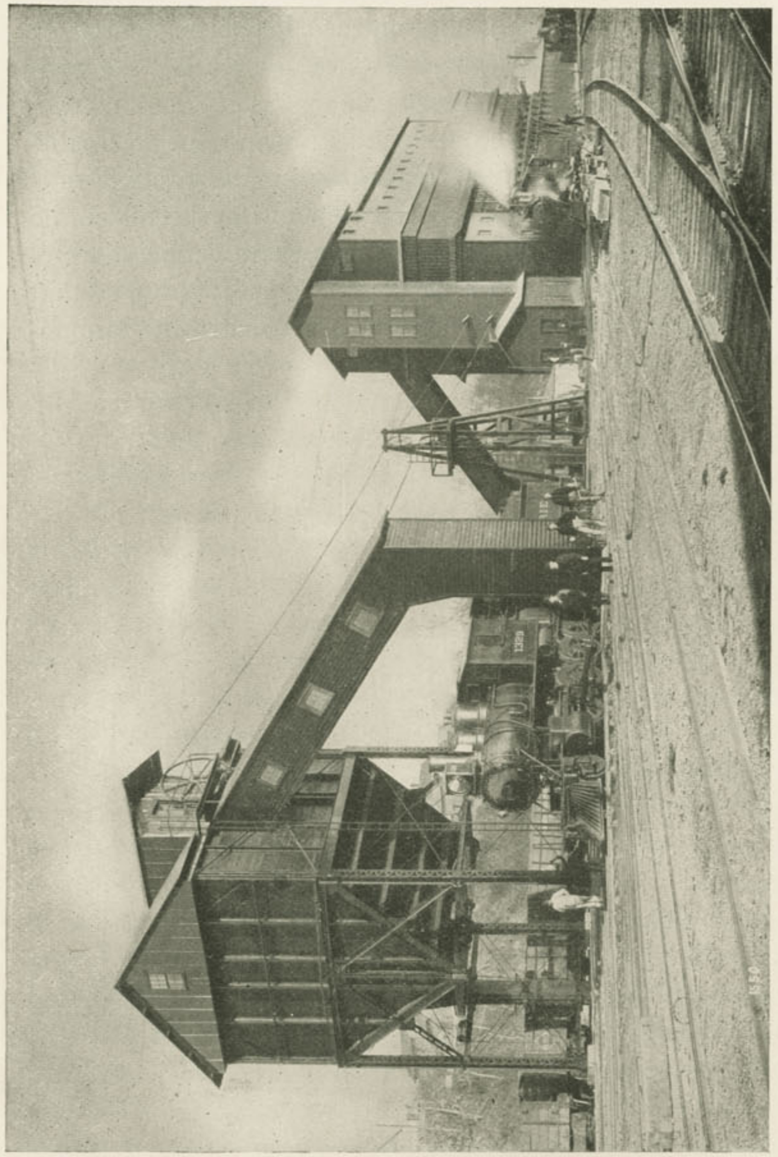
To the student who wishes to study the fundamental problems of locomotive design and construction, there are chapters on the principles of locomotive engineering; mechanical drawing, heat, fuels and combustion, the steam engine indicator, etc. A chapter is also devoted to the important consideration of the use of crude oil as a fuel, in connection with its extensive use on railroads in the West.

In compiling these books, the thanks of the authors are extended to the various manufacturers of railroad equipments, for their kindness in supplying us with the latest data and illustrations pertaining to the newest types of apparatus in use on the railroads, particularly the American Locomotive Company, The Baldwin Locomotive Works, The Lima Locomotive and Machine Co., The Link Belt Engineering Co., The Union Switch and Signal Co., The General Electric Co., The Westinghouse Co., The Kennicott Water Softener Co. and many others. Much valuable information has been obtained from the proceedings of the American Railroad Master Mechanic's Association, The Traveling

Engineer's Association, the American Engineer and Railroad Journal, and Railway and Locomotive Engineering.

In fact, no research nor expense has been spared in making these books at once a reference library for the railway engineer, a text-book for the student, a book of instruction for the locomotive engineer and fireman, and a valuable aid to the thousands of men who work in and around railway shops and round-houses. In view of the success of the two other works written by the same authors, namely, Practical Shop Work and Practical Engineering, it is hoped that these books will meet with the same approval in the locomotive engineering field.

THE AUTHORS.

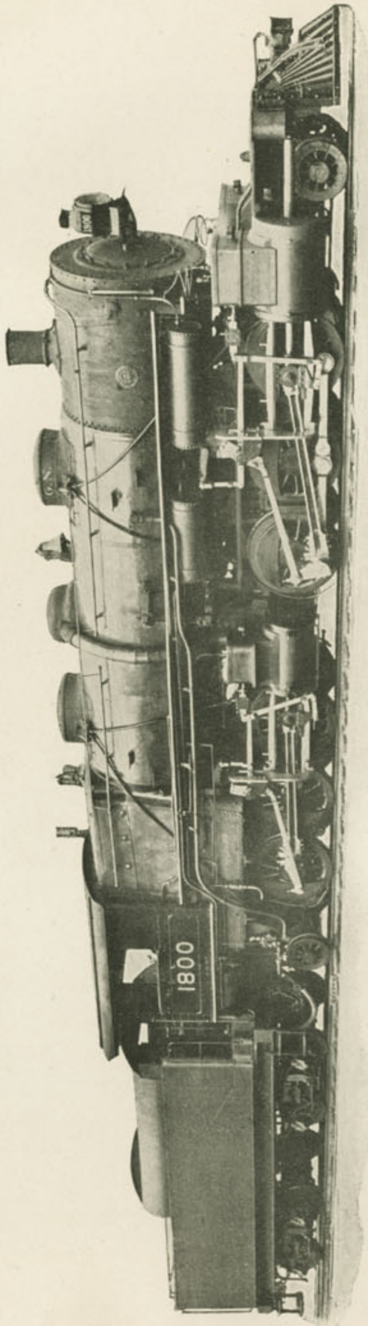


LOCOMOTIVE COALING STATION AND ASHES HANDLING PLANT

Located on the Erie Railroad at Port Jervis, N. Y. Coal Capacity, 2,500 Tons. Ash Pocket Capacity, 120 Tons

(Link-Belt Company)

VOLUME I.



MALLET ARTICULATED TYPE OF COMPOUND ENGINE USED FOR HEAVY FREIGHT SERVICE ON THE GREAT NORTHERN RAILROAD
(Baldwin Locomotive Works)

Locomotive Engineering

PROBLEMS OF ECONOMICAL OPERATION.

A locomotive, in the elementary sense of the term, is a machine used for imparting velocity to a train. The steam locomotive uses the potential energy of coal or other fuel in the production of the impelling or tractive force required to overcome the resistance of the train.

In the transformation of energy from the fuel to the train, there are four steps which are required: 1, the combustion of the fuel; 2, the production of the steam; 3, the utilization of the steam; 4, the traction effort produced by the driving wheels.

Rate of Combustion. Coal and oil are the two most important fuels. Weight for weight, oil is nearly twice as efficient as coal; but in the majority of localities coal is less than half the price of oil, and is therefore the more economical fuel. To obtain the most efficient results with coal, it must be burned at the proper rate, which will depend upon the quality of the coal. If the rate of combustion is too low, there are likely to be losses from excess air and lack of efficient combustion by reason of the firebox temperature being too low. If the rate of combustion is too high, the draft will carry off a large percentage of the smaller coal unburnt. The most desirable rate of combustion of bituminous coal under the average service condition is about 100 pounds of coal per square foot of grate per hour.

Heating Surface. A part of the heat thus produced by the combustion of the fuel is transferred, by radiation from the fire and by convection of the heated products of combustion, to the heating surface. The heat being thus absorbed by the water converts it into steam. A boiler of the regular locomotive type will absorb in every hour sufficient heat to evaporate from twelve to fifteen pounds of water, from and at 212 degrees, for each square foot of total heating surface. The larger part of this transfer of heat takes place at the fire-box and fire-box end of the tubes.

The average amount of heating surface which is desirable in a locomotive using soft coal is about sixty to sixty-five square feet to every square foot of grate surface. If the heating surface is made much less than sixty-five times the grate area, more heat is generated than can be transferred to the water, and the boiler will lose in efficiency. If, on the other hand, the heating surface is made much more than sixty-five times the grate area, the transfer of heat may be too slow, and it may be that if there should be any increase in efficiency the increased cost and weight of the boiler will more than counterbalance it.

Conditions of High Efficiency. To utilize the steam efficiently in the cylinders so as to obtain a satisfactory percentage of heat available in the steam, it is necessary to use steam of high pressure and to use a high rate of expansion. In order to avoid the condensation losses and the mechanical difficulties which attend the use of a high ratio of expansion in a single cylinder, compound cylinders are often used; that is, the steam is expanded successively in two cylinders.

The amount of steam required to develop a given amount of work will vary considerably with the conditions of service. With a single-expansion engine in slow speed service, about forty-five pounds of steam per hour may be required for each horse power developed in the cylinders, while a high-speed compound locomotive has developed a horse power on about twenty-five pounds of steam per hour.

Power Developed by a Locomotive. The power which can be developed by a locomotive is determined by the rate at which the boiler produces steam and by the rate at which the cylinders consume it. For example, suppose the boiler is capable of producing 40,000 pounds of steam per hour, then if the cylinders use forty pounds per horse power hour, the locomotive will be capable of delivering 1,000 horse power continuously, while if the steam consumption of the cylinders is lessened to say 32 pounds of steam per horse power per hour, the locomotive would be capable of developing 1,250 horse power.

Adhesion and Tractive Power. In driving the engine and train, the adhesion of the driving wheels to the rails must be used, as the driving wheels are rotated by the cylinders and by reason of the friction between the wheels and the rail, the locomotive is moved. This sets a limit to the tractive power of a locomotive of given weight, for if the cylinder power be increased beyond a certain point, the wheels will begin to slip and the tractive power will not be increased, but will be actually diminished as the wheel slips.

The tractive power of a locomotive is limited, independently of the cylinder power, by the weight on the driving wheels and by the friction between the driving wheels and the rails. If the rails are dry and well sanded, it is possible to utilize as tractive power as much as thirty per cent of the weight on the driving wheels, but to represent fairly good every-day conditions it is usual to assume that twenty-three and one-half per cent of the weight on the driving wheels is available for tractive power; or, in other words, the weight on the driving wheels must be at least four and a quarter times as much as the maximum tractive power required. This, taken in connection with the allowable load on each wheel, determines the number of driving wheels. For example, a locomotive is required to develop a total tractive effort of 20,000 pounds in starting. This engine must have at least four and a quarter times this amount, or 85,000 pounds, on the driving wheels. Then if the maximum allowable weight per axle is 32,000 pounds, the adhesive weight, as found above, must be distributed over three axles, and the engine must have six driving wheels. It is usual, however, whenever possible to keep down the number of driving wheels to a minimum.

The efficiency of a locomotive, therefore, depends upon the efficiency of each step in the transmission of the power from the fuel to the wheels, and the efficiency as a whole depends upon the proper combination of these different factors.

Horse Power of Locomotives. Horse power of a locomotive is proportional to the product of tractive force and speed, the relation being

$$H = \frac{T\,V}{375}$$

where H = horse power
T = tractive force in pounds,
V = speed in miles per hour,
and the speed at which a train can be hauled is shown in the formula

$$V=\frac{375\,H}{T}$$

from which it can be seen that the speed at which a train of given weight can be hauled is therefore dependent upon the horse power

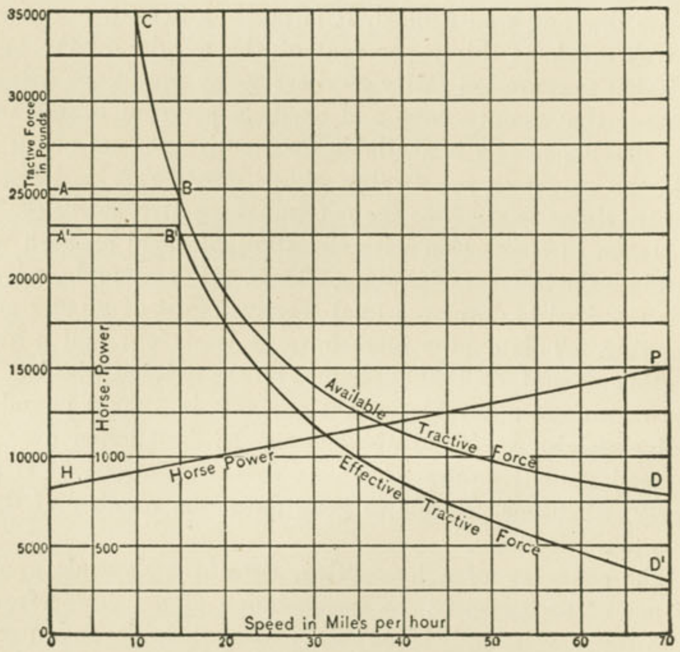


Fig. 1

Characteristic Curves for Atlantic Type of Locomotive.

which the locomotive is capable of producing, and this in turn depends principally upon the capacity of the boiler. From the above formula a characteristic curve can be drawn for any type

of locomotive to show the limitations of its power in relation to the speed. For instance, Fig. 1 shows the curves for an Atlantic

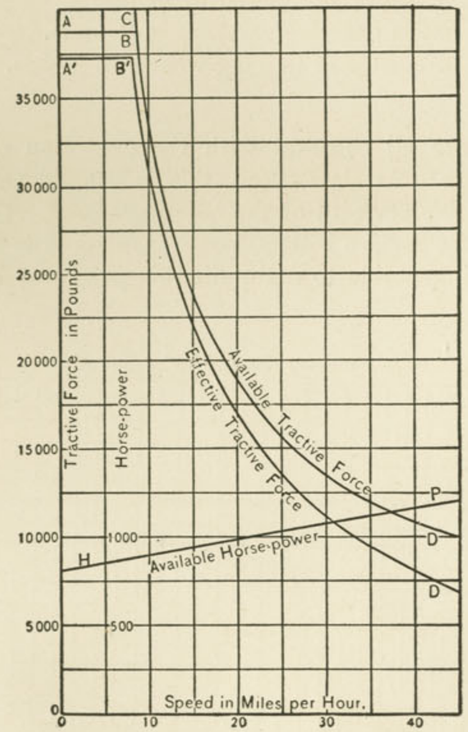


Fig. 2

Characteristic Curves for Consolidation Type Locomotive.

type of locomotive, and Fig. 2 shows the characteristic curves for a Consolidation type of locomotive.

Tractive Force. The tractive force of a single-expansion locomotive is determined by the following formula:

$$T=\frac{C^2\times S\times .85\times P}{D}\times 2,$$

in which

T=tractive force in pounds.
C=diameter of cylinders in inches.
S=stroke of the piston in inches.
P=mean effective pressure in pounds.
D=diameter of driving wheels in inches.

These factors are all constant with the exception of the mean effective pressure. At slow speed, this is usually assumed to be equal to eighty-five per cent of the boiler pressure. Owing to the limited size of locomotive boilers, however, a speed is soon reached at which it is impossible to maintain this pressure; hence an en-

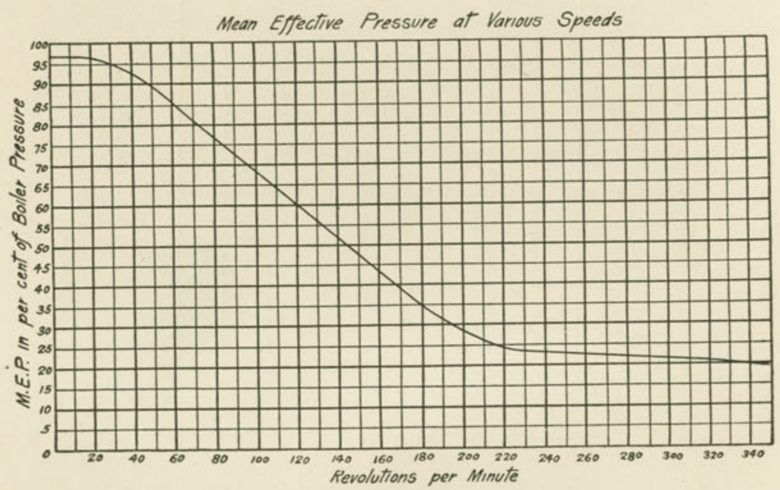


Fig. 3

RELATION OF SPEED AND MEAN EFFECTIVE PRESSURE.

gine must be worked at an earlier cut-off, with a consequent reduction in the tractive force developed. The accompanying diagram, Fig. 3, shows approximately the drop in mean effective pressure which occurs as the speed is increased. This curve is given by the Baldwin Locomotive Works as having been based on

a large number of indicator diagrams taken from locomotives in service, and represents average conditions. It will be noticed in the diagram that after the speed has passed sixty revolutions per minute, a mean effective pressure equal to eighty-five per cent of the boiler pressure cannot be maintained. At 120 revolutions, the mean effective pressure is reduced to sixty per cent; at 180 revolutions to thirty-five per cent; and at 340 revolutions to twenty per cent. The tractive force in each case is reduced in like proportion.

In order to increase the tractive force at high speed, the point of cut-off must be lengthened, which results in raising the mean effective pressure. This in turn requires an increase in boiler capacity to fill the cylinders up to the point of cut-off. Assuming, therefore, that the steam is being efficiently used in the cylinders, the ability of the locomotive to haul a heavier train, or to increase its rate of speed, depends upon the boiler capacity. It is for this reason that locomotives of the Pacific type can develop a high tractive force in heavy service with relation to the weight available for adhesion.

Effective Tractive Force. To determine the effective tractive force which can usefully be employed in hauling a train, the force necessary to overcome the resistance of the locomotive and tender must be deducted from the total available tractive force. The resistance of the locomotive and tender may be calculated by the following formula given by Lawford H. Fry in Cassier's Magazine:

$$T=8+0.087V+0.0036V^2,$$

in which

R=resistance in pounds per ton (2000 pounds) of the engine and tender.
V=speed in miles per hour.

The resistance for the Atlantic type and Consolidation type of locomotive as calculated for a half loaded tender is given in tables 1 and 2, and the force of this resistance, being deducted from the available tractive force, the curves A′B′D′ in Figs. 1 and 2 are obtained.

TABLE I.

Atlantic Type.

Speed M.P.Hr.	Boiler Horse Power	Available Tractive Force Pounds	Resistance of Loco. & Tender Pounds	Effective Tractive Force Pounds
10	928	34,800	1,430	32,370
15	975	24,400	1,570	22,830
20	1,021	19,150	1,730	17,420
30	1,114	13,900	2,150	11,750
40	1,207	11,300	2,670	8,630
50	1,300	9,750	3,310	6,440
60	1,393	8,530	4,070	4,460
70	1,486	7,980	4,910	3,070

TABLE II.

Consolidation Type.

Speed M.P. Hr.	Boiler Horse Power	Available Tractive Force Pounds	Resistance of Loco. & Tender Pounds	Effective Tractive Force Pounds
10	900	33,800	1,450	33,350
15	944	23,600	1,600	22,000
20	988	18,530	1,760	16,770
30	1,076	13,450	2,180	11,270
40	1,164	10,900	2,720	8,180
50	1,252	9,310	3,360	5,950

As will be noted, the Consolidation engine, being designed for heavy trains and slow speeds, has a maximum effective tractive force, or tender draw-bar pull of 37,300 pounds; which is available up to a speed of only about eight and one-half miles an hour, from which point the boiler capacity reduces the draw-bar pull as the speed increases. The small diameter of the driving wheels limits the speed. The characteristic is carried out to fifty miles an hour, but an engine of this type will not do much work at any speed over about half of this figure.

The Atlantic type passenger locomotive at low speeds requires only sufficient tractive force to accelerate a comparatively light train, and the draw-bar pull does not rise above 23,000 pounds, which is available up to nearly fifteen miles an hour.

Tractive Effort for Compound Engines. Using the same letters with the same meaning to each as above, the tractive effort for a cross-compound engine becomes

$$T=\frac{C^2\times S\times\frac{2}{3}P}{D}$$

The formula for a four-cylinder compound is

$$T=\frac{C^2\times S\times\frac{2}{3}P}{D}+\frac{C^2\times S\times\frac{1}{3}P}{D}$$

The formula for a four-cylinder compound working simple is

$$T=\frac{(C^2+c^2)\times .425P\times S}{D}$$

For a Mallet Compound the formula becomes

$$T=\frac{C^2\times P\times .52\times S}{D}$$

Where C is the diameter in inches of the high-pressure cylinder and c is the diameter in inches of the low-pressure cylinder, P is the boiler pressure, S is the stroke in inches, and D is the diameter of driving wheels in inches.

Factor of Adhesion. The factor of adhesion is the number of times the tractive effort is contained in the total weight on the driving wheels; this total being called the adhesive weight. The formula is

$$R=\frac{A}{T}$$

where R is the factor of adhesion, A the adhesive weight and T the tractive effort. In practice the factor of adhesion for switching engines is as nearly as possible 4, and for freight engines 4.5, and for passenger engines 5.

Traction Increasers. What is called a traction increaser is a device usually employed on engines having a rear truck. It consists of an apparatus operated by air pressure for transferring weight from the rear truck, and incidentally from the engine truck to the drivers. The rear truck is connected by equalizers to the back hanger of the trailing drivers, and this equalizer is pivoted about a point which gives the long arm of the equalizer to the rear truck. The pivot pin-hole is usually a slot capable of allowing the equalizer to be pressed down off the pin pivot. The traction increaser is also a device by which, through a lever of the bell-crank type, a new fulcrum is brought to bear down on the top of the equalizer about 5 or 6 inches nearer the trailing driver than the pivoted fulcrum. This has the effect of shifting some of the weight from the rear truck to the drivers, and by thus increasing the overhang of the engine behind the trailing driver takes some of the weight off the engine truck and transfers it to the drivers. The result produced in this way affects the ratio of adhesion only, and does not alter the tractive effort of the engine.

Weight per Square Foot of Heating Surface. With the same total weight of engine, an Atlantic type will have about ten per cent more heating surface than a Consolidation type locomotive. In the cases illustrated in Tables I and II the Atlantic type weighs 56.5 pounds for each square foot of heating surface, while the Consolidation weighs 60.5 pounds. These are favorable examples, and the average weight in American practice will be nearer sixty pounds for the Atlantic type, and sixty-five for the Consolidation. The difference in weight is due to the lighter weight of the driving wheels and connecting rods of the Atlantic type.

The problem that, therefore, confronts the designer of locomotives is to increase the power of a given type of locomotive without excessively increasing the cost of maintenance and fuel consumption. The tendency in passenger service is to increase the weight and speed of trains, and in freight service the tendency is to use powerful engines, so that large train loads can be handled.

Resistance of Locomotives. An inspection of Figs. 1 and 2 will show that at slow speeds the tractive power depends solely on the weight of the driving wheels. At higher speeds the effective tractive force is increased by increasing the horse power or decreasing the resistance of the locomotive and tender. The resistance of the locomotive at high speeds is mainly due to the air resistance, and although efforts have been made to reduce the air resistance by making the smoke-box front conical, no important decrease in air resistance will probably be possible with the modern type of locomotive. A more important consideration in decreasing the total resistance is to make the locomotive and tender as light as possible and increase the available tractive power by increasing the horse power. The resistance of passenger trains may be represented by the formula

$$R=\tfrac{1}{4}V+2$$

where R=resistance in pounds per ton and V the velocity in miles per hour.

Factors which Determine Horse Power. The horse power of a locomotive depends upon the total heating surface, the rate of steam production, and the efficiency of the utilization of the steam. The power of any locomotive may therefore be increased by increasing the heating surface, increasing the rate of steam production, or increasing the efficiency of the utilization of the steam. An increase in the heating surface means an increase in weight, and this increases the total resistance so that the whole gain is not effective in moving the train. The type of boiler used in locomotives determines the rate of steam production; but as the type used on all locomotives at the present time gives such excellent results, it is doubtful if it will be changed for a water-tube or other type of boiler. The economical utilization of the steam is therefore the factor in increasing the horse power which is mostly interesting locomotive designers.

Single-expansion Locomotives. The simplest form of locomotive is, of course, a locomotive which has two single-expansion cylinders operated by a simple link motion. Owing to its very simplicity, the simple locomotive has had the widest use, but with the increasing size and demand for a more economical locomotive various methods, such as high steam pressures, special valve motions, compound cylinders, and superheated steam have been tried in order to meet the demand for a very high speed locomotive.

High Speed Locomotives. For heavy high speed locomotives, the greatest advance in the economical utilization of steam has been along the lines of the balanced compound type, of which a large number have been built. These engines all use high pressure steam and a long expansion, and the arrangement of the four cylinders allows a perfect balance to be obtained in the moving parts.

Slow Speed Locomotives. For heavy, slow freight service, the balancing feature is not so important, so that there are several other systems of compounding in use which give a desirable economical utilization of the steam without unnecessary and troublesome complicated valve gear. Among these types in use are the two-cylinder compound, the four-cylinder tandem compound and the Mallet Compound.

Two-cylinder Compound. The two-cylinder compound can show practically the same efficiency of steam consumption as the four-cylinder, and has fewer working parts. On the other hand, the power developed is not always equally divided between the two sides of the engine and the excessive diameter of low-pressure cylinder, and the consequent excessive width of locomotive required for high powers puts a limit to the growth of this class of engine.

Tandem Compound. The tandem compound gives equal power on both sides of the engine and economical steam consumption. The heavy reciprocating parts, due to both pistons being on the same rod, make the engine difficult to balance, but at slow speeds this is not a great disadvantage. The weight per axle is not susceptible of any considerable increase, so that to obtain an engine of greater hauling capacity it becomes necessary to add another coupled axle. This increases the rigid wheel base, and, apart from the great internal resistance, an excessively long wheel base renders it extremely awkward for curves.

Mallet Compound. If more tractive force is required, the Mallet type compound offers the greatest facilities for development. The wheels are in two groups, and as these groups have a flexible connection between them, the locomotive can curve easily. The rear group of wheels is driven by the two high-pressure cylinders, and the front group by low-pressure cylinders, so that the same power is developed on both sides of the engine. The double expansion of the steam gives economy in fuel, and the whole construction of the locomotive is comparatively simple.

In locomotives of moderate power the simplicity of two cylinders may be of sufficient value to determine the choice in favor of the two-cylinder compound, or even the single-expansion type; but when great hauling capacity is required, the advantage of dividing the power to be developed between four instead of only two cylinders far outweighs the possible disadvantage of the multiplication of parts.

The Future of the Locomotive. The high speed locomotive of the future will therefore probably be a four-cylinder balanced compound, using steam at high pressure. Superheated steam may also be probably used together with the Walschaert, or some other improved type of valve gear. Where fuel, however, is not expensive, it becomes a question whether the small gain due to compounding will compensate for the increased first cost and cost of maintenance of the compound locomotive.

For slow speed service, the typical locomotive will probably continue to be a simple expansion engine using superheated steam; but where heavy hauling power is required, the tandem compound with a rigid wheel base, or a Mallet Compound engine, will probably be the type most used in general service.

Hauling Capacity. The hauling capacity of a locomotive is computed by dividing the tractive force of the locomotive by the rate of resistance per ton due to gravity and rolling friction, and then deducting the weight of the locomotive and the tender, if there is one. This gives the weight in tons of 2,000 pounds of the train which the locomotive can haul.

In the consideration of the practical determination of the proper hauling capacity advisable in any case, the following precautions, based upon experience, should be considered. First, it is always desirable to provide a reasonable amount of surplus power, and not to work a locomotive regularly too close to its full capacity. The reserve of power is economical, because it cuts down the cost of repairs, and also of fuel and oil, to the lowest point, and lengthens the useful life of the locomotive, and also provides for emergencies and increased output. Second, it is not always safe to figure on a grade as level because the land is flat. In these cases the so-called level grade may prove to be one per cent or more, which may cut down the hauling capacity of a locomotive more than one-half what it otherwise would be on a perfect level. Third, it pays to buy a locomotive of the proper design for the requirements; the rolling stock should be kept in good condition; bad grades and sharp curves should be avoided if possible; the roadbed and track should not be allowed to get into bad condition. As can be seen, the hauling power of a locomotive depends to a large extent upon a number of outside influences over which the locomotive itself has no control.

Grade Resistance. The resistance of a grade due to gravity increases in direct proportion to the steepness of the grade. If there is a rise of one foot in every 100 feet, the grade resistance will always be 20 pounds per ton of 2,000 pounds; that is, the locomotive must exert enough force to lift 1 1-100 of the total weight of the train, or, what amounts to the same thing, to exert tractive force enough to overcome a resistance equivalent to the required lift of the train. For a grade of ½ per cent the resistance is 10 pounds per ton, for two per cent grade 40 pounds per ton, for a three per cent grade 60 pounds per ton, and so on.

Grades are designated in various ways. The usual engineer's method is by per cent, or the number of feet rise per 100 feet of track, fractions of a foot being expressed in tenths of a foot instead of in inches. The American Railroad method is to state the number of feet rise in the distance of one mile, in which case, to reduce the grade, stated in feet per mile, to the grade stated in per cent, divide the number of feet rise per mile by 52.8. Grades are sometimes stated in degrees, or the amount of angle which the incline makes with the level; but since this also requires considerable calculation in order to find the percentage of grade, it has not come into general use among practical men.

The proper way of determining grades is by means of surveyors' instruments; but an easy method, which is sufficiently accurate for track purposes, is to use a straight-edge 100 inches long, leveling it with an ordinary spirit level, and measure the distance from the bottom of the straight-edge to the top of the rail. This gives the grade in per cent, which can be reduced to feet per mile by multiplying by 52.8. On very low grades this, of course, is not practical, but will be found useful in finding steep grades.

Rolling Friction. The resistance due to rolling friction varies with the character and condition of the rolling stock and track. With extra good cars and track it may be as low as 5 pounds per ton of 2,000 pounds, but 6½ pounds may be taken as a fair average for first-class cars and track, 8 to 12 pounds for reasonably good conditions, and as high as 20 to 40 pounds for hard running cars and rough track. A poorly laid track and crooked rails increase the resistances very much, as does also the overloading of cars. The resistance is greater in cold weather than in warm weather, and the resistance of rolling friction per ton is greater for empty cars than for loaded cars.

Curves. The simplest way of designating a railroad curve is by giving the length of the radius; that is, the distance from the center to the outside of the circle, or one-half the diameter. The shorter the radius the sharper the curve. The length of the radius is usually stated in feet, and the length of the radius of a railroad curve is measured to the center of the track. Engineers designate railway curves by using the sign degrees and minutes, there being 60 minutes in one degree. The sharpness of the curve is determined by the degree of a curve, or the number of degrees of the central angle subtended by a cord of 100 feet. In other words, let two lines start from the center of a circle in the shape of a V, so that the angle at the point of the V is one degree, which is equivalent to 1-360 of a complete circle, then if the sides of the V are prolonged until they are 100 feet apart, any part of a circle made by using one of these lines for its radius is a one-degree curve. The exact length of radius, which with an angle of one degree has a chord of 100 feet, is found to be 5,730 feet. If the angle at the point of the V is two degrees and the sides are prolonged until 100 feet apart, the length of each side is almost exactly ½ as long as when the angle is one degree, or ½ of 5,730, or 2,865. For a three-degree curve the radius is ⅓ of 5,730; for a four-degree curve ¼ of 5,730, and so on. For perfect exactness the length of the 100 feet should be measured, not along a straight line connecting the ends of the V, but along the line of the circle of which the sides of the V are radii; that is, the arc should be used and not the chord.

The difference, however, is very slight for curves used on standard gauge, but for extremely sharp curves, such as are used on narrow gauge roads, a considerable mathematical error would be involved by using the chord instead of the arc. In practice, however, the formula of dividing 5,730 by the degree of the curve is almost universally used to get the radius, and the accompanying table gives the different lengths of radius in feet for the different curves:

Table Showing Lengths of Radius in Feet for Curves from One to Sixty Degrees.

DEGREES	RADIUS	DEGREES	RADIUS	DEGREES	RADIUS
1 =	5730 feet	21 =	273 feet	41 =	140 feet
2 =	2865 "	22 =	260 "	42 =	136 "
3 =	1910 "	23 =	249 "	43 =	133 "
4 =	1432 "	24 =	239 "	44 =	130 "
5 =	1146 "	25 =	229 "	45 =	127 "
6 =	955 "	26 =	220 "	46 =	125 "
7 =	819 "	27 =	212 "	47 =	122 "
8 =	717 "	28 =	205 "	48 =	119 "
9 =	637 "	39 =	198 "	49 =	117 "
10 =	573 "	30 =	191 "	50 =	115 "
11 =	521 "	31 =	185 "	51 =	112 "
12 =	478 "	32 =	179 "	52 =	110 "
13 =	441 "	33 =	174 "	53 =	108 "
14 =	410 "	34 =	169 "	54 =	106 "
15 =	382 "	35 =	163 "	55 =	104 "
16 =	358 "	36 =	159 "	56 =	102 "
17 =	337 "	37 =	155 "	57 =	100 "
18 =	318 "	38 =	151 "	58 =	99 "
19 =	302 "	39 =	147 "	59 =	97 "
20 =	287 "	40 =	143 "	60 =	95 "

The Resistance of Curves. The frictional resistance to the passage of trains around curves is very considerable, and is also very variable. The shorter the radius of the curve the greater is the resistance. The length of the wheel bases of locomotives and of the cars, the elevation of the outer rail, the speed, the condition of the track and rolling stock, the length of the train and the length of the curved track are all matters which influence the resistance of a train on a curve, so that no formula can be given which will apply to all cases. Excessive or irregular curves, and especially sharp curves, in connection with steep grades, are to be avoided,

as they generally decrease the loads which locomotives can handle, and also increase the cost of operation and repairs required for track and rolling stock. It is usually preferable, therefore, to increase the expense of track construction than to increase the cost of operating expenses.

It is customary when a curve occurs on a grade to reduce the grade on the curved part of the track, so that the combined resistance of the flattened grade and the curve will not exceed the resistance of the steeper grade on the straight part of the track.

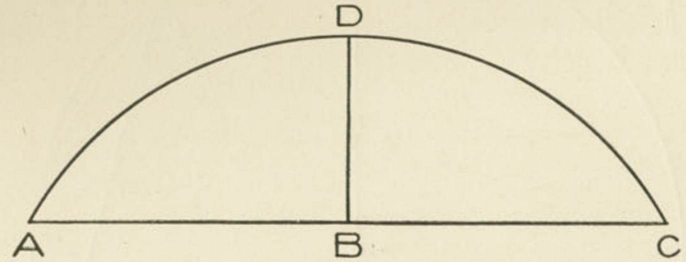


Fig. 4

METHOD FOR MEASURING RADIUS OF CURVE.

In practice engineers compensate for curves on grades at the rate of 2 1-100 feet grade in each 100 feet for each degree of curvature.

Rule for Measuring the Radius of a Sharp Curve. Stretch a string, say 20 feet long, or longer if the curve is not a sharp one, across the curve corresponding to the line from A to C in the diagram, Fig. 4. Then measure from B, the center of the line AC and at right-angles with it, to the rail at D. Multiply the distance AB, or one-half the length of the string, in inches by itself; measure the distance D to B in inches, and multiply it by itself. Add these two products and divide the sum by twice the distance from B to D. This gives the radius of the curve in inches. The formula is stated thus:

$$R=\frac{AB^2+BD^2}{2BD}$$

It may be more convenient to use a straight-edge instead of a string. Care must be taken to have the ends of the straight edge or string touch the same part of the rail as is taken in measuring the distance from the center. If the string touches the bottom of the rail flange at each end, and the center measurement is made at the rail head, the result will not be correct. In practice it will be found best to make trials on different parts of the curve to allow for irregularities. It is a good plan to make measurements on the inside of the outer rail of the curve. In this case, one-half of

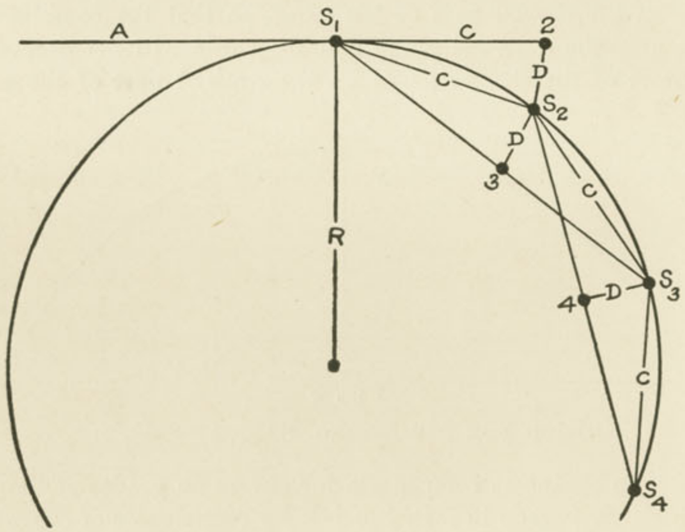


Fig. 5

METHOD FOR LAYING OUT RAILROAD CURVES.

the width of the gauge should be deducted from the radius, when calculated, as the radius of the curve should be measured to the center of the track.

Suppose, for example, that the length of the string is 30 feet, and that the distance BD is 3 inches, then the distance AB is 15 feet, or 180 inches, and 180 multiplied by 180 equals 32,400; 3 multiplied by 3 is 9, so that 32,400 added to 9 gives 32,409, which, divided by twice 3, or 6, gives 5,401.5 inches, or 450 feet $1\frac{1}{2}$ inches, which is the radius of the curve. If the measurements have been taken on the inside of the outer rail of the curve, $28\frac{1}{4}$ inches should be deducted from the above result.

Laying Out Curves. The proper method of laying out of railroad curves comes directly within the province of the surveyor, but it is possible to lay out a curve without surveyor's in-

struments as follows: As shown in Fig. 5, the straight track is represented by the line A, and the point where the curve is to begin is noted as station one (S_1). Continue the straight line beyond S a distance of 100, 50 or 25 feet, according to how sharp a curve is to be laid out, or whether the situation is cramped or not. Start from station S_1 with a line or chain of length C, as given by the table. From the end of this line C measure the offset D, of the length as given in the table to station two (S_2), so that its distance from station S_1 is also measured by the line C. Then measure from S_2 the same offset D to point 3, making the distance from S_1 to point 3 also the same as line C. A line drawn from S_1 to 3 and continued in the same direction an additional distance C fixes the next point station three (S_3). From S_3 make another offset D, so that the distance S_2 to S_3 and S_4 to 4 are each the length of line C, and prolong the line from S_2 through 4 an additional distance C. This fixes station four (S_4). Thus the points S_1, S_2, S_3 and S_4 have been fixed, and the curve must pass through them. This same process is continued until a point is reached where it is desired to discontinue the curve and lay straight track. In cramped locations, the length of the line C, which is the chord of the arc, can be decreased to one-half or one-quarter of the lengths given in the accompanying table.

Table of Radii and Deflections for Curves.

Curves in Degrees	Radius R in Feet	Offset D in Feet C=100 Feet	Curves in Degrees	Radius R in Feet	Offset D in Feet C=50 Feet	Curves in Degrees	Radius R in Feet	Offset D in Feet C=25 Feet
1	5,730	.87	13	441	2.83	25	229	1.362
2	2,865	1.74	14	410	3.05	26	220	1.405
3	1,910	2.62	15	382	3.27	28	205	1.51
4	1,433	3.49	16	358	3.48	30	191	1.615
5	1,146	4.36	17	337	3.7	32	179	1.72
6	955	5.23	18	318	3.92	36	159	1.935
7	819	6.10	19	302	4.13	40	143	2.14
8	717	6.98	20	287	4.35	44	130	2.34
9	637	7.85	21	273	4.56	50	115	2.64
10	573	8.72	22	260	4.77	60	95	3.125
11	521	9.58	23	249	4.98			
12	478	10.45	24	239	5.2			

The offset D for given radius R and chord C is found from formula $D = \frac{C^2}{2R}$

In the accompanying table the length of the line C is taken at 100 feet for curves 1 to 12 degrees; 50 feet for curves of 13 to 24 degrees and 25 feet for sharper curves, for the reason that for the sharper curves the situation is usually so cramped that measuring the longer distances is impracticable. The line R in Fig. 5 represents the radius of the curve, but in actual practice the formation of the ground where the curved track is to be laid is generally such that it is impossible to find the center of the curve. For extremely sharp curves it is practicable to lay off the curve by the above method by using inches throughout instead of feet.

Curves of Track and Wheel Base. The sharpest curve to which two pairs of flanged wheels will adjust themselves depends upon their distance apart, the diameter of the wheels and the size and shape of the flanges. Considering the Master Car Builder's standard for flanges and rails, a sufficiently accurate formula for all practical purposes is as follows:

$$R=\frac{W}{2 \sin a}$$

in which R=radius of sharpest curve that can be passed.
W=wheel base.
A=angle the flanged wheels make with the rails.

The value of sin a for various diameters of wheels is given below:

Diameter	of	wheels,	20″ to 25″,	sin a=.117
"	"	"	25″ to 30″,	sin a=.107
"	"	"	31″ to 40″,	sin a=.09
"	"	"	41″ to 50″,	sin a=.08
"	"	"	51″ to 60″,	sin a=.075

If intermediate wheels are introduced between the two pairs of flanged wheels, their relation with the rail requires a separate consideration. If these wheels are plain, the tires must be of sufficient width to prevent them from dropping between the rails, or an additional rail must be introduced at the curve. If the intermediate wheels are flanged, the sharpest curve is dependent upon the play allowed between the flanges and the rails.

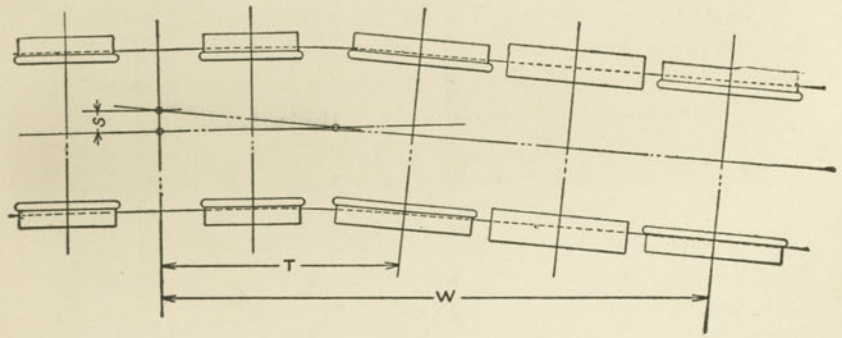


Fig. 6

SWING OF FOUR-WHEEL TRUCK.

When a truck is used, the swing must be sufficient to allow the locomotive to pass the curve. The relationship between the truck swing, wheel base and radius of curve is given by the formula:

$$R=\frac{WT}{2S}$$

in which W=distance from center of pin of truck to rear of rigid wheel base.
T=distance from center pin of truck to front of rigid wheel base.
S=one-half the total swing of truck.
R=radius of sharpest curve which can be passed.

All dimensions must be in either feet or inches. Figs. 6 and 7 show how these dimensions are taken for four and two-wheel trucks.

Resistance Due to Acceleration. The accompanying diagram, Fig. 8, gives the resistance in pounds per ton, due to acceleration

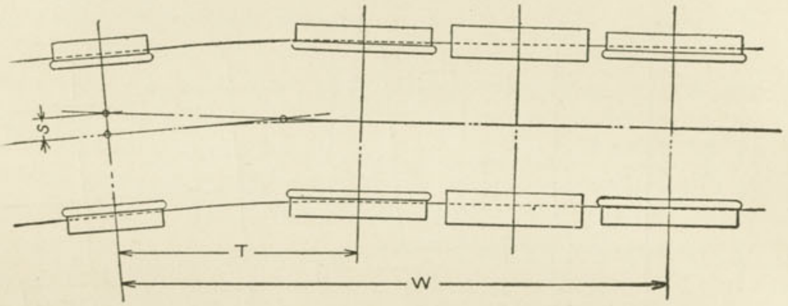


Fig. 7

SWING OF TWO-WHEEL TRUCK.

of speed up to seventy-five miles per hour. The formula on which the calculation is based is as follows:

$$A = .0132\ (V^2 - v^2)$$

in which A = resistance in pounds per ton.

v = initial speed in miles per hour.

V = the accelerated speed, or speed of one mile thereafter.

When the train starts from rest, v = zero.

In using the chart, note the resistance due to the final or accelerated speed, and from this amount subtract the resistance due to the initial speed. The difference will be the resistance developed in an uniform acceleration from one speed to the other in one mile. If the speed is gained at a less distance than one mile, the resistance will be proportionately greater. For example, from Fig. 8 it can be seen that the resistance due to acceleration for fifty miles per hour is thirty-three pounds per ton. The resistance for thirty miles per hour is about twelve pounds per ton. Then it

would require from thirty to fifty miles per hour in one mile and forty-two pounds per ton to produce this acceleration in one half mile.

Gauge of Track on Curves. Theoretically, in order to pass

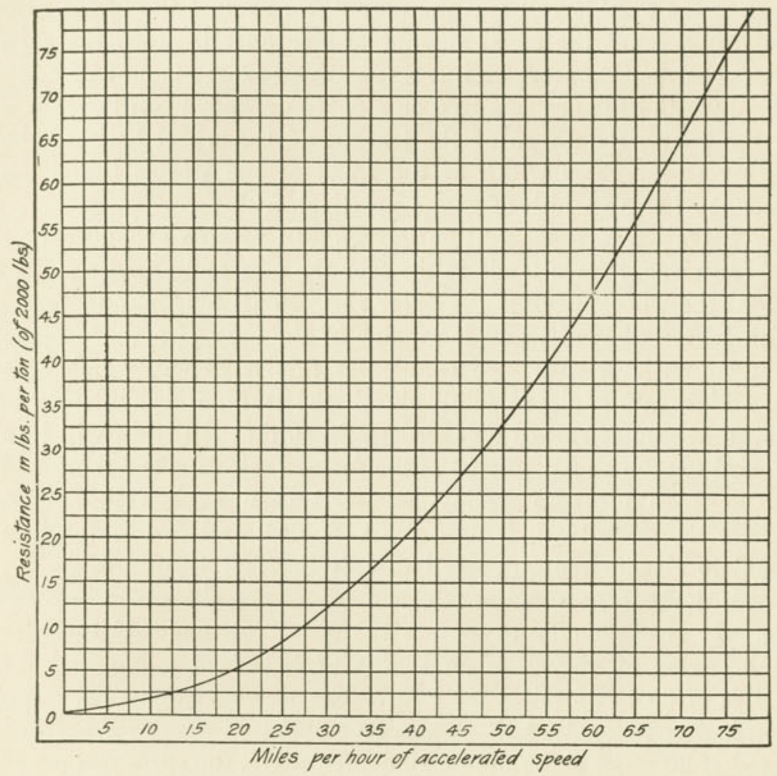


Fig. 8

RESISTANCE DUE TO ACCELERATION.

around curves perfectly, every axle in the train should point to the center of the curve, and the outside wheels should be larger than the inner wheels. In practice, the difference in size of the wheels is supposed to be accomplished by making the tread of each wheel in the form of a cone, so that the diameter close to the flange is greater than at the front face. The radial position of the axles, however, is impracticable, as cars and locomotives are built so that two or more axles are parallel. On sharp curves this arrangement of the axles causes the cars and locomotives to bind; a four-wheeled car or truck having a tendency to press the front wheel against the outside rail and the rear wheel against the inside rail. On this account the usual amount of clearance between the rails and wheel flanges must be increased. The exact amount of additional width of gauge required on a curve depends upon the radius of the curve, the gauge of the track, and the wheel basis of the rolling stock. The width of the tread of the wheels limits the amount of extra width of gauge practicable.

Elevation of Outer Rail on Curves. In passing around curves the centrifugal force tends to tip over the cars and engines and to crowd the wheels against the outer rail. This tendency increases with increased speed, and is greater in the case of a sharp curve than an easier curve. To counteract this tendency, which at a very high rate of speed might derail the train, it is desirable to elevate the outer rail of a curved track, so that the train will lean inward to such an extent that at the desired rate of speed there will be no more pressure against one rail than against the other. Where the same track is used for both slow and fast trains it is usual to elevate the outer rail to suit the fast train. Excessive speeds, however, around very sharp curves are altogether impossible. It is customary to elevate the outer rail one-half inch for each degree of curvature on radius of Standard gauge and for speeds of 25 to 35 miles per hour. For narrow gauges the elevation is proportionally less. Thus, on a standard gauge road with a speed of 30 miles an hour on a 10 degree curve, the outer rail would be elevated 5 inches. If the outer rail is elevated exactly the proper amount, it will be impossible for a passenger to feel any sensation of tipping or rocking while the train is on the curve. The exact elevation, however, to secure this result can only be arrived at in each case by very complicated calculations. It is considered best practice in approaching a curve to begin to make a difference in the level of the two rails, some distance away, 50 or 100 feet before the curve is reached, and to elevate the outer rail and depress the inner rail, so that the center of the track is level. The

accompanying diagram, Fig. 9, will show the elevation required for the outer rail on curves up to 70 degrees and for speeds up to 60 miles per hour for a standard gauge track.

The best difference in level between the two rails, however, on a curved track can only be determined by actual trial after the track is built, so that in practice if any variation is found advisable from the results obtained from the accompanying diagram, it will probably be in the direction of the reduced rather than of increased heights. For instance, if the elevation of the outer rail for standard gauge track on a 20 degree curve for a speed of 25 miles an hour is required, by reading along the diagram and finding where the 25 mile per hour speed intersects the line for the 20 degree curve it will be found that the required elevation will be about 8½ inches.

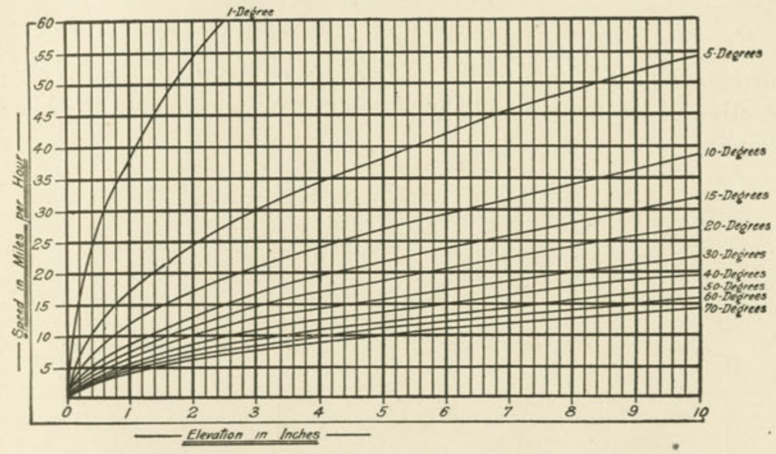


Fig. 9

Relation of Elevation of Outer Rail to Speed of Train.

Gauge of the Track. Gauge of a track of a railroad is always the distance measured in the clear between the rails as shown in Fig. 10, so that a standard gauge road should measure exactly 56½ inches between the rails on the straight track. The gauge of the track is not measured between the flanges of the wheels, and it is considered a mistake to increase the track gauge for sake of clear-

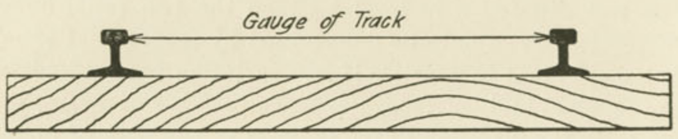


Fig. 10

GAUGE OF TRACK.

ance except as to widening the track gauge on a curve. In the construction of locomotive and car wheels the proper amount of clear-

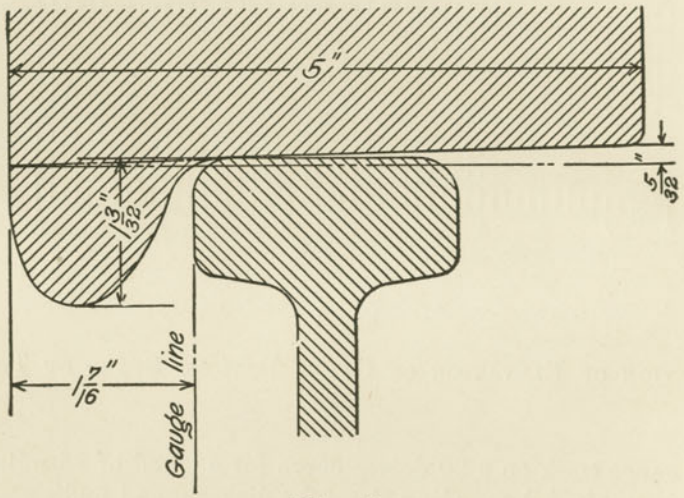


Fig. 11

CLEARANCE BETWEEN WHEEL AND RAIL.

ance or side play is provided, as shown in Fig. 11. The position of the gauge line is 1 7-16 inches from the back face of the tire. The width of the tread is 3 9-16 inches measured from the gauge

line, the width over all being 5 inches; the depth of the flange 1 3-32 inches; the taper of the tread 1-32 inches.

Speed of Locomotives. When considering the speed of a locomotive, it must be remembered that it requires more power to start a train than to keep it in motion after it has been started. This is due to the fact that the resistance of axle friction and of flange friction is greatest in starting, and diminishes very rapidly as the train acquires motion, and then continues to diminish, but less rapidly, as the train speed accelerates. Journal lubrication is more perfect at high speed than at low speed, and in cold weather, when the oil becomes less liquid, the difference is greatest. The lessening of a flange friction with increase of speed is believed to be due largely to the increase of momentum and to the tendency of a body in motion to move in a straight line. For these reasons a locomotive may be relied upon to haul any train it can start. The resistance of the atmosphere is practically zero at slow speed, but increases very rapidly at high speeds. Sharp or badly laid out curves or uneven track may prevent a rate of speed which would be considered moderate on a good straight track. Car trucks out of square, wheels out of center, wheels misplaced on the axles, and other rolling stock defects, increase the resistance with the increase of speed. The resistance due to grade is absolutely constant, whether the speed is fast or slow, but the momentum of fast speed will take the train up a grade of considerable length with very little retarding, while the same grade may stall a slow-moving train.

Maximum Speed and Maximum Load. No locomotive can at the same time haul its heaviest load and make its fastest speed. As speed increases the available tractive force decreases. At slow speed the mean effective pressure is estimated at 85 per cent of the boiler pressure. Steam requires time to move, and as the piston speed is increased the steam from the boilers cannot get into the cylinders quick enough, nor the exhaust steam be expelled quick enough, to maintain the same mean effective pressure as at slow speed, and, besides, the steam must be used expansively for mechanical as well as economical reasons. Together with this loss of mean effective pressure at high speed a considerable amount of power is lost in forcing the exhaust steam through the exhaust nozzles. This ratio of loss of effective tractive power, as the speed increases, varies greatly with the design of the locomotive. A better proportion of maximum load at maximum speed can be hauled by a passenger locomotive than by a freight locomotive, each locomotive being designed for its own particular service. This is because the passenger locomotive with its large driving wheels has a more moderate and effective piston speed when developing high train speed than the freight engine with small drivers at less train speed. This results in the peculiar condition that a passenger locomotive can haul a heavier train at fast speed and can develop more horse power than a much heavier freight locomotive with larger cylinders and greater tractive force.

The Waste of Energy in Railroad Operation. The energy stored in the fuel must be used to make steam, the energy in the steam must be used to move the engine and pull the trains, and the energy stored in the men and officials must be used to properly regulate the whole. The law of the conservation of energy does not permit energy to be created nor destroyed; it may be changed from one form to another, however, and the problem which must be met on all railroads is to convert the stored-up energy in the fuel into useful work with as little waste as possible.

Importance of the Locomotive Fuel Question. Fuel for locomotives is the largest single item of expense in the cost of conducting transportation on most of our American railroads. For nineteen representative roads the cost of fuel on the locomotive tender amounted to $92,492,098, or 11.42 per cent of the total operating expenses of these roads. The next most important item in the cost of conducting transportation is the combined wages of enginemen and roundhouse employees. For seventeen railroads this item amounted to $67,369,934 as compared to $80,554,716, the cost of fuel. These costs are for one year.

Ratio of Cost of Fuel to Operating Expenses. A study of the ratios of the cost of fuel to the total operating expenses on American railways brings out some interesting facts. The ratio is highest (from 13 to 17 per cent) on the New England and Middle Western roads and on the Seaboard Air Line. It is lowest on the Chesapeake & Ohio (7.81), Louisville & Nashville (8.01), Pennsylvania Railroad (9.25), and Baltimore & Ohio (9.34). On the other roads it ranges between 10 and 13 per cent. On fifteen of nineteen representative roads the wages of enginemen and

engine house men combined are less than the cost of fuel—in some instances very much less. On the Pennsylvania Railroad these two items are about equal, while on the Baltimore & Ohio, Chesapeake & Ohio and Louisville & Nashville the wages are higher than the cost of fuel.

It would be reasonable to suppose from the importance of the fuel item that the railroads as a whole would devote considerable attention to its inspection, handling and economical use. It is surprising, therefore, to find how little attention is given to this question, and how little its importance seems to be appreciated.

The energy wasted on railroads may be divided into three classes:

First. Energy wasted by present well-established systems which, while known to be wasteful, nevertheless appear to be in some cases the only practical, or in others the most economical, means to accomplish the desired results. Second. Energy now wasted by improper systems of management or improper or uneconomical machines or devices of various kinds now in use, these being under the control of officials higher than the road foreman of engines. Third. Energy now wasted either by improper system of management or by improper methods of handling of working machines, or the improper condition of the machines themselves.

Amount of Heat Utilized. Of the actual energy known to exist in a pound of coal but a small per cent is realized, the waste taking place in the slacking of the coal, the loss of heat due to improper combustion, the loss of heat in making steam, the additional loss from the steam itself, and the greatest loss in converting the energy in the steam into effective work in the locomotive. The mechanical equivalent of one heat unit (B.T.U) is 778 foot pounds of work, so that to produce one horse power for an hour requires power equivalent to 2,545 heat units. One pound of coal when properly burned will give off about 14,100 heat units, or enough to produce five and one-half horse power for one hour. In locomotive service it takes at the lowest estimate twenty-five pounds of steam per indicated horse power per hour. Neglecting the loss due to friction of the engine, this means that to produce five and one-half horse power per hour in a locomotive requires 137½ pounds of water. As one pound of coal evaporates only about five pounds of water in a locomotive boiler, twenty-seven and one-half pounds of coal would be required, which means that only 3.6 per cent of the actual energy in the coal is realized, the other 96.4 per cent being energy wasted, due to the present method of converting the heat into work.

Improvements in Locomotive Engineering. Practically all the improvements made in the past few years tending to better the economy of the locomotive have been along lines that at the most would save only a fractional per cent of this great loss; but these fractional savings have amounted to hundreds of thousands of dollars in some cases. In view of a greater possibility of saving, efforts have been made for years to obtain power direct from coal without this wasteful method of making steam and converting the energy in the steam into power by means of the engine.

Central Power Plants. With present methods, however, the most economical results have been accomplished by having a large central power plant where boilers reach the highest efficiency in transforming the heat in the coal into steam, and where highly efficient compound engines, or turbines driving generators, convert the power in the steam into electrical energy, which can be transported long distances with small loss and used in motors for practical power purposes. Railroad managers, realizing the economy of this method, are now experimenting on and perfecting systems of this kind to supplant the individual power plants which each locomotive now represents, and which in comparison to this new system are considered wasteful.

Gasoline Locomotives. Other experiments are being made with explosive engines, principally gasoline engines, where power is required in small units, in thinly settled territories This method often shows a large saving on account of the economy of gas engines over steam. It is doubtful, however, if the gas engine will be used extensively in railroad work, except for special service, on account of the many seemingly impractical features connected with its use.

Grade Conditions Affecting Economy. The grade line of the road may also be such that a very large amount of power is wasted. Possibly a small expenditure on grade reduction would more than pay for itself in power saved. The method of handling tonnage is also to be considered, as when the rating is too light energy is wasted by not using the machinery to its economical capacity, and if an engine is overloaded, energy is wasted in slipping, stalling, and to the much slower rate of speed at which the train is moved, which is a controlling factor in considering the amount of energy wasted.

Type of Engine Affects Economy. The type of steam engine used is a factor also, some roads using very large and powerful engines, others using small power, some with compound locomotives, Walschaert valve gear, superheaters and other devices, all endeavoring to give greater economy and better service. Each type of engine, valve gear or special device, if it has merit, shows its greatest economy under certain conditions, and in order to save fuel careful consideration should be given to the selection of not only the locomotive, but the special devices on it, to insure having a machine that will be economical under the conditions under which it will have to work.

The track conditions in a great many cases are such that the friction or train resistance of the cars passing over it is greatly increased over what it would be were the track properly maintained. All increased resistance of this kind, of course, means a corresponding waste of power.

Fundamental and Variable Wastes. The foregoing cases are what might be called fundamental wastes on a road; that is, they are determined by the physical condition of the road, the class of power and equipment and the fixed policy of the management. There are numerous other wastes, however, which can be reduced to a minimum. There is a possibility of a large loss of energy due to improper lubrication of locomotives and cars. Dry valves on a locomotive will make a difference of twenty-five to fifty tons in the train load that can be hauled over the grades, and there is reason to believe that the waste would be as great in proportion on a comparatively level road. Hot pins, eccentrics, driving boxes, etc., cause waste through increased friction of the parts, although the loss of time caused is a much greater and more costly item than the loss through increased friction. The same is true of hot boxes due to improper lubrication.

The Problem of Fuel Consumption. The problem of fuel consumption, or better combustion of fuel, is another serious matter. On most roads there is one man who is held accountable for the amount of fuel used. It has been suggested by the Traveling

Engineers' Association that railroads should have a man whose title might be fuel superintendent, who would have charge of and direct the work now done by the fuel agent, including inspection of coal and the assignment of certain grades of coal to various coaling stations. He would be so closely in touch with the mechanical department that he would be able to advise what class of coal was to be furnished each division point, so that engines might be drafted for the class of fuel to be burned, and he would have on his staff a corps of traveling firemen to see that the men were properly instructed concerning the principles of combustion, and were firing their engines according to correct principles, and that the engines were drafted so that they would burn the fuel in an economical manner when properly fired. Such a man should be able to effect a wonderfully large saving when it is considered that to-day the fuel agent in some cases is trying to make a record of buying cheap fuel, and will not admit there is such a thing as poor coal. The mechanical department, to avoid steam failures, is drafting engines to handle the poorest fuel, and the men, on account of poor coal, improperly drafted engines or lack of interest, are burning from ten to twenty per cent more fuel than necessary.

Other channels through which energy is wasted have been completely given by D. C. Buell in a paper read before the Traveling Engineer's Association as follows:

How Coal is Wasted. Coal not properly inspected at the mines, allowing slack and dirt in considerable amounts to take up space in cars, tanks and fire-boxes that the coal should occupy, to say nothing of the loss caused by dirty fires, clinkers, etc.; coal spilled at coal chutes and not picked up; coal stolen all along the line; coal wasted on account of improper or wasteful methods of firing up engines at the roundhouse; coal spilled from engine tanks being filled too full; coal spilled from engine deck on account of its not being kept clean; coal wasted through grates on account of the fireman shaking grates improperly; coal wasted on account of firing not being properly done.

How Heat is Wasted. Ash-pans not properly made for admission of air to give proper combustion or not kept cleaned out; engines not drafted right to give proper combustion; boilers or flues being dirty; steam leaks in fire-box or front end that interfere as well as wasting heat by the leakage; forcing the fire too hard, drawing the gases out of the stack at too high a temperature; engines not properly lagged; heat wasted which might be saved by hollow fire-brick arches, combustion tubes, feed-water heaters, or special devices of this nature that have been proven economical.

How Steam is Wasted. Valves or cylinder packing blowing; cylinders not smooth; that is, where the inside of the cylinder wall has not become glazed so as to reflect the heat and keep it in the cylinder, instead of absorbing it, and radiating it out as a cylinder which is pitted or unglazed will do; leaks across steam passages; leaks in steam valves; pipes or fittings leaking, either on the engine or in the cab; improper location of piping or working of the injectors; air leaks on the engine or cars; steam heat leaks; hot water leaks at any point from boiler or fittings; steam wasted through the pops on account of the engine not being fired properly.

How Power may be Wasted. Valves set improperly; lack of lubrication; improper feeding and firing of the boiler; improper running and handling of the engine; drafting the engine so as to give excessive back pressure; improper handling of the air; brakes set up too close; the waste of time on a railroad is almost always accompanied by a waste of energy because cars, engines and men are lying around when they might be doing useful work.

Time Wasted at Roundhouse may be Due To:—Engineers not making proper work reports; inefficient or insufficient force not getting work done promptly, thus delaying a $15,000 machine for want of machinist or helper; sand-house, coal chute, water tank and cinder pits not properly arranged; lack of proper supplies at storehouse, requiring engineers to hunt up foremen, and to spend more time robbing other engines to get what they want; lack of tools on engines, so that engineers cannot do necessary work promptly; not having a proper record of where men live and can be called; not having extra men enough to keep power moving as fast as ready and wanted; not having men called in time so they can get ready to go out on their call.

Time Wasted on Road may be Due To:—Not having proper tools on engines in case anything happens; trying to stop an engine at water tank with a long train instead of stopping short and cutting the engine off; not having fire in condition to go after meeting a train or getting orders; not oiling around promptly; engineer and conductor not working together to make meeting points or figure on station work; careless handling of train and pulling out draw-bars and bad order of cars; not watching for signals from train crew; not having a supply of sand at convenient points between terminals for bad weather or emergencies; engines not properly washed out, causing foaming and consequent loss of tonnage or time; allowing coal to get in tanks, stopping up injector supply pipes; not cleaning strainers in injector supply pipes at frequent intervals; water accumulating in main reservoir, thus requiring a longer time than necessary to release brakes; not keeping sanding devices in good working order, with result that engine slips badly in starting train or on hard pulls; engineer and fireman not working together so they will have steam and water where needed; fireman not awaking to the fact that ash-pan needs cleaning until engineer and train crew are ready to go; engineer laying down when something goes wrong with his engine, when with a little thought and some energy he could have fixed things and brought his train in; crew stopping to eat just where it suits them without notifying the dispatcher or regarding the possible disarrangement of his plans; engineer or conductor not advising dispatcher if anything is going wrong so they cannot make the time expected of them; engineer not willing to admit there is anything wrong with his engine when he knows he could not make ten miles an hour with the train.

Waste of Energy in Yard. There is a great deal of energy wasted in the yard and on the road directly chargeable to the transportation department, part of the cost of which in many cases falls on the mechanical department. For example, time wasted in not having trains made up, crews ready or the yard open so the engine can get to the train and get out on call, and indifference in matter of switching coal to chutes.

Along this line may be mentioned the seeming delight some switchmen take in blocking the roundhouse leads, so engines cannot get in or out; there is also time wasted getting bills and orders, all of which is reflected in cost of coal charged against engines and wages of enginemen, etc.; on the road there may be waste due to poor distribution of time on schedules, poor dispatching, slow orders which should have been cancelled, orders

put out at points where it is hard to stop and start when some place where train would have to stop for water or a meeting point could have been used just as well; another waste is due to trains being made up improperly, loads behind instead of ahead, empty car doors open, short loads in what is supposed to be a through train, etc.; slow orders put out by the maintenance department also add to the fuel bill, because unfortunately they are usually necessarily placed on track just at the foot of a grade or on a curve or some hard pull; many tanks are located so that it is uphill both ways away from them. Streams are usually found at the bottom of the hills, but it is cheaper to pump water to a tank at the top of the hill than to pull the train from a standstill to the same point.

It is toward the reduction of these wastes that the entire organization of every large railroad is striving, and considerable success is being attained along these lines, not only by properly educating the various employees in their respective duties, but by using suitable apparatus and methods required to meet each problem.

REVIEW QUESTIONS.

PROBLEMS OF ECONOMICAL OPERATION.

1. What is the most desirable rate of combustion on locomotives using bituminous coal?

2. What four steps are required in the transformation of energy from the fuel to the train?

3. How is the efficiency of a locomotive affected when the rate of combustion is too high?

4. What is the average amount of heating surface allowed in a locomotive per square foot of grate surface?

5. What effect on the fuel economy will it have if the boiler contains too much heating surface?

6. What are the conditions necessary in order to utilize the steam efficiently in the cylinders of a locomotive?

7. What is the usual amount of steam required to develop one horse power in the cylinders?

8. How does the boiler capacity affect the horse power of a locomotive?

9. What limits the tractive power of a locomotive for a given weight?

10. Suppose an engine is required to give a total tractive effort of 35,000 pounds in starting, what would be the required weight of the engine to obtain this tractive effort?

11. What would be the horse power required to obtain a tractive effort of 20,000 pounds when the locomotive is running at a speed of 15 miles an hour?

12. What are the different factors which enter into the problem of finding the tractive force of a locomotive?

13. What is the difference between the available tractive force and the effective tractive force?

14. What is the difference between the tractive force of a Consolidation engine and that of an Atlantic type engine, and why do they vary from each other?

15. How do you obtain the factor of adhesion of a locomotive, and what are the usual amounts found in practice?

16. What are traction increasers and why are they used?

17. What is the usual weight of engine per square foot of heating surface for Consolidation freight locomotives?

18. What factors enter into the problem of finding the resistance of a locomotive?

19. Give three factors which determine the horse power of a locomotive, and how could you best increase the horse power and at the same time economically utilize the steam?

20. How is economy of steam obtained in high speed locomotives, and what are the tendencies of economical steam utilization in locomotives used for heavy slow freight service?

21. Why is it that the Mallet Compound is giving such good service in moving heavy freight trains?

22. Upon what conditions does the hauling capacity of a locomotive depend, and how can you increase the hauling capacity of a given locomotive?

23. Name several methods of designating the grade on a road.

24. If a road has a grade of 20 feet to the mile, what percentage of grade is this?

25. Not having any surveyor's instruments at hand, describe a rough rule for finding a grade.

26. What is the average rolling resistance in pounds per ton?

27. If there is a three-degree curve on the road, what would be the radius of it?

28. Why is it that a curve has more resistance than a straight track?

29. Give a rough rule for finding the radius of a sharp curve.

30. What effect has the wheel base of a locomotive upon the degree of curves which can be used on a road, and describe how the degree of curve is obtained with a given swing of truck?

31. How does the resistance of a train increase due to the acceleration of speed?

32. Is the gauge of track on curves larger or smaller than a standard gauge?

33. Why are the outer rails on curves elevated, and how can the difference in level between the two rails be determined?

34. What is the Standard gauge of a track used on American

railways, and how is it measured, from the inside or outside of the rail?

35. How does the speed of a locomotive affect the horse power required, and what conditions should be fulfilled to obtain the maximum speed with a given locomotive?

36. Describe the relations existing between the maximum speed and maximum load of a locomotive, and why is it that no locomotive can at the same time haul its heaviest load and make its fastest speed.

37. Describe various ways in which energy is usually wasted on railroads.

38. What percentage of heat is generally utilized in one ton of coal?

39. What are the general improvements that are being made in locomotive engineering?

40. Why are central power plants with electric transmission being used, and what economy in operation are they supposed to attain?

41. Having given two roads of different grades, would you use the same kind of motive power on each road?

42. How does the condition of the track affect the economy of an engine?

43. What effect will imperfect lubrication of a locomotive have upon the train load that can be hauled over a road?

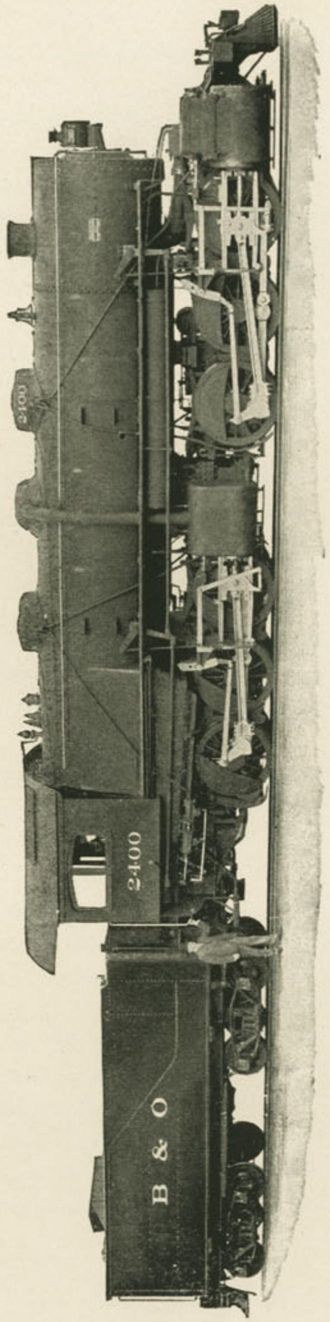
44. Give five methods by means of which coal may be wasted on a locomotive.

45. If a locomotive cannot keep up steam pressure, what would you examine to find out if steam is being wasted?

46. Suppose everything pertaining to an engine and train were steam-tight, and the locomotive was not giving its proper power, what may be the probable causes?

47. What precautions must be taken by road officials to see that time is not wasted at the roundhouse or on the road?

48. Give a brief description of what you would consider to be an ideal condition in building a road so that there would be no energy needlessly wasted.



BALTIMORE & OHIO FREIGHT LOCOMOTIVE—FOUR CYLINDER ARTICULATED COMPOUND
(American Locomotive Company)

Heat.

Nature of Heat. Heat is a form of energy, and is said to depend upon the molecular motion of the particles within a body. Since it is energy, it has capacity for doing work; thus, it may cause steam to drive a piston; it may cause solids or liquids to expand and contract, or it may change the molecular condition of the bodies as when solids are fused or liquids vaporized. Heat does not act the same as matter, because a heated body is no heavier than it was before it was heated, and that, unlike matter, heat can be lost, as in melting two pieces of ice by rubbing them together, in which case a quantity of heat entirely disappears.

Sources of Heat. Since heat is a form of energy, there are numerous sources from which it is derived, because energy can be transferred into heat. The energy which provides us with heat exists in both the kinetic and potential forms. The first form is illustrated by the energy of moving air and water, as in winds, tidal waves or ocean currents; and the energy in stored water or in coal is an example of potential energy. Friction, compression, percussion, or any process by which motion is arrested, produces heat.

Combustion. The most general method of heat production upon the earth, however, is combustion, by which is meant chemical combination of fuels with oxygen. The most usual substances which are burned consist of hydrogen, carbon, sulphur, and phosphorus, of which carbon and hydrogen are the most important. The combination of hydrogen and carbon forms the basis for all commercial fuels, such as coal, oils, or gases. When one pound of pure hydrogen is burned, it develops 62,000 heat units, and when one pound of carbon is completely burned, it will give out 14,500 heat units.

The following table gives the heating value of the most usual sources of heat used in engineering:

	Approximate Total Heat in 1 pound of fuel Thermal Units.
Hydrogen	62,000
Petroleum Oils (benzine, etc.)	27,500
Petroleum, crude	20,400
Petroleum, refuse	20,000
Coal Gas	17,800
Carbon	14,500
Coal, good quality	14,000
Coke	13,500
Wood Charcoal	11,000
Wood, dried	8,000
Peat, 25% moisture	7,000

Other fuels which are sometimes used include straw, tan or bark, and bagasse. Straw is very bulky, but will give out about 8,000 heat units. Tan is oak bark which has been used in tanning, and when burned dry will give out 6,100 heat units per pound. Bagasse is the name given to the fibrous portion of sugar cane after the juice has been extracted, but, unless dried, it is difficult to burn, and as usually burned contains only about 3,000 heat units per pound.

Measurement of Heat. The intensity of the heat of a body is indicated by a thermometer, and has nothing directly to do with the quantity of heat that a body contains. Thus, if a pound of iron has the same temperature as a pound of water, the latter will give out about eight times as much heat as the former for each degree it is cooled. Temperature is, therefore, only a measure of the heat which affects the senses. It cannot be measured directly, but only by one of the effects produced by heat, usually expansion. An instrument in which expansion is made use of, for determining temperatures, is called a thermometer; or a pyrometer if the temperatures are high. Air, mercury, and alcohol are the substances generally used in thermometers. The air thermometer has great range and great accuracy, and is generally used as a standard. The alcohol thermometer is used only for very low temperatures. The mercury thermometer is the most convenient form of instrument, and is therefore commonly used. It consists of a capillary glass tube called the stem, on the lower end of which a spherical or cylindrical bulb is blown, of such a size that the expansion of the mercury it contains, between the limits within which the thermometer is to be used, exactly fills the stem.

When thus filled with mercury the upper end of the stem is sealed.

In order that the indications of all thermometers shall be comparable, two fixed points are marked upon their stems. These fixed points are the melting point of ice and the boiling point of water, which, under proper conditions, represent the same temperature everywhere. The lower point is called 32 degrees and the upper point 212 degrees, according to the Fahrenheit scale, or zero, and 100 degrees, according to the Centigrade scale, which is used for all scientific purposes. There are, therefore, 180 degrees between the melting point of ice and the boiling point of water according to the Fahrenheit scale, and only 100 degrees according to the Centigrade scale. These graduations are either marked on the stem or alongside.

In engineering, temperatures are usually measured on the Fahrenheit scale, but sometimes the Centigrade is used. In order to convert degrees Centigrade into Fahrenheit, multiply by 1.8 and add 32. For instance, to change 40 degrees C into degrees F multiply 40 by 1.8 and add 32 degrees, which gives 104 degrees. Conversely, to change Fahrenheit into Centigrade subtract 32 and divide by 1.8.

The process of measuring the *amount* of heat in a body is called calorimetry, and the instruments used are called calorimeters. The amount of heat necessary to raise the temperature of a body is proportional: (1) to the size of the body and (2) to the temperature rise; the total amount of heat required, therefore, being the product of its mass and temperature change. On comparing different substances, however, it is found that they are heated or cooled differently with the same amount of heat, even though their masses be the same. That amount of heat which will raise one pound of water one degree will raise one pound of iron ten degrees, or one pound of mercury thirty degrees.

Unit of Heat. It is therefore necessary to agree upon a particular substance, so that the amount of heat required to raise a unit mass through unit temperature is called unity. Such a substance is water. It is readily obtained pure, and it requires a greater amount of heat than any other substance to produce in it a given temperature change. A unit of heat is, therefore, defined as the amount of heat required to raise one pound of water one degree, and is called a British thermal unit.

Specific Heat. Since other substances require a less amount of heat to change the temperature one degree, the ratio of this amount to unity is called the specific heat. The specific heat can therefore be defined as that fraction of a unit of heat which is required to raise the temperature of unit mass of that substance one degree. The specific heat of various substances is as follows:

Liquids.		Solids.		Gases.	
Water	1.0000	Copper	0.0951	Air	0.2375
Mercury	0.0333	Gold	0.0324	Oxygen	0.2175
Alcohol	0.7000	Wrought Iron	0.1138	Hydrogen	3.409
Benzine	0.4500	Cast Iron	0.1298	Nitrogen	0.2438
Ether	0.5034	Steel	0.1170	Superheated Steam	0.4805
		Lead	0.0314	Ammonia	0.5080
		Zinc	0.0956	Salt solution—15% salt	0.8606
		Ice	0.5040		

If, therefore, the specific heat of a substance be known, the amount of heat which it contains can be calculated, if it does not change its state. For instance, suppose a copper ball weighing 10 pounds is raised from 60 to 132 degrees, how many heat units are required? It is only necessary to multiply the difference in temperature by the weight and specific heat, or $72 \times 10 \times .0951 = 68.47$ heat units.

Expansion by Heat. When heat is applied to a body it generally expands, and the amount of expansion for each degree of rise in temperature is quite regular, and is called the co-efficient of expansion. This co-efficient is the amount a body of unit length will expand or contract for each degree difference in temperature. The co-efficients of expansion for a few of the important solids are as follows:

Aluminum	.0000123
Brass—sheet	.0000105
Lead	.0000157
Wrought iron	.0000064
Cast iron	.0000055
Copper	.0000088
Steel	.0000065

For liquids and gases the co-efficient of cubic contents per unit rise in temperature is given rather than linear expansion. A few of these follow:

Air	.002034
Mercury	.000099
Alcohol	.000610
Sulphuric Acid	.000270

Expansion of Water. There is one important substance that does not always expand upon the application of heat, and that is water. When water at 32 degrees Fahrenheit is heated, it contracts instead of expanding, and this continues until the temperature reaches 39.2 degrees, which is the point of minimum volume. Above that temperature the addition of heat causes the water to expand.

Change of State. In addition to change of temperature and change of volume, heat produces change of state. There are three states in which a substance is found: solid, liquid, and gaseous. When a solid body is exposed to the heat, not only does its temperature rise and its volume increase, but it liquefies, if it is not previously decomposed. When a liquid body is sufficiently heated, it is vaporized, and becomes a gas or vapor. The former is called liquefaction and the latter vaporization. The laws of liquefaction and vaporization are quite important in engineering, for water, which is used extensively, is commonly found in the three states: solid, liquid, and gaseous. For solids such as ice there are two important laws: 1st. Every substance begins to melt at a definite point of temperature, which is always the same for the same substance and pressure. 2d. After melting begins, the temperature of the liquid remains constant until the liquefaction process is complete.

In general, solids expand on melting, so that the volume of the liquid is greater and its density less than that of the solid. Water, bismuth, type metal, and cast iron are exceptions to the rule. Were it not for the fact that ice is lighter than water, all the rivers would be frozen solid in the cold weather.

Solidification. As a solid may be melted by the addition of heat, so may a liquid be solidified by the subtraction of heat. Therefore for every liquid there is a definite solidifying point, the temperature of which is constant so long as the solidifying process is in progress. Substances like bismuth and antimony, which expand on solidification, give sharp castings, while gold, silver, and copper, which contract, do not give good castings, but must be stamped in a die to get good effect.

Latent Heat of Fusion. Since during the time a solid body is melting or a liquid body is freezing no change of temperature takes place by the addition or subtraction of heat, it follows that a certain amount of heat is not accompanied by any temperature change. Consequently this heat energy is stored up in the body as potential energy, and is called the latent heat of fusion. The latent heat of liquefaction is the same as the latent heat of fusion, except that it is the amount of heat, measured in heat units, which is required to change a solid of unit mass into a liquid under the atmospheric pressure without alteration in temperature.

The following are a few examples showing the melting points of solids and their latent heat of liquefaction in British thermal units per pound:

	Melting Point.	Latent Heat.
Ice	32	144.
Beeswax	140	148.
Phosphorus	177	9.06
Sulphur	405	16.86
Tin	426	500.—

Vaporization. Still more important than solidification and liquefaction is the vaporization of a body, which is the process of converting a liquid into vapor. Vaporization may be effected in two ways: by evaporation or by ebullition. Evaporation takes place solely from the surface of a liquid, while ebullition is the production of vapor throughout the mass. When liquids produce vapors readily, they are called volatile liquids, as ether or alcohol, and those which do not are called fixed liquids, such as heavy oils or mercury.

A vapor in contact with its liquid is called a saturated vapor, because evaporation of the liquid will continue until the maximum pressure for that temperature is reached. If, however, all the liquid is evaporated and heat is continued to be added, the resultant vapor is called unsaturated or superheated vapor, in which case it follows the laws of a gas.

A superheated vapor may be converted into a saturated vapor by increasing the pressure or by decreasing the temperature; and by the continuance of either one or both the vapor may be converted into a liquid. The pressure at which a gas liquefies is

called the critical pressure, while the temperature required to liquefy a gas is called the critical temperature.

Laws of Boiling. There are two important laws which relate to the formation of vapor from a liquid. It has been found that for a given pressure (1) every liquid has a definite boiling point, and (2) this point remains constant after boiling commences until all the liquid has been vaporized. The following are a few of the boiling points of liquids under atmospheric pressure:

Alcohol	173° Fahrenheit
Alcohol, wood	151.
Ammonia, liquefied	37.3
Ammonia water	140.
Benzine	177.
Mercury	670.
Naptha	186.
Petroleum, refined	316.
Water, pure	212.
Saturated Brine	225.

Since the boiling point depends directly on the pressure, it is evident that the boiling point of a liquid may be raised by increasing the pressure and lowered by diminishing it.

Heat of Vaporization. Since a liquid and its vapor may have the same temperature, that heat which is given to the liquid to form vapor is used in doing internal work and is stored up in the vapor. A vapor therefore possesses more energy than its liquid. This heat of vaporization is not indicated by the thermometer, and is therefore generally called the latent heat of evaporation. At atmospheric pressure water boils at 212 degrees, and its latent heat of evaporation per pound is 966 British thermal units. Alcohol boils at 173 degrees under atmospheric pressure, and its latent heat is 364 heat units.

The steam table shows the variation of the boiling temperatures and the heat of vaporization with the pressure. The pressure of the atmosphere is always taken at 14.7 pounds per square inch, which is the zero reading on the steam gage. If the temperature of boiling and the latent heat of vaporization are required at 100 pounds gage pressure, by referring to the table found on page 68 in this section on Heat it will be found that the temperature of vaporization will be 337.8 degrees and the latent heat of evaporation will be 876 heat units.

Transfer of Heat. Heat may be transferred in three ways: by conduction, by convection, and by radiation. The transfer of heat within a body is called conduction, and takes place between adjacent particles. Those substances which transmit heat readily are called good conductors; among which may be classed silver, copper, brass, iron, and the metals in general. Poor conductors of heat include wood, glass, liquids, and gases. Silver is one of the best conductors of heat, and, based upon its conductivity, the following values of the metals are given:

Silver	100	Iron	11.9
Copper	73.6	Steel	11.6
Gold	53.2	Lead	8.5
Brass	23.1	Platinum	8.4
Zinc	19.0	Bismuth	1.8

The conductivity of liquids is exceedingly small, and that of gases is still less.

While in solids the heat is transferred from one part of the body to another by conduction, in liquids and gases the transfer of heat is effected chiefly by convection. For instance, if the water in a boiler be heated at the bottom, the water rises, and, coming into contact with the colder water, heats, and thus produces a circulation until all the parts are at the same temperature. The convection of gases is very important, since they are such poor conductors of heat. The air in a room in which there is a radiator is heated principally by convection. The third method of the transfer of heat is by radiation. This is caused by the formation of wave motion in the " aether " which pervades all space. Certain bodies have the property of emitting more radiation than other bodies, and these bodies also have different properties of absorption. The brighter a substance is the less radiating power it has. Lampblack is one of the best substances for absorbing heat, since it reflects none of it. The radiating powers of various substances compared with lampblack are as follows:

Lampblack	100
Glass	90
Bright Lead	19

Silver	12
Clean Tin	12
Blackened Tin	100
Copper	12
Mercury	20

The radiator in a room should therefore not be polished, but should be kept dull.

Mechanical Energy and Heat. Heat, which is molecular energy, may be made to do work. The principle of this conversion is quite simple, and is affected by some agency like steam in a steam engine, which by its expansion transforms some of its heat into work. It has been found by careful experiments that one British thermal unit, which is the amount of heat necessary to raise one pound of water one degree, is equivalent to 778 foot pounds of work. For instance, it has been stated above that a pound of good coal will give out about 14,000 heat units, which is equivalent, should all the heat be utilized, to 10,892,000 foot pounds of work.

When heat energy disappears as heat, it must, according to the principles of the conservation of energy, appear or exist in some other form of energy. When the heat in the steam drives the piston of an engine, the steam loses heat by the operation and an exact equivalent of the energy so disappearing reappears as work done or as energy of the moving parts of the engine, except that which is taken up by radiation and friction. The mechanical equivalent of a heat unit is called Joule's equivalent, because it was he who made the first determination of the mechanical equivalent of a heat unit in Manchester, England. After a series of experiments, extending over seven years, he at that time came to the conclusion that its value was 772 foot pounds, yet later experiments have proved this value to be too small, so that Joule's equivalent is now universally taken as 778 foot pounds.

The first law of thermodynamics, which is the science of heat, can now be stated: Heat and mechanical energy are mutually convertible in the ratio of about 778 foot pounds for the British thermal unit.

Heat Engines. In general, heat engines are machines for continuously transforming heat into work. Such engines in practice work in cycles. One of the best known principles on which an imaginary heat engine works was devised by Carnot.

It involves the most important fundamental principle of this science, and is known as Carnot's cycle.

In any heat engine it is essential that there should be, 1st, a working fluid; 2d, a source of heat; and 3d, a receptacle for unexpended heat, both of which latter must be external to the working fluid. In operation a heat engine must receive the heat of the working fluid at a certain temperature, it must convert the heat into work, and it must discharge the unconverted heat at a lower temperature than that at which it was received. The difference between such higher and lower temperature is called the "range of temperature," and the engine is called a perfect engine when the whole heat corresponding to its range of temperature is converted into work. The ratio of the maximum mechanical effect in a perfect heat engine to the total heat expended on it is a function solely dependent upon the initial and final temperatures at which heat is received and rejected and is independent of the nature of the working fluid.

Based upon the experiments made by Joule, Rankine and others, the following laws have been established:

1. In any heat engine the maximum useful effect, expressed in foot pounds or in percentage, bears the same relation to the total heat expended that the range of temperature bears to the absolute temperature at which heat is received.

2. In any heat engine the minimum loss of heat bears the same relation to the total heat expended as the temperature at which the heat is rejected bears to the temperature at which it is received, both being reckoned from absolute zero.

Absolute Zero. The absolute zero of temperature upon which all calculations for the efficiency of heat engines are based corresponds to the condition of the total deprivation of heat. This temperature has never been reached, the nearest approach to it being produced by the expansion in liquefying air, oxygen, and hydrogen. It has been determined by computation that 460 degrees below the zero on the Fahrenheit scale is the point of absolute zero.

The above laws, expressed in Algebraic form, are as follows:

$$E=\frac{t_1-t_2}{t_1}$$

where E is the efficiency and t_1 and t_2 the initial and final temperatures respectively and based upon the absolute zero of temperature. The only theoretical way, then, of increasing the efficiency of an elementary engine is to increase the range of temperatures between which it is worked.

This, therefore, shows that the latent heat which is common to steam is not necessarily wasted. It is often supposed that if all the heat received by the steam was expended in elevating its temperature, instead of going into a latent condition, a larger percentage could be turned into power. It has been upon this supposition that the use of most of the substitutes for steam has been based. To show that this supposition is not true, it is only necessary to consider the engine using steam as a gas without expenditure of latent heat, and compare it with results attained in engines in which latent heat is expended in the boiler and discharged in the condenser. Assume, for instance, that steam be supplied at 320 degrees temperature and exhausted from the engine at 28 inches vacuum or 100 degrees, then, according to the above formula the heat efficiency of the engine will be

$$E=\frac{780-560}{780}=28 \text{ per cent.}$$

The heat expended per pound of steam would be $220\times.475\times778=81,301$ foot pounds, of which the engine would utilize 28 per cent, or 22,764 foot pounds. Since the horse power is equivalent to 1,980,000 foot pounds per hour, there would, therefore, be required $1,980,000\div22,764=86.9$ pounds of steam per horse power per hour and that in a perfect engine; but within the same limits in an ordinary steam engine, using water with its large latent heat, a horse power is often obtained on from 16 to 18 pounds of steam. Latent heat must therefore be an efficient source of energy.

Water the Best Fluid. As the lowest available temperature and highest practical pressure are the same for all vapors, it becomes evident that that fluid having the highest temperature at the limit of pressure has the advantage, theoretically, in possible economy. Of all available liquids water fulfils this condition best, and its great abundance and low cost more than counterbalance any other advantages which other liquids might have.

Generating Steam. The chemical composition of water consists of two parts hydrogen and one part oxygen, and exists in three states or conditions—ice, water, and steam—the only difference between these states or conditions is the presence or absence of a quantity of energy which may be either indicated on the thermometer or be in the form of latent heat. If we have a pound of ice say at zero degree, by adding heat to it it will grow warmer until a temperature of 32 degrees is attained. At this point heat can be added until all the ice is melted without any difference of the temperature. After all the ice is melted, the addition of more heat will cause the temperature to again rise, but more slowly than before, because it takes about twice as much heat to raise a pound of water one degree as it does a pound of ice. The addition of more heat will cause the temperature to rise until another critical point is reached, and that is when the water starts to boil. If the water is under atmospheric pressure, it will boil at 212 degrees, and it will be found that a large quantity of heat will be required before all the water is turned into steam without raising the temperature above 212 degrees. The amount of heat which one pound of water will require in being raised from water at 212 degrees into steam at 212 degrees is equal to 966 heat units, or enough heat to have raised the water to a temperature of 1,178 degrees if the specific heat of the water had remained constant. Thus over four-fifths of the heat which has been added to the water has disappeared or become insensible to the thermometer.

After steam has been formed, a further addition of heat increases the temperature again at a much faster ratio to the quantity of heat added, according as to whether the steam is kept at a constant pressure or a constant volume. This can be continued until such a point is reached that the steam will disassociate into its original gases of hydrogen and oxygen.

The accompanying diagram, Fig. 1, shows graphically the relation of heat to temperature, the horizontal scale being the quantity of heat in British thermal units and the vertical scale the temperature in Fahrenheit degrees, both reckoned from zero. The horizontal lines of the curve show the effect of latent heat in changing from ice to water and from water to steam. In changing ice from zero to 32 degrees $32 \times .504 = 16.1$ heat units are required. In changing ice at 32 degrees to water at 32 degrees, 144 heat units are required. In changing water from 32 to water at 212 degrees, $212 - 32 = 180$ heat units are required. In changing water from 212 degrees to steam at 212 degrees, 966 heat units are required, and in changing steam to a temperature above 212 degrees, 0.48 heat units are required for each degree the temperature is raised.

Boiling Point. The above data applies only when the water is at atmospheric pressure. At any other pressure not only is the melting point and boiling point changed, but the latent heat of vaporization is also changed. The temperature of boiling and latent heat for different pressures has been found carefully by experiment, and will be found in the steam tables in this section on page 68.

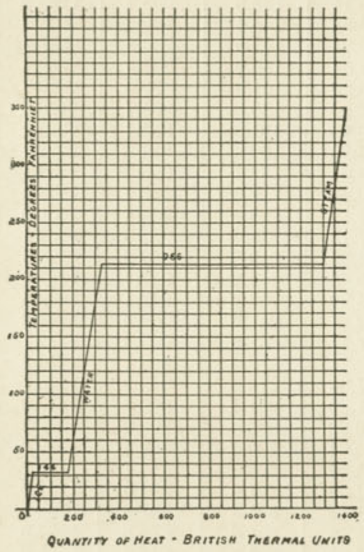


Fig. 1

Total Heat in Steam. As a result of experiments, the total heat above 32 degrees of steam for any temperature can be found from the formula

$$H = 1019.7 + .305\ (t - 32°),$$

in which t is the temperature of boiling and H the number of heat units above 32 degrees.

TABLE OF PROPERTIES OF SATURATED STEAM.

Gauge pressure in pounds per sq. inch.	Pressure in pounds per sq. in. above vacuum.	Temperature in degrees Fahrenheit.	Heat in liquid from 32°. Heat units.	Heat of vaporization, or latent heat. Heat units.	Total heat from water at 32°. Heat units.	Density or weight of cubic ft in pounds	Volume of 1 pound in cubic feet.
	1	101.99	70.0	1043.0	1113.1	0.00299	334.5
	2	126.27	94.4	1026.1	1120.5	0.00576	173.6
	3	141.62	109.8	1015.3	1125.1	0.00844	118.5
	4	153.09	121.4	1007.2	1128.6	0.01107	90.31
	5	162.34	130.7	1000.8	1131.5	0.01366	73.21
	6	170.14	138.6	995.2	1133.8	0.01622	61.67
	7	176.90	145.4	990.5	1135.9	0.01874	53.37
	8	182.92	151.5	986.2	1137.7	0.02125	47.06
	9	188.33	156.9	982.5	1139.4	0.02374	42.12
	10	193.25	161.9	979.0	1140.9	0.02621	38.15
0	14.7	212.00	180.9	965.7	1146.6	0.03794	26.36
0.3	15	213.03	181.8	965.1	1146.9	0.03826	26.14
5	20	227.95	196.9	954.6	1151.5	0.05023	19.91
10	25	240.04	209.1	946.0	1155.1	0.06199	16.13
15	30	250.27	219.4	938.9	1158.3	0.07[illegible]60	13.59
20	35	259.19	228.4	932.6	1161.0	0.08508	11.75
25	40	267.13	236.4	927.0	1163.4	0.09644	10.37
30	45	274.29	243.6	922.0	1165.6	0.1077	9.287
35	50	280.85	250.2	917.4	1167.6	0.1188	8.414
40	55	286.89	256.3	913.1	1169.4	0.1299	7.696
45	60	292.51	261.9	909.3	1171.2	0.1409	7.097
50	65	297.77	267.2	905.5	1172.7	0.1519	6.583
55	70	302.71	272.2	902.1	1174.3	0.1628	6.143
60	75	307.38	276.9	898.8	1175.7	0.1736	5.762
65	80	311.80	281.4	895.6	1177.0	0.1843	5.426
70	85	316.02	285.8	892.5	1178.3	0.1951	5.126
75	90	320.04	290.0	889.6	1179.6	0.2058	4.859
80	95	323.89	294.0	886.7	1180.7	0.2165	4.619
85	100	327.58	297.9	884.0	1181.9	0.2271	4.403
90	105	331.13	301.6	881.3	1182.9	0.2378	4.205
95	110	334.56	305.2	878.8	1184.0	0.2484	4.026
100	115	337.86	308.7	876.3	1185.0	0.2589	3.862
105	120	341.05	312.0	874.0	1186.0	0.2695	3.711
110	125	344.13	315.2	871.7	1186.9	0.2800	3.571
115	130	347.12	318.4	869.4	1187.8	0.2904	3.444
125	140	352.85	324.4	865.1	1189.5	0.3113	3.212
135	150	358.26	330.0	861.2	1191.2	0.3321	3.011
145	160	363.40	335.4	857.4	1192.8	0.3530	2.833
155	170	368.29	340.5	853.8	1194.3	0.3737	2.676
165	180	372.97	345.4	850.3	1195.7	0.3945	2.535
175	190	377.44	350.1	847.0	1197.1	0.4153	2.408
185	200	381.73	354.6	843.8	1198.4	0.4359	2.294
210	225	391.79	365.1	836.3	1201.4	0.4876	2.051
235	250	400.99	374.7	829.5	1204.2	0.5393	1.854
260	275	409.50	383.6	823.2	1206.8	0.5913	1.691
285	300	417.42	391.9	817.4	1209.3	0.644	1.553
310	325	424.82	399.6	811.9	1211.5	0.696	1.437
335	350	431.90	406.9	806.8	1213.7	0.748	1.337
360	375	428.40	414.2	801.5	1215.7	0.800	1.250
385	400	445.15	421.4	796.3	1217.7	0.853	1.172
485	500	466.57	444.3	779.9	1224.2	1.065	.939

Latent Heat of Steam. The formula for the latent heat of steam has also been found by experimentation, and is given as follows:

$$L = 1091.7 - .695\ (t - 32°),$$

in which t is the temperature of boiling, and L the latent heat of vaporization.

Saturated and Superheated Steam. Saturated steam is steam whose temperature is due to its pressure, and is the kind of steam always given off from a body of boiling water. It may be either wet or dry, depending upon whether or not it contains particles of water suspended in it. Superheated steam is steam which is heated to a temperature *above* that due to its pressure. In order to superheat steam, it must be done outside of the pressure of the water from which it was generated.

Quality of Steam. In general practice the steam given off by a steam boiler contains more or less moisture. If it contains no moisture, it is said to be dry, and the quality is 100 per cent, but if it is wet, the amount of water in the steam is expressed by the quality of the steam. Thus steam of a quality of 98.5 per cent contains 1.5 per cent moisture. The amount of moisture in the steam as given off by the boiler depends upon the design, the kind of feed water used, and the degree to which the boiler is forced.

Calorimeters. The apparatus used for determining the amount of water in the steam is called a calorimeter. In its earlier forms a barrel filled with water was used, but at the present time modern calorimeters of the throttling or separator type are used, especially if accuracy is essential.

When making boiler or engine tests, for the purpose of finding the efficiency and economy of the engine or boiler, it is very important that the amount of water in the steam be known, because in the case of a boiler, if the amount of water in the steam were not known, the efficiency of the boiler would appear higher than it actually would be, because if a certain percentage of the feed water is not evaporated the boiler does not give up the whole amount of heat which is indicated by the number of pounds of feed water evaporated, the temperature of the feed, and the pressure of the steam. In the case of a steam engine it is not fair to credit the engine with a certain steam consumption unless it is known that all the steam flowing into the engine is dry steam. Consequently it is of importance to know the general methods in use for finding the moisture in the steam.

Barrel Calorimeter. The barrel calorimeter consists of a wooden barrel placed upon a platform scale, as shown in Fig. 2. The scales should weigh accurately to the quarter pound. Into this barrel is led a pipe, either of iron or a piece of rubber hose, from the main containing the steam to be tested. The barrel should contain about 300 pounds of water, and when careful

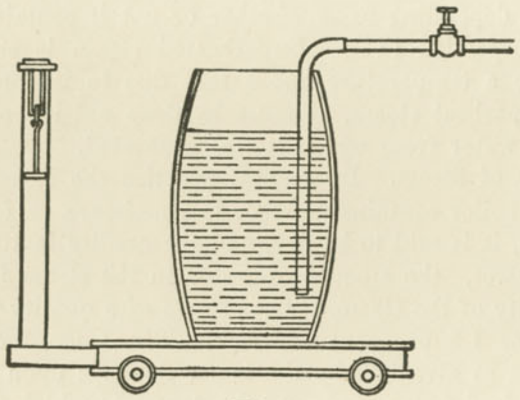


Fig. 2

measurements are required it should be covered with a lagging of good non-conducting material to prevent radiation.

In making the test for the quality of the steam the weight of the water in the barrel should be closely determined and its temperature taken, for which purpose an accurate Fahrenheit thermometer should be used. Now blow steam through the pipe into the air until all condensation is blown out of the pipe and the pipe thoroughly heated. Then turn the current of steam into the water in the barrel, keeping the end of the pipe near the bottom of the barrel, so that all the steam will be condensed. While the steam is being condensed the water should be thoroughly stirred with a wooden paddle, so as to obtain a uniform temperature throughout. When the temperature has risen to about 110 degrees, the flow of steam should be stopped and the steam pipe

removed. At the same time the temperature of the water and its weight should be found. The necessary data is now obtained for making the calculation of the quality of the steam. The steam that enters is composed partly of dry steam and partly of water, the percentage of which can be found from the formula:

$$Q = \frac{W(t_2 - t_1)}{wl} - \frac{t_1 - t}{l}$$

in which Q is the quality of the steam, W is the weight of cold water in the barrel at first; w is the difference between the first and

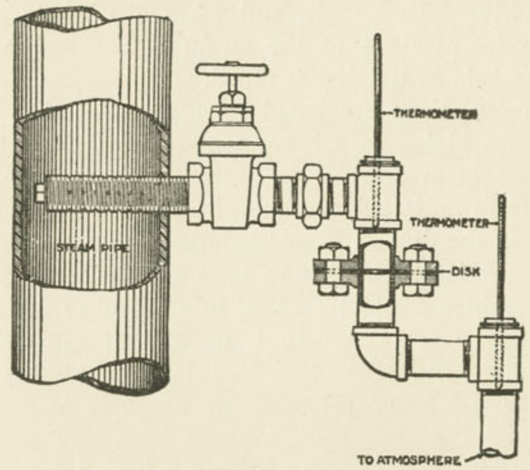


Fig. 3

last weights of water in the barrel; t_2 is the final temperature of the water in the barrel; t_1 is the original temperature of the water; t is the temperature of the steam being tested, and can be obtained from the steam table if the pressure is known; l is the latent heat of the steam at the pressure in the steam pipe, which also can be found in the steam table. The quantity Q will give the quality of the steam in per cent.

Throttling Calorimeters. Fig. 3 shows a section through a typical form of instrument. Steam is drawn from the vertical pipe by a nipple. It should be made of ½-inch pipe, and should extend across the diameter of the steam pipe to within half an inch of the other side, being closed at the end and perforated with not less than twenty $\frac{1}{2}$-inch holes equally distributed along and around its cylindrical surface, but none of these holes should be nearer than a $\frac{1}{2}$ inch to the inner side of the steam pipe. The calorimeter and the pipe leading to it should be well covered with felting. These precautions should be taken with all forms of calorimeters, so that a proper sample of the steam is obtained.

Having connected the calorimeter to the sampling pipe, steam is led around the upper thermometer cup, then through a hole about $\frac{1}{8}$ inch in diameter in the disc, as shown. It next passes around the lower thermometer cup, after which it is permitted to escape. Thermometers are inserted in the cups, which are filled with cylinder oil, and when the whole apparatus is heated the temperature of the steam before and after passing through the hole in the disc is noted.

The calculations are based upon the fact that when steam passes from a higher to a lower temperature, as in this case, no work is done in overcoming resistance, and, assuming that there is no loss from radiation, the quantity of heat is exactly the same after passing the disc as it was before. Suppose that the higher steam pressure is 150 pounds by gage and the lower pressure that of the atmosphere. The total heat in a pound of dry steam at the former pressure is 1193.5 B. t. u., and at the latter pressure 1146.6 B. t. u., difference 46.9 B. t. u. As this heat still exists in the steam of lower pressure, its effect is to superheat that steam. Assuming the steam to have been dry originally, and knowing that the specific heat of steam is 0.48, the steam will then be superheated 46.9÷0.48=97.7 degrees. Suppose, however, the steam had contained one per cent of moisture. Before any superheating could occur this moisture would have to be evaporated into steam at atmospheric pressure. Since the latent heat of steam at atmospheric pressure is 965.8 B. t. u., it follows that one per cent of moisture would require 9.65 B. t. u. to evaporate it, leaving only 46.9—9.65=37.25 B. t. u. available for superheating; hence the superheat would be 37.25÷0.48=77.6 degrees as against 97.7 degrees if the steam were dry.

Based upon these principles, any amount of moisture in the steam can be found.

Let H=total heat of steam at boiler pressure,

L=latent heat of steam at boiler pressure,

h=total heat of steam at reduced pressure after passing disc,

t_1=temperature of saturated steam at reduced pressure,

t_2=temperature of steam after expanding through disc,

0.48=specific heat of saturated steam,

x=proportion of moisture in steam.

The difference between the heat units in a pound of steam at boiler pressure and after passing the disc is the heat which must evaporate the water in the steam and do the superheating; hence

$$H-h=XL-0.48\ (t_2-t_1),$$

Or,

$$X=\frac{H-h-0.48\ (t_2-t_1)}{L}$$

In most throttling calorimeters the lower pressure is taken as that of the atmosphere, in which case h=1146.6 and t_1=212; hence the formula becomes

$$X=\frac{H-1146.6-0.48\ (t_2-212)}{L}$$

In practical work the upper thermometer can be dispensed with and an accurate steam gage used.

Napier's Law of the Flow of Steam into the Atmosphere. When steam flows through an orifice into the atmosphere, such as the hole in disc, Figs. 3 and 4, the amount of steam flowing through is proportioned to the pressure of the steam and the area of opening. Napier's approximate formula is as follows:

$$\text{Pounds of steam per second}=\frac{p\,a}{70}$$

in which p=absolute pressure in pounds per square inch and a= area of orifice in square inches.

Separating Calorimeter. The separating calorimeter mechanically separates the entrained water from the steam and collects it in a reservoir, as shown in Figs. 4 and 5. The steam flows out of the calorimeter through an orifice of known size, so that either its total amount can be calculated by the Napier formula, or it can be condensed and weighed. Fig. 4 shows one form of separator calorimeter that can be easily made. It consists of a main chamber B, to which is attached a water gage A. Above this chamber B are several other pipe connections. One of these, F, admits the steam which is to be tested for moisture. It opens into E, which

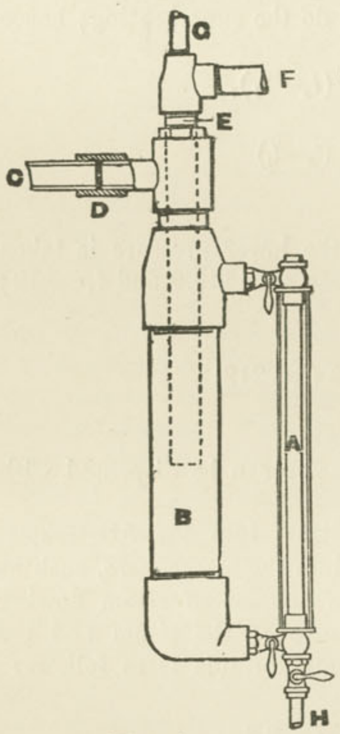


Fig. 4

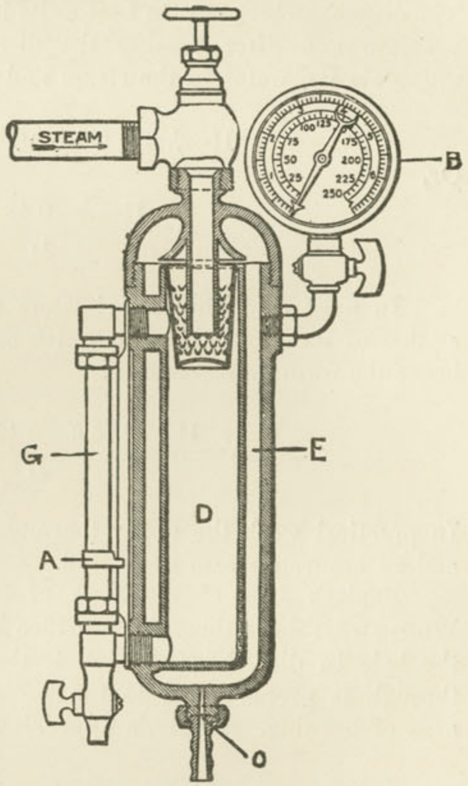


Fig. 5

is continued downward into chamber B, as shown by the dotted lines. This pipe is perforated with a large number of holes about $\frac{1}{8}$ inch in diameter. The steam, entering at F, is deflected into pipe E, and escapes into chamber B through the small holes, in doing which the moisture is removed, and falls to the bottom of chamber B. It is on this account that the name separating calorimeter has been applied to this instrument, since it acts upon

the principle of the ordinary and familiar steam separator. The steam, freed thus of its moisture, passes up and out of the pipe C. In this pipe is placed a diaphragm D, in which is drilled a hole $\frac{1}{16}$ inch in diameter. At G is a pipe opening into the space connecting F and E, to which a steam gage may be attached.

The operation of this style of calorimeter is as follows: The steam to be tested is admitted through the pipe F. As it escapes from pipe C it should be led into a tank of cold water and condensed. In beginning a test first blow steam through the calorimeter to heat it. Then turn the escaping steam into the condensing tank and note the level of the water in the gage glass A. This water level should be kept constant during the test, which can be done by d awing it off as fast as it collects through the cock A, this moisture being kept and carefully weighed at the end of the test. When the steam has run for about half an hour, the test is stopped by shutting off the steam, drawing off the water in the gage to its original level, and weighing the steam condensed in the tank. Then knowing the weight of steam W discharged from C and condensed; *w*, the weight of moisture drawn from chamber B; and the loss R due to radiation from the surface of the calorimeter; we have for the quality of the steam

$$Q=\frac{W+R}{W+w}$$

The radiation loss R is found by coupling another separator calorimeter, just like the one shown, to the pipe C. The steam leaving the first calorimeter and entering the second is dry steam, so that any moisture which collects in the latter, called R in our formula, is due to the condensing effect of the second instrument. And since the two are alike it may be taken as the radiation loss of the first also.

It may be that in some cases it would be very inconvenient to condense the escaping steam. In such a case the amount of steam escaping may be calculated according to the Napier formula by taking the exact time during which steam flows, as well as the steam pressure by gage at G.

Fig. 5 shows a separator calorimeter in which the readings can be made directly on the gages A and B. Gage A shows the number of ounces of water collected from the moisture in the steam, and gage B indicates not only the steam pressure but the amount of steam flowing through orifice 0 in 10 minutes. The steam flows through the steam pipe as shown, and is made to change its direction in going through the calorimeter, the moisture being thrown down in the interior chamber D, while the dry steam flows through the outside chamber E and out through orifice 0. The method of procedure is as follows: After the calorimeter is connected, it should be carefully insulated and warmed up by allowing steam to flow through it. When the test is started the gage hand A should be set to the level of water in D, which is indicated on gage glass G. Steam should be allowed to flow for 10 minutes, when the level of water in D should again be found, the difference in the level being the amount of moisture in the steam passing through the calorimeter. The amount of dry steam passing through 0 is indicated on gage B, which has been calibrated for all pressures. If, then, W represents the weight of dry steam and w represents the weight of the moisture, then the quantity Q can be found from the formula:

$$Q = \frac{W}{W + w}$$

Superheated Steam. Superheated steam is steam whose temperature exceeds that of saturated steam of the same pressure. It is produced by adding additional heat to saturated steam which has been removed from contact with the water from which it was formed. Its properties approximate those of a perfect gas, and it does not conduct heat as well as saturated steam.

There are several reasons why superheated steam is favored in engineering. It is used because there is always a loss of heat from radiation in steam pipes, and the heat so lost represents an equivalent condensation when the pipe conveys saturated steam. Superheated steam cannot condense; it must first lose all its superheat and be reduced to saturated steam. In consequence, if sufficiently superheated, it can lose the amount of heat represented by radiation from the steam pipes and at the same time reach the engine perfectly dry.

In the steam turbine it is used because the energy in the steam is transformed into velocity, in which case should there be any moisture in the steam it will have a tendency to corrode and

wear away the turbine blades, which would cut down its efficiency. In an engine steam is admitted to the cylinder after the metal has been cooled by the exhaust. The heat necessary to bring the temperature from that of the exhaust to that of the entering steam must be supplied by the entering steam with the result that when saturated steam is used some of it must inevitably condense. This amount of condensation may run as high as 20 to 30 per cent of the weight of the steam used. If, however, an amount of heat could be brought with the steam sufficient to warm the cylinder walls without condensing the steam, an amount of steam very much less could be used. This can be done by superheating.

Fuel Needed for Superheating. The superheating of saturated steam naturally requires heat. Based upon the fact that for every pound of saturated steam that is raised one degree, 0.48 B. t. u. is required, it can be calculated that the fuel used to generate saturated steam must be increased by about the following percentages, in order to superheat the steam to the degrees named:

Degree of Superheat.	Additional Fuel Needed.
75°	5%
100°	7
150°	11
200°	15
250°	20

In engineering practice it has not yet been definitely determined whether economy is effected by the use of superheat. It depends to a large extent upon the design of the engine. In a reciprocating engine the superheat which may be used to advantage is limited by the design of the working parts, and any considerable amount of superheat increases the difficulty of lubrication, and causes trouble with the packings. With the steam turbine the use of high superheat is not so limited, but the blades have a tendency to warp, due to the high temperature.

REVIEW QUESTIONS.

HEAT.

1. What is the nature of heat?
2. What are the sources of heat?
3. How is heat measured?
4. What is the difference between temperature and quantity of heat?
5. Explain the reasons why it requires a comparatively large amount of heat to vaporize water.
6. What is a British thermal unit?
7. How many foot-pounds of work are equivalent to one British thermal unit?
8. What is meant by an engine working in a cycle?
9. Is a steam engine a heat engine?
10. What is the absolute zero of temperature, and of what use is it in making calculations for efficiency of heat engines?
11. Describe the difference between saturated and superheated steam.
12. What kind of steam is usually given off by a steam boiler?
13. What is a calorimeter?
14. Mention some of the different types of calorimeters in general use.
15. What is Napier's law?
16. When would you use superheated steam to replace saturated steam?
17. Suppose steam was supplied to an engine at 350 degrees Fahrenheit, and exhausted from the engine at 212 degrees, what would be its heat efficiency?
18. If in a sample of steam 100 pounds of steam were condensed for every 2½ pounds of water that was collected in the calorimeter, what per cent of moisture would the steam contain?
19. Suppose in a throttling calorimeter the initial pressure was 100 pounds absolute, and it was found that the steam was superheated 10 per cent after it was expanded to atmospheric pressure, what per cent of moisture would the steam contain?
20. What precautions should be taken when using a barrel calorimeter?
21. Explain the difference between radiation, conduction, and convection.
22. Are there any substances that expand when they are solidified ?
23. How can superheated steam be changed to saturated steam?
24. If a pound of good coal gives out 14,000 heat units, how many foot-pounds of work would it give out if all the heat was utilized?

COALING STATION OF THE LAKE SHORE & MICHIGAN SOUTHERN RAILROAD

Located at Wick, Ohio. Delivery is Made from Four 10-Ton Auxiliary Scale Pockets. Total Storage, 500 Tons

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Fuels and Combustion.

COAL.

The vegetation that flourished on the earth in bygone ages, long since buried and stored, has, after undergoing certain changes, yielded to man the energy stored within itself and is now depended upon universally in the conduct of business and manufacturing. Long before man existed, the vegetable kingdom stored up carbon in trunks, branches, stems, and roots. These fell into the water, which made around them and were later covered by clay and sand beds, excluding the air, which would have caused the disintegration of the carbon. In layers are found these deposits, and in such quantity that, though we have been picking out the coal for long years, yet by various soundings and borings we know that there is still enough beneath the surface to last some generations.

Anthracite Coal is very nearly pure carbon; some organic matter is held with the carbon, and usually some hydrogen, oxygen, nitrogen, and sulphur. Usually there is little or no hydro-carbon, that is, chemically combined hydrogen and carbon.

The anthracite from Pennsylvania is a standard type, while there is a variety found in Rhode Island which is exceedingly hard, almost as hard as graphite, being one of the amorphous forms of carbon; it burns with some difficulty. Anthracite of a good grade burns with but little smoke, if dry; is hard, breaks with a vitreous fracture; makes a very hot fire, but is likely to crack into small pieces when fired into a hot furnace, occasioning some loss through the grate bars.

Bituminous Coal contains less fixed carbon than anthracite, and correspondingly more volatile matter. Its chief distinguishing characteristic is its *coking* property. As the mass heats up, after the volatile portions are drawn off, it is found to have swelled up, taking on the new form. The coke so formed burns freely and with intense heat. Coke for metallurgical and other purposes is made in retorts where the by-products are illuminating gas, ammonia liquor, and coal tar, this latter compound yielding a variety of substances, prominent among which are benzene, creosote, pitch, aniline, and alizarine.

Semi-Anthracite and *Semi-Bituminous* coals are often referred to as grades lying between the two principal classes, and are named according to which class each lies the nearer. Bituminous coals are often further classified as follows:

Clean burning or dry, without caking.

Coking, rich in bitumen, which swells up and cakes—good for gas distillation.

Long Flaming or *Cannel,* which may or may not cake.

Lignite, often referred to as brown coal, is probably of more recent formation than coal proper, and can be considered only in the light of a substitute where coal is unobtainable. It is lighter than coal, and does not emit as much heat upon combustion.

Peat. In bogs the accumulation of roots, branches, etc., continuing for some time, gives a fuel known as peat. It is cut out in blocks, stacked up to dry, and in the absence of other fuel becomes quite serviceable. As in the case of lignite, it would scarcely be considered for steaming purposes, except where coal cannot be had.

Slack. Hard coal is screened to separate the dust from the coal proper. Several different sizes of coal are sorted out and named from furnace to rice, the names varying with locality, but the refuse too small for use is often called slack. Some of the sizes may be mentioned as follows: Furnace, egg, stove, nut, pea, buckwheat, numbers are one, two, and three, and rice.

Some authorities refer to the larger screenings as *rough slack,* the smaller as *small slack,* and the dust as *duff or smudge.*

Buckwheat is a favorite size for many, as it handles readily, permits of a grate bar with openings large enough to secure a good draft and yet not allow the fuel to waste.

In many cases buckwheat does not give out as many heat units as average bituminous, but the cost of the coal, where transportation allows, still makes it the cheaper fuel. As a general thing, too, it will not permit of as much forcing as will soft coal, but except for some special reason it is not a good thing to depend upon forcing a boiler. Rather increase the battery the necessary amount to secure the desired steam. Buckwheat and soft coal are sometimes mixed in proportions ranging all the way from one-third to two-thirds of the mixture or more, the exact proportions, fitted to the steaming qualities, cost, etc., being arrived at quite easily in any one plant. Among the points to be considered are the heat units in each kind of coal, freight rates, steaming capacity, draft, etc.

Wood may be classed with peat and lignite, so far as steaming properties are concerned. It is likely to have, when normally dry, about one-fourth of its weight water; it kindles quickly, and when used in a boiler test to start a new fire may be figured as from $\frac{1}{4}$ to $\frac{1}{2}$ of its weight in coal. Hard wood is often considered as the equivalent of a little less than one ton of average coal per cord of wood, while the soft woods may go to less than one-half this amount. Some plants have a sufficient amount of sawdust, shavings, and waste pieces to make all the steam used. The furnace doors are ordinarily made large with accompanying mouthpiece, so that the pieces of wood may be thrown in with as little labor as possible. In a planing mill where a sufficient quantity of planer shavings is made continuously, a very neat and profitable arrangement is to carry the shavings directly from the bonnets over the planer cylinders to the boilers. There should, of course, be a separator to allow the escape of such portion of the air blast as is not necessary to throw the shavings across the grates without cooling the fires by too much air overhead.

Charcoal is made by subjecting wood to heat, without allowing access of air, which would cause it to burn. The volatile portions are driven off and the remainder is nearly pure carbon. Charcoal burns with a very clean, strong heat, and is useful in certain reductions, but is seldom thought of in connection with a boiler plant as fuel.

Liquid Fuel. Usually this is some form of petroleum, and is used by spraying it into the furnace, either by air or steam jet, and gives an intense heat which is easily controlled. Unless special precautions are taken, there will be a soot, tending to choke up passages and tubes; an elevated temperature, assisted by a form of muffle and plenty of air, will reduce the difficulty, however. The accompanying diagram, Fig. 1, represents an ordinary horizontal boiler; an arch M made of the best fire brick is thrown over in the furnace directly in front of the blast coming in through the nozzle N. The arch acting as a muffle serves to render the combustion more complete. For burning coal, some boilers have been set to advantage with an arch directly over the front of the grate. The arch reflects heat on the green coal as fired, helps to cake it and to render the combustion of the volatile products more complete.

Gaseous Fuel. In the fields of natural gas, or by the blast furnaces of the iron districts, a boiler may be set to be operated by these forms of heat to good advantage. As generators are now set in "producer" plants, it is both desirable and economical to lead the hot gases from the combustion chamber through a boiler, thereby cooling the gases on their way to the holders, or directly en route to the cylinders, if it be a suction plant, and securing a

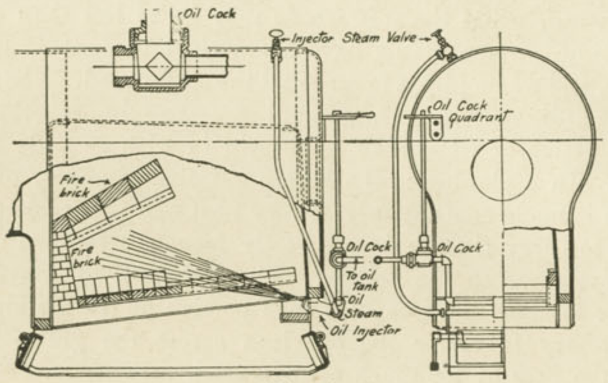

Fig. 1

source of steam for auxiliary purposes and for generating water gas from time to time.

Alcohol, Gasoline, or **Petrol,** as the latter is sometimes called, and *Kerosene* may be used in small units for the generation of steam, though the question is one more of convenience than of efficiency. The future of alcohol, denaturized, that is, containing some poison rendering it unfit to use internally, is somewhat problematical, but at present looks promising. Alcohol,* sometimes known as Spirits of Wine, may be made from a great variety of vegetable growths; chemically, it is merely carbon two parts, hydrogen six parts, and oxygen one part. In isolated districts, with the excise tax removed, it may serve the small user of power very acceptably, either in an explosive engine or to generate steam. It burns with a great heat in a clean, blue flame.

* Chemically there are many alcohols; this one is *ethyl* alcohol.

Pressed Fuels. All sorts of combustible material may be pressed into briquettes by the use of some bonding material, such as tar, and thus serve to save fuel, which, where its cost is high, would occasion a considerable loss.

Other fuels might be mentioned, such as bagasse, the refuse of cane after extracting the juice, spent tan bark, straw, etc., but their uses are local, and the question of efficiency as steam producers is not of moment. There is, of course, an importance connected with the particular industry to which each waste product may lend an item of saving, but in many cases the question is partly that of saving the cost of disposition of the waste, or some other local question which is apart from the one of buying fuel outright.

COMBUSTION.

By this term is meant in general the chemical combination of oxygen with the various elements of the fuel, attended by the evolution of heat; in short, it is *burning.* In coal we find by analysis carbon, hydrogen, oxygen, nitrogen, sulphur, and ash. Of these, certain portions are already in combination, as for instance in the case of water, known chemically as H_2O, where two parts of hydrogen are combined with one part of oxygen. Water can be broken up by heat, but it would absorb a certain amount of heat to do this, and the heat would be given back again only when the hydrogen is burned. Carbon burns to two gases, carbon monoxide, CO, that is, one atom of carbon combined with one of oxygen, and also to CO_2, carbon dioxide, more commonly known as *carbonic acid gas,* in which one part by volume of carbon is combined with two parts of oxygen.

Carbon monoxide may be further burned to carbon dioxide.

Hydrogen burns to H_2O (water), and sulphur to SO_2 (sulphurous acid), but the amount of sulphur in most coals is so small that the heat liberated by this combustion is negligible. Nitrogen acts as a diluent to the oxygen, and does not enter into combination during the combustion. It carries away a certain amount of heat, however, in passing through the fire. Oxygen combines with the combustible elements in burning; it is the element which supports life as we breathe it in from the air.

All coals leave a certain amount of ash or incombustible residue. As ashes are raked out from the pit hot, they withdraw a certain amount of otherwise useful heat, and thereby reduce the efficiency proportionally; then, too, they serve to make trouble above the grate bars in forming clinker.

Atmospheric Air is composed of oxygen and nitrogen mechanically mixed in the ratio of nearly four parts of nitrogen to one of oxygen. The atomic weight of nitrogen is 14 and of oxygen 16, hence the mixture of the two is sensibly uniform at all times. It may be noted in passing that, although the air is considered as constituted as above stated, there is a difference between the weight of nitrogen obtained from air by extracting the oxygen and that obtained from ammonia. Lord Rayleigh and W. Ramsay have demonstrated that nitrogen obtained from the air contains about one per cent of *argon,* a heavier substance. It does not seem to influence combustion, however, and as it is present in so small an amount, may for practical purposes be disregarded. Surely we know that some other errors are greater than this. Some other gases are present in air, but they are even less in amount than the argon.

COMPOSITION OF FUELS IN PER CENTS.

Mahler gives a table from which the following figures were obtained:

Kind of Coal	Carbon %	Hydrogen %	Oxygen and nitrogen %	Hygroscopic water* %	Ash %	Per cent volatile matter exclusive of water and ash
Anthracite.........	86-87	1-2	2-4	3-5	4-6	2-3
Semi-anthracite......	82-85	2-3	3-6	1-2	5-6	5-6
Semi-bituminous....	85-88	4-5	4-5	1-2	2-4	11-14
Bituminous.	82-84	4-5	5-6	1-2	4-5	20-22
Cannel.......	78	5	5	1	11	32
Lignite..............	60-65	4-5	24-26	1-3	5-7	49-51
Norwegian Pine....	47.4	5.6	39.8	6.9	0.3	68.9
Coke................	90-95	0.4-0.7	2-3	0.3-0.5	3-6	68.9

Other writers quote figures showing that from Anthracite the carbon falls off until in Bituminous we have only in the neighborhood of 60 per cent. Often the "fixed carbon" is quoted,

* Not the water that the coal would hold, as, for instance, after being wet with hose, but rather that taken up from the air by dry coal.

meaning such portion as is not distilled off as smoke or vapor by the heat of the fire. A "proximate analysis" gives

Water,
Volatile matter,
Fixed carbon,
Ash,

while an "ultimate analysis" gives the proportions of the several elements in the fuel. As we shall see later, the carbon which is burned is the chief source of heat in coal, and, therefore, when we have a proximate analysis before us we can judge well of the commercial value of the sample. In an ultimate analysis some sulphur is in the ash, hence *volatile sulphur* is reported separately. It is obvious that for the purposes of a boiler test the total sulphur is not of as much interest as is the part that enters into the combustion.

Mechanical Mixture. If a pile of sulphur and copper filings were well stirred, the particles of each could be separated by the exercise of great patience, aided perhaps by a magnifying glass. Here the mixture would be called *mechanical* or *physical.*

Chemical Compound. If now we apply heat to our pile of copper filings and sulphur, the mass will fuse and glow and we cannot distinguish either copper or sulphur, even with a strong glass. We have a new compound, namely, sulphide of copper. When we burn coal, we are making new chemical compounds, partly by the combination of simple elements, such as carbon and oxygen, and partly by breaking down combinations and forming others. The various elements combine with one another in response to well-defined laws, and the proportions of each are multiples of their atomic weights, the atomic weight being with reference to hydrogen, which is thus far the lightest known substance.

For example, water is H_2O, that is, two volumes of hydrogen and one of oxygen; assuming H (hydrogen)$=1$, then O (oxygen) $=16$. Hence the molecule of water is $(2\times1)+16=18$ times as heavy as an atom of hydrogen. Again, when carbon and oxygen combine to form carbonic acid gas or CO_2, we have 1 volume of carbon, or 12 parts by weight unite with 2 volumes of oxygen, or 32 parts by weight making $12+32=44$, the molecular weight of the CO_2 gas. If the carbon is brought into contact with more oxygen under the same circumstances, it will not take up any more. If it does not find as much as this, it will form CO or carbon monoxide, or 12+16=28 parts by weight. But this same CO gas would, if presented with a supply of oxygen, burn into CO_2 gas, as CO+O=28+16=44. Only about one-third the heat is generated when C burns to CO as when C burns to CO_2; hence it is important in a boiler to have sufficient air for complete combustion.

Chemical Symbol or Letter.		‡ Atomic Weight.	Molecular Weight.	§ Specific Volume.	Weight One Cubic Foot or Density.	Specific Heat of Gas
Hydrogen - -	H	1		178.881	0.005590	3.409
Carbon - -	C	12		. . . . . .		
Nitrogen - -	N	14		12.7561	0.07837	0.2438
Oxygen - -	O	16		11.2070	0.08928	0.2175
Sulphur - -	S	32				
Water - -	H_2O		18			0.4805 ||
Carbon Monoxide	CO		28	12.81	0.07806	0.2450
*Carbon Dioxide	CO_2		44	8.10324	0.12341	0.2169
Air - - - - -		. .	. .	12.3909	0.08071	0.2375
Ash - - - - -		. .	. .	....	....	0.2†

|| Superheated steam.

† Solid state.

‡ The figures in this column are given in round numbers. The exact values vary slightly in some cases.

§ Temperature 32° F., atmospheric pressure.

* Another name for carbonic acid gas.

HEAT OF COMBUSTION.

A British thermal unit, written for brevity B.t.u., is defined as the amount of heat necessary to raise a pound of water one degree on the Fahrenheit scale; or more exactly, is the heat necessary to raise the temperature of one pound of water from 62° F. to 63° F., the specific heat of water being at this point unity. The Calorie is the French unit and is the heat necessary to raise the temperature of one kilogram of water from 15° Centigrade to 16°. The heat evolved in the combustion of fuel is commonly expressed in one of the above units; experimentally, it is found by burning a given weight of the fuel in some form of calorimeter, a device which is so arranged as to allow an amount of water to be heated by the combustion. One form of calorimeter is a bomb, made in halves, allowing the fuel to be placed within, then igniting it while surrounded by oxygen under pressure. If the bomb be placed in a vessel containing water, the initial and final temperatures may be taken, when, knowing the weight of water, the B.t.u. may be determined. For instance, assume

Water, 3 pounds	
Initial Temperature,	60° F.
Final Temperature,	65° F.

Then (65—60)×3=15 B.t.u.

A correction must be applied for the metal of the calorimeter itself, and this is previously determined by experiment. The inside of the bomb should be plated with gold to resist chemical action, while the bomb should be of wrought iron or high grade gun-metal to withstand the pressure. The charge is ignited by an electric current. Many experiments are necessary in the actual manipulation of such a piece of apparatus; for example, the charge is relatively small, so that the actual rise in temperature is necessarily read by means of a thermometer with a very fine bore; and the water in the calorimeter must be properly circulated that the temperature read may represent the true one. A correction should be made for radiation also. Thus it will be seen that the work is to be performed in a laboratory and by a physicist rather than by an engineer.

A form of calorimeter has been devised where the operation is more simple than in the case of the bomb, the source of oxygen for the combustion being some compound which will liberate it, not too fast, but suitably to complete the combustion;* sodium peroxide is an example. Many large industrial concerns having laboratories are installing such calorimeters, and are requiring that all cargoes of coal shall not fall below a certain number of B.t.u. to the pound.

*Chlorate of potash and nitrate of potash mixed are also used. The chlorate should be used with caution, however, as it liberates oxygen very readily.

The following table, quoted from Peabody & Miller, gives values for the heat evolved in several different cases:

1 lb. Hydrogen	burned	to H_2O	- -	62100 B.t.u.
" Carbon	"	" CO_2	- -	14650 "
" Carbon	"	" CO	- -	4400 "
" CO	"	" CO_2	- -	4393 "
" Marsh gas	"	" H_2O & CO_2	-	23513 "
" Olefiant gas	"	" " " "	-	21343 "
" Sulphur	" "	" SO_2	- - -	4032 "

When CO is formed we have

C+O=CO, that is by weight,
12+16=28, or for one pound of C

$$\frac{28}{12}=2.33+\text{lbs. CO.}$$

1 lb. C burned to CO_2=14,650 B.t.u.
1 lb. C burned to CO=4,400 B.t.u.

Hence, as one pound of C forms 2.33+ pounds CO, then when 1 pound of CO burns to CO_2 we shall have

$$\frac{14650-4400}{2\frac{1}{3}}=4393 \text{ B.t.u.}$$

Of course, if the CO, which is the product of burning one pound of carbon, (forming $2\frac{1}{3}$ pounds of CO) is burned to CO_2, then the difference between 14,650 and 4,400, or 10,250 B.t.u., will be liberated.

To calculate the heat of combustion we can take each of the component parts of the fuel, and, knowing what the products of combustion are, find the heat produced by each; the sum of these parts will represent the total heat. For example, if we have one pound of a mixture of phosphorous* and carbon, 70 per cent of the former and 30 per cent of the latter, then will the total heat be

$$0.70\times 13{,}500+0.30\times 14{,}650=13{,}845 \text{ B.t.u.}$$

So far as we know or can analyze the action of the combustion, we can come very close in the above method of computation

*1 pound of phosphorous liberates 13,500 B.t.u.

to the results obtained by experiment with the calorimeter. Unfortunately, however, carbon and hydrogen, for example, seldom exist entirely independent of each other in coal, so that we are in error when we assume that they burn as simple elements. It is of value, however, to be able to predict results from analysis, and a discussion of the computations is given.

Dulong proposed that the following formula be used:

$$14{,}650C+62{,}100(H-\tfrac{1}{8}O)=\text{total heat.}$$

Here C, H, and O are the weights of these several elements in one pound of the fuel, and not as heretofore used in the chemical formula. This formula assumes that the oxygen in the fuel unites inertly with so much of the hydrogen as is necessary to make H_2O, or water, and this is from the atomic weights and atoms of each in a molecule of water

$$2\times 1\div 16=\tfrac{1}{8}$$

Hence, one-eighth of the weight of the oxygen is taken from the hydrogen, and the remainder assumed to burn independently and with the evolution of sensible and useful heat. The results of this equation are likely to be somewhat in error. Mahler has given an equation

$$14{,}650C+62{,}100H-5{,}400(O+N)=\text{heat in B.t.u.,}$$

where the letters represent as before the weights of the several elements in one pound of fuel.

A certain coal analysis is as follows:

C=	78.53	per cent.
H=	5.61	" "
N=	1.00	" "
S=	1.11	" "
O=	9.69	" "
Ash=	4.03	" "

By Dulong's formula the heat would be

$$14{,}650\times 0.7853+62{,}100\left(0.0561-\frac{0.0969}{8}\right)=14{,}240 \text{ B.t.u.}$$

Mahler's formula gives for the same sample

$$14{,}650\times0.7853+62{,}100\times0.0561-5{,}400\times(0.0969+0.0100)=14{,}412 \text{ B.t.u.}$$

By experiment the heat was found to be 14,868 B.t.u.

In the foregoing the sulphur was ignored; this would have amounted to $0.0111\times4{,}032=44.8$ B.t.u., which added to the units as above computed would make.

14,240+45=14,285....Dulong.
14,412+45=14,457....Mahler.

It may be remarked that the sulphur is rather high in this case for good coal; very often it goes below one per cent.

That one formula gives a result nearer the experimental figure than the other is not to be taken as of any great significance as to the merit of one over the other. In the long run Dulong's formula gives results which are useful in securing some general notion of the heat of a sample, where an analysis is available, but where no calorimeter test is made. For data in computing a boiler test, recourse should always be had to the calorimetric determination of the B.t.u. in the coal used.

Air for Combustion. As previously stated, the ratio of O to N in the atmosphere is very nearly 1 to 4 by volume. By weight it is about 23 to 77.* As explained previously, the argon may be left out of consideration.

One pound of hydrogen requires for its combustion to water $\frac{16}{2}$ or 8 pounds O. As the air is 23 per cent O by weight, then will one pound of H require $\frac{8}{0.23}=34.8$ pounds of air. One pound of carbon requires for its combustion to carbonic acid gas, CO_2, $2\times16\div12=2.67$ pounds of oxygen, and as above this is $2.67\div0.23=11.6$ pounds of air, meaning, of course, that to burn the carbon completely there must be furnished at least 11.6 pounds of air in order to supply the oxygen for the combustion. The

* A more exact ratio is 0.232 to 0.768.

nitrogen is entirely inert and dilutes the oxygen. If the carbon is burned to CO then we shall need $\frac{16}{12}=1.33$ pounds of oxygen per pound of carbon, or $\frac{1.33}{0.23}=5.8$ pounds of air.

Marsh Gas, CH_4 burns to CO_2, and H_2O.

$$CH+4O=CO_2+2H_2O.$$

To burn this will require

$$\frac{4\times16}{12+(4\times1)}=4 \text{ pounds oxygen per pound } CH_4, \text{ or } 4\div0.23=17.4 \text{ pounds air.}$$

The calculated heat of combustion would be*

$$\frac{12}{12+(4\times1)}\times14{,}650+\frac{4\times1}{12+(4\times1)}\times62{,}100=26{,}510 \text{ B.t.u.}$$

Olefiant Gas, C_2H_4 burns to CO_2 and H_2O.

$$C_2H_4+6\,O=2\,H_2O+2\,CO_2.$$

$$\frac{6\times16}{(2\times12)+(4\times1)}=3.43 \text{ pounds oxygen,}$$

or $3.43\div0.23=14.9$ pounds air.

The heat evolved would be

$$\frac{4\times1}{(2\times12)+(4\times1)}\times62{,}100+\frac{2\times12}{(2\times12)+(4\times1)}\times14{,}650=21.430 \text{ B.t.u.}$$

Sulphur burns to sulphurous anhydride (SO_2)

$$S+2O=SO_2$$

$$\frac{2\times16}{32}=1 \text{ pound oxygen per pound S}$$

$$1\div0.23=4.35 \text{ pounds air.}$$

* Disregarding the heat due to the methane:

Substance to be burned.	Atomic or molecular wt.	Product of combustion.	O per lb. combustible.	* Air per lb. combustible.	B. t. u. liberated per lb. combustible.
Hydrogen (H)	1	H_2O	8.0	34.8	62,100
Carbon (C)	12	CO	1.33	5.8	4,400
Carbon (C)	12	CO_2	2.67	11.6	14,650
CO	28	CO_2	0.57	2.5	4,393
Marsh Gas (CH_4)	16	CO_2 & H_2O	4.00	17.4	26,510†
Olefiant Gas (C_2H_4)	28	CO_2 & H_2O	3.43	14.9	21,430†
Sulphur (S)	32	SO_2	1.0	4.4	4,032

A convenient figure for general use is, that one pound of carbon requires 12 pounds of air, and it is arrived at as follows: Assuming that the atmosphere is composed of one volume of oxygen to four of nitrogen, and remembering that with the atomic weight of hydrogen 1, oxygen is 16 and nitrogen is 14, to find the amount of air necessary to yield one pound of oxygen we shall have the following:

$$\frac{(16\times1)+(14\times4)}{(16\times1)}=4\tfrac{1}{2}.$$

We have already found that in burning one pound of carbon $2\frac{2}{3}$ pounds of oxygen are necessary, so that the air necessary to burn one pound of carbon will be $4\frac{1}{2}\times2\frac{2}{3}=12$ pounds, as above stated. Eight pounds of oxygen are necessary to burn one pound of hydrogen, hence the air to furnish this amount of oxygen will be $8\times4\frac{1}{2}=36$ pounds. We have already seen that the greater part of the heat evolved in the combustion of coal is due to the carbon, and next comes the hydrogen. Sulphur is not desirable, but even if present adds but little to the heat units.

Even though it may not be extremely accurate, the formula of Dulong is convenient for an estimation of the value of a sample, and, combined with the constants just calculated, forms a ready means of computation, as for instance for the air per pound of fuel. The formula would read then

* Using the proportions of O & N as 0.23 and 0.77.
† Calculated by formula.

$$12\ C+36\ (H-\tfrac{1}{8}\ O)=\text{pounds air per pound of fuel.}$$

C is taken as the amount of carbon in a pound of fuel, H similarly for the hydrogen, O similarly for the oxygen; and the formula assumes that of the combined hydrogen and oxygen each pound of the latter renders one-eighth of a pound of the hydrogen inert. A certain coal is analyzed as follows:

Carbon, 81.0 per cent.
Hydrogen, 5.0 per cent
Oxygen, 4.0 per cent.

Then applying the formula we shall have

$$12\times0.81+36\ (0.05-\frac{0.04}{8})=11.34 \text{ pounds air per pound of coal.}$$

This is, of course, but a rough-and-ready method, and the results must be used accordingly.

We may further apply this method to CH_4, Marsh gas, which is composed as follows:

$$\frac{12}{12+(4\times1)}=\tfrac{3}{4}\text{ carbon}$$

$$\frac{4\times1}{12+(4\times1)}=\tfrac{1}{4}\text{ hydrogen}$$

$$\tfrac{3}{4}\times12+\tfrac{1}{4}\times36=18\text{ pounds air,}$$

while by the previous method we found that but 17.4 pounds were necessary.

Excess of Air. When green (fresh) coal is thrown on the fire there is an immediate distillation of the volatile portions of the coal, together with the formation of more or less carbon monoxide (CO), all of which pass over into the combustion chamber. It has been found in practice that more air must be admitted than that which is absolutely necessary for complete combustion, so that these various gases may be burned before leaving the boiler. The amount of this additional supply varies from one-half to an amount equal to the supply as figured. It necessitates heating up so much the more air, which, escaping up the stack, takes away a certain amount of heat, but usually this loss is less than would be occasioned by incomplete combustion.

Upon reference to the table it will be seen that carbon burned to CO_2 gives off 14,650 B.t.u., while burned to CO but 4,400 B.t.u. are liberated. The question of smoke is largely regulated by this matter of air supply as well; to be sure the stoking is the prime factor, quite as much in fact as the question of fuel, that is at least, considering the soft coals in general. Anthracite coal gives little or no smoke, even if badly fired; there may be a considerable waste, but so there is with soft coal if it is dropped through the grate bars. Even though it contains a large proportion of fixed carbon, there are gases which should be burned in the combustion chamber. With the soft coals there are the gases as well, but in addition are the unfixed portions of the carbon which add to the smoke, particularly if a large amount of coal is fired in one charge, and then the fire vigorously sliced. Of course, it is detrimental to leave the fire doors open too long, or what amounts to the same thing to open them too often, for the cool air admitted chills the fire and interferes with the steaming; but, nevertheless, thin, even firing, or firing one door of the furnace, that is, for example, firing the left-hand doors, then the right-hand doors, gives much better results than filling up a furnace all at once. In such a case, the volatile gases have a chance to be heated up by the bright side of the fire and there burned.

On the foregoing basis we should furnish air as follows:

	Normal	50% excess	100% excess
Carbon	12 pounds	18 pounds	24 pounds
Hydrogen	36 pounds	54 pounds	72 pounds

Volume of Air. In the case of any fluid flowing through an opening or a pipe, if we know the area of the opening and the velocity of the current, we can calculate the quantity flowing in a unit of time. Air currents are measured by anemometers, which are usually instruments fitted with revolving vanes, the speed of the revolution being proportional to the velocity of the current. These instruments must be carefully calibrated and then are subject to corrections for the different speeds.

If a pipe of known area be fitted over the ashpit doors, removable, of course, to allow for cleaning the ashes out, and the air velocity found by means of an anemometer, the quantity of air can be found for the given temperatures. Perfect gases obey the law

$$\frac{pv}{T}=\frac{p_1v_1}{T_1}=c$$

where p=pressure,
v=volume at the given pressure,
T=absolute temperature corresponding,
c=constant,
and p_1v_1 and T_1 any other set of pressure, volume, and temperature determinations.

T is found by adding to the observed temperature on the Fahrenheit scale the constant 460.7; that is, the absolute zero is 492.7° below the freezing point of water on the Fahrenheit scale. On the Centigrade scale it would be —273.7°. If then, from the table* showing specific volumes we take air=12.3909, this means that at 32° F. and under an absolute pressure of 14.7 pounds per square inch one pound of air will occupy 12.3909 cubic feet, or one cubic foot of air will weigh 0.08071 pound. To find the volume of the pound of air at, for instance, 65° F. we have

$$\frac{14.7\times 12.3909}{32+460.7}=\frac{14.7\times v_1}{65+460.7}$$

$$v_1=13.22 \text{ cubic feet.}$$

In the above the pressure of the atmosphere is taken as 14.7, and, of course, appears on both sides of the equation. If the final pressure were changed, that is, if the barometer reading showed another pressure and the refinement were necessary, the pressure should be used accordingly.

To find the atmospheric pressure from the barometer reading, multiply the latter in inches by 0.491, the weight of a cubic inch of mercury. When the barometer height is 29.96 inches, then 29.96×0.491=14.7 pounds per square inch nearly.

* P 86

At 60° F. the volume of one pound of air is very nearly 13 cubic feet, this figure being close enough for approximations; in the case of the coal, where it was found to require 11.34 pounds of air per pound of coal, we should have $11.34 \times 13 = 147.4$ cubic feet of air, or with 100 per cent excess $2 \times 147.4 = 294.8$ cubic feet. Suppose we wish to find the weight and volume of air, allowing 100 per cent excess for this same coal; barometer, 30.3 inches, temperature of air, 75° F.

Coal Analysis.

Carbon	-	-	81.0 per cent.
Hydrogen	-	-	5.0 per cent.
Oxygen	-	-	4.0 per cent.

Assuming that the oxygen combines directly with one-eighth of its weight of the hydrogen, there will remain $0.05 - \frac{0.04}{8} =$ 0.045 pound of hydrogen from each pound of fuel, to which oxygen must be supplied from the air. Each pound of carbon requires $2\frac{2}{3}$ pounds of oxygen and the hydrogen 8 pounds, so that the oxygen per pound of the coal chosen will be $(0.81 \times 2\frac{2}{3}) + (0.045 \times 8) =$ 2.523 pounds, but as air contains by weight 23.2 per cent of oxygen, we shall need $2.523 \div 0.232 = 10.88$ pounds. With 100 per cent excess we shall have 21.76 pounds air at 32° F. and at 14.7 pounds per square inch pressure.

At 30.3 inches the air pressure is $30.3 \times 0.491 = 14.9$ pounds per square inch, nearly. Then the volume at this pressure and a temperature of 75° F., the volume at 32° F. being $21.76 \times 12.39 = 269.6$ cubic feet, is found as follows:

$$\frac{14.7 \times 269.6}{492.7} = \frac{14.9 \times v_1}{535.7}$$

$v_1 = 290$ cubic feet, nearly.

Analysis of Flue Gas. It is both useful and important to know what gases are escaping through the stack, and sometimes to know about the gases directly over the fire, in the combustion chamber, or at other points. While a complete analysis showing all these gases, including water vapor or steam and the compounds of carbon and hydrogen, would be interesting, still such an analysis would be attended with many difficulties, and to be of value should be made with considerable refinement. As the conditions of the fire are constantly changing, a single determination is not of much value. When the fresh coal is fired there is, of course, an inrush of air while the doors are open; then the volatile matters, such as pass off in the smoke, are thick. When the charge of coal has burned for a while, the more stable portions of the fuel give off the more regular products of combustion. Again, when the fire is sliced still other conditions come, so that, in order to be able to draw any conclusions from our analysis, we must have many samples, drawn successively as the conditions vary. As the combustion is well determined by the relative amounts of carbonic acid gas, carbon monoxide, and free oxygen, a device known as the *Orsat Gas Apparatus* has been constructed, enabling the speedy and accurate determination of the above-mentioned gases. Its action depends upon the power of certain solutions to absorb the gases in question.

Caustic potash solution absorbs carbonic acid; pyrogallic acid and caustic potash, together in solution forming pyrogallate of potash, absorb oxygen; and chloride of copper dissolved in hydrochloric (muriatic) acid absorbs carbon monoxide.

The apparatus is mounted in a neat wooden case, whose sides are removable, so that while it may be readily carried from place to place with the glassware within properly protected, the parts may be made entirely accessible when working with it. It consists chiefly of three receptacles (see Fig. 2), A, B, and C containing respectively the solutions of caustic potash, pyrogallate of potash, and copper chloride in hydrochloric acid. Each receptacle is of glass, and is connected at the bottom by an inverted siphon with another similar receptacle, A, B, and C, respectively, of equal volume; these have at the tops a stopper and nipple carrying a rubber bag, tight except where drawn over the nipple and capable of receiving the contents of the glass receptacle to which each is attached, then allowing these contents to flow back when the pressures permit. The receptacles A, B, and C may be connected with the leading tube D through which (and controlled by the three-way cock *E*) comes the gas to be analyzed. *R* is a burette, graduated and marked with 100 divisions, enabling per cents to be read directly. *F* is a bottle connected with the bottom of the burette by means of a flexible rubber tube, this latter being provided with a pinch clamp *h*. Ordinarily, the bottle *F* is filled with water, although should it be desired to determine the water vapor in the gas mixture some other fluid could be used in *F*. The several solutions, as already noted, are placed in the proper receptacles A, B, and C, filling them up to the marks *a, b,* and *c* on the narrow stems, and the cocks connecting with *D* are closed.

Open the three-way cock *E* to the atmosphere, and, raising

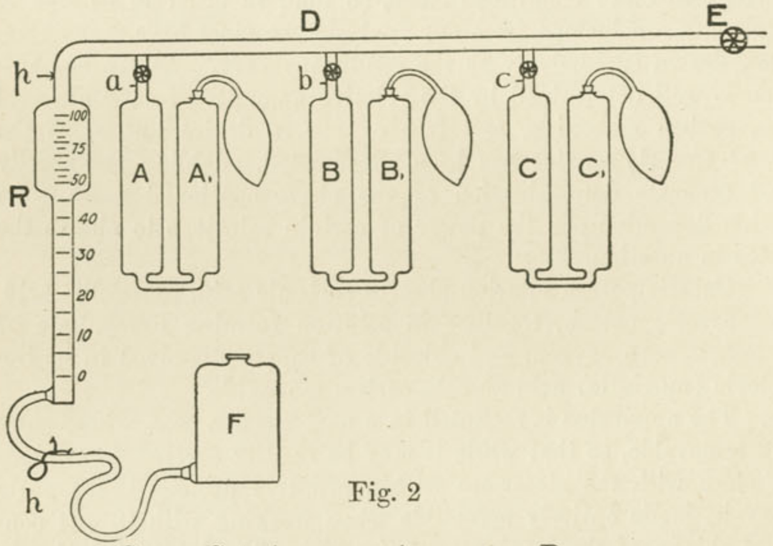

Fig. 2

ORSAT GAS ANALYSIS APPARATUS DIAGRAM.

the bottle *F*, the clamp *h* being released, allow the water to run into R, filling it to the point *p* in the narrow tube. Turn *E* to connect with the flue, when upon lowering *F* the sample will be drawn into *R*, following the water as it falls. It is usually better to have a sample of the flue gas drawn into some form of reservoir which may be easily constructed by the aid of a few large bottles or flasks; for the flue gases are hot, and the results would be in error if the temperature changed during the determination. Drawing the sample into an independent receiver allows it to arrive at the temperature of the room before manipulating it. When the pressure bottle *F* is lowered it should bring the water level in the

burette *R* slightly below the 0 mark, and allowed to stand about two minutes for the sides to drain. Then the bottle *F* should be raised, the cock *E* being open to the air until the surface of the water in *F* is brought level with the surface of the water in the burette at the zero mark. The cock *E* is closed, and being assured that the pressure in R is the same as the atmosphere, the bottle *F* raised, the valve *a* being now opened, forcing the sample into A. As A contains a number of glass tubes open at both ends, a considerable amount of the caustic potash solution is held on the large amount of surface presented, while the body of the solution is forced into A, the air formerly in A entering and distending the flexible rubber bag attached to its upper end. It is advisable to raise and lower *F* several times to circulate the sample thoroughly, ensuring the complete absorption of the CO_2. Care should be taken in forcing the sample into each of the pipettes A, B, and C to raise the water level in *R* uniformly to the reference point *p* in the narrow part of the stem. Three minutes should be sufficient to allow for the absorption of the CO_2 by the caustic potash, with the above-mentioned precaution, when the sample can be drawn back into *R* by lowering *F;* before closing the cock connecting with A, the level of the water in *R* should be read, holding the pressure bottle *F* beside *R* so that the two levels agree. The pressure of the gas is thus not influenced by the water column, while if *F* were allowed to be held lower than the water level in *R*, or, what would be more easy of occurrence, placed on the table, then would the water column in *R* tend to attenuate the gas, making an apparent increase in its volume; or, if *F* should be placed above the level in *R*, a compression would follow. The difference between the reading taken and 100 indicates the per cent of CO_2 gas.

Repeating the process for the determination of oxygen with pipette *B*, we can find the latter by taking the difference between the final reading in this case and that in the first, this giving the per cent of oxygen. The absorption of oxygen by pyrogallate of potash is slower than that of CO_2 by caustic potash, and it is advisable to circulate the gas freely. In any such work it is often wise to take a reading, and then repeat the operation after allowing some further time for the gas to be absorbed. After a few trials of this kind the readings will agree more and more closely until at last the result may be depended upon.

The determination of carbon monoxide by absorption in the chloride of copper solution is similar to the foregoing, the amount being the difference between the final reading in the oxygen determination and the last reading in this case. The solutions are made up as follows:

A. Caustic potash 1 part; water 2 parts.
B. Pyrogallic acid 1 gramme; caustic potash 25 c.c.
C. Chloride of copper dissolved in hydrochloric acid to saturation. The acid should have a specific gravity of $1\frac{1}{10}$.

One cubic inch of each of the reagents used should absorb the following amounts of the several gases:

Caustic potash -	40 cubic inches	CO_2
Pyrogallate of potash	22 " "	O
Chloride of copper	6 " "	CO

As before stated, samples of the gases should be taken from several different places; for instance, combustion chamber, bonnet, uptake, and stack. Not only can the completeness of the combustion be determined, but leakage of air as well, for the free oxygen will increase in such a case. Carbon monoxide, if present in any quantity, indicates incomplete combustion, although a trace of it may not be of importance.

CALCULATION OF AIR.

A certain coal has the following analysis:

Carbon - -	81 per cent.
Hydrogen - -	5 per cent.
Oxygen - -	4 per cent.

And an analysis by means of Orsat's apparatus gives the following figures:

Carbonic acid gas -	10.86 per cent.
Oxygen - -	8.19 per cent.
Carbon monoxide -	0.16 per cent.

Then, using these percentages as cubic feet of the several

gases in one hundred cubic feet of flue gas, we shall have for the weights in each case the volume multiplied by the density.

Carbonic acid gas	$10.86\times0.12341=1.3402$
Oxygen	$8.19\times0.08928=0.7312$
Carbon monoxide	$0.16\times0.07806=0.01249$

Now, by composition, carbonic acid gas is CO_2, that is, one part carbon and two parts oxygen; as the atomic weight of carbon is 12, and of oxygen 16, then in one pound of CO_2 we shall have:

$$\frac{16\times2}{12+(16\times2)} \text{ or } 0.7272+\text{pound of oxygen,}$$

and

$$\frac{12}{12+(16\times2)} \text{ or } 0.2727+\text{pound of carbon.}$$

In one pound of CO we shall have similarly,

$$\frac{16}{12+16} \text{ or } 0.5714+\text{pound oxygen,}$$

and

$$\frac{12}{12+16} \text{ or } 0.4285+\text{pound carbon.}$$

The total oxygen, therefore, as found by the analysis, will be

$0.7272\times1.3402 \;=0.9747$ from the CO_2
$0.5714\times0.01249=0.0071$ from the CO
0.7312 the free O

1.7130 lbs. oxygen

and similarly we may find the carbon,

$0.2727\times1.3402 \;=0.3655$ from the CO_2
$0.4285\times0.01249=0.0054$ from the CO

0.3709

Then as air is 0.232 oxygen by weight, we shall need

$$\frac{1.713}{0.232 \times 0.3709} = 19.91 \text{ pounds of air per pound of carbon.}$$

This method takes account only of the CO_2, CO, and free O. The combinations of H and O with unburned volatile matter pass off together with the nitrogen.

As this coal contains 81 per cent carbon we shall need $0.81 \times 19.9 = 16.1$ pounds of air to consume the carbon in one pound of coal. To find the air necessary to take care of the hydrogen, assuming that the oxygen in the coal combines with one-eighth of its weight of hydrogen, and that 36 pounds of air are necessary to take care of each pound of hydrogen, we have the following:

$36\left(0.05 - \frac{0.04}{8}\right) = 1.6$ pounds of air to take care of the hydrogen in this coal. The total air, therefore, per pound of coal is: $16.1 + 1.6 = 17.7$ pounds.

The foregoing solution may be effected by use of the vapor densities, so called. The vapor density is one-half the molecular weight, the atom of hydrogen being taken as unity.

The molecular weight of CO is $12 + 16 = 28$, and its vapor density is, therefore,

$$\frac{28}{2} = 14;$$

while for CO_2 it is

$$\frac{12 + (2 \times 16)}{2} = 22.$$

Using the analysis as before, namely, that in 100 cubic feet of our flue gas we have

CO_2	-	-	-	10.86 cubic feet.
O	-	-	-	8.19 " "
CO	-	-	-	0.16 " "

we have the following weight, referred to hydrogen as unity:

$$\begin{aligned} 10.86 \times 22 &= 239 \\ 8.19 \times 16 &= 131 \\ 0.16 \times 14 &= 2 \\ \hline & 372 \end{aligned}$$

We have already found that one pound of CO_2 contains 0.7272 pound O, and one pound CO contains 0.5714 pound O.

From the above we shall have $239 \times 0.7272 = 174$ pounds oxygen in the carbonic acid gas, and $2 \times 0.5714 = 1+$ pound oxygen in the carbon monoxide, or a total of $174 + 1 = 175$ pounds oxygen.

The carbon will then be $372 - 175 - 131 = 66$ pounds, or, to check using the fractional form of the proportions of carbon in the CO_2 and CO,

$$\begin{aligned} \frac{3}{11} \times 239 &= 65 \\ \frac{3}{7} \times 2 &= 1 \\ \hline & 66 \end{aligned}$$

Dividing the weight of oxygen by the weight of carbon, we have $\frac{174 + 1 + 131}{66} = 4.636 +$ pounds.

As before, to find the air necessary to furnish this amount of oxygen, divide by 0.232.

$$\frac{4.636}{0.232} = 19.98 \text{ pounds of air.}$$

agreeing very closely with the result obtained by the other method.

Losses. All combustible volatile matter passing out in an unburned condition gives rise to a loss of heat, and the imperfect combustion of carbon into carbon monoxide is a still further loss. Even though the CO be as small an amount as previously quoted, namely, sixteen-one-hundredths of one per cent, still the loss is a considerale amount expressed in heat units. The analysis referred to shows:

CO_2	10.86 per cent.
O	8.19 " "
CO	0.16 " "

Then the carbon per hundred pounds would be, using the fractional parts of carbon in CO_2 as $\frac{3}{11}$, and of carbon in CO as $\frac{3}{7}$, and remembering that the vapor densities of CO_2 and CO are 22 and 14 respectively:

$$\frac{3}{11} \times 10.86 \times 22 = 65 \text{ parts C in the } CO_2$$

$$\frac{3}{7} \times 0.16 \times 14 = 1 \text{ part C in the CO}$$

$$\overline{66} \text{ parts C altogether.}$$

If we burn 65 pounds of carbon to CO_2 we shall liberate $65 \times 14,650 = 952,250$ B.t.u., and 1 pound of carbon burned to CO will yield $1 \times 4,400 = 4,400$ B.t.u., a total of $952,250 + 4,400 = 956,650$ B.t.u.; while if all the carbon had been burned to CO_2 we should have had $66 \times 14,650 = 966,900$ B.t.u. The per cent of loss due to this incomplete combustion is then

$$\frac{966900 - 956650}{966900} \times 100 = 1$$

But one per cent is a considerable amount, particularly in the case mentioned, where the test showed that the boiler was developing a little more than one thousand horse power, burning about 3,280 pounds of coal per hour. It would have been better to keep out even this small loss; but, considering the fact that the boiler, of the water-tube variety, or at least depending upon water tubes for the greater part of its evaporating surface, was developing a horse power, A. S. M. E. standard, for 5.52 square feet of heating surface, and was pushed, it may be said that this amount of CO was low.

LOSS DUE TO EXCESS OF AIR.

The excess air admitted to the fire box has already been discussed; but it is important to note that in heating up all

this extra air, and particularly because of the fact that about $\frac{4}{5}$ of the air is nitrogen, which cannot be of service in producing heat, we are likely to have our loss on this account no small amount.

Let us take again our sample of coal where the analysis was as follows:

C=	78.53
H=	5.61
N=	1.00
S=	1.11
O=	9.69
Ash=	4.03

We know that we cannot get along with the bare amount of air as figured to be just necessary to supply the oxygen called for, so that for the present we shall assume that we are doubling this amount. Further, owing to the uncertainty of its action, we shall omit reference to the sulphur and the ash. To include these would but complicate the problem, and surely there cannot be very much importance attached to the sulphur in this regard. We know that three and two-thirds pounds of carbonic acid gas are produced by one pound of carbon, and when hydrogen and oxygen unite to form water, we can see from the symbol, H_2O, that two parts of hydrogen unite with 16 parts by weight (see table of atomic weights)* of oxygen, or, in other words, one pound of hydrogen produces nine pounds of water. Then we shall have in the case of the coal in question

$$3\tfrac{2}{3} \times 0.7853 = 2.880 \text{ pounds } CO_2$$
$$9 \times 0.0561 = 0.505 \text{ pounds } H_2O$$

Assuming air to be 23 per cent O by weight, and knowing that 8 pounds O combine with 1 pound H, we have 34.8 pounds of air necessary for one pound of H, $0.0561 \times 34.8 = 1.95$ pounds air for the hydrogen in this sample. And the carbon will require $11.6 \times 0.7853 = 9.11$ pounds of air; together we shall need $1.95 + 9.11 = 11.06$ pounds air; of this amount, 2.54 pounds are oxygen, and the difference 8.52 pounds, nitrogen. The coal itself contains 0.01 of a pound of nitrogen. Hence the total nitrogen is $8.52 + 0.01 = 8.53$ pounds.

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Specific heat is defined as the heat necessary to raise one pound of the substance in question one degree in temperature. It differs with different substances, and for the physical states of the same substance. For example, the heat to raise the temperature of water one degree is 1, while that of gaseous (superheated) steam is 0.4805, and the total heat necessary to raise the temperature of a substance through 1 degree Fahrenheit would be its weight multiplied by its specific heat. Performing the computation for the case in hand, we have:

	Weight.		Specific Heat.		B. t. u.
CO_2, carbonic acid gas	2.880	×	0.2169	=	0.6247
H_2O, steam	0.505	×	0.4805	=	0.2427
N, nitrogen	8.53	×	0.2438	=	2.0796
Air excess 100 per cent	11.06	×	0.2375	=	2.6268
					5.5738

Assuming a temperature of 70° F. for the external air and a flue temperature of 570° F., the heat in the flue gases over the atmospheric temperature will be (570—70)×5.5738=2,787 B.t.u. Taking the heat of combustion as 14,240 B.t.u., and allowing 10 per cent for losses by radiation, convection currents and conduction, we shall have $14{,}240-\frac{14{,}240}{10}-2{,}787=10{,}029$ B.t.u. as that doing the work; $\frac{10{,}029}{14{,}240}=0.70$, that is, 70 per cent of the total heat generated is available for evaporating water into steam.

If no air were allowed for dilution, then we should have the following:

CO_2	0.6247
H_2O	0.2427
N	2.0796
	2.9470 B.t.u.

Multiplying by the difference in temperature, 500×2.9470= 1,474 B.t.u. Subtracting 10 per cent loss and the above loss from total heat, $14{,}240-\frac{14.240}{10}-1{,}474=11{,}342$ B.t.u.

$$100\times\frac{11{,}342}{14{,}240}=80 \text{ per cent, nearly.}$$

Combustion Temperature. This is often referred to as the *Hypothetical* temperature of combustion; it may be calculated by assuming that all of the heat units liberated are applied to raising the temperature of the products of combustion, the ash being included. The products of combustion of the coal just used in calculating the losses due to excess air require 5.5738 B.t.u. to raise them one degree in temperature where 100 per cent excess air is allowed. The ash from the analysis is 4.03 per cent, and the specific heat of ash may be taken at 0.2, hence we shall have 5.5738+(0.2×0.0403)=5.5819. Now, if there shall be available, as is given by Dulong's formula, 14,240 B.t.u. and 5.5819 B.t.u. are necessary to raise one pound of the product 1 degree on the Fahrenheit scale, then $\frac{14240}{5.5819}=2{,}550°$ F., nearly. Strictly this is the amount the temperature is *raised*, hence the actual temperature would be higher by the amount of temperature of the fuel as fired; suppose this to be 70° F. Then 2,550+70 =2,620° F., is the hypothetical temperature of the fire. By way of comparison we may calculate the temperature with no excess air admitted.

B.t.u. per pound of products of combustion without excess air=2.947
B.t.u. ash= .008

2.955

$\frac{14{,}240}{2.955}=4{,}820$ nearly, to which, theoretically, should be added the temperature of the fuel as fired.

Even in the case of the dilution, the temperature as calculated is much above that which is really obtained, for the combustion is not instantaneous and the gases burn far beyond the furnace proper, reaching through the combustion chamber and often into the tubes. The heat is conducted very rapidly from the fire to the water within the boiler, and radiation takes away much. The greater the difference of temperatures between two bodies the faster will be the flow of heat, just as in the case of water where the flow increases with the difference of pressure.

Temperatures of very hot substances may be measured by means of a specially constructed pyrometer. This consists essentially of a pair of wires of different metals, for example, one of platinum, the other an alloy of platinum and iridium, twisted together. The other ends of the wires are continued in an electric circuit, connecting with a galvanometer. Upon heating the twisted pair of wires, a current of electricity is set up, proportional to the degree of the heat. The scale of the galvanometer can be calibrated by means of the melting points of various substances into which the twisted pair of wires may be thrust, and the position of the pencil of light marked on the scale. As the deflection will vary with resistance of the circuit, the calibrating should be done with the circuit connected as it is ready for use.

The temperature of the fire is more likely to be found at from 1,000° to 1,200° F. than higher, while the gases in the uptake may be between 400° and 650°. The temperature of saturated steam at 150 pounds on the gage is 366° F., so the temperature of the gases must be more than that, and then too, if natural draft is used, some amount of heat is necessary to insure that the column of air in the stack shall be enough lighter than the outside air to produce the necessary difference of pressure, and this in turn the draft.

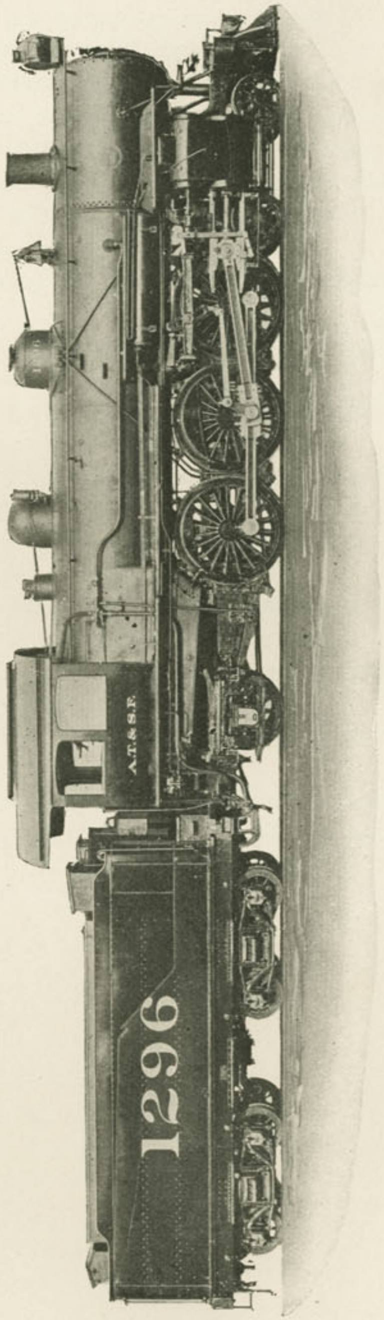
It may be remarked, however, that where a feed-water heater is used, a reduction in temperature beyond that of the steam is allowable, provided that the draft be maintained; but in most cases of this sort either forced or induced draft would be used.

REVIEW QUESTIONS.

FUELS AND COMBUSTION.

1. What is coal? How formed? Constituents?
2. Name at least three kinds of coal. Use of each.
3. What is coke? Charcoal? Lignite? Peat?
4. What is the heating value of wood as compared with coal?
5. What liquid fuels are there?
6. What is meant by combustion?
7. Compare "chemical compound" and "mechanical mixture."
8. What is a British thermal unit? Abbreviation is what? What is calorie?
9. What element gives out the greatest heat when burned? What is the product of the combustion?
10. What element gives the greatest part of the heat when coal is burned?
11. How is heat of combustion found?
12. Of what is air composed?
13. What is the action of each element of air during combustion?
14. What is Marsh gas? Olefiant gas? Carbonic oxide? Carbon monoxide?
15. Upon what principle do we depend in determining how much oxygen is necessary to consume a given amount of combustible?
16. Knowing the amount of oxygen necessary to burn a given amount of carbon, how would you find the amount of air necessary to supply this oxygen?
17. Upon what assumption is Dulong's formula for heat of combustion founded?
18. Why is an excess of air admitted to a furnace?
19. What injurious effect has an excess of air?

20. What law do perfect gases obey?
21. What is meant by absolute zero?
22. How would you find the volume of a given weight of air?
23. What is specific heat? Specific volume?
24. What apparatus is used for the analysis of flue gases?
25 What gases should be looked for in the flue?
26. What is meant by atomic weight? Molecular weight? Vapor density?
27. How may the theoretical temperature of combustion be found?
28. Is the theoretical temperature of combustion obtained in practice? Reason.
29. What should be the flue temperature where natural draft is used?
30. What tends to prevent smoke issuing from the stack when firing soft coal?
31. Why is anthracite coal less likely to emit smoke than bituminous coal?
32. Name at least two losses occasioned by ash.
33. What is a convenient figure to remember as the number of pounds of air necessary to consume one pound of carbon? For one pound of hydrogen?
34. How may the atmospheric pressure be found, knowing the height of the barometer?
35. Knowing the chemical formula for a substance, how would you find the proportion of each of the component parts (by weight)?



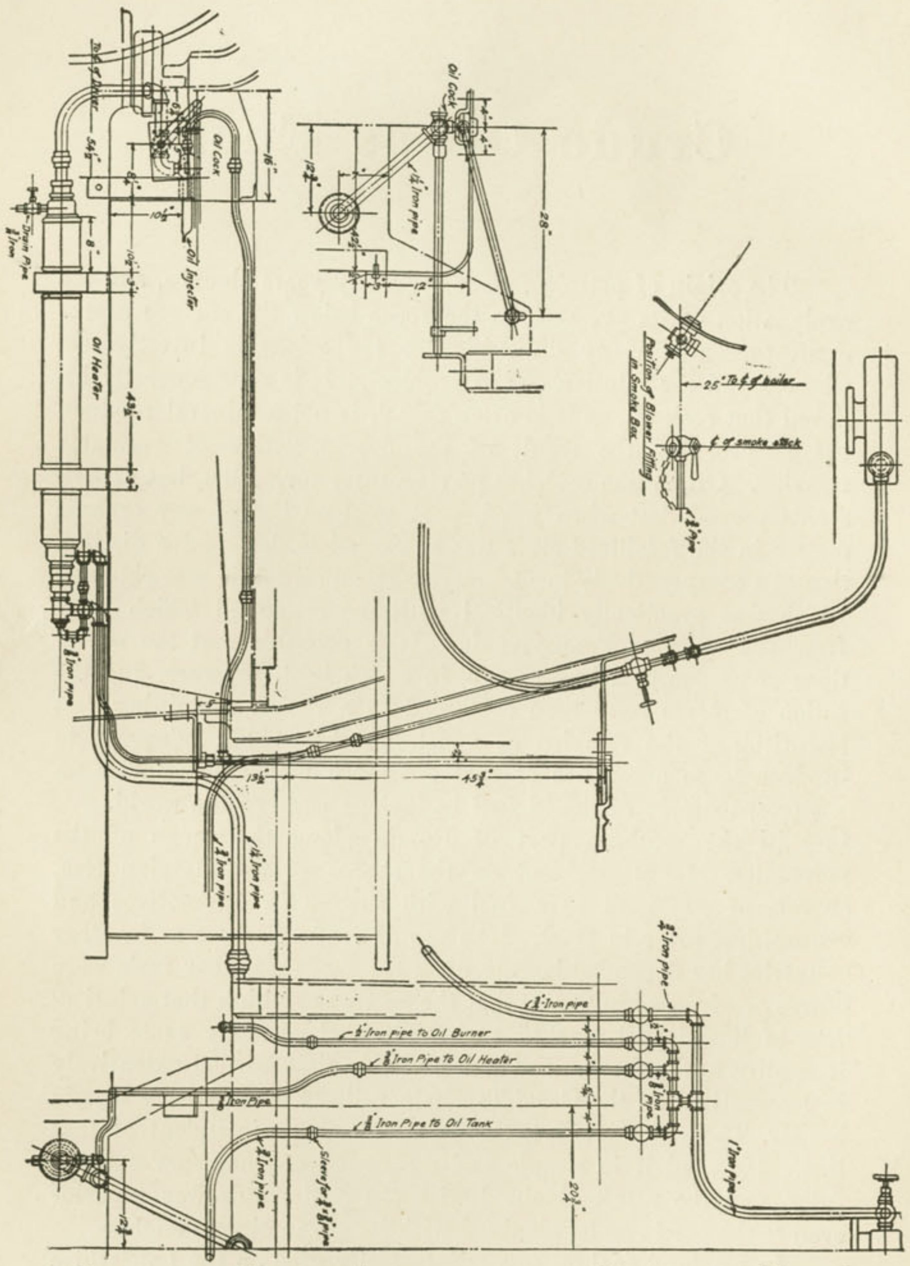
PACIFIC TYPE OIL-BURNING PASSENGER LOCOMOTIVE USED ON THE ATCHISON, TOPEKA & SANTA FE R. R.
(Baldwin Locomotive Works)

Crude Oil as Fuel.

The origin of petroleum was for many years obscure, and the explanation of its presence in the rocks below the surface of the earth presented many difficulties to the scientific investigators who essayed the solution of the problem. It is now generally believed that rock oil, as it is often called, is not a mineral product, but is probably the result of the decomposition of vegetable remains. Oil, unlike coal, has no structural formation, but experiments proved that when wood, peat, coal or indeed any organic matter in the fossilized state was subjected to destructive distillation at a comparatively low temperature, an oily fluid was obtained which was practically identical with the crude oil which flows from the wells of Pennsylvania. It is probable that the operations of nature in a bygone age, in which heat, pressure, and the action of steam have been combined in a region containing vast quantities of the remains of vegetation have been adequate to produce large quantities of that substance which now forms an important supply of liquid fuel in various parts of the world.

In the southern part of Russia along the range of the Caucasian Mountains, and on the shores of the Caspian Sea, petroleum was used as a fuel with success in locomotives and steamships, prior to 1890. The use of crude oil here as in other countries has depended largely upon the fact that other fuels were scarce or of poor quality or that the cost was so high that substitution of liquid fuel marked such a decided economy as to bring it readily to the front. Oil was probably first burned extensively in locomotives on the Grazi-Tsaritsin railway in Southern Russia by Mr. Thomas Urquhart, the locomotive superintendent of that line. He used it in simple and compound engines very successfully, and the result obtained with the compounds was superior even to the good results obtained with its use in simple engines.

In England fuel oil was satisfactorily used on the Lancashire



OIL-BURNING PIPING ARRANGEMENT AS APPLIED TO PACIFIC TYPE LOCOMOTIVE NO. 1296, ATCHISON, TOPEKA & SANTA FE R. R.

& Yorkshire Railway, and also on the Great Eastern, but its adoption was not general. In South America, however, it was used where coal had to be imported. On the railways of the Argentine Republic, the system adopted was that invented and used by Mr. James Holden, and was similar to the equipment of the oil burning engines of the Great Eastern of England, of which road Mr. Holden is locomotive superintendent.

The same causes which had lead to the introduction of oil fuel in other countries, namely; the scarcity of wood or coal or the high price of these fuels, operated also in the United States to bring oil into prominence as a means of supplying the deficiency or of reducing the cost of locomotive operation. In the beginning, however, the greater value of oil for other commercial uses, to a certain extent, retarded its introduction. About 1895 oil fuel was experimented with on the Atchison, Topeka & Santa Fé, and it was found that one ton of crude oil about equalled from 1¼ to 1½ tons of coal. The cost of oil as against that of coal showed a saving of about $3.60 per ton, on the tender, and from the standpoint of fuel cost, that fact alone justified its use.

The use of liquid fuel possesses certain advantages over that of coal, not the least of which is the constant supply in firing, and the resulting steadiness of the steam pressure, and ease with which the supply can be regulated in accordance with the work to be done. It must, however, be remembered that the supply of oil though exceedingly plentiful in various regions, would not be adequate to supply all the railways in the United States, and that if more generally adopted, some roads would find the cost of transportation of oil to their lines practically prohibitive.

The oil burners used in locomotive practice to-day may be divided into two general classes. Those in which the mixing of oil with the necessary amount of air for its combustion is effected inside the burner, form one class, and the burners which supply oil to the fire-box where it is mixed with air outside the burner form the other class.

The burner which was first used on the Atchison, Topeka and Santa Fé, had been in successful operation in locomotives in Peru, and was invented by Mr. Booth. When tried on the Santa Fé it was patented in the United States, as the "Booth-Wade" burner, Fig. 1. The name being derived from the inventor, and from that of Mr. K. H. Wade, the general manager of the Santa

Fé, who was instrumental in the introduction of oil as a locomotive fuel into this country. The Booth-Wade burner consists of a flat casting about 12 inches long by about 4 inches wide and $2\frac{5}{8}$ inches deep. In this casting are two rectangular passages, each $\frac{1}{2}$ an inch deep, one above the other. The upper one is for oil and the orifice through which the oil issues is $3x\frac{1}{2}$ inches. Below this is the steam passage $3\frac{1}{2}x\frac{1}{2}$ inches which terminates in a slit $\frac{1}{32}$ inch deep, and $3\frac{1}{2}$ inches wide. When steam and oil flow, each through its own passage, the oil issues in a comparatively sluggish stream, and is caught upon what may be called a broad, flat jet

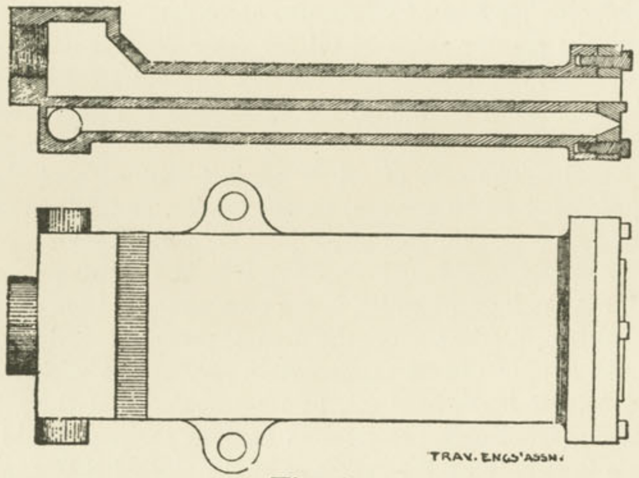


Fig. 1

BOOTH-WADE BURNER.

of rapidly moving steam. The effect is to carry the oil to a considerable distance from the mouth of the burner, and to roll its particles over and over and break up the stream into a fine spray, in which state it is mixed with air which is introduced into the fire-box from below, through a damper opening. In order to quicken the movement of the oil, and to assist in its atomization it is, previous to its entering the burner, heated by a steam coil immersed in the oil chamber of the tender; and to give the oil a certain velocity, it is urged by the pressure of compressed air acting upon its surface in the oil chamber of the tender. The oil chamber is air tight, and a reducing valve on a pipe leading from

the main reservoir of the brake system supplies a constant pressure of about five pounds per square inch on the surface of the oil confined in the tank.

The Lassoe-Lovkin burner is cylindrical in form, and there are twelve circular holes through which steam and oil pass to the fire-box, Fig. 2. Oil is pumped through a long central tube in the burner at a pressure of 120 pounds. The oil tube is surrounded by steam which has the effect of heating it. Steam entering the burner is throttled down so as to be at a pressure somewhat less than that of the oil, so that there will be no tendency to blow the oil back in the burner when the two come together at the orifice. The oil issues in a cone-shaped spray of about 45 degrees, from each of the twelve openings, and the steam having been mixed with it just previous to its emergence from the outwardly

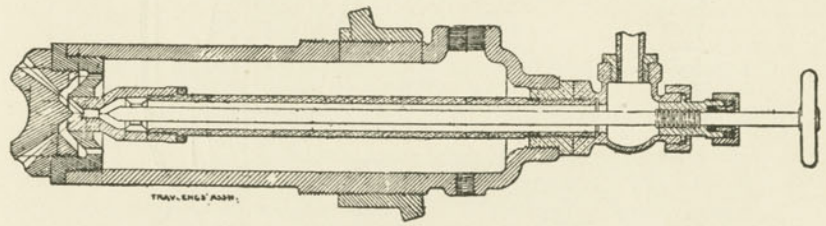


Fig. 2

LASOE-LOVKIN BURNER.

tapered orifices, a still further dispersing and spraying action is produced by the steam, so that the oil particles may be very effectually mingled in the fire-box with the air necessary for their complete combustion. These burners have been used on the Santa Fé Coast Lines, and are placed in the fire-box door, a pair of burners being used side by side as shown in Fig. 3. What corresponds to the grate bars of an ordinary fire-box is made into a floor of firebrick, under which air from the outside passes, and this air enters in an upward stream at the back of the box, and behind a low bridge wall of firebrick, and mixing freely and throughly with the oil spray from the burners or atomizers, as they may be called, supplies the necessary oxygen for the complete combustion of the liquid fuel.

The Hammel burner, Fig. 4; which is used on the San Pedro, Los Angeles & Salt Lake Railroad, consists of a box-like casting, into the interior cavity of which the oil pipe is introduced. Oil issuing from the pipe fills the cavity and flows over a small vertical projection and down the outer side, like water over a weir, into what is called the mixing chamber. Here steam from above enters the mixing chamber in a thin flat jet, and at the bottom of the mixing chamber another thin, flat, and horizontally moving jet of steam blows the oil and steam out in a similarly thin, wide and

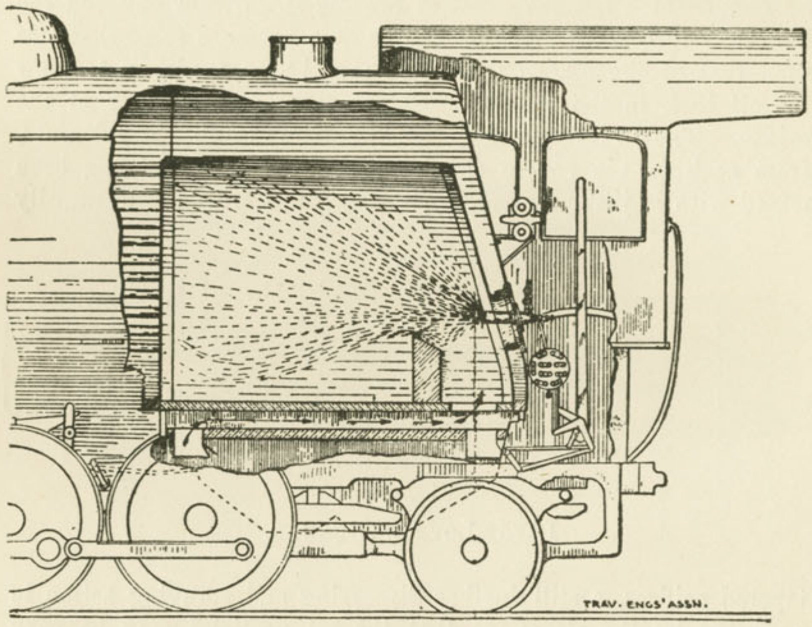


Fig. 3

HEAVY SANTA FÉ ENGINE EQUIPPED WITH TWO LASOE-LOVKIN BURNERS PLACED IN FIRE-BOX DOORS.

spreading jet. In this burner, steam and oil are mixed before being expelled, but air is brought in contact with the oil outside the burner. Air for the combustion of the oil is introduced into the fire-box around the burner, and also at the base of the fire-brick arch against which the flame strikes.

The Sheedy burner, Fig. 5, used on the Southern Pacific Railway is an example of the type of burner where oil, steam, and air are mixed before leaving the orifice, and in general appearance this burner resembles the Booth-Wade device already described.

It consists of a long flat casting in which there are three similarly shaped passages, the upper one being for oil, the central one for steam, and the lower one for air. The oil passage is $3\frac{3}{4}$x$\frac{9}{16}$ of an inch, the steam passage is $3\frac{3}{4}$x$\frac{1}{4}$ inches and the air passage is

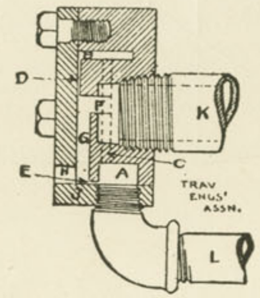


Fig. 4

HAMMEL BURNER.

A. Lower Steam Chamber. B. Upper Steam Chamber. C. Ports connecting Steam Chambers. D. Top Atomizer. E. Bottom Atomizer and Outlet. F. Oil Inlet to Mixing Chamber. G. Mixing Chamber. H. Outlet Orifice. I. Front Plate. J. Bottom Plate. K. Oil Supply Pipe. L. Steam Supply Pipe.

$4\frac{1}{8}$x$\frac{1}{4}$ inches. The oil, steam and air passages are about 12 inches long, and meet at what may be called the nozzle. The oil passage turning slightly downward and the air passage turning slightly

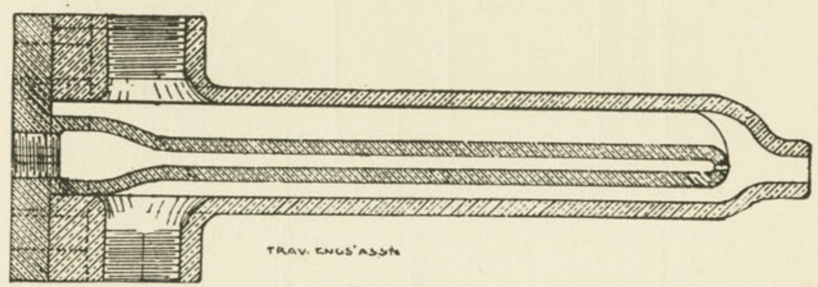
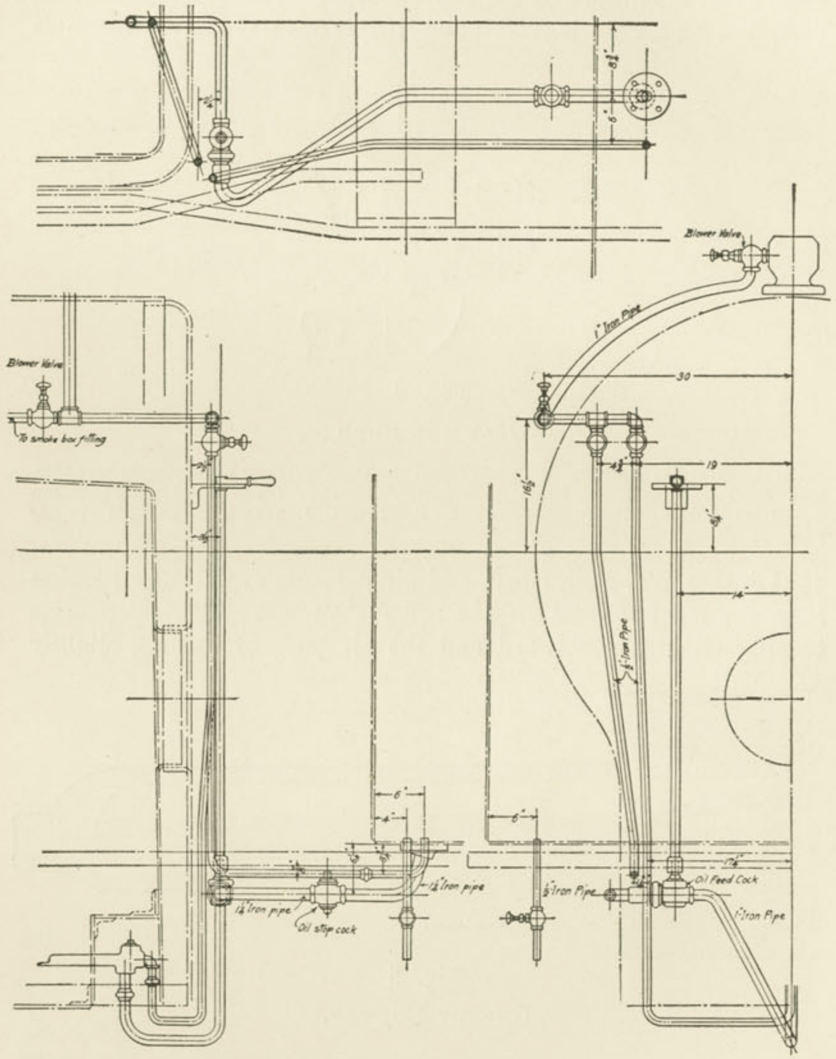


Fig. 5

SHEEDY BURNER.

upward, come together in front of the flat steam orifice $3\frac{1}{2}$x$\frac{1}{16}$ inches, exactly opposite the discharge opening through which the mixture is expelled. This opening is $4\frac{1}{4}$x$\frac{1}{4}$ inches. By this means, oil, steam and a quantity of air pass out together, the air having been heated by its passage through the atomizer under



OIL-BURNING ARRANGEMENT AS USED ON LIGHT LOCOMOTIVES (BALDWIN LOCOMOTIVE WORKS).

the steam space through which the steam flows. The result is that the oil is very effectively broken up into minute globules and flies out in the form of a thin vapory spray which also mixes with the air in the fire-box.*

There are other forms of oil burners or atomizers, but all have the same object, namely, the reducing of the oil to a thin filmy spray thoroughly broken up so that each minute particle of oil may be in intimate contact or completely surrounded by air for the purpose of securing complete combustion. In actual practice the particular form of the burner does not seem to be of vital importance as long as this result is obtained, and a glance at the possible reason why this may be so, and also for the high efficiency of this fuel, may be interesting.

Mr. Wm. H. Booth, whose name was mentioned in connection with the Booth-Wade burner, has advanced an interesting theory concerning the burning of the volatile constituents of coal in an exhaustive work on "Liquid Fuel." The theory has been commended by the editor of the British "Electrical Review" as placing the whole subject of the combustion of bituminous fuels in an entirely new light. The hydrocarbons obtainable from coal must be distilled on the grate, and much heat is absorbed in the gasification of these hydrocarbons or volatile constituents of the fuel. With liquid fuel, the first step may be said to have been taken by Nature in consequence of the fact that the fuel is in the form of a liquid. In this respect coal, petroleum and illuminating gas may be said to stand to each other in a relation somewhat analagous to that of ice, water and steam. Just as ice has been advanced a step toward the form of steam when it has been changed to water, so the hydrocarbon constituents of coal are one degree nearer the vaporous state required for rapid and complete combustion when they are in the liquid form known to us as fuel oil. "With liquid fuel, the gasification is already practically effected, and combustion is rendered more perfect by heating the liquid and also heating the air by which it is atomized. Thus, if oil and air are both heated to 200 degrees F., the temperature of combustion (assuming the air to be 60° F.) will be higher by

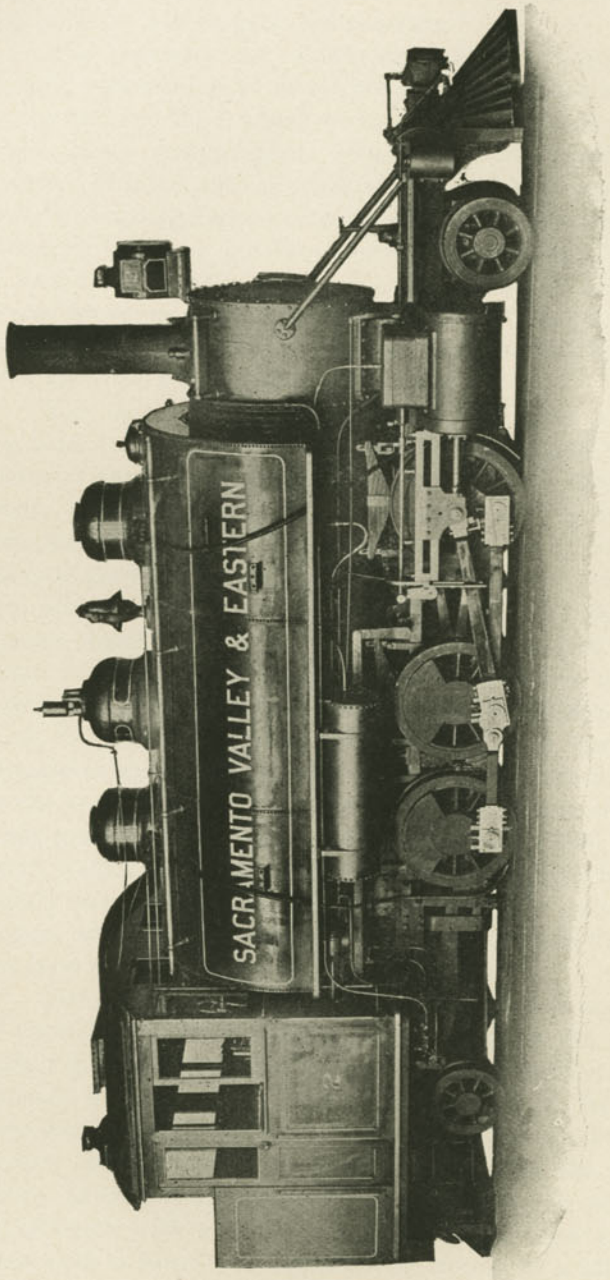
* The cuts of these burners are reproduced from a paper read by Mr. J. B. Galivan, at a recent meeting of the Traveling Engineers' Association. The burner made by the Baldwin Locomotive Works is shown in Fig. 6; and Fig. 11 shows the Baldwin burners applied to a Vanderbilt corrugated fire-box.

about 140 degrees F., than if both oil and air were supplied at the ordinary atmospheric temperature."

The necessity for atomizing fuel oil is also mechanical. A solid rectangular jet of oil presents a comparatively small area to the air, and indeed may be compared to a thick plank of wood which burns comparatively slowly from the outside toward the center. This property of wood is made use of in what is known as the slow-burning form of construction where wooden floors of considerable thickness are introduced into buildings. The leaves of a book burn rapidly when touched by flame if each leaf is separated by an air space from those on either side, but the book itself when tightly shut burns slowly and imperfectly, though composed of a series of highly inflammable pages.

The theory of the explosion of dust gives a good idea of the behavior of sprayed oil fuel in the fire-box, and exemplifies the necessity for its thorough mixture with air. A large log of wood burns slowly on the outside, perhaps requiring half a day to complete the process. If split into cord wood sticks, an hour's burning may consume it all. If in the form of kindling wood, a few minutes will see it entirely burnt up. As shavings loosely thrown together, still less time would be required, while in the form of dust floating in the air, it might be almost instantaneously consumed. The total heat given out in every case has been the same, but the time occupied in its generation has decreased in proportion as the inflammable material was reduced in size, and as the areas exposed to the action of the oxygen of the air were made greater and greater. In the case of oil fuel, the atomized spray is such that each minute particle of oil floats in, and is completely surrounded by air and is thus readily get-at-able by the oxygen when the temperature necessary for their chemical union has been secured.

The similarity between the explosion of dust and the burning of particles of finely divided oil as it leaves the orifice of the burner in a fine spray may be carried a step further without doing violence to the analogy, because the burning of the oil vapor as described, is really a series of minute explosions which follow one another in such quick succession as to produce the roaring sound which invariably accompanies the burning of oil. Tyndall's experiments with a small vibrating flame of coal gas prove that when such a flame was examined by means of a rotating mirror,



OIL-BURNING SADDLE TANK LOCOMOTIVE USED ON THE SACRAMENTO VALLEY & EASTERN R. R.
(Baldwin Locomotive Works)

what appeared to the naked eye as a single flame burning continuously, revealed itself to the mirror as a beaded line of flame images. In some instances, he tells us, he was unable to observe any union of one flame with another; the space between the reflection of each flame being absolutely dark to the eye. These dark spaces were caused by the total extinguishing of the flame at intervals, with a residue of heat, however, remaining sufficient to re-ignite the gas. In one experiment he tells us, he found that the little flame was able to extinguish and rekindle itself 453 times a second, and that in doing this the vibration set up caused a musical note to be sounded in a tube held over the flame.

The flame caused when a spray of oil and steam closely mingled with air, is burned in the fire-box of a locomotive would in all probability be found, if scientifically examined, to be made up of an almost infinite number of minute explosions, the sound arising therefrom causing the familiar roar which the oil flame gives. This flame, however, like the small one of gas which Tyndall examined, appears to the eye to be one large irregularly shaped blaze which burns not far from the mouth of the nozzle of the atomizer, and expands as it is blown forward, not only on account of the conical direction of the sprayed particles, but on account of the heat developed as each particle becomes oxidized or burnt. The flame itself does not give one the idea that a liquid is being consumed, but rather that a powerful jet of incandescent gas is being urged from the orifice of the burner.

The total heat of the flame is not greater than would be generated if the same quantity of oil were slowly consumed, but its high evaporative power lies in the fact that by means of the scattering spray, the maximum quantity is burned in a given time, and consequently the heat is more intense; just as the stick of wood, cut into shavings and liberally supplied with air, gives the total heat due to the burning of the whole log in perhaps a very few moments.

The flame from the sprayed oil is particularly severe on the fire-box sheets and on the flues, and it is not uncommon to find that oil burning locomotives require the renewal of the fire-box in less than two years while the life of the flues is about half that time. A patched fire-box does not stand well. The intense heat developed in the burning of oil acts destructively on the extra thickness of metal where the patch laps over the original sheet. This heat is not abstracted quickly enough by the water in the legs of the fire-box, and although rapid circulation is set up and steam generated freely, the patch gradually burns away. For this reason seams are dispensed with wherever possible, and it has been found beneficial to reverse the flanges at the door, and on the flue sheet, so as to bring the riveted seams into the water

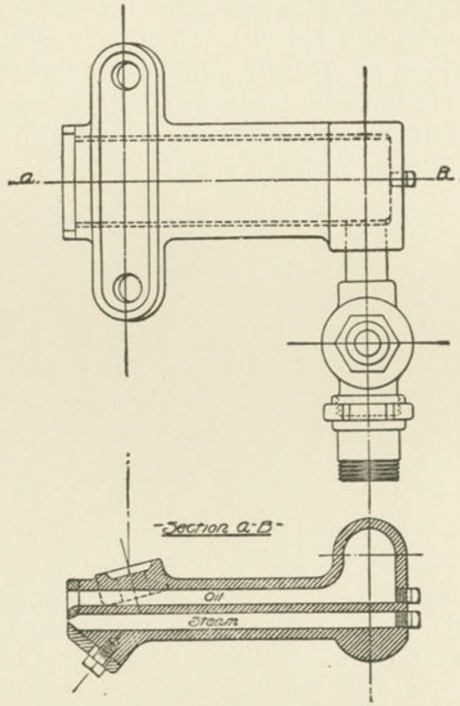


Fig. 6
BALDWIN LOCOMOTIVE WORKS OIL ATOMIZER.

space, and away from the action of the flame. For the same reason crown bolts with thick heads have been replaced by radial stays with thin flat heads. An engine which is reported to have been successful on the Santa Fé, has three corrugated fire-boxes, 28 inches in diameter, leading into a combustion chamber, which is 40 inches long, and in this chamber the flues are set in the usual way. In case any work must be done on the flues, it has been found necessary to remove all the brick work from the fire-box and

allow the engine to cool for about 12 hours before a man can get into the combustion chamber to do the work. This arrangement of the fire-box has been found to stand longer than the ordinary box, but the drawback is found in the prolonged periods of enforced idleness of the whole machine while the internal heating surface cools down, whenever repairs have to be made. The noise in the cab of this engine is said to be excessive as the burners are practically in the cab and not below the deck as in other engines. Shields composed of asbestos, one inch thick with a sheet-iron plate on each side of the asbestos, have been tried. These shields although they undoubtedly deaden the sound, have not reduced it down to even the comparative quiet of the standard engine. In order to protect the fire-box plates from the direct action of the oil flame, and at the same time to prevent too great a volume of the heat passing out of the smoke stack, various arrangements of fire-brick walls and arches are used, and the position of the burner has been varied with more or less satisfactory results.

Two features in connection with oil burning engines may be mentioned. There is no need of a fire grate nor of an ash pan in the ordinary acceptation of those terms, and the intensity of the fire is not dependent upon the force of the blast caused by the exhaust steam. In oil burning engines, what corresponds to the ash pan is usually lined with fire-brick and often forms a convenient receptacle through which air may be introduced into the fire-box and the amount governed by a damper or dampers conveniently placed.

In the first engines fitted up for crude oil fuel, the burners were placed in the doors and the effort was made to have everything so arranged that a return to coal firing could be readily resorted to. These engines carried a certain amount of coal. When the burners were placed in the doors a brick arch was used to prevent the flame from striking directly on the flue sheet and the heated gases from passing at once into the flues. The burners were, in later designs, placed below the deck.

The arrangement of the fire-box brick-work and the position of the burner, as well as the style of atomizer used, differ on various roads. The first experiment on the Sante Fé was made on a Baldwin engine with cylinders 19x26 inches, and is shown approximately in Fig. 7. The changes made on this engine so that oil fuel might be used were the removal of the diaphram plate in the smokebox, and an ordinary petticoat pipe was placed over the exhaust nozzle. The grates were left as they had been, but were covered with fire-brick. In this fire-brick floor several rectangular openings, evenly spaced, were left for the admission of air. The burner was placed below the mud ring at the back and set at such an angle that the flame was directed slightly upward so that the center of it would strike a point about 9

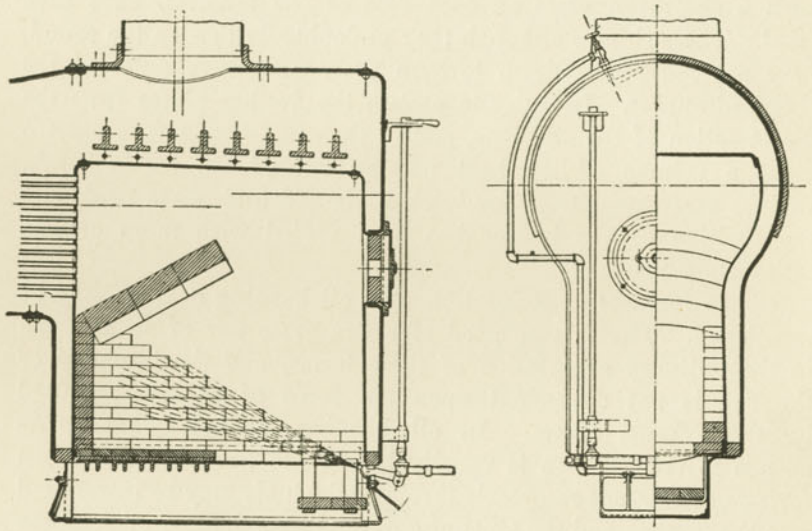


Fig. 7

BALDWIN OIL BURNING SYSTEM APPLIED TO AN ORDINARY LOCOMOTIVE FIRE-BOX

inches above the upper edge of the mud ring on the wall built against the flue sheet. The sides of the box were lined with fire-brick about up to the level of the door and a brick arch extended back from the flue sheet more than half-way through the box.

This arrangement worked fairly well, but when the engine was working hard, the fire-bricks lying on the grate bars were disturbed by the action of the blast caused by the heavy exhaust, and this led to the removal of the grates and the substitution of a false bottom made of cast iron with rectangular openings for air as before. The ash pan was left in place and the supply of air

was regulated in the usual way by the damper openings. Later developments of the art placed the burner still lower, but retained the position at the back of the fire-box, and what had been the ash pan became a sort of brick-lined combustion chamber partly below the level of the mud ring; the flame was forced to beat against a solid fire-brick wall with an overhanging brick arch above. Other arrangements were tried, one of which was to place the burner at the front of the fire-box below the mud ring

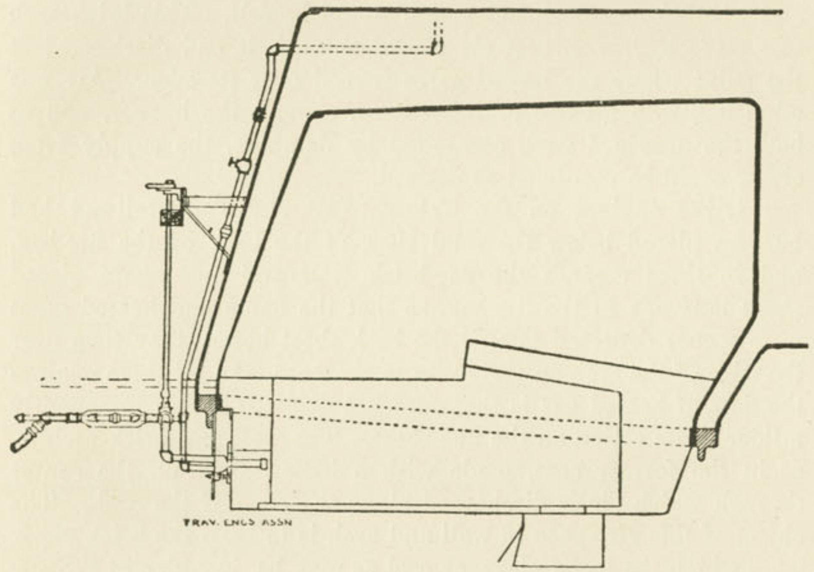


Fig. 8

SANTA FÉ ARRANGEMENT WITH BURNER BELOW MUD RING AT BACK OF FIRE-BOX.

level and so force the flame against a brick wall built close to the fire-box back sheet and resting on the bottom of the draft pan, as the altered ash pan is called, as in Fig. 8. In some of these arrangements the burner was placed horizontally, and in others it was inclined in an upward direction, but in all of them the flame beat directly upon, and was reflected by, a wall of fire-brick. The utilization of the draft pan for sustaining the brick work combined with the low set burner, permitted, in some cases, the uncovering of a considerable area of the fire-box side sheets which had originally been screened by fire-brick, and thus an increase of the effective heating surface was obtained.

Some engines on the Tehuantepec National Railway were arranged with the brick arch placed against the flue sheet and the upward inclined burner below the mud ring at the back end. The principal air opening here, as on the Santa Fé, the Southern Pacific and other roads, was placed immediately in front of the brick wall which was overhung by the brick arch. This had the effect of introducing air at the place where the flame strikes, and where its most violent action would be felt. This brick arch was made hollow so that air passed through it and discharged at the point where the heated gases turned over its edge. Air was admitted, to a greater or less extent, around the burner, and as both the openings were controlled by dampers, the supply from either could be regulated as desired.

Other engines on the Tehuantepec National Railway had burners placed below the mud ring, at the back of the fire-box, and in these engines the fire-brick wall and arch were placed about half-way in the fire-box, so that the flame and heated gases were sooner deflected toward the back sheet before they turn over the edge of the arch on their way to the flues. In all these engines the flow of heated gas is therefore not direct, and is consequently milder in its action on the flue sheet. The wall and brick arch is, as in the former case, made with a hollow duct up the center through which air is discharged along the edge of the arch. The object of this air space in wall and arch is to keep the brick work, upon which the flame plays, as cool as may be, in order to prolong its life, and the duct probably hastens to some extent the time required for the cooling of the arch when boiler repairs have to be made.

Some engines recently built for the Mexican Central Railroad, by the Baldwin Locomotive Works, have the burner inside the fire-box proper and some distance above the mud ring, and close to the flue sheet, Fig. 9. The burner so placed is horizontal and is accessible from the outside, as the brick work is carried on iron plates. The flame is blown toward a wall built up against the back fire-box sheet, and the heated gases pass first backward and return again higher up in the fire-box on their way to the flues. There is a 10-inch air opening in the draft pan near the fire wall and a restricted air opening around the burner.

It may be thought that the oil burning locomotive entirely does away with the troubles of the fireman, and while it is true that it lightens his toil, the proper firing of a heavy oil burner, hauling full tonnage demands a considerable amount of skill and judgment in order to bring about the most satisfactory results.

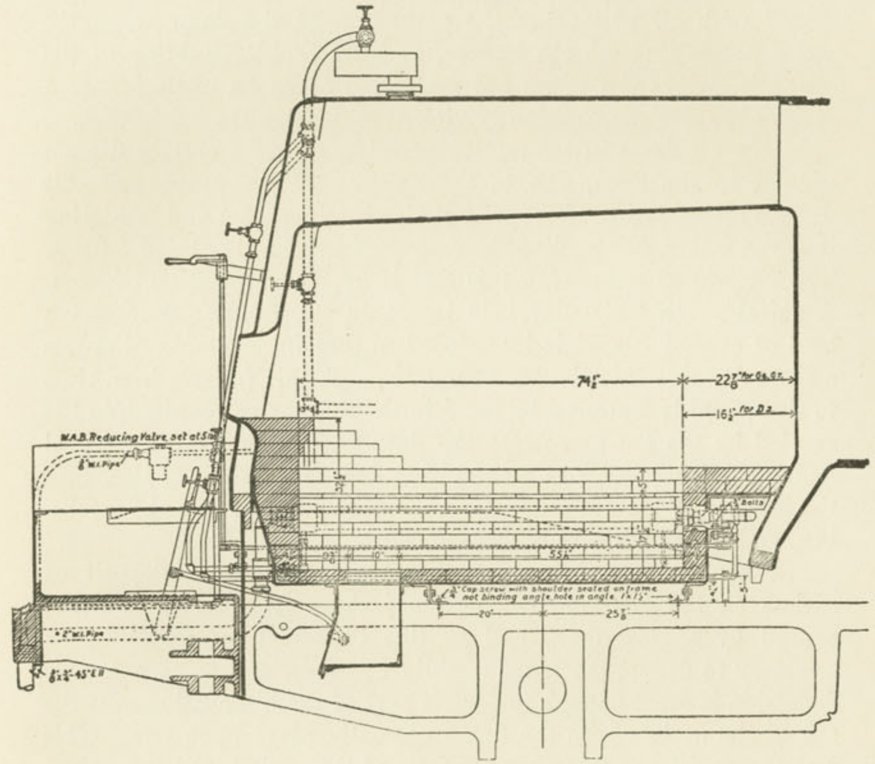


Fig. 9

Oil Burning Fire-box of a Mexican Central Engine with Burner in Front Part of Box.

Engines burning oil were originally supplied with a small device for heating the oil just before it reached the burner. The burner itself, as usually designed, permits a small amount of heat being imparted to the oil as it passes through, but as the train loads to be hauled became heavier, and as the quantity of oil consumed became greater, it was found necessary to heat the oil by a coil of steam pipe placed in the oil storage chamber in the tank. This is the method usually employed, but in some cases an arrangement is made by which steam can be admitted directly to the oil in the tank for the purpose of quickly heating it. Most of the oil used to-day contains a certain percentage of water, and this and the water of condensation where steam is directly admitted to the oil, must be drained off from time to time, as an excessive quantity of water mixed with oil will cause the extinction of the flame when the water passes through the burner, and the rapid relighting of the oil as it strikes the white hot arch may cause an explosion or a series of explosions sufficiently violent to damage the brick work.

The oil flame in locomotive practice, causes a certain deposit of soot in the flues, due to the chilling of the gases, and this deposit seriously interferes with their absorbing heat and conveying it to the water and in time the soot would seriously obstruct them. The method of remedying this evil is by the application of sand. A suitably sized circular hole is cut in the fire-box door and a bent or curved funnel is introduced so that its smaller end enters a short distance into the fire-box. Through this funnel, from time to time, sand is scattered by hand in the fire-box as required, and is carried by the hot gases into the flues. Its action is mechanical and it acts practically as a sand blast does on paint. It cleans off the interior of the flues, and sand and soot pass out into the smoke-box, and most of it goes out of the stack.

When heavy oil is used there is frequently a deposit of carbon on the floor of the fire-box just in front of the burner, caused by a slow drip, and as this deposit piles up it has a tendency to deflect the flame slightly upwards, and sometimes this deflection is great enough to permit part of the blaze going over the top of the arch, where the flame normally plays upon one. This interferes with the steaming qualities of the engine, and the carbon formation must be removed or broken down from time to time by the fireman, who does it by the use of a small bar made for the purpose. An air opening directly below the burner shown in Fig. 10 has been found to be efficacious in preventing the drip of oil from lying on the pan and caking.

The amount of air admitted as well as the supply of oil must be constantly regulated by the fireman. Every change of throttle or reverse lever requires a new adjustment of the air and fuel. Too small a quantity of air causes heavy black smoke, and a diminution in the amount of heat in the fire-box. Too much

air also means loss of heat, and the effect of either of these is at once apparent on the steam gage. Fireman and engineer must work harmoniously and intelligently together on an oil burning engine in order to secure the best results, just as they are compelled to do on a coal burning locomotive.

Some of the advantages claimed for the use of fuel oil in locomotives may be summarized as follows:

A decrease in the waste of heat due to the clean condition in which the tubes may be kept, and the close approximation to the requisite amount of air to insure combustion, which may be obtained.

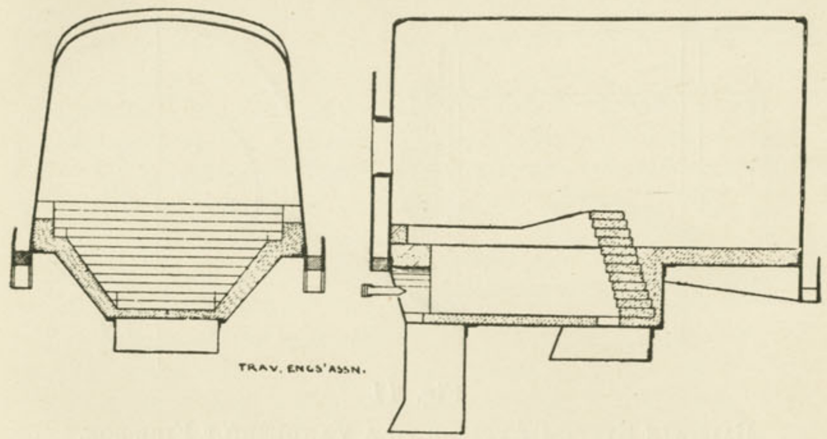


Fig. 10

Arrangement on Southern Pacific Engines.

There is a more complete distribution of heat, with less marked fluctuations of temperature in the fire-box, owing to the fact that the fire door need not be opened.

The use of oil entirely obviates the production of what are known on coal burners as " dirty " fires, on long hard runs.

There is a reduction in the cost of handling fuel, as the filling of the tanks at divisional points is accomplished mechanically or by gravity.

There is no fire cleaning at terminals.

There is certainly a great reduction of the physical labor of the fireman.

The equipment of tools required on an oil burning locomotive is less than that of a coal burner.

There is a complete absence of dust, ashes or clinkers.

Petroleum does not deteriorate in quality while in storage as coal does.

The ease with which an oil fire can be regulated far surpasses coal.

An intense heat can be produced in a very much shorter time than with solid fuel.

The increase in the steam producing qualities of fuel oil per pound over that of coal is very considerable.

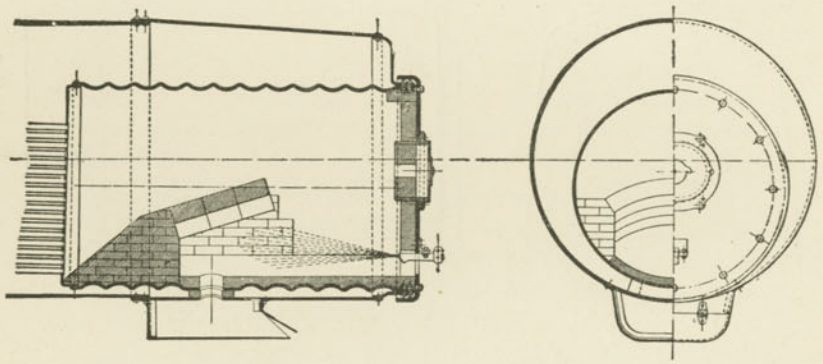


Fig. 11

Baldwin System Applied to a Vanderbilt Fire-box.

There is less waste of fuel where oil is used. Coal may be lost by passing out in the form of smoke or unburned gases.

There is practically no smoke with fuel oil except when sand is thrown into the fire-box and the deposit of soot in the flues is carried out, and this deposit is less than with coal.

Where coal is used, unburned cinders are thrown out of the stack and a certain amount of coal drops through the grates, this is not so with oil.

The absence of smoke, cinders and ashes about a locomotive renders it easy to keep clean.

Where oil is properly used there is less waste of steam at the safety valves, as the fire is more easily controlled, especially where stops are frequent, than is possible with coal.

The absence of cinders thrown on the track is advantageous,

as the ballast along the track is always clean and the drainage of the road-bed through the ballast is not obstructed or clogged as it is where cinders constantly fall from passing locomotives.

Sparks are not thrown from oil burning engines and consequently fires are not liable to be caused along the right-of-way.

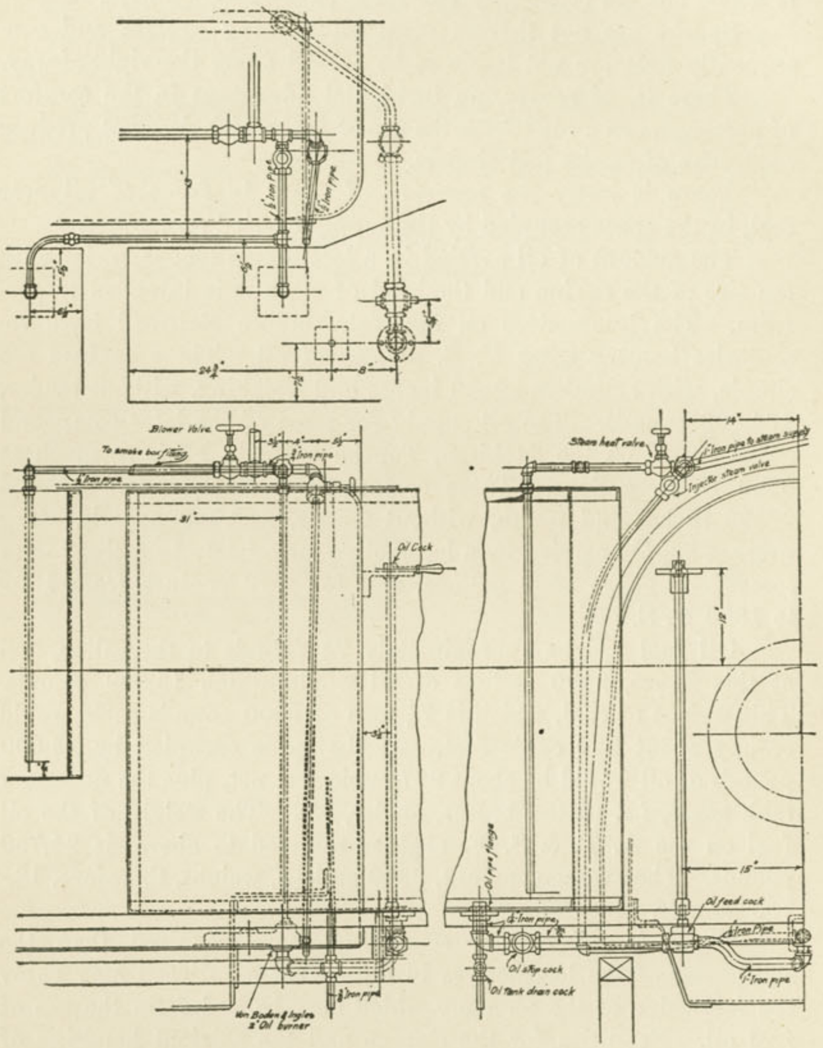
There is, of course, an incidental advantage in the comfort of passengers on a road from the use of fuel which does not produce quantities of smoke and cinders.

There is lastly the economy of space in favor of oil over coal, in the space occupied by the supply carried on tenders.

The amount of oil carried in a locomotive tender varies with the size of the engine and the kind of work it is intended to perform. The locomotives on the Tehuantepec Railroad have receptacles holding 2000 U. S. gallons of oil. These engines are simple, with cylinders 20x26 inches and weighing, without tender, 134,000 pounds. The oil supply for some of the later compound engines used on the Atchison, Topeka & Santa Fé is as much as 3300 U. S. gallons. These compounds have cylinders 17 and 28x28 inches and weigh, without tender, 226,700 pounds. The average supply carried by a locomotive may fairly be estimated as somewhere about 2500 gallons, and for yard engines from 1500 to 1800 U. S. gallons.

Oil fuel weighs approximately 7½ pounds to the gallon, and at this figure, 2000 gallons of oil would weigh 15,000 pounds. This weight of coal, which is 7½ tons of 2000 pounds each, would occupy about 281 cubic feet, and the space occupied by 15,000 pounds of oil would be about 267 cubic feet net, plus the necessary tank space, *i.e.* plates, braces, angles, etc. The weight of the oil fuel on the A. T. & S. F. engines referred to above, is 24,750 pounds. The average amount, 2500 gallons, weighs, therefore, 18,-750 pounds.

There is, of course, something more required than the equipment of the locomotives in order that a railroad may enjoy the full value of the economy which may be had from the use of fuel oil. Facilities for the storage and the efficient handling of the oil must also be provided. An outline of the "plant" necessary for the accomplishment of this purpose may be had by a glance at the Tehuantepec Railroad, which is a small road on the Isthmus. At the Atlantic terminus there is the main storage tank. This is made of steel plate and is 92 feet in diameter and



Piping Arrangement of Locomotive No. 2, Sacramento Valley & Eastern R. R.

contains 1,478,543 U. S. gallons. The tank is supported on a structure so that its base is 29¾ feet above rail level. At the Pacific terminus and at three other stations there are in all four auxiliary storage tanks, each 20 feet in diameter and 12 feet high. Each tank holds 28,200 U. S. gallons of oil. There is thus a stationary supply on the road of more than a million and a half gallons of oil, available for use. Oil is brought to these stations in tank cars of 6,600 gallons capacity. The average cost of oil as issued by the stores department of the road is $2.52 per barrel of 42 gallons.

The large tank at Coatzacoalcos, at the Atlantic terminal, supplies engines, and also tank cars for the transportation of oil to the other stations. To accomplish this an eight-inch pipe is run from the tank to the ground, and through the yard to a basin-shaped depression in the ground. The end of the main is closed by a valve and there is another valve placed close to where the pipe comes out of the tank. This valve is always open. The object of the pipe leading to the basin-shaped depression and being closed by a valve at that point is to provide means for emptying the large tank in case of fire or other emergency. At a suitable point along the 8-inch oil pipe, a branch pipe comes off and this is connected to a stand pipe conveniently placed near the track. The filling of the locomotive receptacle is accomplished at the stand pipe in much the same way that water is supplied at a water column. The tank cars for carrying the oil to the outlying stations are filled at this stand pipe in the same way.

The main storage tank and also the auxiliary storage tanks are filled by pumping the oil, in the one case from vessels and in the other from the tank cars. This is carried out on that road by the use of a steam pump mounted on a flat car which can be moved from place to place as required. Each of the oil supply stations is equipped in a manner similar to the Atlantic terminal station. The filling of locomotive and tank cars is by gravity flow.

Some railroads use inclined tracks, similar to those at coaling stations, up which the oil tank cars are run, and their contents discharged by gravity flow into the storage tanks, and by gravity flow to the locomotives. Other roads use underground reservoirs into which oil from the tank cars is discharged, and subsequently pumped into the storage tanks. Where very large quantities of oil are stored and handled, these plants are probably more economical than the system used on the Tehuantepec Railroad. Fuller information concerning the equipment of this road is given in a paper read by Mr. Louis Garven, before the Institution of Mechanical Engineers of Great Britain.

When we come to consider the relative values of oil and coal as far as their evaporative efficiency is concerned, we find the advantage on the side of oil. It is, however, important to compare oil and coal where the greatest economy has been secured in the burning of the latter. It is manifestly unfair to compare oil burned under favorable conditions with coal burned where unchecked losses form a considerable item in the results obtained.

In a series of tests made by Prof. Denton, in 1901 on the efficiency of Texas oil used under return tubular boilers the following facts were brought out: The weight of Beaumont crude oil was 7.66 pounds to one U. S. gallon. The number of pounds of oil in a barrel, containing 42 gallons, was therefore close to 322 pounds. The net evaporation of water from and at 212 degrees F. was 15.1 pounds. Mr. Booth states that results obtained from Pennsylvania bituminous coal in the best boilers with 10 square feet of heating surface per horse power is 9.5 pounds of water. With other coals of semi-bituminous character 10 pounds of water can be evaporated per pound of coal. Where mechanical stokers and smoke preventing devices are used the evaporative efficiency may be increased to 10½ and 11 pounds.

Taking these figures as a fair statement of average results, and allowing 10 pounds to be the evaporative efficiency of coal, Texas oil has an evaporative efficiency of about 50 per cent over that of Pennsylvania coal. To put it another way, 1 gallon of this oil is capable of evaporating 115.6 pounds of water while the same weight of this coal would turn 76.6 pounds of water into steam.

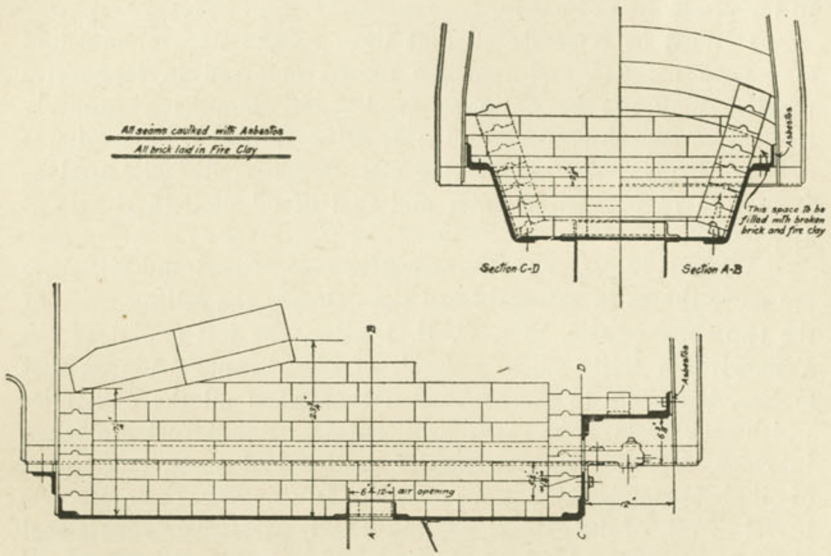
In the test of Texas crude oil referred to, it was found that the theoretical heat units per pound of combustible as measured by a calorimeter was 19,060 British thermal units for the oil, while the coal contained per pound 14,680 B. T. U., or 30 per cent greater for the oil. The heat units obtained from the oil and coal as fired were 19,060 and 12,100 B. T. U., respectively, or 57 per cent greater for the oil. The heat units actually utilized in the production of steam were 14,963 for the oil, and 8,636 for the coal or 73 per cent greater for the oil. The oil, therefore, however high its theoretical value, maintained an actual superiority in heat

units, over the coal, of 73 per cent. Not only were there more heat units in the oil than in the coal but more of them were used in the production of steam.

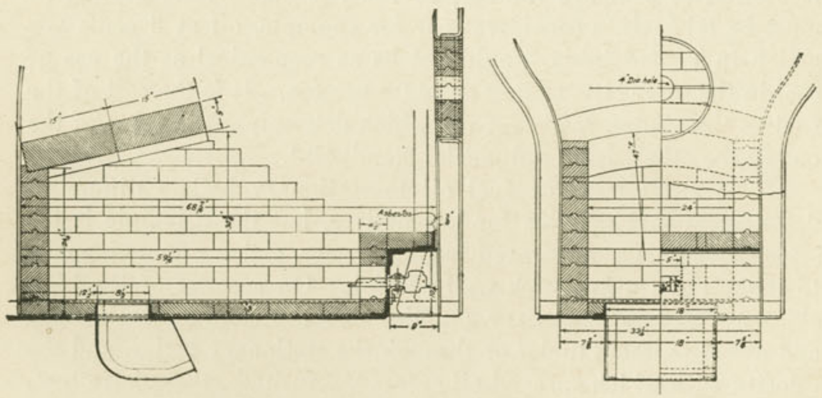
It must be remembered that these results were obtained in stationary practice and that the results obtained in locomotive practice may not be quite as good. Mr. Urquhart, formerly locomotive superintendent of the Russian railway where oil was first tried, gives the evaporative efficiency of anthracite coal as from 7 to 7½ pounds of water and that of oil used in Russia at 12¼ pounds.

When it comes to the comparative cost of coal and oil, there are more things to be considered than simply the selling price of the two commodities. Dr. C. B. Dudley, the test expert of the Pennsylvania Railroad, as a result of experiments made on that system, has come to the conclusion that when all the economies which may be brought about by the use of liquid fuel are taken into consideration, as a matter of dollars and cents, one pound of oil about equals two pounds of coal. In this case, therefore, one barrel of oil, of 42 gallons, costing $1.00, practically equals coal at $3.26 per ton where all the economies due to the use of oil have been considered, and at these respective figures there would be no choice from a financial standpoint between the two forms of fuel. When based on the relative value of the two fuels as steam producers, the point of equality is reached with oil at $1.00 per barrel and coal at $3.73 per ton. In every instance where it is desired to compare the cost of the two fuels, local conditions must be taken into consideration, for example, oil at 3 cents per gallon in Philadelphia, would not be as economical as the use of coal in the same city, selling at $4.00 per ton. It is the cost of the fuel on the tender, ready for use which determines the value of the one or the other, from a financial standpoint.

The application of fuel oil to stationary boilers differs in detail from that suitable for locomotives, but the principle is the same in each. Oil is sprayed from a burner, and the flame is made to strike upon a fire-brick wall or arch. On account of the high chimney used in stationary practice and the comparatively open and direct passages under or through the stationary boiler, and the velocity with which sprayed oil enters the furnace, there have been several methods employed to restrict the flow of heated gases on their way to the chimney.



Oil-burning Arrangement Used On the Locomotives of the Goldfield Consolidated Mines Co.



Oil-burning Equipment as Applied to the Sacramento Valley & Eastern R. R. Locomotives.

The Holden system as applied to a Lancashire boiler is a good example of the effort to delay the passage of heated gas. This system has no grate, and oil is sprayed into the furnace which consists of two long internal flues each perhaps about $\frac{1}{3}$ of the diameter of the boiler. The burner is inserted in the furnace door, and the blaze passes down the flue. Heated air is supplied below the mouth of the burner and the oil is atomized by a steam jet. A pillar with an inclined face and a small overhanging coping is built up in the center of the furnace flue, at a suitable distance from the burner. Against this pillar the blaze strikes and the gases pass over and on each side of the pillar. Beyond the pillar is what may be called an open screen of fire-brick, built so as to entirely fill the flue. In this screen are large rectangular openings, and through these the gases must pass. This screen is about 18 inches or 2 feet beyond the pillar. About the same distance beyond this screen is a second screen with smaller oblique openings placed near the edges and so disposed as to still further break up and retard the heated gases and deflect them along the surface of the furnace flue. With boilers arranged in this way an evaporative efficiency of from 14 to 15 pounds of water per pound of Texas oil is said to be obtained, while that obtained from fine coal burned in the same boiler was about $6\frac{1}{2}$ pounds.

The application of this system to a boiler having a grate is made by covering the fire bars with brick or other refractory material, and building the pillar and screens as before. In this method, space is left through one end of the grate for the passage of air, and the supply is controlled by dampers. This arrangement allows for the rapid change from oil to solid fuel when occasion demands. The locomotive type of stationary boiler is made suitable for oil burning by introducing the burner through an opening in the back of the fire-box some distance below the door and making other arrangements as in the locomotive. Oil and coal are sometimes burned together, and a successful application of this has been made with the water-tube boiler. The practice being to start with coal and as the fire becomes dirty to gradually increase the supply of oil which is sprayed in over the bed of coal, and thus readily sustain the required steam production. Mr Booth suggests that for the use of oil and coal together, or for the use of oil alone in water-tube boilers, the brick arches be extended so as to restrict the heated gases, especially from the oil, from passing too rapidly up among the water tubes. Atomizers may be worked by steam, compressed air, or air supplied by a positive blower. The Billow system was successfully used at the World's Columbian Exposition. The Billow is a burner in which oil passes down a central tube and the atomizing agent passes down a chamber outside the oil tube. Both are mixed just before discharged and a whirling motion is imparted to the jet, owing to the shape of the end of the outer passage close to and just inside the mouth of the burner.

In the use of oil on board ship there are two things which are usually taken into consideration which are not specially prominent in either stationary or locomotive practice. One of these is the fact that steam used in atomizing oil fuel is lost as far as any condensation and use again is concerned, and therefore requires to be replaced from without; the importance of this drain on the fresh water supply is apparent. The ability to quickly change from oil to coal, or from coal to oil is more important at sea than on land, and in the case of locomotives it is practically disregarded.

In seagoing equipment stationary boiler practice is followed in some instances. The striking pillar and the screen are used in the furnaces. The burners are generally arranged to swing out of the way when the furnace doors are opened. Air for atomizing is heated in its flow through pipes which come in contact with the waste gases from the furnace, and oil is delivered under a constant pressure by pumping.

A system of oil burning designed for rapid change from oil to coal is one in which the fire bars and the brick work of the furnace remain permanently in place, and a layer of broken fire-brick 8 or 9 inches deep is spread over the grates. The oil burner is so placed that the blaze passes over the irregular surface of the broken brick and the whole mass soon becomes intensely hot. The burners can be swung out of the way when the change to coal has to be made and the broken brick raked out of the furnace, and coal thrown upon the grates. The advantage gained in this rapid change system compels the probable sacrifice of a more suitable arrangement in which the striking, deflecting and retarding walls and screens of brick form a desirable feature in the burning of oil. The removal of some parts of these, when a change from oil to coal has to be made, is not very difficult when at sea, though the

change occupies considerably more time than where broken brick is used upon the grates.

A modern steamship lends itself readily to the satisfactory storage of oil fuel. The water bottom of the ship, which consists of the space between the outer plates of the hull and what a landsman would call the floor of the hold, is usually appropriated for the carriage of water ballast. The space is divided into tanks which can be filled or emptied as required. When these tanks are used for the storage of oil, provision is made to fill with water any tank from which the oil has been pumped. It has been urged that the storage of oil below the boiler and the engine room compartments is a source of some risk as in the event of a vessel grounding in such a way as to pierce or open the inner skin of the ship, the engine room, or the stoke hold with fires going, might become flooded with oil.

The advantage in the economy of space in the storage of oil over coal at sea may be realized from the fact that 36 cubic feet of oil are stated to be equivalent to 27 cubic feet of coal, as usually stored in ships' bunkers, and moreover the spaces in a vessel which are not available for cargo or coal can be utilized for the storage of oil, and with war vessels the problem of " coaling at sea " becomes comparatively easy when the fuel is in a form which can be delivered by pumping, and furthermore when the vessel is going at full speed, the telltale black smoke of coal disappears entirely with the use of liquid fuel.

In closing this article a few observations on the origin and composition of fuel oil may not be out of place. Fuel oil or, as it is generally called, crude oil is usually found associated with coal. Chemically speaking, fuel oil is obtained by the destructive distillation of vegetable matter, and it was at one time obtained from bituminous shales. Shale when considered from a geological standpoint, is simply hardened mud, and its presence often, as one of the separating strata between layers of coal, represents the encroachment of the sea and the deposit of sediment upon the mass of huge non-flowering plants whose gradual compression and transformation, without access to the air, resulted in the formation of what we call coal.

If at any time of its deposition, the mud was more or less mixed with vegetable matter, it would form, in the lapse of ages a stratum rich in carbonaceous matter which we now call bituminous shale. These shales when slowly distilled in iron retorts at a low red heat, give off volatile matter, and from this is obtained by a process of condensation, the burning and lubricating oils, also paraffine and ammonia.

It is probable that the production of crude oil was the result of a process in nature analagous to the distillation of the bituminous shales. The richer varieties of shale yield from 30 to 40 gallons of crude oil to the ton. There are a large number of hydro-carbons existent in nature; many can be produced artificially from organic substances. In all the hydro-carbons the percentage of carbon is high. They are practically insoluble in water, and all combustible. Crude oil when refined gives about 38 to 44 per cent of oil for fuel, 15 to 20 per cent of lubricating oil and from 9 to 12 per cent of paraffine.

The process of refining consists of distilling the crude oil and variously treating it with sulphuric acid and caustic soda. As a result of the process, gasoline, naphtha, burning oil and heavy oil used for lubrication are obtained. Gasoline is a mixture of paraffine sufficiently volatile, when air is passed through it, to become a combustible gas. Naphtha is a mixture of hydro-carbons which about equals crude benzol, which is a by-product of coal gas. Burning oil is a mixture which is sufficiently volatile to light readily and to feed through lamp wicks and yet is practically free from the dangerously inflammable constituents which would be liable to explode. Heavy oil is too viscid to rise in a lamp wick, but suitable for lubricating purposes, after as much of the solid paraffine has been extracted as can be, by comparatively simple processes.

A curious circumstance which grew out of the original use of crude petroleum was a lawsuit in which the question, What is coal? was practically the point at issue. In 1847 a Glasgow chemist, James Young, had his attention called to a petroleum spring at Alfreton in Derbyshire. Young took a lease of the spring and at once began to manufacture from this crude oil, two varieties, one suitable for burning in lamps and the other for lubricating purposes. Two years later this spring gave out, and Young conceived the idea of producing similar oils from the distillation of coal. This he succeeded in doing, and the illuminating oil so obtained was naturally called coal oil. The coals originally employed were parrot coal, cannel coal and gas coal. Later he acquired by lease a property yielding what was called Boghead mineral. This

he used in the same way for the production of coal oil; but as his lease entitled him only to the removal of coal from the property, a lawsuit was instituted by the owners of the land to restrain him from removing the Boghead mineral.

The question as to what was and what was not coal came up at the trial, and indeed formed the crux of the dispute. Expert testimony was given on both sides; but it was finally decided that, as far as the purpose of the lease was concerned, Boghead mineral came within the definition of the word coal. Young had previously patented his process as applied to the distillation of bituminous coal, and if the decision of the court had gone against him, his patent would have been of little or no value. The essence of Young's process consisted of the distillation of bituminous substances at the lowest temperature at which they could be most satisfactorily volatilized.

The development of the industry which grew up under Young's patents, practically led to the rise of the petroleum industry in America. The United States Acting Commissioner of Patents in reporting upon Young's claim for an extension of patent rights here said: "That manufactures of coal oil in this country had their origin in Mr. Young's discovery. The use of petroleum followed so directly and obviously from the use of coal oils, that it can hardly be denied that one originated from the other." Thus it appears that the original discovery and use of a petroleum spring and its failure paved the way for the manufacture of coal oil, and so back to the use of petroleum where that substance had been most abuntantly provided by nature.

REVIEW QUESTIONS.

CRUDE OIL AS FUEL.

1. Explain the reasons why it is necessary to atomize fuel oil in order that it may be burned economically.

2. Name several different types of burners in general use.

3. When was the first oil burner used in a locomotive in the United States?

4. What are the principal reasons why fuel-burning locomotives are being used in preference to coal-burning locomotives?

5. Upon what part of a locomotive boiler is the flame of an oil burner very severe?

6. In the design of a fire-box for oil-burning locomotives, explain the reasons why all seams should be dispensed with.

7. Explain why the tubes of an oil-burning locomotive rapidly become filled with soot.

8. How should the tubes of an oil-burning locomotive be cleaned?

9. Describe the kind of apparatus used for cleaning the tubes.

10. Name twelve advantages claimed for the use of fuel oil on locomotives.

11. How much does crude oil weigh a gallon?

12. What is the effect on an oil flame if the oil contains water, which is often found mixed with it?

13. Explain the value of a brick arch in the fire-box of an oil-burning locomotive.

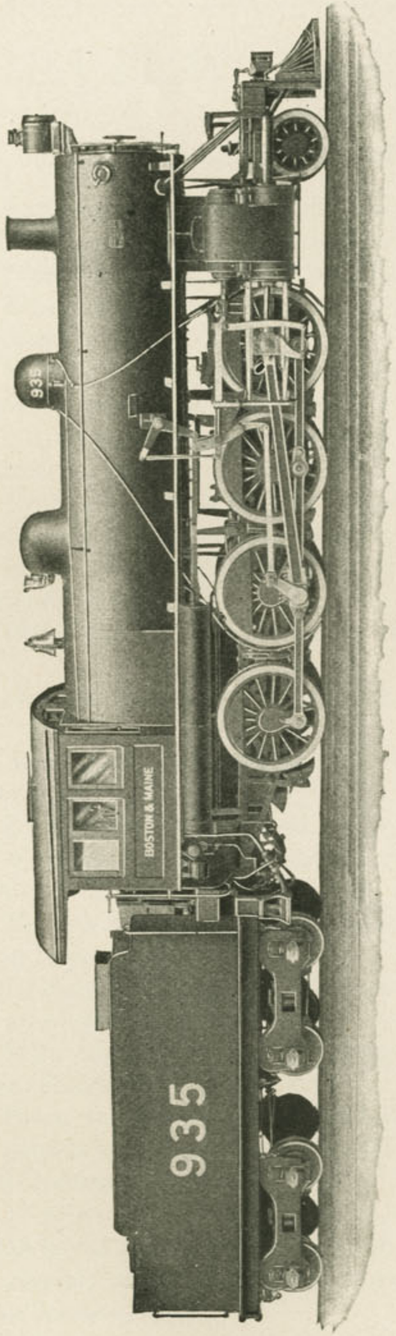
14. Explain how you would convert a coal-burning locomotive into an oil-burning locomotive.

15. What are the fundamental principles upon which all oil burners are designed?

16. Since one pound of crude oil will equal about one and one-half pounds of coal, explain why oil is not more universally adopted in locomotive practice.

17. If a locomotive tender is filled with 1800 gallons of oil, what would be the approximate weight of this oil?

18. Explain one method which is used for storing and handling oil for locomotive use.



CONSOLIDATION TYPE FREIGHT LOCOMOTIVE
(American Locomotive Company)

Locomotive Firing and Fuel Economy.

The principles of heat and combustion having been discussed, it remains for the locomotive fireman to put these principles into execution when firing his boiler with fuel. While a good fireman may not always understand the reasons why he is firing in a certain manner, some knowledge of the science of combustion will often enable him to overcome difficulties and produce the best results under the given conditions.

Possibilities of Fuel Saving. The possibilities of fuel saving are probably greater after the coal has been placed upon the locomotive tender than at any point in its journey from the mine to the ash-pan. On a great majority of locomotives, which are easily within the capabilities of hand-firing, the limit of coal consumption is about two tons per hour. Should there be a small saving of the needless waste that is going on on most locomotives all the time, it can easily be seen that the total amount of heat, and consequently the amount of fuel saved, would be a considerable item each day.

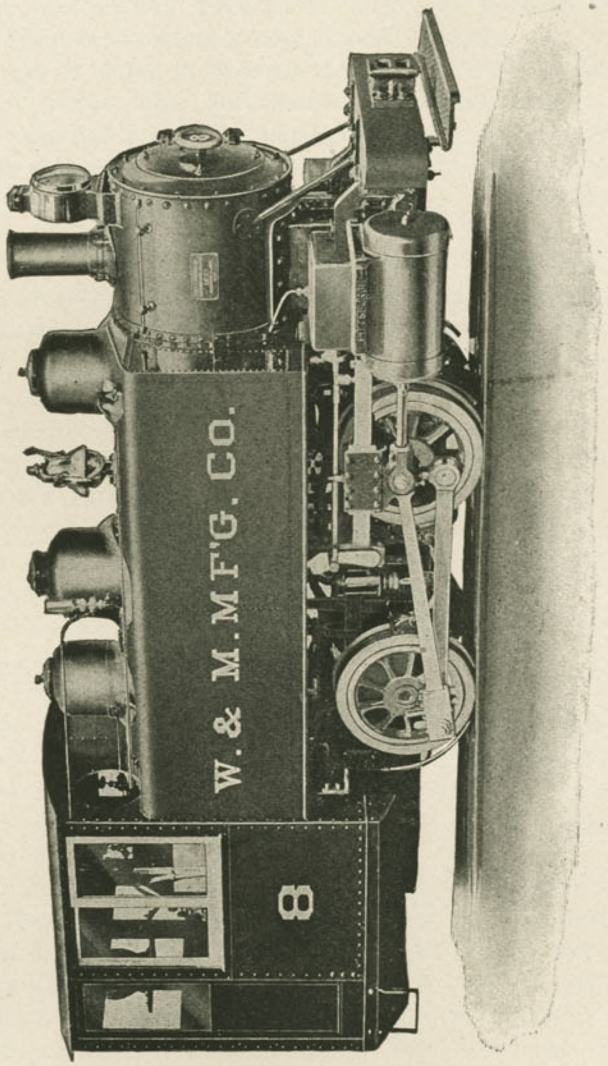
Qualifications of a Good Fireman. The qualifications of a good fireman are, first, intelligence or brightness, and second, physical strength and endurance. The highest type of fireman is one who, with the smallest possible quantity of fuel, can keep up the required pressure of steam without waste through the safety valves. To be able to do this no large amount of strength is required in the majority of cases, as the factor of strength only enters into the problem of locomotive firing when the action is constant and continued for a long period of time.

The best firemen are not usually those who can raise the heaviest weight, but rather the men of moderate strength and great endurance. The best firemen are those who fire properly and keep doing it continuously. A strong man will handle more coal and work harder, and consequently will be more exhausted and will require a longer period of rest, than one who has learned the science of firing, all because the poor fireman will have performed much useless labor, and incidentally thrown away a large amount of valuable fuel. Comparison between the man who uses his head and the man who only heaves coal almost universally results in the favor of the former, provided, of course, he has been given the proper instruction.

Education of Firemen. The results that can be obtained from the education of firemen apparently have not been sufficiently impressive to cause the introduction of a practical course on most of the railways. A few companies, however, are furnishing their men with literature, which goes more or less fully into the theory of combustion, and which gives them detail instructions as to the proper method of firing. Some few roads have followed up this method with a thorough course of individual instruction which has worked out very satisfactorily. Where the proper grade of men can be obtained and the work of instruction is systematically followed out, the roads using these methods have found that they have improved fuel records, increased interest in the work and a loyal set of firemen.

Cases of good firemen quitting because they could not understand the work, which was easily within their strength if they had been properly instructed, are not by any means uncommon throughout the country, and it is this feature that has caused the greatest regret that more attention has not been given to the subject of education.

Method of Instruction. The method of instruction used, as far as the actual placing of the coal on the fire is concerned, consists very largely in convincing the men, both by sound reasoning and actual example, that it will pay, and pay well, to scatter well broken coal in small amounts in various parts of the grate in succession, with an interval between charges that will make it necessary to again cover the first part of the fire as soon as the whole grate has been gone over. This method, of course, with an ordinary locomo-



FOUR WHEEL SIDE TANK 0-4-0-T-TYPE LOCOMOTIVE
(American Locomotive Company)

tive means continuous work, but in most cases it can be done leisurely, even though the locomotive is working at full power. Time for resting may be had on the down grade stretches, stops for water, the waits at meeting points, signals, flags, etc.

This is the way the fireman should fire and the way an intelligent, educated fireman will fire, provided he is not expected to take care of a large number of other things at the same time. Unfortunately, in many cases he has to break up all his coal, he must climb up and shovel it down from the back of the tender every half hour or so, he is sometimes expected to watch every signal, and if, besides, he has to clean out the ash-pan frequently, is given poor coal, or the engine is not steaming properly, it is not to be expected that the best results can be obtained.

Preparing the Locomotive Before Starting. Before starting the fire in a locomotive it should always be noticed whether the boiler has the requisite quantity of water in it; whether all cinders, clinkers and ashes have been removed from the grates and ash-pan, and from the brick-arch or water-table, if the boiler has either of these appliances. The grates and drop-door should be in their proper position and securely fastened; the throttle-valve should be closed and the lever secured; and, if the boiler was filled through the feed-pipe by means of the engine-house hose, it should be observed whether the check-valves are closed. If they are not closed, it will be shown by the escape of water when the engine-house hose is detached, or by the water and steam blowing back into the tank when the tender-hose are coupled up, and after steam is generated in the boiler. Locomotive boilers are sometimes seriously injured by building a fire in them when they have not been filled with water. This can only occur from the grossest carelessness on the part of the person who starts the fire. In filling a boiler it must be remembered, however, that when the water is heated it will expand, and that when bubbles of steam are formed they will mix with the water and thus increase its volume, so that after the water is heated its surface, as shown by the water-gauge and gauge-cocks, will be considerably higher than when it is cold.

Starting the Fire. The fire in a locomotive should be started slowly, so as not to heat any one part suddenly, as some of the worst strains which a locomotive boiler has to bear are those due to the unequal expansion and contraction of its different parts.

When the fire is started, the parts exposed to it are heated first, and consequently expand before the others do. If the fire is kindled rapidly, the heating surfaces will become very hot before the heat is communicated to the parts not exposed to the fire. Thus the tubes, for example, will be expanded so as to be somewhat longer than the outside shell of the boiler, and therefore there will be a severe strain on the tube-plates, which will be communicated to the fire-box, stay-bolts, braces, etc. The inside plates of the fire-box will also become much hotter than those on the outside, and as they are rigidly fastened, to which both the inside and the outside shells are attached at the bottom, the expansion of the inside plates will all be upward, which thus strains the stay-bolts in that direction. As the motion due to this expansion is greatest near the top of the fire-box, the top stay-bolts are of course strained the most, and it is those in that position which are the most liable to break. It is, therefore, very important both to heat and cool a locomotive boiler slowly, and it is best to kindle the fire several hours before the engine starts on its run.

If the fire in the fire-box has been banked, the fire should be broken up with a bar and the ashes shaken out of it, and fresh coal should be thrown on the fire if it is needed.

First Requirement of Firing. The first and chief purpose of firing is to make steam enough, so that the locomotive can pull its train and "make time;" second, it should make the requisite quantity of steam with the least consumption of coal; and third, with the least production of smoke, although the latter, independent of the economy of combustion, is considered of importance only with passenger trains. It often happens that it is a matter of extreme difficulty to make enough steam to do the work required of the engines. When a freight train is struggling up a grade with a heavy train, or an express engine is obliged to make time under similar conditions, it often depends entirely upon the quantity of steam which can be generated in the boiler in a given time whether the engine will fail or not. In firing, therefore, the most important end to be aimed at is often simply to produce the largest amount of steam possible in a given time, even at the sacrifice of economy or by producing any quantity of smoke. Any means of economizing fuel or of smoke prevention which reduces the steam-producing capacity of boilers, is therefore quite sure to be abandoned in time.

How the Largest Quantity of Steam Can Be Produced. The largest quantity of steam which can be produced in a given time is obtained by burning the greatest quantity of fuel possible on the grate in that time. This can be done by keeping the grates free from clinkers and the ash-pan from ashes, and then distributing the coal evenly over the grates in a layer six to twelve inches thick. The thickness of the layer which will give the best results will, however, vary with the quality of the fuel, and must be determined by experience. If the layer is too thick, not enough air will pass through it to burn the coal. If it is too thin, then so much air will pass through that the temperature in the fire will be reduced.

The rapidity of combustion will also be promoted by breaking up the coal into lumps the size of a man's fist or smaller. If fine coal is used, it should be wet, otherwise it will be carried into the flues by the blast before it is burned, or caked, or before it even reaches the grate. Experience will indicate the amount of air which can advantageously be admitted above the fire in order to secure the maximum production of steam. The best size of the exhaust nozzles and the position of the petticoat-pipe must also be determined by experience. It will usually be found, however, that if enough air is admitted above the fire to prevent smoke, it will reduce the maximum amount of steam which can be generated in a given time. The fire should also be fed regularly and with comparatively small quantities of fuel at a time, although if the feeding is too frequent there is more loss from the cooling effect which results from the frequent opening of the furnace door than is gained from the regularity of the firing. In this, too, a fireman must consult experience to guide him.

Banking System of Firing. Two systems of firing are practiced in this country, one known as the "banking system" and the other the "spreading system." When the banking system is employed, the coal is piled up at the back part of the fire-box, and slopes down towards the front of the grate, where the layer of coal is comparatively thin and in an active state of incandescence. The heap of coal behind is gradually coked by the heat in the fire-box, and the gases are thus expelled. Openings in the furnace door admit air, which mingles with the escaping gases, which then pass over the bright fire in front, and are thus supposed to be consumed. When the "bank" of coal behind becomes thoroughly coked, it is pushed forward on the bright fire, and fresh coal is again put on behind to be coked. This system of firing is practiced on some roads with good results, but it cannot be used successfully with coal which cakes and clinkers badly.

Spreading System. The spreading system is most commonly employed in the Western States, where the coal contains a great deal of clinker. When this is practiced, the coal is spread evenly over the whole of the grate in a thin layer, and its success and economy depend upon the regularity and evenness with which this layer of coal is maintained and the fire fed. The thickness of the coal must be adapted to the working of the engine. When it is working lightly, the layer of coal should be thin, but when the engine is pulling hard the layer of coal must be thicker, otherwise the violent blast may lift the coal off the grates. The success of this system depends upon the manner in which the thickness of the fire is regulated, on the admission of the proper amount of air above the fire, and on the frequency with which the fire is supplied with coal. When this system of firing is employed not more than two shovelfuls of coal should be put into the fire-box at once, and if the engine is not working hard, one or even less will be sufficient. The fireman must, however, determine by experience the thickness of fire, amount of air which should be admitted and the frequency of firing which will give the best results in practice. These will vary with different kinds of fuel and the construction of engines.

Short Rules for Burning Bituminous Coal. (1) Keep the grate, ash-pan and tubes clean. (2) Break the coal into small lumps. (3) Fire often and in small quantities. (4) Keep the furnace door open as little as possible. (5) Consult the steam-gauge frequently, and maintain a uniform steam pressure, and, if necessary to reduce the pressure, do it by closing the ash-pan dampers rather than by opening the furnace doors.

Duties of the Fireman at Stops. The fireman should examine the tank, and see whether it is necessary to take in a fresh supply of water. He should then examine the grates and ash-pan, and clean the cinders and clinkers from the former and the ashes from the latter. Neglecting to clean the ash-pan may result in melting and destroying the grate-bars, and by obstructing the admission of air to the grates the ashes prevent the combustion from being as complete as it would otherwise be. With some kinds of fuel it is necessary to clean the tubes frequently, which must often be done at stations where the train stops.

During the stop as thorough an inspection of the engine should be made by the engineer and fireman as the time will permit; but any unnecessary waste of time must be avoided, and the firing should be so managed that nothing need be done about it during the halt at the station. On starting again the same precautions should be observed as on making the first start.

Firing at End of Run. Before reaching the last station the firing should be so managed that there will be as little fire as possible remaining in the fire-box at the end of the run. After the arrival the engine should be run over a pit which is usually provided for the purpose, and the fire should be raked out of the fire-box by dropping the drop-door, if there is one to the grate, or turning the grate-bars edgewise, or withdrawing one or more of them, if it is necessary to do so. In this way the fire will fall into the ash-pan, from which it can be easily raked. After all the fire is withdrawn, the dampers and furnace door should be closed so as not to allow the cold air to cool the fire-box and tubes too rapidly.

Duties of a Fireman. Among the many duties which the fireman has to perform, the following are those which are necessary under all conditions:

The fireman should reach the engine house in time to see that all the necessary tools and supplies are on the engine; that the tank is full of water and is provided with the coal necessary for the trip; he should see that the fire has a good foundation for starting, and if not, he should give it the necessary coal, so that the fire will be in good condition before starting out; the ash-pans should be examined and cleaned, and the grates should be examined to see that they are level. When the train is ready to start, the fire should be in such a condition that it will keep up steam until the reverse lever is notched back after the train has worked into its normal speed. When the fire needs attention only a few shovelfuls of coal should be fired at a time, by scattering it over the surface of the fire, so that it does not cool off the fire, yet at the same time burns up the gases, which are an important factor in giving their heat to the boiler. If too much coal is thrown on at one place at any time, a large amount of smoke will come out of the stack, which will be of no value in aiding the boiler to steam properly. With thin firing a supply of air passes through it sufficiently to provide the necessary oxygen to burn these gases, so that any heat which the coal is capable of giving out is obtained. Should there be any spots showing up in the fire, they should be immediately filled with coal, and the corners and sides of the fire-box should be kept well filled. The supplies of air should be regulated to suit the given conditions and the kind of fuel which is being burned, and the ash-pan dampers should be regulated accordingly. If too small a volume of air is admitted, the fire will not burn as it should, and if too much air enters the fire-box the gases will be chilled. Should indications appear that the fire is not receiving sufficient air, the grates should be shaken at intervals sufficient to keep the fire as clean as possible. This should always be done lightly, so as not to disturb the fire any more than is necessary. Good coal requires no more shaking than that which will prevent clinkers from forming between the grate openings, and should the fire be shaken any more than this large holes will be formed in the fire, which will admit cold air and be detrimental to the fire and boiler. This is also a matter of experience, as each coal contains more or less clinkers, which will be more or less difficult to break up.

Before a stop is made the fireman should place sufficient fuel in the fire-box, so that it will not be necessary to fire again until after a new start is made. When this has been done, it avoids having to fire while the engine is standing at the station, and prevents the fire from being in a cold condition when the hardest pull is upon the boiler. Where there are grades which require the throttle of the engine to be opened full, the amount of steam required by the locomotive is very heavy, in which case the fireman should make his fire heavy to suit the circumstances. This, however, should be done, not by piling the coal on all at one time, but by gradually firing it so as to have a very heavy bed of incandescent fuel during the time when the grade is the heaviest.

Firing Anthracite Coal. When firing anthracite coal, the size of the pieces will determine the frequency with which the coal must be shoveled and the thickness of the fire. When the coal is in large lumps, the fire must be of considerable thickness, and constant care must always be exercised to prevent loss of heat from excessive quantities of air passing through the holes caused by the

large lumps. When the smaller grades of anthracite are burned a very large grate area is necessary, as the fire must be burned thin, and a thin fire will not stand the action of a sharp exhaust unless the blast is divided over a large area. It is particularly important when firing with anthracite coal to prevent spots from forming in the fire, and the fireman must be continually on the watch to put coal on any such spots which are formed.

Firing Liquid Fuel. When starting an oil burner, provided it is where steam pressure cannot be obtained for use as a blower, throw into the fire-box a piece of oiled waste, then start the oil lightly, then open the atomizer valve enough to atomize what oil is passing from the boiler, and the oil will instantly ignite. Care should be taken not to turn on too much oil, for there may be a slight explosion in starting, which may cause injury to the fireman. After the fire begins to burn, close the door tight and watch the burner to see that it is giving the required amount of heat, has not gone out, and if there is any water in the oil, or any defect in the burner. These may very likely happen, and will be indicated by smoke coming out of the stack. Should there be no steam available for the purpose of atomizing the oil when starting, it will be necessary to fire up with enough wood to get steam pressure in the boiler sufficient to work the atomizer. Care should be taken in doing this so that the brick wall or arch will not be injured in any way. After the burner has started to make steam it is very important that the proper amount of steam be admitted to the burner as an atomizer. It will be necessary occasionally to use sand for cleaning off the ends of the flues in the fire-box, this will clean off the gum or soot which may be formed there.

Difficulties of Firing Properly. One of the greatest difficulties in having a fireman to fire the coal properly has been that he is often given a locomotive of a size and power which no one man can shovel coal enough into in order to develop its rated capacity, and again there are times when the fireman is given such poor fuel that, even though the engine is working under normal conditions, it is almost impossible to burn enough fuel to give the required amount of steam, and in such cases it may be advisable to use some form of a mechanical device, either to burn the fuel itself in the furnace of the locomotive or to supply it to the fireman in sufficient quantities to enable him to fire large amounts without undue labor.

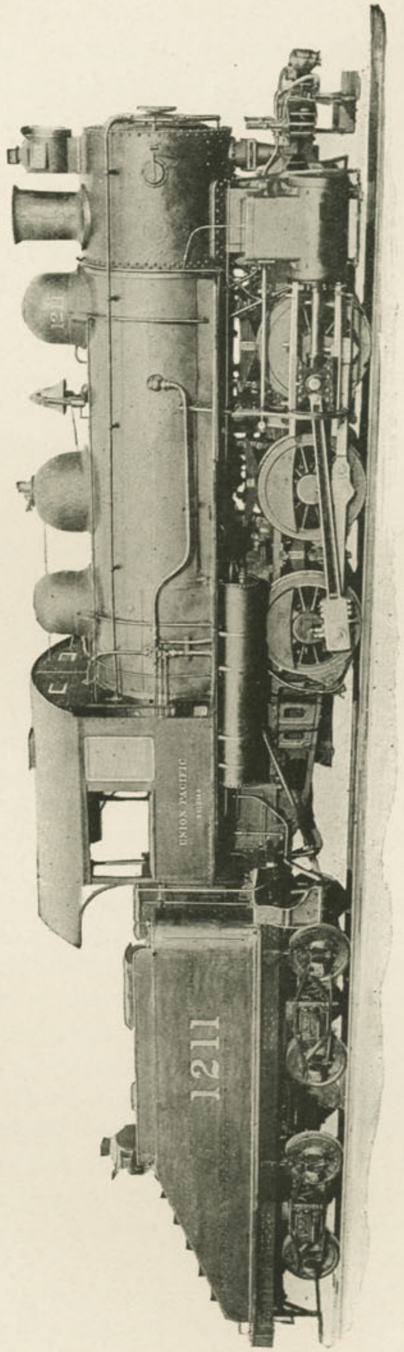
Use of the Blower. The blower should be used when the engine is on the cinder pit with just enough force while cleaning the fire to prevent the escape of gases from the fire door and possible injury to the fire cleaner.

When the engine is at rest it is sometimes necessary to use the blower to prevent the emission of smoke. In this case the fire door should be kept on the latch. The blower has sometimes to be used for stimulating the fire when the engine is not steaming freely. In such cases it can be employed to best advantage when descending grades or approaching stations with the steam shut off.

Methods of Reducing Smoke from Locomotives when Starting. It is the effort of all railroads using soft coal to reduce the smoke nuisance as much as possible, not only on account of the fuel which is saved, due to perfect combustion, but also on account of the objections which are raised by those who live close to the railroad. In order to attempt to reduce the smoke nuisance, the fireman must be instructed to fire properly, for no matter what the other conditions may be, it is impossible to eradicate black smoke without intelligent and faithful work on the part of the fireman and engineers. In some instances, the road puts the problem up to the engine crews entirely, holding them responsible for any excess of black smoke, and suspending them in all cases where black smoke is produced and no good excuse for same can be given.

Mechanical devices are used on several roads to assist the fireman in his attempt to fire properly. These devices have shown good results, and are being used more extensively on a number of large roads. Among these devices used are mechanical stokers and pneumatic fire-box door closers. Hollow fire bricks have been used, and, while they have aided in diminishing black smoke, their cost of maintenance does not indicate their increased use. Smoke consumers, consisting of a strong blower in the front end and steam jets into the fire through the side sheets, have given good results when the engine was fired light.

Preparing Coal Before Putting on Tender. Few railroads prepare their coal that goes on the tender. Those that do, generally break the large pieces into lumps from four to six inches in diameter. This is done by providing coal sheds with breakers made by placing $\frac{3}{4}'' \times 3''$ iron bars on edge five inches apart. The coal is dumped on these breakers and must be broken into pieces less than five inches in diameter before it will fall through.



SIX-COUPLED SWITCHING LOCOMOTIVE WITH SEPARATE TENDER, USED ON THE UNION PACIFIC R. R.
(Baldwin Locomotive Works)

Preparing Fire when Starting Train. Without exception the following plan is used by all railroads when starting the fire. The fire is built up gradually until a good level of coals is secured of sufficient thickness to hold without tearing under heavy exhaust. The single scoop system is then used for replenishing the fire. When stops are made, the fire should be in such prime condition that it will not be necessary to put on much coal when starting the train, and the engineer should use every effort to assist the fireman in holding his fire by pulling out carefully.

When the stop is to be a short one, the fireman should endeavor to have his fire in such condition that no green coal need be added until the train has left the station.

The blower should be used to pull just enough air through the fire to combine with the gases, and the grates and ash-pans should be kept clean and in good condition. The condition of the grates has much to do with suppression of black smoke.

Railroad Instructions to Firemen. On most roads firemen are instructed to fire as light as possible, from one to four scoops at a time being advocated. The " one-scoop " system is generally advised, but in large engines with large fire-boxes it is not practical. The coal should be well and evenly scattered, first on one side of the fire-box and well into the corners and then on the other, so as to retain a bright fire on one side of the fire-box in order to burn the gases discharged from the green coal applied to the other side. The door should be swung after each shovelful is applied, and for this reason some roads use pneumatic door closers.

Grade of Coal Used. One of the worst troubles which firemen have to contend with is the different grades of coal used. The poorest grade of coal seems to be used by most of the roads, and as many as sixteen different grades have been used on one road. If possible, the fireman should be given the same grade of coal, even though it be of poor quality, as he will get accustomed to using it to the best advantage, rather than giving him good coal one trip and poor coal another. On some roads, fifty per cent of bituminous and fifty per cent of anthracite have been used successfully with very little trouble from the smoke nuisance.

Fine coal is found to produce more smoke than lump coal, as it ignites more rapidly, and the smoke and gases formed have less chance of being burned off. It is also more difficult to prevent smoke when coking coals are used than with non-coking coals, and smoke is still more difficult to prevent when slack coal is used. While in general good coal will produce less smoke than poor coal, it will often be found that good coal will give off blacker smoke, owing to the large amount of carbon it contains, and because the fireman has not become properly acquainted with its use.

Combustion Chambers. While combustion chambers have been used successfully in preventing smoke, their use has been discontinued on some roads on account of steam failures and the banking of cinders and fire against the lower flues, causing them to leak.

Auxiliary Exhaust Devices. While in foreign countries an auxiliary exhaust appliance when starting trains has been used very successfully, but little has been done along this line in this country. Whenever used, however, auxiliary exhaust devices have demonstrated that they act not only as smoke reducers but also as coal savers, on account of their equalizing the draft through the smoke box, and thereby making lighter and more systematic firing possible.

Smoke Prevention. The following recommendations if carried out will prevent smoke in most locomotives: Standardize the grades of coal used; mechanical devices should be used to assist the firemen, as his duties are now becoming too heavy, especially with the heavy power locomotives; preparation of coal before it is put in the tender; the single scoop system of firing with the closing of the door after each scoopful; fire-boxes equipped with properly designed brick arches; the use of the auxiliary exhaust which will make light and economical firing possible.

B. & O. Instructions on Firing Locomotives. The following instructions to govern the firing of locomotives for the suppression of dense smoke have been put into force on the Baltimore & Ohio Railroad by Mr. J. E. Muhfeld, general superintendent of motive power:

Engineers will be responsible for the proper operation of locomotives with respect to the handling of the reverse and throttle levers and the supplying of feed water.

Engineers and firemen will be equally responsible for the operation of the steam blowers or smoke suppressors and for the

smokeless and economical method of firing locomotives, in accordance with the following general instructions:

Preparation Before Starting. Before the commencement of a trip or day's work, the rocking and drop grates, ash-pan dampers, ash-pan slides and steam jets, and grate and ash-pan operating gear should be examined and tested to see that all grates set level when latched, and that all parts are in good working order and in proper position. The smoke-box and ash-pan should be clean and the smokestack and ash-pan steam blowers in good order. All necessary fire tools must be on the locomotive. The fire must be put in good condition on the grates by spreading and replenishing with fresh fuel, in small quantities at a time, until properly built up preparatory to starting with a full supply of water and steam in the boiler. The coal on the tender should be wet down.

Lumps of coal should be broken to as near the size of a man's fist as is consistent before putting into the fire-box.

Method of Firing. A thin, clean fire should be maintained, so that the fuel can be supplied with sufficient air through the grates for proper combustion, and the production of a clear, bright flame. Cross-firing should be practiced to maintain an even bed, free from holes, and localized heavy or lumpy firing should be avoided, as the latter method does not permit sufficient air to pass through the fuel, and results in dense smoke and clinkers. The use of the rake and "puddling" of the fire should be resorted to only when absolutely necessary to spread an uneven fire caused by uneven draft or improper firing. The banking of green fuel at the furnace doors should be restricted.

The grates should be kept well supplied with coal at the sides, ends and corners of the fire-box, and not more than two or three shovelfuls, each scattering the coal, should be supplied at one time. Heavy, intermittent firing should be avoided. Only sufficient fire should be kept on the grates to prevent loss of heat on account of cold air passing through the grates so freely as to reduce the temperature of the gases, and to suit the way the locomotive is being operated.

Operation of Injector, Reverse and Throttle Levers. Injectors and reverse and throttle levers should be operated to favor the firing when starting from a station and on heavy pulls. The smokestack blower should be used when necessary to prevent reduction in boiler pressure, and the boiler feed should be increased to prevent release of steam through the pop valves.

Previous to the closing of the throttle valve, the fireman should apply the steam blower or smoke suppressor to such an extent as practice may demonstrate is necessary to suppress smoke. When locomotives are working steam, the smoke suppressor should be used lightly. The supply of steam to the air induction jets should be regulated by the size of the opening in the gasket, so that on locomotives not equipped with brick arches there will be no tendency to blow the smoke to or through the flues.

When Grates Should Be Shaken. Rocking grates must be shaken lightly and frequently, instead of violently at long, intermittent periods, and, if possible, when the steam is shut off. As a general rule, all rocking grates on passenger locomotives should be shaken every 30 miles, on freight locomotives every 15 miles, and on switching locomotives every three hours. This practice will break any clinker that may be forming over or hardening between the grate openings, and will allow dead ashes to fall into the ash-pans and keep the grates and fire clean. It will also allow air to pass through the grates and fire, and prevent the formation of clinker on the fire-box flue and crown sheets, which occurs when air cannot get through the grates and must pass over the fire.

Opening Furnace Doors. The practice of opening the furnace door unnecessarily should be avoided, and firemen must regulate the ash-pan damper openings to suit the requirements. When locomotives are drifting, the fires must be maintained in a clean and bright condition over the entire grate area, more especially at the flue sheet.

Cleaning Ash-pans. Hopper sides of ash-pans must not be opened when the locomotive is running. Ash-pans and fires should not be cleaned near any frog, switch, crossing, de-rail or wooden building or structure.

Treatment of Special Fuels. Certain fuels and locomotives will require special treatment, but in general the above methods are those of the most successful firemen, and the highest type of fireman is one who can maintain the working steam pressure within a range of ten pounds variation with the smallest amount of fuel and the least waste of steam through the pop valves.

Exhaust nozzle openings and draft appliances must be adjusted to suit the winter and summer conditions, and when necessary on account of change in quality or kind of fuel furnished.

Reporting Defects. Engineers must immediately report any irregularities in connection with the cleaning or building of fires at terminals. They must also report defects in connection with piston or side valves; cylinder or rod packing; dry, steam and exhaust pipes; smoke-box draft appliances; stopped up or leaky flues; rocking and drop grates, ash-pans and dampers; smokestack and ash-pan; steam blowers and smoke suppressors, and all other auxiliary equipment pertaining to the economical use of steam and fuel, and for the prevention of dense smoke. All adjustments or repairs that may be found necessary must be promptly and properly made.

Relation of Fireman to Public. Since railroads have been and are now expending a considerable amount of money to put machinery, boilers, fire-boxes, flues, grates, ash-pans and draft appliances of locomotives in a substantial condition for service, and with the grade and quality of fuel supplied it is expected that some returns in fuel economy through proper methods will result from the operation and firing of locomotives. Passengers and the public at large are also entitled to consideration, and the elimination of dense smoke will contribute to their comfort, as well as to reduce steam failures and waste of fuel.

Instructions to Govern the Use of Coke on Locomotives. The following instructions are given to firemen on the B. & O. R. R. to govern the use of coke on the locomotives on that road. This is a subject that is of much importance as a possible solution of the smoke problem, particularly on those roads having freight terminals within the limits of large cities.

Quality of Coke. Coke should be of a hard quality, as free from dust as practicable, and of 48 or 72 hours' burning.

Handling of Coke. When coke is furnished from chutes to locomotive tenders the floor of the chute should be arranged as a screen, so that the fine dust will be removed and not passed to the tender. The screen should be made of one-inch round steel bars, spaced one inch, and running longitudinally.

When coke is handled from a car into buckets, from which it is to be supplied to the tender, ballast forks should be used for handling the coke when filling the buckets.

After the tender has been furnished with a supply of coke, it should be thoroughly wet down to further eliminate the fine dust by carrying it to the bottom of the tender, from which point it should be removed from time to time.

Blast for Coke Fire. As a sharper blast is required for a coke fire, locomotives using coke as fuel should be equipped with exhaust nozzle openings, about one-quarter inch smaller in diameter than those for bituminous coal-burning locomotives.

Grates for Coke-burning Locomotives. Coke-burning locomotives should be equipped with finger style of rocking grates, in order to crush the clinker and to give better draft than can be secured with the bar types of rocking grates. The grate area should be as large as practicable, and the rocking, dead and drop grates and operating gear should be kept in good adjustment to permit of free operation and without lost motion. As coke contains a much greater percentage of fixed carbon and ash than bituminous coal, it is very essential that the grate gear be maintained as above specified to insure against any difficulty of removing the ash and incombustible matter from the fire-box.

Locomotives with large diameters and short flues will give the best results on account of remaining unobstructed and giving freer draft than smaller and longer flues.

Brick Arches not Recommended when Burning Coke. Brick arches should not be used in fire-boxes or coke-burning locomotives, as they interfere with maintaining the proper depth of fire. With coke a much heavier fire is required than with bituminous coal, as it does not pack so closely and there is liability for the introduction of cold air through the grates, which will lower the temperature of the gases and cause failures to steam.

Starting a Coke Fire. The preparation of the coke fire must be given careful attention. Wood and semi-bituminous, low volatile soft coal should first be applied to the grates. This will assist in igniting the coke and preventing it from clinkering over the grate surface. After the coal has been thoroughly ignited the coke should be introduced until the fire-box has been filled. The steam blower must be used until the coke is well burned through and makes a solid body of fire. The fire should then be left in this condition until the locomotive has commenced work, and until 15 or 20 miles have been run; then at the first opportunity, preferably

when steam is not being worked, the fire-box should be filled with a fresh supply.

Cleaning Coke Fires. The fires should be cleaned after each 24 hours of service, and at the same time the flues should be blown out with the air blower equipment, that should be installed at each of the fire cleaning stations.

Engineers will be responsible for the proper operation of locomotives with respect to the handling of the reverse and throttle levers and to the supplying of feed water.

Engineers and firemen will be equally responsible for the operation of steam blowers and for the economical firing of locomotives, in accordance with the following general instructions:

Preparations Before Starting. Before the commencement of a trip or day's work, the rocking and drop grates, ash pans and dampers, ash pan slides and grate and ash pan operating gear, should be examined and tested to see if all grates set level when latched, and that all parts are in good working order and proper position. The smoke box and ash pan should be clean, and the smokestack and ash pan steam blowers in good order. All necessary fire tools, including a slash bar to prevent formation of clinker on grate surface, and scraper to remove the honeycomb that accumulates on the flue heads, must be on the locomotive. The fire must be put in good condition on the grates preparatory to starting, with a full supply of water and steam in the boiler. The coke on the tender should be wet down.

Methods of Firing Coke. As heavy a fire should be kept on the grates as is necessary to prevent loss of heat, on account of cold air passing through the grates so freely as to reduce the temperature of the gases, and to suit the way the locomotive is being operated. Fresh coke should be supplied to the fire-box when the throttle is shut off. The use of the rake and puddling of the fire should be resorted to only when absolutely necessary to spread an uneven fire, caused by uneven draft or improper firing.

The smokestack blower, however, should not be operated any more than necessary, on account of coke burning out more quickly than coal, and when the ash commences to accumulate the blower will tend to draw cold air and ash into the flues instead of heat.

When Grates should be Shaken with Coke Fire. Rocking grates must be shaken lightly and frequently instead of violently at long intermittent periods, and, if possible, when steam is shut off. As a general rule, all rocking grates on passenger locomotives should be shaken every 20 miles; on freight locomotives every 10 miles, and on switching locomotives every hour. This practice will break any clinker that may be forming over or hardening between the grate openings, and will allow dead ashes to fall into the ash-pans and keep the grates and fire clean. It will also allow air to pass through the grates and fire, and prevent the formation of clinker on the fire-box flue and crown sheets, which occurs when air cannot get through the grates, and must pass over the fire.

Regulating Ash Dampers. The practice of opening the furnace door unnecessarily should be avoided, and firemen must regulate the ash pan damper openings to suit all requirements. When locomotives are drifting, the fires must be maintained in a clean and bright condition over the entire grate area, more especially at the flue sheet.

Hopper slides of ash pans must not be opened when the locomotive is running. Ash pans and fires should not be cleaned near any frog, switch, crossing, de-rail or wooden building or structure.

The above methods are those of the most successful firemen, and the highest type of fireman is one who can maintain the working steam pressure within a range of 10 lbs. variation with the smallest amount of fuel, and the least waste of steam through the pop valves.

Instructions for Firemen on the Chicago & Northwestern Railway. Among the various roads that issue bulletins of fuel economy, one of the most successful has been issued by R. Quayle, surperintendent of motive power of the Chicago & Northwestern Railway. Besides these instructions, he gave what is known as a chapter of "don'ts," which should be read very carefully by every fireman. As a result of these instructions, a marked economy and efficiency was noted on the road. These "don'ts" are as follows:

DON'T think because you are only one engineer or fireman that what you do does not amount to much. It is the little drops of water that make the mighty ocean, and the little grains of sand that make up this earth of ours; so each individual, in the aggregate, can do a great deal. If each engine crew saves one-quarter of a ton, or five hundred pounds, of coal, this, on a thousand locomotives, would result in a daily saving of two hundred and fifty tons, or in round figures $157,000 a year.

DON'T neglect being at roundhouse in ample time to examine the firing tools on the engine before leaving the roundhouse. See that your ash pan, grates and flue sheets are in good condition to make the run.

DON'T fill the boiler full of water as soon as you get out of the house. Leave a space so the injector can be worked to prevent popping, while air pump exhaust is fanning the fire, pumping air to make the terminal air brake test. If you do this your fire will be in better condition to pull out with. The noises of open pop prevent trainmen from locating leaks.

DON'T forget to start the lubricator a few minutes before leaving a terminal. Set it to feed regularly. The proper lubrication of valves and cylinders saves coal.

DON'T forget, when starting trains, to do so carefully, thus preventing damage to drawbars and draft rigging. By so doing you will save serious delays to your own as well as other trains. All delays mean extra fuel consumption to make up time lost.

DON'T neglect using the blow-off cock, as it keeps the boiler clean and water in good condition, and insures better circulation in boiler. Result: Better steaming engine and a saving in coal.

DON'T allow the engine to slip. This is an unnecessary waste of coal, wears out tires and rails, causes great damage to pins, axles and running gear, and generally results in spoiling a fire.

DON'T pull out of a station with a train (after engine has stood for a while and fire was allowed to get low) without first giving the fireman a chance to build up the fire. The time lost waiting to do this will save coal, and can better be made up before reaching the next station. Remember this when you get a time order.

DON'T leave the reverse lever down in corner longer than necessary when pulling out of stations. No rule can be made to govern how the throttle and reverse lever should be used. This must be acquired by practice and observing the performance of the engine. Bring the lever up gradually, as speed is acquired. The lever hooked well towards center of quadrant, with throttle well open, usually gives better results than using the throttle to govern the speed. Up to five years ago we considered it good practice with our smaller power to run with wide open throttle, and as short a point of cut-off as possible consistent with weight of train, but in our heavier and larger engines we find that it is better at many times to throttle the engine. Particular attention is called to all wide fire-box type locomotives. The engineer can permit the reverse lever in these engines to remain low in the quadrant when starting from a station, for a greater length of time than with the other types of locomotives, without pulling the fire or losing steam. When you are running on short time, it would be good judgment for the engineer to take advantage of this when pulling out from a station. In this, engineers will use their best judgment.

DON'T put four or five or more shovelfuls of coal into the fire at once. One or two shovelfuls will give better results, and these two should not be thrown in the same spot. It is good practice to fire on one side of the box at one time, and the next time on the other side of the box, in order that the bright fire on one side may take up the gases from the fresh coal on the other side. This will reduce the smoke and give more steam.

Always fire as light as possible consistent with your work. Very heavy firing will make your flues and staybolts leak, and in time will crack your fire-box sheets. The reason for this is that when you have a very heavy fire, the air will not pass up through it readily, and the gases pass off, because there is not sufficient oxygen to unite with them to produce combustion, and as the gases must get air from somewhere the air is then pulled through the fire door, causing the chilling of flues and sheets as referred to above.

DON'T allow steam to escape at pops unnnecessarily. Frequent blowing off at pops shows improper judgment, and implies that the engine crew is not practicing economy. Tests have demonstrated that ¼ lb. per second, or 15 lbs. per minute, is wasted. This amounts to about one ordinary scoopful, and in most cases may as well have been thrown on the ground as into the fire-box. There are only 133 scoopfuls in a ton of coal, so you can see that you would only have to have your pops open one hundred and thirty-three minutes in a whole day in order to throw a ton of coal away.

DON'T open the fire-box door to prevent steam blowing off at pops when engine is working; dropping dampers is a better practice; the supply of air is cut off, and combustion is partially suspended. When engine stops blowing off, open dampers again before putting in coal. This method keeps fire in better condition and saves coal. You have no doubt noticed that on Class R locomotives, when working hard on a hill, you have to shut your dampers in order to keep your fire from turning over. This is because the exhaust pulls too much air up through the grates, and causes your coal to be too active. To prevent this activity of coal as well as increased combustion which follows, we consider it a good thing to drop your dampers, as per above.

DON'T insist on having the maximum steam pressure with pops opening occasionally when handling light trains, when less pressure will handle the train on time, thus avoiding the opening of pops.

DON'T forget, when engine is shut off for stations, to drop your dampers, opening the fire-box door slightly if necessary, and using the blower to carry off the black smoke.

DON'T blame the engine or coal if engine is not steaming properly before you have ascertained whether or not both of you are doing your duty. Talk it over; see if injector is not supplying more water than is being used, or that fireman is not firing too light or too heavy. Heavy firing is responsible for more poor steaming engines than the lighter method. You all know some engine crews have better success than others with the same engines and conditions. Think a little: there must be some cause for this.

DON'T wait until you get the signal to pull out before building up the fire. This should be done gradually until the proper thickness has been reached. A good fire to start with is essential to maintain the proper steam pressure, while engine is working hard getting train under way. Afterwards distribute the coal evenly on sides, ends and corners. Do this systematically, keeping in mind where you have placed the last shovelful, thus avoiding getting holes in fires, and preventing piling up coal all in one place. Endeavor to keep the steam pressure uniform, with as little black smoke as possible. Experience has taught that engines with draft appliances properly adjusted require very little coal in center of fire-box.

DON'T permit the water to get so high in boiler that it is carried over into the valves and cylinders. This usually occurs when pulling out of stations, and the water carries off the oil, which not only results in cut valves and cylinders, but the extra friction damages the entire valve motion, to the detriment of the power of engine and the coal record.

DON'T gauge the amount of water an engine will safely carry by water coming out of stack. Keep it low enough to insure dry steam being used, because moist steam has the same effect as water. Usually one-half glass or two gauges give best results. Be careful, however, that when ascending a grade, and you are about to pitch over the other side, that you have sufficient water to keep your crown-sheet thoroughly covered. If your custom has been to carry high water, try less and note results in better handling of tonnage, also saving in coal and oil.

DON'T neglect to take advantage of your excess steam before your engine is about to pop off by making a heater of your injector, blowing steam back into tank to warm the cold water, but avoid getting it so hot that the injector will not lift the water. By doing this you will keep your engine from blowing off at pops when standing at stations after the boiler is filled up. You have all tried warming the water in the tank to help a poor steaming engine with good results. What is good for a poor steaming engine will surely help a good steaming engine do better. Try it, and you will find that it will not only save work for the fireman, but will make a better coal record for the engine crew, besides keeping the tank from sweating, which you are aware spoils paint.

DON'T think the fireman alone to blame for your coal record. The best and most economical fireman cannot make a showing with an engineer who supplies more water to boiler than is being used, and who shuts injector off only when boiler is pumped full. The proper handling of the injector is one of the most important matters in saving coal. Feed water to boiler according to demands. If on a through train, keep water level as possible. If on way, freight or switch trains, lose a little water between stations. Fill up again while drifting into, standing or switching at station. The advantages of supplying less water than is being used between stations are: It requires less coal to keep up steam pressure when running; also leaves a space so injector can be worked to avoid pops opening, and heavier fire can also be maintained to do switching, without the possibility of the fire being pulled.

DON'T pull out, after making a stop, with injectors working. The cool water introduced during period throttle was shut off is put in circulation throughout the boiler, and pointer on gauge drops back from five to twenty-five pounds. The fireman must then fire heavier to regain the lost steam, and naturally will use more coal. This condition exists also when engine has gone down grade with throttle shut or slightly open. Shut the injector off before opening the throttle. If this is not your practice, try it and note the difference.

DON'T wait for the pops to open, and use this as a signal to put on the injector. Keep an eye on the air gauge, steam gauge and water glass. You all know this can be done without distracting your attention from the track ahead. A look for an instant every mile or two will keep you informed, and is a good habit. Doing this will also keep you posted on air pressure, and may avoid difficulties should the air pump stop. The fireman should also keep an eye on the water glass, as the engineer is sometimes compelled to keep the injector at work to prevent the engine blowing off. When glass is full, the fireman should fire lighter, to give the engineer a chance to shut off the injector, and not have engine blow off. However, this condition should only exist when injector cannot be worked fine enough to just supply amount used. This sometimes occurs when card time is slow, or on down grade, or when running with light train.

DON'T put too much coal under the arch of engines with sloping fire-boxes, because these engines naturally pull the coal ahead, which results in forward section of grates becoming stuck and clinkered over, and fire is pulled in back end of fire-box. Experience and observation will teach you to put most of the coal in back end of fire-box.

DON'T think engine having two fire-box doors requires twice the quantity of coal it would if it had but one. The extra door is for the purpose of distributing the coal more evenly over the grate surface, with less effort on the part of the fireman.

DON'T shovel large chunks of coal into fire-box because you find them on the tank. The coal-house men have instructions to break it in the size of an apple. If not properly broken, report it to road foreman of engines or to master mechanic, instead of fellow-engineers or firemen, but don't think it a hardship to break some occasionally. Better break it than to throw in large chunks. They are foundations for clinkers.

DON'T expect the fireman to fire the engine with one or two scoops to each fire, and also ring the bell for highway crossings and stations. Some engineers expect this. If engine is equipped with an air bell-ringer, get into the habit of starting the bell-ringer when blowing the whistle. By so doing the habit will become as fixed as whistling for crossings and stations. Besides, it is just as important. Remember, the engineer is responsible.

DON'T put in a heavy fire about the time the engine is shut off for a station or down-grade. The heavy cloud of black smoke is evidence the engine crew is not working in harmony or practicing economy. If on train that stops at all stations, the fireman should guard against it and learn when to stop firing. He will be governed by grade, service, and weather conditions. If train does not make all station stops, the engineer should keep the fireman informed of intended stops.

DON'T forget that diffierent qualities of coal and different makes of grate used govern the shaking of grates. Coal that fills up and clinkers requires more attention than the better grade. The object is to keep the grates free so the proper amount of air can be admitted.

DON'T neglect cleaning your fire on trains that are long hours on the road. Make use of the first opportunity. You will get better results with less labor and coal and avoid leaky flues. Better clean out a small amount two or three times than not clean it at all.

DON'T take coal or water oftener than necessary, as it requires an extra amount of coal to again get a heavy train in motion, especially on a grade. Good judgment is required, in order not to run short before getting to next coal chute or water tank. Where possible take water only from tank containing good water, and as little as you can from tanks containing poor water.

DON'T forget that leaks in the air pressure are being kept up by an equal amount of steam pressure. As it takes coal to make steam, air leakage means a waste of coal. Keep apparatus on your engine tight, and insist on trainmen doing their part.

DON'T try to put more coal on tank than will lay on it securely. All coal dropped off by overloading is wasted. Also keep coal from falling out of gangway when running. This may be only a little each day, but it all counts against your coal records, besides it looks badly when strewn along the tracks. You can not save coal by the ton; it must be in pounds, which in time make tons.

DON'T forget to make an intelligent report on your work slip on arrival at roundhouse. Consult your fireman in regard to any defect that has come to his notice, especially with grates, dampers or firing tools.

DON'T neglect reporting the pop valves ground in when leaking or when they blow back eight or ten pounds before seating. Also report leaky piston rod and valve stem packings, or if cylinder packing or valves are blowing. All these leaks draw on the coal pile unnecessarily; it takes coal to generate the wasted steam. This also applies to leaky steam heat appliances, cylinder cocks, etc.

DON'T neglect looking at coal report each month to see how you stand in relation to others in same service with whom you are comparable. The other crews get the same pay you do, and it should be your aim to be as economical with both fuel and supplies as they are, other things being equal. Keep posted, and be with the average. It will be to your credit and interest some time; therefore aim to be at the top.

DON'T think when coal reports show you using only two pounds more per 100 ton miles than other crews in same service it is close enough. This means more used for every mile you hauled 100 tons—or another way, two pounds for every 100 tons hauled one mile. Figure this up and you will find in hauling 1,000 tons 100 miles, a difference of 2,000 pounds or one ton. This method of showing up the individual record is more equitable to all than on basis of miles run per ton of coal.

DON'T think, after reading over this chapter of "DON'TS" you should save coal to the detriment of the service. The actual amount required to make up time, keep on time, or handle tonnage, is not what we are trying to save; it is the waste. You will notice the proper method of handling the engine to the extent of the economical use of fuel only has been considered.

REVIEW QUESTIONS

LOCOMOTIVE FIRING AND FUEL ECONOMY.

1. What is the first and chief purpose of firing a locomotive?
2. How may the largest quantity of steam be produced in a given time by a given locomotive?
3. Describe two general systems of firing locomotives with bituminous coal.
4. How may the proper amount of air for a given coal be determined?
5. What are the qualifications of a good fireman?
6. How should a locomotive be prepared before starting?
7. Give five rules which should be followed when burning bituminous coal.
8. What are the duties of a fireman when the engine is resting at stations?
9. How should an engine be fired near the end of a run?
10. What are the causes of a spotty fire and how should they be remedied?
11. Suppose the coal does not seem to get sufficient air what would you do?
12. What is the effect of throwing too much coal on one part of the grate?
13. Explain the difference between firing anthracite and bituminous coal.
14. Why is a larger grate area necessary for anthracite than for bituminous?
15. How thick should a bituminous coal fire be kept?
16. Describe a method for starting an oil burner.
17. When should the blower be used to prevent smoke?
18. What are the principal difficulties of preventing smoke with the average locomotive?
19. How should the coal be prepared before it is put on the tender?
20. How should the blower be used when running?

21. Has the different conditions of the grates anything to do with the suppression of black smoke?
22. Which coal will produce the most smoke, fine coal or lump coal?
23. Of what use are combustion chambers on locomotives?
24. What are the advantages and disadvantages of the combustion chamber?
25. Describe the method of firing used on the B. & O. Railroad.
26. How often should rocking grates be shaken when using bituminous coal?
27. When should the furnace doors be opened?
28. Should brick-arches be used when burning coke?
29. How is a coke fire started, and what attention does a coke fire require?
30. How are coke fires cleaned?
31. Does it require a larger or smaller blast for a coke fire than for a bituminous coal fire?
32. Describe the methods recommended by the B. & O. Railroad for firing coke.
33. If the steam is blowing off at the safety valves what should be done to prevent it?
34. What should be done when the engine is stopping at stations?
35. What is usually the cause of steam being wasted from the safety valve?
36. Within what limits should the steam pressure be allowed to vary?
37. Why are the grates made to shake, and when should they be shaken?
38. How is a locomotive injured when a fire is started too rapidly?
39. If the fire in the fire-box has been banked, how should it be prepared before starting?
40. About how much steam is wasted per minute when the pops are blowing off?
41. When the engine stops blowing off, should you put more coal on the fire, or open the dampers first?

42. In case large chunks of coal are found on the tender, is it advisable to break them before firing?

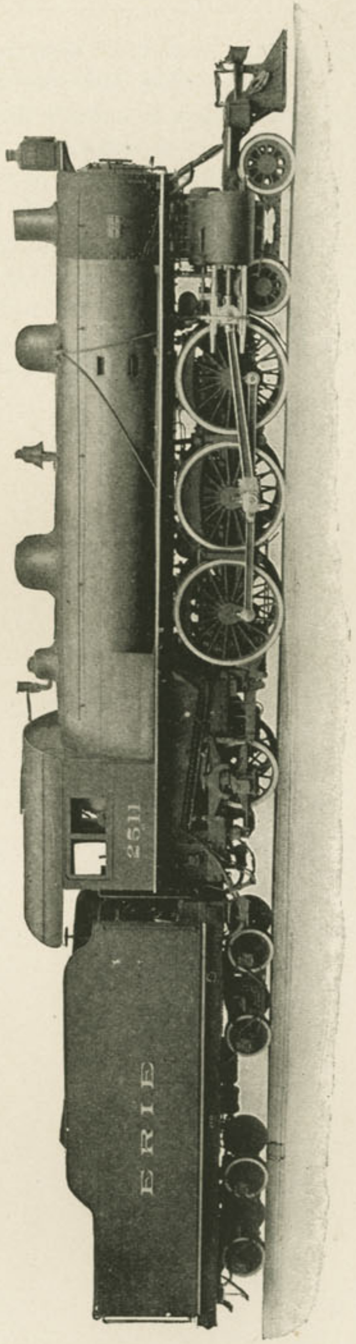
43. Do large chunks of coal make more or less clinker?

44. When the engine is on grades which require the throttle of the engine to be opened full, how should the fireman fire?

45. When firing anthracite coal, what determines the frequency of firing and the thickness of the fire?

46. When pulling out of a station, should the injector be shut off before or after the throttle is opened?

47. Explain how heating the feed water with the injector will help a poor steaming engine.



PACIFIC TYPE PASSENGER LOCOMOTIVE
(American Locomotive Company)

Mechanical Stokers

While the use of the mechanical stoker on locomotives is still more or less in the experimental state, there are a number of railroads using them in order to determine accurately what saving there will be in fuel, how much it will relieve the fireman, how it can maintain an even steam pressure, and to what extent it will abolish the smoke nuisance. All that can be expected of a mechanical stoker is to equal average good firing. It cannot be expected to equal the best hand-firing, but it must, of course, do better than a poor fireman. This, however, is but one of the conditions which a successful mechanical stoker must meet, although it is the most important. A stoker which is to receive general adoption, however, must also possess a number of other important features.

Requirements of a Mechanical Stoker. In the first place, a mechanical stoker must be absolutely reliable. No railroad company can afford to put anything on its locomotives which has any possibilities of causing an engine failure. Again, a satisfactory stoker must be comparatively noiseless. There is already sufficient racket in the cab of a locomotive to make communication between the engineer and fireman somewhat difficult, and it will not do to increase this to any appreciable extent, and thus make such communication practically impossible. In addition to this, any great addition to the noise on a locomotive is going to make it extremely difficult for an engineer to hear torpedoes. Another desirable feature is that the stoker should take up as little room as possible. It should further consist of the fewest possible number of parts, so as to permit a quick and easy change to hand-firing in case such a move becomes necessary. In addition to these strictly mechanical qualifications, a stoker must be able to show a direct saving, which will at least pay the interest on its cost, a liberal rate of depreciation and all charges for maintenance

Saving Due to the Use of Mechanical Stokers. The saving due to the use of mechanical stokers may be made up in several ways, viz: by improved combustion, leading to the use of a smaller amount of fuel; by the use of a lower grade fuel, due to the stoker's ability to fire properly; by the opportunity of operating large engines over divisions of a length which exhausts a good fireman and leads him to waste coal by improper firing on the latter end of his run; by the reduction of leaky flues and fire-boxes directly due to the proper firing; by the reduction of the smoke nuisance in large cities, owing to the better condition of combustion, and possibly also by the ability to hold a better grade of men.

While practically all of the designs of mechanical stokers, which have been given practical trials, have sought to follow the principles of hand-firing, accomplishing this by several different methods, there are designs now in the process of evolution which seek to accomplish the desired result in other ways. One of these is an underfed type in which the coal is forced up from below and is burned by means of the forced draft. This permits the elimination of the vacuum in the front end, and thus a considerable reduction in back pressure on the cylinders. This type of stoker is claimed to be capable of burning very low-grade fuel, giving practically complete and smokeless combustion.

Another arrangement which has been suggested, and is being worked out, which also presents possibilities for use of extremely low-grade fuels, is a stoker in which the fuel is pulverized and blown into the fire-box through a jet, burning much the same as oil. Properly arranged, this stoker should be able to give practically perfect combustion.

Types of Mechanical Stokers. The stokers which imitate hand-firing can be divided, roughly, into three different types, one in which the coal is thrown on the different parts of the grate by means of a plunger, a deflection plate being used to govern the direction; another blows the coal to different points on the grate by means of air or steam jets, and the third type uses a revolving fan arrangement, the wings of which throw the coal through a spout, which is capable of adjustment to determine the point on the grate which shall be reached.

In all of these types the principles of correct hand-firing are followed out; that is, a small amount of well broken coal is scattered in either a thin layer over certain separate sections, or in small pieces miscellaneously over the whole area of the grate. In the former case the different sections are covered in succession, with such a time interval as to make the action of the stoker continuous while the engine is working at full capacity. The best examples of each of these types incorporate a conveyor from the tender to the hopper, forming part of the stoker proper, thus permitting the fireman to devote his entire time to watching the condition of his fire, shaking the grate, and assisting in keeping a lookout ahead.

One design of each of these types has proven itself to be successful in practical service, and while perfection has not yet been reached, still there are a number of designs of mechanical stokers which have proven themselves capable of properly firing locomotives now in service in this country, each being designed on a different principle.

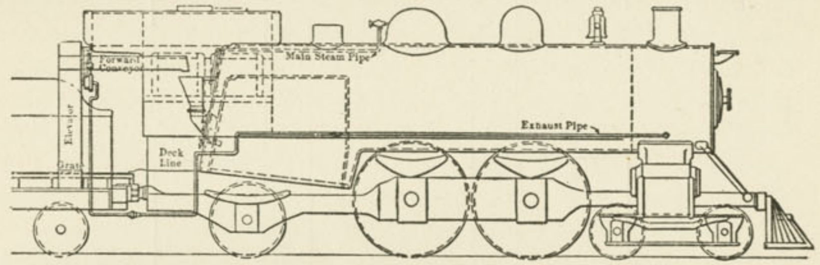
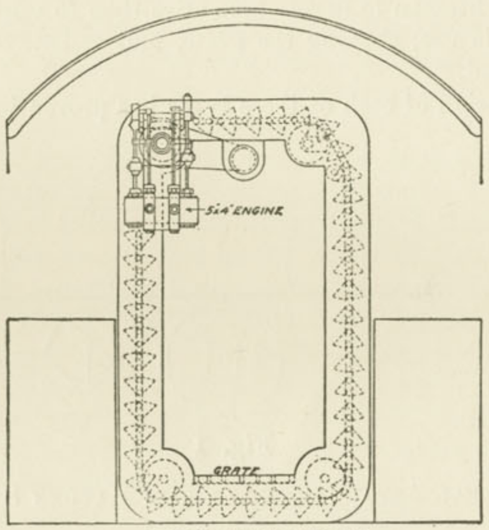


Fig. 1

General Arrangement of the Hayden Stoker.

Hayden Mechanical Stoker. This stoker is of the type wherein the coal is blown in small amounts on to the grate by means of a steam jet. The combined delivery and feeding mechanism used in this design of stoker, and by which coal is taken from the fuel space in the tender and delivered in the fire-box, may be considered to be, as it actually is, two distinct pieces of apparatus, as shown in Fig. 1. The function of the tender equipment is to convey coal to a hopper on the back boiler head, and the engine equipment consists of the appliance by which the coal in the hopper is introduced into the fire-box and spread upon the fire. The operation of the stoker, as a whole, may be rendered continuous, or either or both parts of the mechanism may be stopped at will. Hand-firing may be resorted to without altering the stoker mechanism, as it is practically out of the way of the fireman and engineer all the time.

Tracing the coal from tender to fire-box, there is first the



FRONT ELEVATION OF TENDER

Fig. 2

FRONT ELEVATION OF TENDER.—
HAYDEN STOKER.

receiving grate. This is a heavy casting placed in the floor of the tender close in front of the coal gates. The casting has a series of openings separated by narrow bridges, and through these openings the coal drops into a conveyor trough, immediately under the receiving grate. In this trough, which extends across the fuel space from water leg to water leg of the tank, are a series of buckets carried on a pair of endless chains. The conveyor system as shown in Fig. 2 consists of the bottom trough, at each end of

which are two upright hollow tubes of oblong section, with an overhead tube, corresponding to the conveyor trough in the floor of the tender. The conveyor buckets move along the trough toward the right, up the hollow tube at that end, then back along the overhead horizontal tube, and down the lefthand hollow tube of the system. The conveyor buckets therefore travel in a rectangle, and elevate coal to a height of about six feet above the receiving grate. When the coal, moved along by the buckets, comes to the center of the overhead tube, it is discharged into a worm conveyor at the same level, which is placed fore and aft, and by means of the worm the coal slowly travels forward toward the engine, and on reaching the end of the worm conveyor trough it drops into the hopper, which is carried on the back head of the boiler.

The overhead worm conveyor trough is carried on angle-iron supports, reaching in arch form from the top of the water legs of the tank, and additional support is afforded by attachment to the overhead conveyor tube. There is no connection between the tender equipment and that on the engine, so that by uncoupling the small steam pipes and other regular connections between engine and tender, the tender may be readily disconnected from the engine. The worm conveyor trough passes in below the overhanging roof of the cab, and is above and free from the hopper, so that inequalities of motion of engine and tender do not disturb the constant delivery of coal from the tender to the engine while the conveyor mechanism is at work.

The motion of the buckets and that of the worm in the longitudinal overhead conveyor is produced by the operation of a small twin engine shown in Fig. 2, the piston rods of which are fitted with Scotch yokes, which secure the rotation of the gear and sprocket wheels necessary to drive the mechanism. The engine is bolted to the right upright conveyor tube, and steam and exhaust pipes are carried through the floor of the tender and connect with pipes on the engine by means of flexible joints. The steam used for driving the engine is taken from the outside at the top of the dome, and the exhaust connects with the blower pipe, and waste steam is discharged up the stack in a manner similar to that of the air pump. The carrying of coal from the tender to the hopper on the boiler head is performed by this small engine, and the speed of the conveyor mechanism and the speed of delivery may be regulated according to work the engine is doing at any time. Shutting off the steam supply to the small engine stops the delivery of coal.

The conveyors and small engine thus perform what is probably the greater part of the physical work of the fireman, and as such the tender equipment might be called a mechanical coal-heaver, while the task of distributing coal to the fire is performed by the engine equipment, and this latter constitutes the mechanical stoker proper.

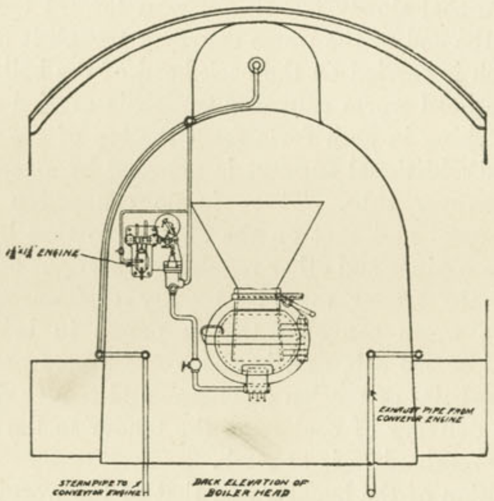


Fig. 3.

BACK ELEVATION OF BOILER HEAD.—
HAYDEN STOKER.

The engine equipment consists of a hopper with a feed tube at the bottom, by means of which coal passes through the fire door. There is also a set of steam nozzles and a small engine for operating an intermittent steam blast for distributing the coal over the fire. The hopper is bolted to the back head of the boiler above the fire door, and has an opening at the top and bottom. The bottom opening is controlled by a slide operated by hand, and the amount of coal which passes out of the hopper is thus regulated at will.

The hopper when full contains about 175 pounds of fine coal, which is the kind for which the stoker is designed.

Immediately below the hopper is the fire door, modified to suit conditions. The door contains a slightly tapering coal passage or chute, set at an angle of about 45 degrees. The function of this passage is to permit coal from the hopper, on the back boiler head, to be delivered to the inside of the fire-box. The door is not connected with the hopper in any way, and when the slide at the base of the hopper is closed the fire door can be opened or closed by hand quite readily, as it is not a fixed part of the mechanical stoker. The coal, after it passes through this tapering chute in the door, is delivered on the door flange above the water space and on a flat table which is bolted to the inside back sheet of the fire-box. The fine coal thus delivered remains heaped on the table and up to the mouth of the tapering chute in the door. The size of this loose heap may be altered from time to time by the adjustment of the movable plate on the outside and upper part of the tapering chute.

The final distribution of coal over the grate is accomplished by means of an intermittent steam blast, which is driven out flat over the table from five radially directed nozzles. The blast undermines and blows away the heap of coal on the table, and in the interval, before the succeeding blast of steam issues forth, the coal quickly feeds down on the table and makes a heap as before.

The mechanism by which the intermittent blast for automatic firing is produced consists of a smaller size of twin engine than that used on the tender, but similar in design, as shown in Figs. 3, 4 and 5. The rotation of a small shaft which it accomplishes turns a small gear wheel placed in an upright position, which carries on its face a striking pin with a beveled end.

The striking pin is attached to the revolving gear wheel, and is adjustable in a guideway. This striking pin, when revolving, strikes the beveled end of a ball crank lever and rocks it on its fulcrum at its center. This bell crank lever, when rocked, lifts a small auxiliary valve that is seated in the top cap of the blast valve. This auxiliary valve has a stem on it that extends downward through the piston valve, but the piston valve works freely on this stem and is not attached to it. The idea of extending this stem into the piston valve is to keep the steam pressure off the bottom of the auxiliary valve, so that the auxiliary valve is practically a balanced valve when open.

When the auxiliary valve is lifted it opens a by-pass port leading from the main steam supply to top of piston valve, thus equalizing pressure on top head of piston, allowing it to move downward and opening the passage to blast nozzles. The interior

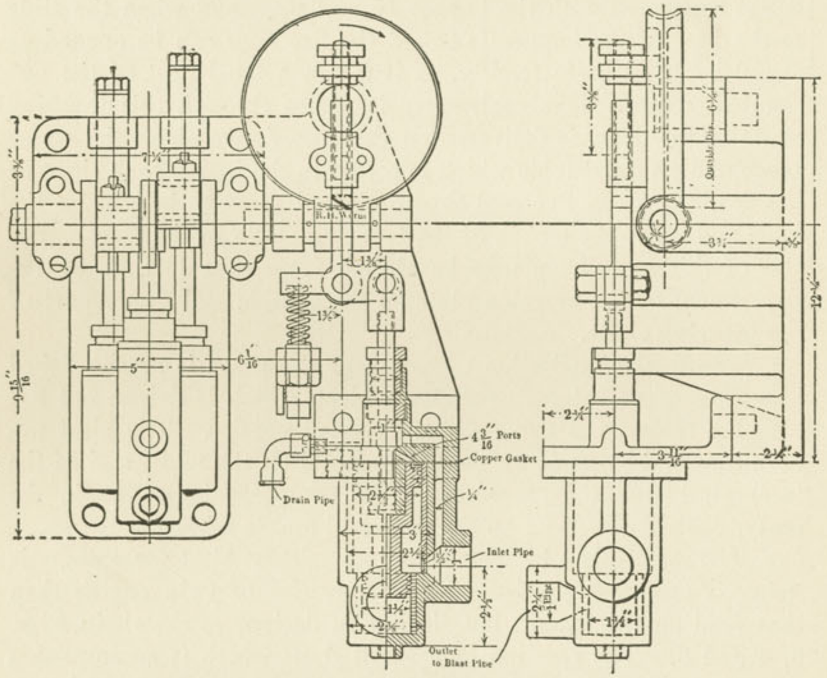


Fig. 4

BLAST VALVE OF HAYDEN STOKER.

cavity of this piston valve is, when in use, always filled with steam direct from the boiler. The upper end of this piston valve has a greater area than its lower end, and, as the valve is vertical, it is normally held by steam pressure at the upper extremity of its stroke. In this position the valve is shut, for though the internal cavity is constantly full of live steam, it cannot escape. The opening of this valve takes place only while the bevel faces of the

striking pin and lever are in contact, and as soon as the striking pin on the rotating wheel has passed beyond the lever, the internal pressure of the piston valve and the action of the coil spring at the end of the lever promptly carry the piston valve up, and so shuts off the flow of steam to the nozzles.

The travel of the piston valve, and the consequent width of opening by which steam enters the blast pipe, is determined by the adjustment of the striking pin on the small rotating wheel, and this regulates the volume of steam which gets into the blast

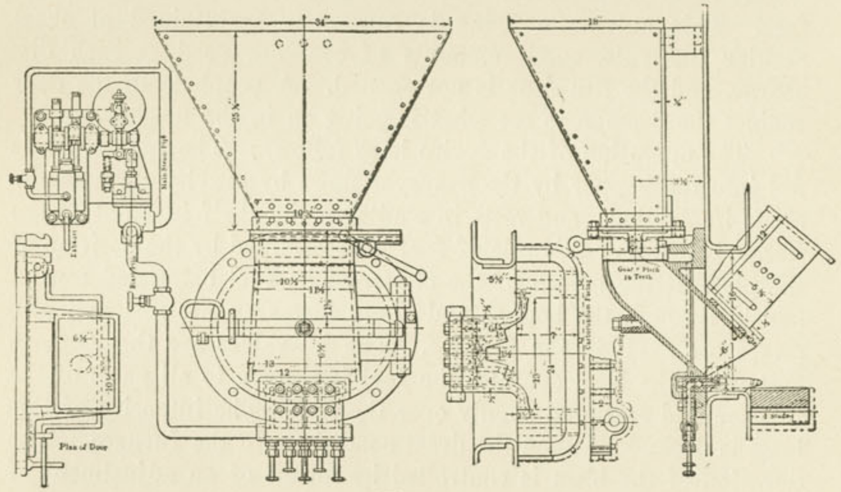


Fig. 5.

ARRANGEMENT OF CHUTE, HOPPER AND SHELF.—HAYDEN MECHANICAL STOKER.

pipe. The frequency with which the steam blasts are delivered depends upon the speed at which the small engine is run, and the pressure of the steam depends upon the amount of opening of the hand valve governing the flow of steam to the small piston valve.

The casting from which the jets of steam issue lies flat on the lower lip of the fire door. It is practically out of the way all of the time, and does not interfere with hand-firing. A hand valve below each of the five blast nozzles makes it possible to restrict the opening or shut off any particular nozzle, at any time. The intermittent blast passing down the pipe from the piston valve subdivides itself and issues forth from the nozzles, which are each ¾ by ⅛ inch. The heap of coal lying on the table is thus blown off and distributed over the grate. The nozzles are divergent, the outer two blowing the coal off the table toward the two back corners of the fire-box. The next two, slightly less divergent, blowing the coal in the direction of the forward corners, while the center one is directed straight ahead. The effect of this distribution, when all the adjustments have been made, is to secure approximately an even spreading or sprinkling of coal over the grate surface. This automatic firing is constantly maintained at short regular intervals, small amounts of coal are used at each discharge, and the fire door is not opened. A peephole in the door enables the fireman to see what is going on in the fire-box.

The operation of the device is as follows: The fuel which is fed into the hopper by the conveyor flows by gravity through the chute in the door, and rests in a pile on the shelf in front of the jets. The size of this pile of fuel is determined by the position of the plate at the mouth of the chute. The fuel being fed continuously through the hopper and chute forms an air seal and preserves the draft in the furnace. The jet valves are throttled, so that when the blast operates the fuel is thrown to all parts of the furnace and scattered evenly over the fire. The intensity of this blast is dependent upon the draft conditions in the furnace. The duration of the blast is controlled by means of an adjustment of the trip finger, which operates the auxiliary valve by means of the bell crank lever, and thus holds this valve open for a varying period of time. The usual period of blast is about one second. The speed of the conveyor engine determines the amount of coal that is fed to the hopper, and can be varied to suit the conditions. For very light firing the stoker is able to place two or three pounds of coal at one charge as often as may be desired, and for ordinary heavy firing it can place ten pounds of coal per charge with a blast of from 1½ to 2 seconds' duration, operating seven times a minute. If desired, the blast can be made continuous, and as much coal as the conveyor will deliver can be put on the fire.

The advantages claimed for the Hayden Stoker are as follows: No changes of the grates or boiler front are necessary; the device is located on boiler head above the fire door out of the way

of the engine crew, and the conveyor from the tender comes forward high enough to clear the fireman; the feeding apparatus lies entirely upon the exterior of the boiler, and can be examined at any time without discontinuing the use of the boiler; if desired, the fuel can be fed by tripping the bell crank lever on the blast valve by hand; it provides for continuously maintaining a supply of fuel at the mouth of the furnace, and for intermittently discharging any desired amount into the furnace; the opening and closing of the blast valve is instantaneous, therefore the full force of the blast is projected from the jets; means are provided to regulate the force and duration of the blast independent of each other; the amount of steam used by the blast is very small, as ordinarily one second duration of the blast is sufficient; the amount of each charge of coal depends on the duration of the blast, and a very small charge can be thrown, insuring more perfect combustion and very materially decreasing the amount of smoke; slack coal that could not be used by hand-firing can be used by machine very successfully and keep up steam pressure; takes coal from tender and distributes it in fire-box without opening fire door, therefore boiler repairs due to the frequent opening and closing of fire door are entirely eliminated; the distribution of fuel in the fire-box, including back corners, is more evenly accomplished than by hand-firing; one fireman only is necessary on large locomotives, as the steam pressure is maintained at the maximum capacity of boiler of the largest locomotive; the stoker in no way interferes with hand-firing. The hopper slide can be closed and fuel underneath worked out; then fire door can be opened in the usual manner to fire by hand, or for any other purpose.

Crosby Mechanical Stoker. This stoker is of the revolving blade type, in which the coal is thrown into the furnace by means of revolving blades, the chute on the inside of the fire door directing the coal to the point desired, as shown in Fig. 6.

In the working of this mechanical stoker on locomotives there are practically three operations. They are the transfer of coal from the tender to the fire door, the application of the force requisite to throw the coal into the fire-box, and the operation which consists of properly distributing it.

The first step is obtained by means of a screw conveyor extending from the coal space in the tender to the fire door, and running in a sheet metal trough with a circular bottom and flaring sides. This conveyor is in two parts, one section extending from the back of the coal space to a point just in front of the coal gate, where both the spiral and the trough are joined to the inclined section in a manner which provides perfect freeness for adjustment to the relative movement between the locomotive and tender, and also to allow the inclined section to be thrown back against the coal gate when not in use. The section in the bottom of the tender is covered from its rear end to within a few inches of the coal gate by plates about a foot long. These plates are removed one by one as the coal pile gets further back in the tender.

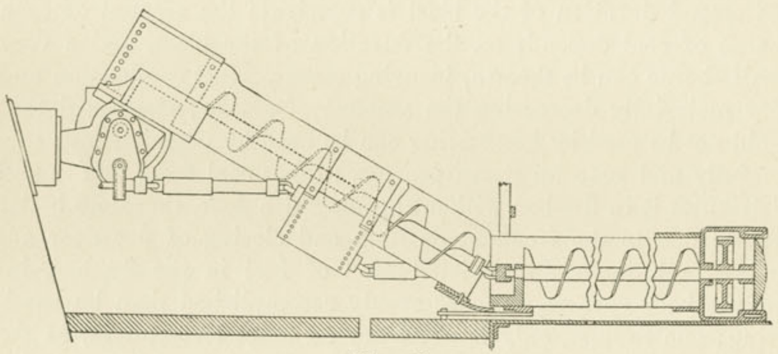


Fig. 6

CROSBY MECHANICAL STOKER.

This conveyor is driven from the same source of power as are the revolving blades, but is provided with a cone gear arrangement, which permits it to have a variable speed. A lever, conveniently placed, controls the speed or the starting and stopping of the conveyor by the fireman. The conveyor will handle lumps of coal up to about ten or twelve inches in size.

The conveyor discharges the coal into a small receiving hopper, where the rapidly revolving blades gather it and discharge it through a round nozzle in the door. These each discharge one-half of the receiving hopper, being offset for that purpose, and run at a constant speed while in operation. The receiving hopper forms part of the casting, which is bolted to a specially designed

door, replacing the regular fire door. Alongside of it is a steam-tight chamber, in which is mounted a steam turbine disc, upon which four small steam jets impinge. The turbine wheel and rotating blades are mounted on one shaft, which at the turbine end projects through the bearing and carries a fly-ball governor mechanism, which operates the steam valve and provides an automatic constant speed arrangement for the blades. The opposite

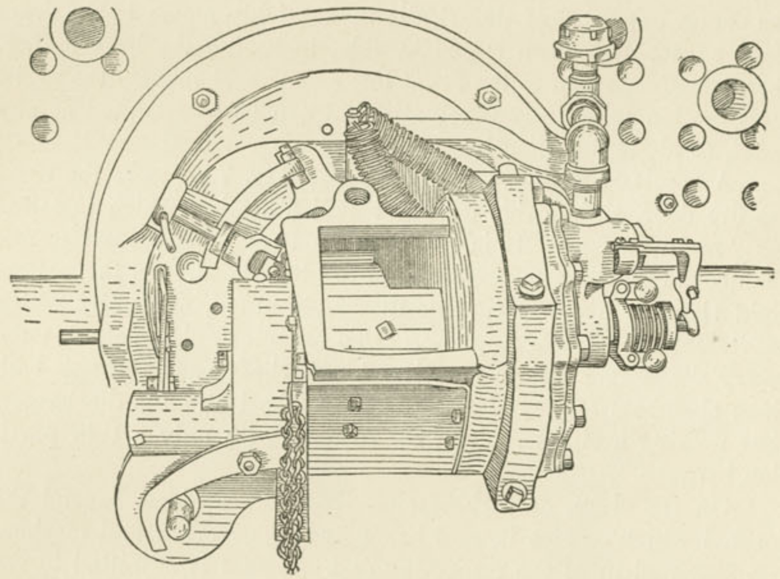


Fig. 7

CROSBY STOKER WITH FEED ARRANGEMENT THROWN BACK.

end of this shaft projects beyond the case, and carries a worm, which drives a worm gear, all being contained in an oil-tight case bolted to the frame. The worm gear shaft provides the motion for the screw conveyor; it also, on the opposite end, carries a small worm meshing with a gear, which further reduces the speed and drives the mechanism controlling the motion of the spreading chute, which directs the stream of coal in the fire-box. This small worm may be engaged or disengaged from the shaft by a small lever, and thereby stop the spreader at any point in its cycle and build up the fire where it may need special attention.

The spreading arrangement automatically passes through a cycle of movements, which accomplish the following results: The thin stream of coal issuing from it is distributed in a thin layer over a strip one-third of the width of the fire-box down the left side, starting from the flue sheet and extending back into the back corner; then with a quick movement the spreader starts at the flue sheet in the center of the fire-box, and distributes the coal over the center one-third of the width; then quickly moves to the front right corner and down the right side, including the back corner, then transfers again to the front left corner and repeats the cycle. This motion is entirely automatic, but can be interrupted at any point, as above mentioned.

A specially designed door shown in Fig. 7 replaces the regular fire door, and to this door is bolted a casting which is called the "main frame." It is essentially a two-chamber casting, one chamber of which is covered steam-tight by a head. In this steam-tight chamber a steam turbine disc is mounted, and upon which four small steam jets impinge. The other chamber contains the rotary discharger before mentioned. A shaft runs through both these chambers and carries the turbine wheel and the discharger, thus making a simple, direct connection, with only a thin partition between.

On the right, or turbine end, the shaft projects beyond the journal which carries it, and has a fly-ball governor and mechanism mounted upon the projecting end. Steam is admitted to the governor valve at full boiler pressure, and the governor controls the speed from no lead to full lead without attention from the fireman.

The other end of the shaft also projects beyond its journal, and carries a spur gear, which, in turn, drives a worm gear. This gearing is contained in an oil-tight case bolted to the main frame. The worm-driven shaft, running at a suitable speed, projects from this case, carrying a feather key, over which slips the sleeve connection which drives the conveyor cone gear. The other, or inner, end of this worm-driven shaft carries a smaller worm, which further reduces the speed for driving the spreader mechanism. This worm may be engaged or disengaged from the shaft by means of a

small and conveniently placed lever, and by moving this lever the spreader may be stopped at any point of its cycle, in order to build up the fire where it may have become weak. This worm and clutch are also enclosed in an oil-tight case.

In case of necessity this stoker can be disconnected and put out of the way, and permit hand-firing to be started in the usual manner within a space of thirty seconds. The total weight of the stoker and conveyor is about 900 pounds.

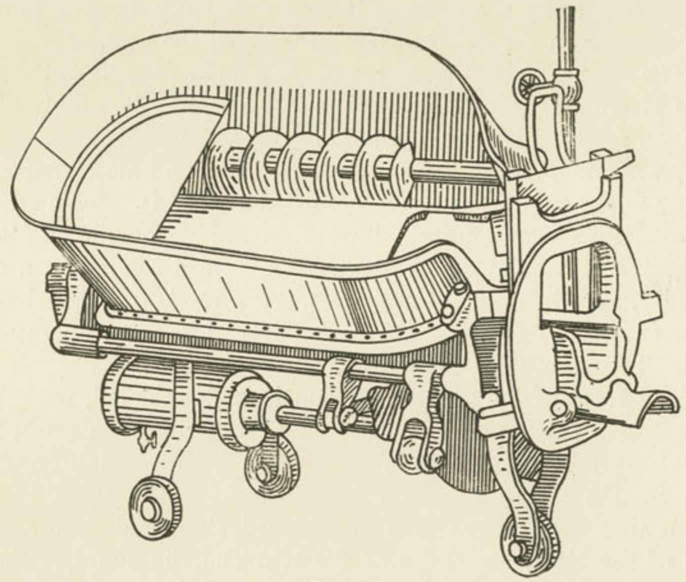


Fig. 8

VICTOR STOKER.

The work of developing this stoker was all done on the Chicago & Northwestern Railroad, where it, after a certain series of preliminary experiments had been completed, showed itself to be entirely reliable.

Victor Mechanical Stoker. The Victor Stoker consists of a coal hopper, which stands on a frame, as shown in Fig. 8. The frame, which is attached to the boiler and is supported upon three small wheels, stands on the foot-plate of the locomotive. Underneath the hopper is a steam cylinder placed horizontally, which operates a ram or plunger for throwing coal into the fire-box. Under the hopper and at the forward end, placed crosswise, is a small reciprocating engine, which operates the valve of the plunger engine, and it also keeps a pair of conveyor screws in motion.

The conveyor screws lie along the bottom of the coal hopper, one on each side, and their motion is effected by the rotation of their shafts by ratchets; pawls being attached to a lever with connection rod, actuated by the small reciprocating engine. Coal thrown into the hopper by the fireman is thus constantly worked forward and delivered on the stoking plate in front of the ram.

The reciprocating movement of the ram or plunger is the same as the piston of the plunger engine which drives it. This piston is driven forward by live steam pressure, but it makes, in regular order, what may be called a rapid, medium and slow stroke, according to the amount of steam admitted behind it. This effect is produced in a regular cycle by the successive opening of three valves, one at each stroke, and these valves are rotated in a regular order, and thus opened and closed by a ratchet-and-pawl mechanism similar to that for the conveyor screws, and operated by the small reciprocating engine.

The front of the plunger or ram is wedge-shaped, resembling a locomotive pilot, and when driven rapidly into the small heap of coal on the stoking plate, which has been previously placed there by the action of the conveyor screws, the little heap is thrown into the fire-box over an upward sloping deflector. The force of the blow, the shape of the ram and the angle of the deflector plate all conspire to produce a spreading and shower-like distribution of the coal over the front area of the grate. The second and less violent stroke of the ram causes a similar distribution of coal over the middle area of the grate, and the third and slowest stroke showers the coal upon the rear area of the grate.

The rapid, medium and slow strokes of the plunger follow each other in regular sequence, and thus the coal falls upon the back, middle and front of the fire-box. The return of the plunger and piston being in each case produced by live steam pressure, the exhaust from the reciprocating and plunger engines enters the fire-box over the deflector plate.

As the plunger is drawn back there is for a moment a rush of

air into the fire-box through the space left by the receding plunger; but this space is at once filled by coal, urged forward by the action of the conveyor screws. With this stroke the work of the fireman is to shovel the coal into the hopper and regulate the speed of the whole mechanism as circumstances may require.

The Strouse Stoker. This stoker is of the plunger type, as shown in Fig. 9, and although it was not evolved from what was

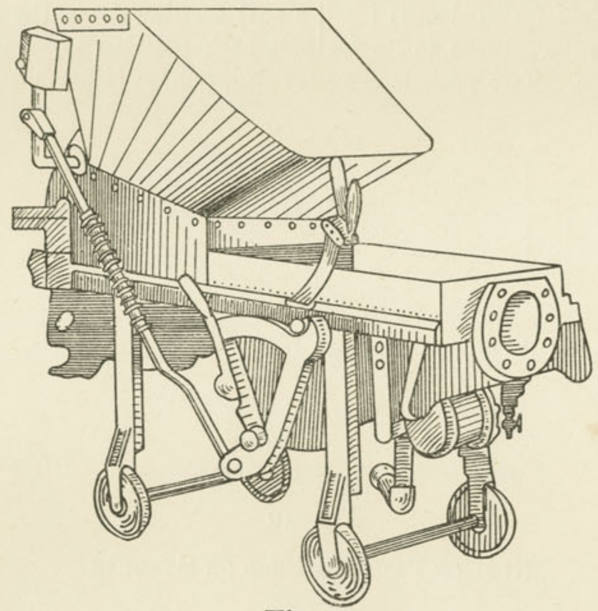


Fig. 9

STROUSE STOKER.

formerly known as the Day-Kincade stoker, its general appearance is somewhat similar. It consists of a detachable frame mounted on wheels for easy handling. This frame carries a detachable hopper, a reciprocating plunger, which distributes the coal, and a horizontal steam cylinder with valves, valve motion, throttle lever, etc. There is a special fire door, hinged at the top, which opens inwardly and is operated automatically. A simple conveyor takes coal from the bottom of the tender and delivers it to the hopper.

The delivery and distribution of coal is effected by the action of a steam-driven plunger moving horizontally and mounted in guides. This plunger is fitted with a specially shaped steel nose, as shown in Fig. 10. Coal from the hopper feeds down into the pockets and upon the plunger nose platform in the fire-box doorway. The forward movement of the plunger scatters the coal forward and to the sides, so that the forward part and front corners of the grates are properly covered. The body of the plunger when pushed forward cuts off the coal feeding from the hopper until the nose returns to its farthest back position to receive the next charge. Two pockets are provided, one on either side of the

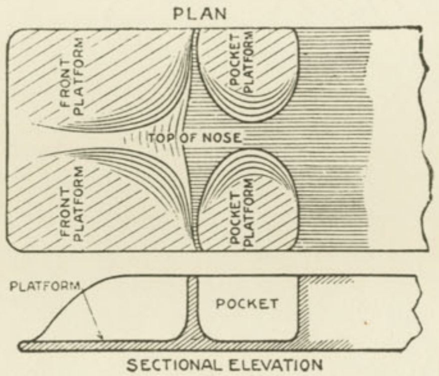


Fig. 10

NOSE OF PLUNGER USED ON STROUSE STOKER.

rear portion of the nose, and these carry a part of the coal into the fire-box on the forward stroke of the plunger, and on its backward stroke these pockets discharge this coal onto the back corners and rear part of the grates.

This specially designed fire door is hinged at the top, and is opened and closed automatically by the operation of the stoker throttle mechanism. The whole apparatus, with the exception of this door, is secured to the fire door ring by two slotted lugs and keys, and by suspension turn-buckle rods, which hook into eyes on the boiler head. The stoker is thus easily detachable, and can be quickly removed for hand-firing in case of breakage. The

hopper is so arranged that it can be used to fire alternate sides of the fire-box, if desired.

The operation of the stoker by the fireman consists in regulating the speed of the conveyor mechanism and governing the length and intensity of the plunger stroke by the stoker throttle lever. The movement of the plunger is not automatically reduced to a cycle as with other forms of mechanical stokers, as the

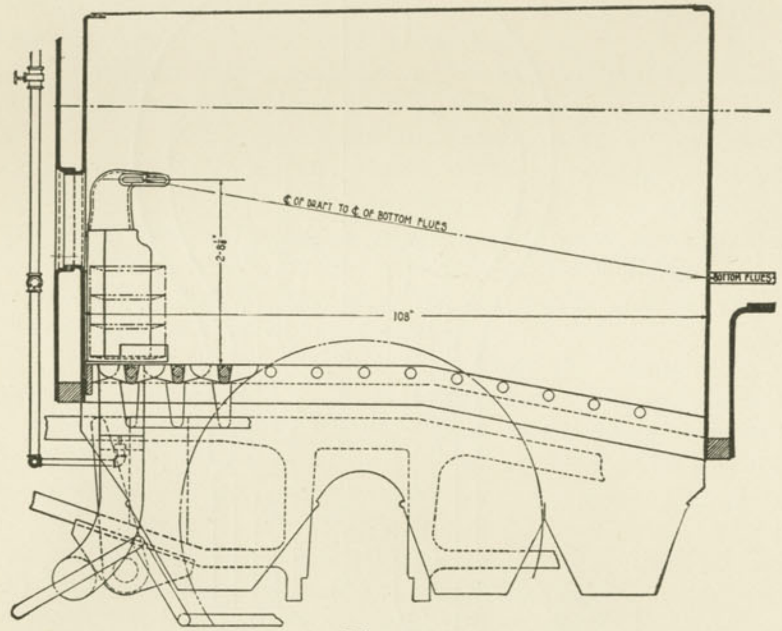


Fig. 11

LONGITUDINAL SECTION THROUGH FIRE-BOX EMPLOYING THE PARSONS SYSTEM.

design and action of the plunger make this unnecessary. The plunger stroke can be shortened or lengthened at will by the fireman, who can also vary the speed with which it moves. After having set it to work, the plunger movement remains constant until altered by the fireman. Heavy Consolidation locomotives on the Iowa Central are being successfully fired by this stoker.

Other Systems of Combustion. Besides the improvements which have been going on in the development of mechanical stokers, there have been a considerable number of fuel-saving devices invented and tried on various locomotives with only partial success, very few of them having ever reached more than the experimental stage. Most of these devices, or systems, employed

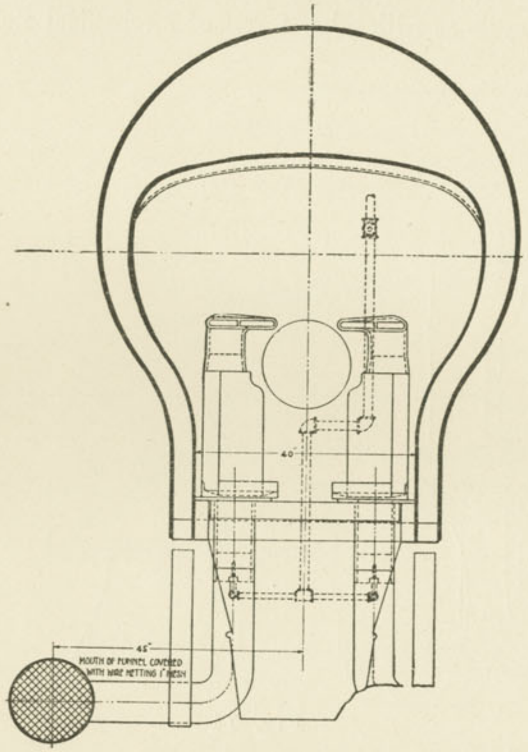


Fig. 12

Cross-Section Through Fire-box Showing the Parsons Arrangement of Steam Pipe.

some form of steam jet and blower; but as these consumed more power than they saved, they were all discontinued as being impractical for locomotive use. There is one system, however, which seems to have weathered the experimental stage, and is being equipped on some locomotives, and that is the Parsons system of combustion.

Parsons System of Combustion. The Parsons system as applied to locomotives has been in the process of development for a number of years, and consists principally of two heater boxes, one of which is located in each of the back corners of the fire-box of the locomotive, without any change in the fire-boxes. These heater boxes are hollow, each suitably connected at the bottom with an intake pipe, terminating on the outside of the locomotive with a suitably designed funnel or air scoop, by which fresh air is forced through the heater boxes as the locomotive moves, very much as tanks are filled with water from track tanks.

The heater boxes, protected by suitably designed fire brick, stand in the bed of fuel, and are necessarily always very hot. The incoming air passing through them is heated to a high temperature, and is discharged through the nozzles on a line with the centers of the bottom row of tubes, and completely across the width of the fire-box, so that a correct mixture of the gases rising from the bed of fuel, with a proper amount of highly heated fresh air, is obtained, and complete combustion is the result. No smoke is generated, and the cinders are consumed in the fire-box.

The arrangement of the air openings and connections is shown in Figs. 11 and 12. Fig. 11 represents a longitudinal section through the fire-box, and illustrates the discharge of heated air from the nozzles over the bed of fuel in the direction of the centers of the bottom row of tubes and across the gears rising from the fuel. Fig. 12 is a cross section through the fire-box looking from the back flue-sheet towards the fire door, and shows the steam pipe connection which is needed to supply the fresh air when locomotives are standing or when running at low speeds.

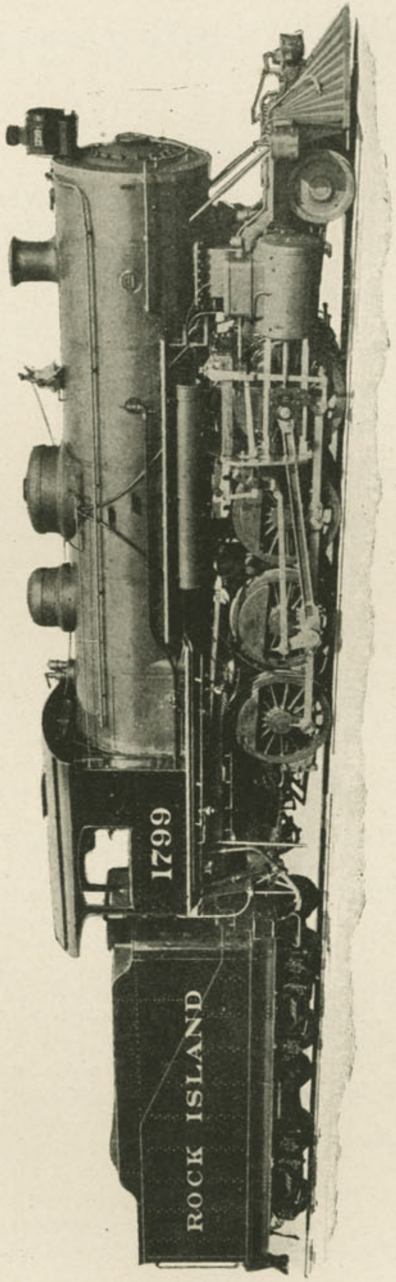
When the locomotive is standing the blower is turned on, and the valve in the steam pipe on the back head of the boiler is opened sufficiently to draw through the heater boxes sufficient air for the combustion of the gases. Enough air is admitted to prevent smoke from issuing from the stack.

The locomotives equipped with the Parsons arrangement are fired the same as with an ordinary locomotive; but it is claimed that there is less trouble with the fire, thus allowing firemen to more easily fire the large power locomotives in use to-day.

REVIEW QUESTIONS.

MECHANICAL STOKERS.

1. Name several reasons why the mechanical stoker is being introduced upon locomotives.
2. Explain in what way a mechanical stoker can help a fireman to properly fire the boiler.
3. Give several requirements of a mechanical stoker which are absolutely necessary before it can be used on a locomotive.
4. Explain in what way a mechanical stoker will aid the fireman in saving fuel.
5. Give a brief description of three different types of mechanical stokers, and explain the different methods with which they fire coal in the fire-box.
6. Give the general method of firing coal as used in the Hayden mechanical stoker.
7. Explain how the coal is carried from the tender to the fire-box in a Hayden stoker.
8. How is the delivery of coal in a Hayden stoker shut off from the tender to the fire-box?
9. What kind of coal is used for a Hayden stoker and how is it distributed over the fire?
10. Of what use is the intermittent steam blast in a Hayden stoker?
11. Name some of the advantages claimed for the Hayden stoker.
12. Describe the Crosby mechanical stoker, and explain how it differs from the Hayden stoker.
13. How is the coal distributed over the fire when a Crosby stoker is used?
14. What kind of a fire door is necessary in connection with a Crosby stoker?
15. Explain how this stoker can be disconnected so that the boiler can be fired by hand.
16. Describe the general arrangement of the Victor stoker, and explain how it conveys the coal into the fire-box.
17. Describe the general principles of the Strouse mechanical stoker, and explain how it differs from the Victor stoker.
18. In what way can the fireman regulate the amount of coal delivered by a Strouse stoker?
19. Explain how the fireman regulates the amount of coal fed to the boiler by a Victor stoker.
20. Explain the Parsons system of combustion which is used on locomotives.
21. What changes in the fire-box are necessary when the Parsons system of combustion is used?
22. Explain the use of the blower in connection with the Parsons system.



CONSOLIDATION TYPE OF LOCOMOTIVE FOR HEAVY FREIGHT SERVICE USED ON THE CHICAGO, ROCK ISLAND & PACIFIC R. R.
(Baldwin Locomotive Works)

The Locomotive Boiler

The locomotive boiler is one of the most important parts of a locomotive, and although apparently it may not seem to demand the same attention from the designer and engineer as the more delicate moving parts, yet, unless properly constructed and cared for, the steaming capacity and efficiency of the locomotive will be considerably reduced. The power that a locomotive is capable of developing depends upon the size of the cylinders and boiler. Owing to transverse limitations imposed by structures on either side of the track, the size of the locomotive must be kept within certain limits. Up to the present time, it is the boiler that sets the limit to the power that a locomotive is capable of exerting. Cylinders can easily be constructed that will use all of the steam that the boiler can generate. The tendency, therefore, of modern locomotive construction has been towards an increase in the size of the boiler. The larger the boiler the greater will be the amount of heating surface that it will contain and the more steam it will supply.

Requirements of a Locomotive Boiler. The chief requirements of a boiler are (1) that it should be amply strong in all its parts to withstand the pressure to which it will be subjected; (2) that it should provide an abundant supply of steam for the cylinders of the engine it is attached to; (3) that it should do this with the least possible expenditure of fuel; (4) that it should be of such design as to admit of repairing cheaply and readily; (5) and that it should be easily kept clear of scale and sediment.

Principal Parts of the Boiler. The principal parts of a locomotive boiler are the fire-box, flues, dome, steam or dry pipe, throttle valve, and smoke arch, in which are the steam pipes leading to the steam chest, the exhaust nozzles and the stack. The

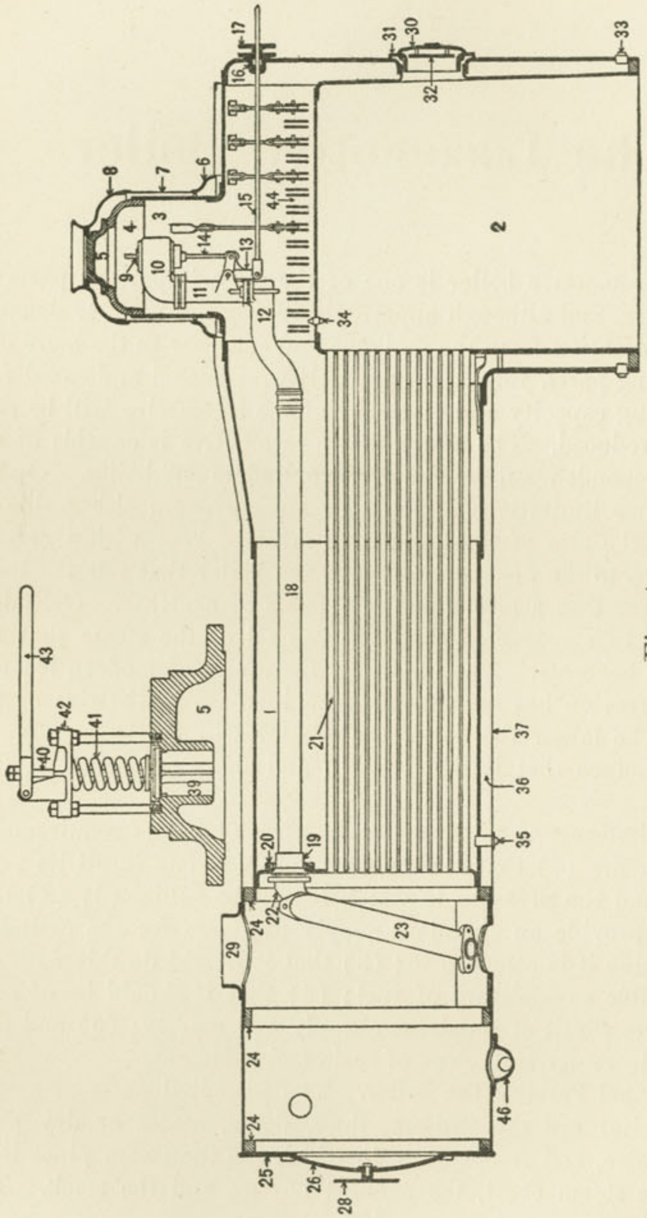


Fig. 1. Crown Bar Type Boiler.

details of several types of locomotive boilers are shown in Figs. 1 and 2.

Fig. 1 represents the crown bar type of boiler, and Fig. 2 the radial stay type. The boiler proper is represented by 1; 2 represents the fire-box; 3, the dome; 4, the dome ring; 5, the dome cap; 6, the dome base; 7, the dome casing; 8, the dome cover; 9, the throttle valve; 10, the throttle valve box; 11, the throttle pipe; 12, throttle pipe elbow; 13, throttle valve crank; 14, throttle valve rod; 15 throttle valve stem; 16, throttle stuffing-box; 17, throttle stuffing-box gland; 18, dry pipe; 19, dry pipe front end; 20, dry pipe ring on tube sheet; 21, boiler tubes; 22, double cone; 23, steam pipes; 24, smoke-box rings; 25, smoke-box front; 26, smoke-box door; 28, number plate; 29, smokestack base; 30, fire door; 31, fire door frame; 32, fire door liner; 33, corner plug; 34, fusible plug; 35, waist plug; 36, lagging; 37, jacket; 38, smoke-box band; 39, safety valve; 40, safety valve stem; 41, safety valve spring; 42, safety valve spring cap; 43, relief lever; 44, crown bar; 45, staybolts; 46, spark ejector.

The boilers used upon locomotives are of a distinct type. They consist of a cylindrical barrel or shell, which is nearly filled with tubes. The back ends of these tubes open into the fire-box, which is formed by two plates of metal spaced from 3 in. to 4 in. apart. All locomotive boilers conform to this general description, but there are many variations in the shape and size of the fire-box and the method of staying the flat surfaces.

Heating Surface. In order that the heat produced by the combustion of the fuel may be absorbed by the plates and communicated to the water, it is necessary to provide as large an area as possible for the heated gases to move over. It is not necessary to have the actual flame of the fire reach all, or indeed any, of the heating surface, because flame becomes chilled by contact with any metallic surface, and if by contact with a body it may be made to part with heat, the incandescent gas, which is usually called flame, may thus be cooled before it has fully combined with the oxygen of the air, and this condition, known as imperfect combustion, is obtained with corresponding loss of the heat units contained in the fuel.

The heating surface is the internal area of the boiler exposed to the direct action of the heated gases due to combustion, and this

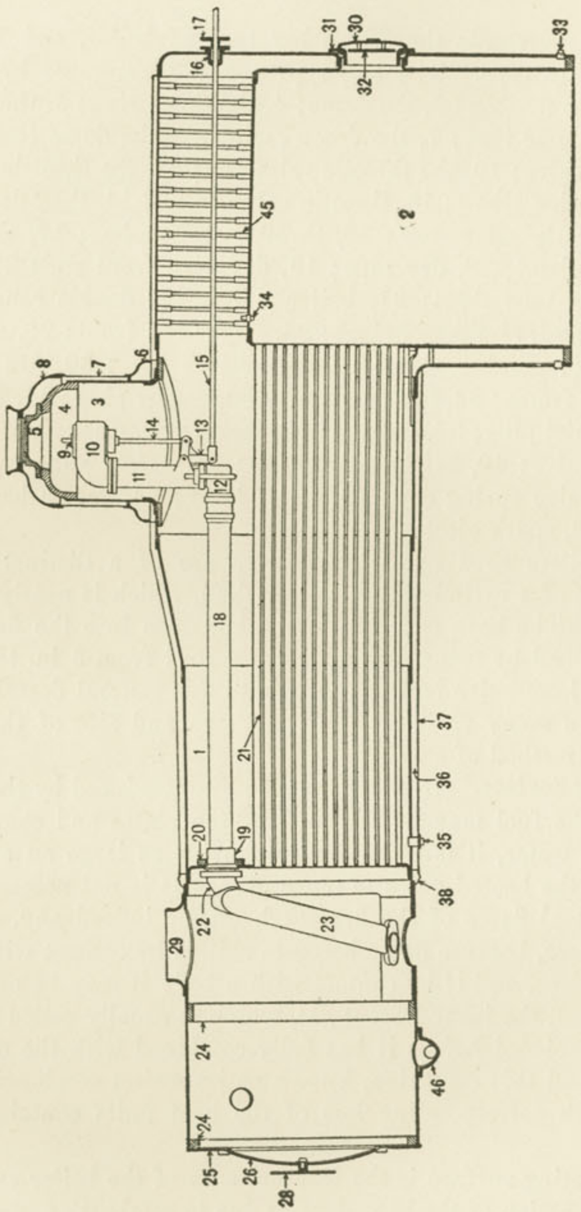


Fig. 2.
Type of Radial Stay Boiler.

area is usually divided into fire-box heating surface and flue heating surface. Other things being equal, the greater the heating surface the greater the efficiency of the boiler. The fire-box heating surface is made up of the area of all the fire-box sheets above the grate level. It consists of the inside back sheet, minus the opening made for the fire door, the area of both the side sheets, the area of the flue sheet, minus the total area of the openings for the flues, and the area of the crown sheet.

The flue heating surface is found by taking the outside surface of any one flue and multiplying the number of square feet in it by the total number of flues in the boiler. The outside or water-side of the flue is taken because that is the area which parts with heat to the water. When the outside diameter and length of a flue are known, the heating surface is found by multiplying the circumference of the flue in inches by the length in inches, and reducing the product to square feet. This result, when multiplied by the number of tubes, gives the total flue heating surface in the boiler.

Grate Area. The amount of grate area required is the factor, more than any other, that influences the main design of a boiler, and this factor is dependent upon the nature and the quality of the fuel that is to be used. Wood, for example, requires for its proper combustion a deep fire-box, and as the requisite depth cannot be obtained except by placing the fire-box between the axles, the size of a wood-burning box is practically limited to the distance between centers that it is considered expedient to place the coupled wheels. Hard coal, on the other hand, requires a large, shallow fire-box in which to burn to advantage, consequently the fire-box has to be extended over one or more axles according to the type of the engine. Thus each of these two fuels requires a particular kind of fire-box; for wood, a deep one, and for hard coal, a shallow one. These are essentials, and cannot be successfully deviated from. With soft coal, however, the case is different; it can be burned in either a deep or a comparatively shallow fire-box, and it is generally the size of grate needed that determines which it shall be. About 120 pounds of coal per square foot of grate area per hour can be burned economically, although, when occasion requires, as high as 200 pounds can be consumed, but not economically. Knowing the service the engine is to be employed in, it is possible, by estimating the amount of steam required per hour, to calculate the quantity of coal that should be consumed, and so get at the size of the grate.

Relation of Size of Cylinders, Grate Area and Heating Surface. Taking the piston displacement, or the space swept through by the piston at each stroke of cylinder, in cubic feet as a starting-point, and dividing it into the number of square feet of grate area of a large number of successful soft coal-burning engines, having cylinders ranging from seventeen to twenty-one inches diameter, it has been found that the piston displacement of one cylinder in cubic feet multiplied by six gives the grate area of the boiler. After deciding what area of grate is necessary, the length and width may be readily found, and if the former is as long as to be prohibitive of a box between the axles, then the box must go over the back axle or axles, and either between or on top of the engine frames, as may be deemed most desirable. Taking a 20 x 24-inch engine, the piston displacement, or the volume swept through by the piston in one stroke, is 4.36 cubic feet. This, multiplied by 6, gives 26.16 square feet of grate surface required for the boiler.

The amount of heating surface of both flue and fire-box may be obtained in a similar way. Taking a large number of engines now running, and dividing the piston displacement into the number of square feet of fire-box and flue heating surface, the result in the case of the former is 36 and of the latter 370. Therefore, to obtain the fire-box heating surface, many authorities follow the rule of multiplying the piston displacement by 36, and to obtain the flue heating surface they multiply the piston displacement by 370. The proportion of grate area to heating surface is generally made about 1 to 70, although a great diversity of practice prevails, and no fixed ratio is strictly adhered to. An average of eleven typical engines, taken at random among those built for American railways recently, and burning soft coal, was 69.3 square feet of total heating surface to 1 square foot of grate area. The design of the engine determines how long the flues shall be, and when once this dimension and the diameter of the flues to be used are settled upon, it is an easy matter to find how many flues will be needed in the boiler.

Materials Used for Construction. The materials used in the

construction of locomotive boilers in this country are wrought iron and mild steel. Steel is universally used for the shell, heads and fire-box sheets. The grade of steel used for the shell sheets is known to the trade as flange or boiler steel. The desired tensile strength is 60,000 pounds per square inch, with minimum and maximum limits of 55,000 and 65,000 pounds. According to standard specifications adopted by the American Railway Master Mechanic's Association, the elongation in eight inches shall not be less than twenty-five per cent for sheets three-quarters of an inch thick, or under. For thicker sheets deduct one per cent from specified elongation for each one-eighth inch additional thickness. The chemical requirements demand that the phosphorus and sulphur shall be as little as possible, not exceeding 0.06 of one per cent for phosphorus and 0.05 of one per cent for sulphur. The manganese in the boiler steel is allowed to vary from 0.3 to 0.6 of one per cent.

Specifications for Fire-box Steel. According to the same specifications, the desired strength of fire-box steel is 57,000 pounds per square inch, with minimum and maximum limits of 52,000 and 62,000 pounds. The elongation in eight inches shall not be less than twenty-six per cent. The chemical requirements of fire-box steel demand that the carbon be not less than 0.15 of one per cent, or more than 0.25 of one per cent; phosphorus and sulphur should not exceed 0.04 of one per cent, and manganese may vary from 0.3 to 0.5 of one per cent.

The general requirements for boiler and fire-box steel demand that with special sized pieces it must be possible to bend the metal double, either hot or cold, without having it show any crack or flaw on the outside portion, after it has been heated to a cherry-red and quenched in water having a temperature between 80 and 90 degrees.

Specifications for Braces and Staybolts. The bar iron used for braces and other parts should have a tensile strength of from 50,000 lbs. to 60,000 lbs. per square inch of section. The strength desired is 55,000 lbs., with an elongation, before breaking, in an 8-inch test piece of 25 per cent.

The strength of staybolts should be about 50,000 lbs. per square inch of section, but it must not be less than 48,000 lbs. As this metal is usually softer than the bar iron, the elongation is greater, and should be 30 per cent. If the elongation falls below 28 per cent, the staybolt should be rejected.

Boiler Tubes. Boiler tubes are made of either charcoal iron, cold drawn steel or spellerized steel. In former years boiler tubes were made almost exclusively from charcoal iron, but most roads are now using steel tubes in some form.

Modern Steel Boiler Tubes. The steel boiler tube made to-day, both seamless and lapweld, is the outcome of many years' experience with charcoal iron. With the greatest care and supervision, charcoal iron tubes will give good results, but at the present time the supply of raw material of necessary high grade quality is difficult to obtain, and the skilled labor, which is even more essential, is becoming scarcer every year. The manual work required to produce a ball of charcoal iron, weighing about 250 to 300 pounds, taxes the endurance of the men, and requires, besides, considerable experience and skill on the part of the "knobbler." Men with the necessary capacity for acquiring this experience and skill in knobbling iron can now make more money at occupations which put far less tax on their vitality, hence the younger generation is going into other pursuits, and it is becoming more and more difficult to recruit the ranks of knobblers and puddlers with good men. As the quality of the material depends largely upon its manipulation at the hands of the operator and the amount of thorough working it receives under the hammer, the manufacture of charcoal iron for boiler tubes by this process has become anything but satisfactory.

During recent years the development of weldable steel has offered a solution for this difficulty; the manufacture of welded goods has grown to such proportions that it is now possible to keep large plants, making thousands of tons a day, working on the manufacture of very low carbon weld steel exclusively. This insures a degree of uniformity and a control over the product which were formerly hard to get. Instead of being dependent on hundreds of operators making a small amount per day, a few highly skilled men are held responsible for the whole output of the steel works. This steel is now giving far better satisfaction in welding than did charcoal iron, because of its uniformity.

Spellerized Steel. Recently this material has been still further improved by introducing the process of kneading the metal before rolling into plates. This additional mechanical work at proper temperature removes any local irregularities in the surface of the bloom, and improves the texture of the surface portion of the plate so that it resists corrosion uniformly. Pitting of steel boiler tubes has been one of the hardest problems which the metallurgist has had to contend with. This process of spellerizing has so far given the most encouraging results in overcoming this difficulty. Practical tests are now being made with a view to increasing the endurance of the tube in the flue sheet, so that it will stand more cold work and be tightened oftener without becoming brittle.

SPECIFICATIONS FOR SPELLERIZED STEEL TUBES AND SAFE ENDS.

Material. Tubes to be made of soft Spellerized Steel and lapwelded.

Dimensions and Weights. The minimum weights for tubes of various diameters and thicknesses are given in the following table:

Outside Diameter	Nominal B. W. G.	Thickness M. M. G.	Minimum weight per foot
1¾ inch	No. 13	.095 inches	1.65 lbs.
	No. 12	.110 "	1.89 "
	No. 11	.125 "	2.07 "
	No. 10	.136 "	2.29 "
2 inch	No. 13	.095 inches	1.91 lbs.
	No. 12	.110 "	2.17 "
	No. 11	.125 "	2.38 "
	No. 10	.135 "	2.64 "
2¼ inch	No. 13	.095 inches	2.16 lbs.
	No. 12	.110 "	2.46 "
	No. 11	.125 "	2.70 "
	No. 10	.135 "	2.99 "
2½ inch	No. 12	.110 inches	2.73 lbs.
	No. 11	.125 "	3.02 "
	No. 10	.135 "	3.37 "

Surface Inspection. Tubes must have a smooth surface, free from all laminations, cracks, blisters, pits and imperfect welds; they must also be free from bends, kinks and buckles, signs of unequal contraction in cooling, or injury in manipulation, and must be within .01 inch of the thickness specified except at the weld, where .015 inch additional will be allowed; they must also be circular within .02 inch and cut to length ordered.

PHYSICAL TESTS.

1. **Ring Tests.** One-half in. Tubes—Coupons ⅝ in. long cut from tube must stand hammering down vertically into the shape of a ring, and be without cracks or flaws of any kind, either at weld or elsewhere when hammered down solid.

Two in. and 2¼ in. Tubes—Coupons 1¼ in. long cut from tube must stand hammering down vertically into the shape of a ring, and be without cracks or flaws of any kind, either at weld or elsewhere when hammered down solid.

2. **Expanding Test.** Sections of tubes 8 in. long, with or without heating, shall be placed in a vertical position, and a smooth turned, tapered steel pin will be driven into the end of the tube by light blows of a ten pound hammer. The pin used shall be of tool steel, tapered 1½ in. to the foot for 2 in. outside diameter tubes. Pins of proportional dimensions to be used for other size tubes. Under this test the tube must stretch to 1⅛ times its original diameter without splitting or cracking. When this test is made hot the tube shall be heated to a bright cherry red in daylight and the pin at a blue heat driven in as described.

3. **Flange Test.** Sections of tubes 8 in. long shall have a flange turned over at right angles to the body of the tube, which shall have a width equal to ⅛ of an in. without crack or flaw. All the work shall be done cold.

4. **Flattening Test.** A section 12 in. longmust stand hammering flat cold for one-half its length from one end, having the weld at the edge of the flattened section, and hammering cold in the same manner for the other half of its length, having the weld in the center of the flattened section, without cracking at the edges or elsewhere.

Two tubes to be tested as required in paragraphs 1, 2, 3, 4 and 5 in each lot of 250 tubes or less. If only one of the tubes so tested fails, that tube will be rejected, and the inspector will take two more tubes from the same lot and subject both to the same test as the one that failed, and both of these tubes must be found satisfactory in order that the lot may be passed.

5. **Hydraulic Test.** Each tube must be subjected by the manufacturer to an internal pressure of 750 pounds per square inch.

GENERAL REQUIREMENTS.

In addition to above tests, tubes when inserted into boilers, must stand expanding and beading without showing crack or flaw, or opening at the weld.

Each tube must be plainly stenciled "Spellerized Steel Tested to 750 lbs.," and tubes must be so invoiced. Each tube must also be subjected to careful inspection, as provided for above, and those measuring more than $\frac{1}{64}$ of an in. over or under the diameter ordered shall be rejected.

All tests to be made at place of manufacture, under the supervision of the Railroad's Inspector or his deputy.

SPECIFICATIONS FOR IRON LOCOMOTIVE BOILER TUBES.

The following specifications and tests for iron locomotive tubes have been adopted by the American Railway Master Mechanics' Association as a standard:

1. Tubes are to be made of knobbled, hammered charcoal iron lap-welded.

2. Tubes must be of uniform thickness throughout, except at weld, where an additional thickness of .015 will be allowed. They must be circular within .02 in., and the mean diameter must be within .015 in. of the size ordered. They must be within .01 in. of the thickness specified and not less than the length ordered, but may exceed this by .125 in.

3. The minimum weights for tubes of various diameters and thicknesses are given in the following table:

Outside Diameter	Nominal B. W. G.	Thickness M. M. G.	Minimum weight per foot
1¾ inch	No. 13	.095 inches	1.65 lbs.
	No. 12	.110 "	1.89 "
	No. 11	.125 "	2.07 "
	No. 10	.135 "	2.29 "
2 inch	No. 13	.095 inches	1.91 lbs.
	No. 12	.110 "	2.17 "
	No. 11	.125 "	2.38 "
	No. 10	.135 "	2.64 "
2¼ inch	No. 13	.095 inches	2.16 lbs.
	No. 12	.110 "	2.46 "
	No. 11	.125 "	2.70 "
	No. 10	.135 "	2.99 "
2½ inch	No. 12	.110 inches	2.73 lbs.
	No. 11	.125 "	3.02 "
	No. 10	.135 "	3.37 "

SURFACE INSPECTION.

4. Tubes must have a smooth surface, free from all laminations, cracks, blisters, pits and imperfect welds. They must be free from bends, kinks and buckles, and from evidence of unequal contraction in cooling or injury in manipulation.

PHYSICAL TESTS.

5. **Bending Tests.** Strips ½ in. in width by 6 inches in length, planed lengthwise from tubes, after having been heated to a cherry red and quenched in water at 80° F., shall bend in opposite directione at each end, without cracks or flaws, and when nicked and broken by slight blows, these strips must show a fracture wholly fibrous.

6. **Expanding Test.** Sections of tubes 12 inches long shall be heated a length of 5 in. to a bright cherry red in daylight, and then placed in a vertical position, and a smooth taper steel pin at blue heat will be driven into the end of the tube by light blows of a 10-pound hammer. Under this test the tube must stretch to 1⅛ times its original diameter without splitting or cracking. The pin used shall be of tool cast steel, tapered 1½ in. to the foot. In making this test, care must be taken to see that the end of the tube is smoothly trimmed.

7. One tube is to be tested, as required in paragraphs 5 and 6, in each lot of 250 tubes or less.

8. **Crushing Test.** A section of tube 2¼ in. long, when placed vertically on the anvil of a steam hammer and subjected to a series of light blows, must crush to a height of 1⅛ in. without splitting in either direction, and without cracking or bending at weld.

9. **Hydraulic Test.** Before shipping, each tube must be tested by manufacture to 500 pounds per square in., and each tube must be plainly marked in the middle: "Knobbled charcoal, tested to 500 pressure."

10. In addition to the above tests, tubes which, when inserted into boilers, split or break while being expanded or bended, and also individual tubes which fail to pass surface inspection will be rejected and returned to the makers at their expense.

11. **Etching Tests.** In case of doubt as to the quality of material, the following test shall be made to detect the presence of steel. A section of tube, turned or ground to a perfectly true surface on the end, will be polished free from dirt or cracks, and the end of the tube will be suspended in a bath of nine parts water, three parts sulphuric acid and one part hydrochloric acid. The bath will be prepared by placing water in a porcelain dish, adding the sulphuric and then the hydrochloric acid. The chemical action must be

allowed to continue until the soft parts are sufficiently dissolved, so that the iron tubes will show a decided ridged surface, with the weld very distinct, while the steel tube will show a homogeneous surface.

SPECIFICATION FOR SEAMLESS, COLD DRAWN STEEL LOCOMOTIVE BOILER TUBES.

1. Tubes are to be cold drawn, seamless and made of open hearth steel. It is desired that the steel from which the tubes are manufactured should have the following chemical composition:

	Per Cent.
Carbon	.15 to .20
Manganese	.45 to .55
Sulphur, below	.03
Phosphorus, below	.03

Tubes containing more than .03 phosphorus or sulphur will be rejected.

2. Tubes must be of uniform thickness throughout. They must be circular within .02 of an in., and the mean diameter must be within .015 of in. of the size ordered. They must be within .01 in. of the thickness specified and not less than the length ordered, but may exceed this by .125 in. They must be free from bends, kinks and buckles.

3. The minimum weight of the tubes of various diameters and thicknesses are given in the following table:

Outside Diameter	Nominal B. W. G.	Thickness M. M. G.	Minimum weight per foot
1¾ inch	No. 13	.095 inches	1.69 lbs.
	No. 12	.110 "	1.92 "
	No. 11	.125 "	2.15 "
	No. 10	.135 "	2.29 "
2 inch	No. 13	.095 inches	1.91 lbs.
	No. 12	.110 "	2.19 "
	No. 11	.125 "	2.47 "
	No. 10	.135 "	2.65 "
2¼ inch	No. 13	·095 inches	2.16 lbs.
	No. 12	.110 "	2.48 "
	No. 11	.125 "	2.80 "
	No. 10	.135 "	3.01 "
2½ inch	No. 12	.110 inches	2,73 lbs.
	No. 11	.125 "	3.04 "
	No. 10	.135 "	3.41 "

PHYSICAL TESTS.

4. **Bending Test.** Strips ½ in. in width by 6 in. in length, planed lengthwise from tubes, after having been heated to a cherry red and quenched in water at 80° F., shall bend in opposite directions at each end, without cracks or flaws.

5. **Expanding Test.** Sections of tubes 12 in. long shall be heated a length of 5 in. to a bright cherry red in daylight and then placed in a vertical position, and a smooth taper steel pin at blue heat will be driven into the end of the tube by light blows of a 10-pound hammer. Under this test the tube must stretch to 1⅛ times its original diameter without splitting or cracking. The pin shall be of tool steel tapered 1½ in. to the foot. In making this test, care must be taken to see that the end of the tube is smoothly trimmed.

6. **Crushing Test.** A section of tube 2½ in. long, when placed vertically on the anvil of a steam hammer and subjected to a series of light blows, must crush to a height of 1⅛ in. without splitting in either direction.

7. **Flattening Test.** A test piece of tube 5 in. long, when flattened lengthwise cold until the sides are separated by a distance equal to the gauge of the tube, must not show any splits or cracks.

8. One tube is to be tested as required in paragraphs 4, 5, 6 and 7 in each lot of 250 tubes, or less.

9. Each tube must be subjected by the manufacture of an internal pressure of 1,000 pounds to the square in. and must be plainly stenciled "Seamless Steel Tubes, tested to 1,000 pounds."

Boiler Shell. One of the easiest parts of the boiler to construct is the cylindrical portion or waist of the boiler. Allowing a suitable factor of safety, it is only a question of using good material and workmanship. As soon as the boiler is put in service, however, deteriorization begins, and it is the retarding of this as much as possible that should be considered in the design. There is no doubt whatever that when the butt joint is used, corrosion along the seam is much less than with the lap joint. With the butt joint the strain due to the steam pressure is uniformly distributed over the whole circle, while with the lap joint, when the boiler is under steam, there is a tendency for the plates to straighten out, the result being that the plate bends to some slight degree each side of the lap; this tendency causes scale, that may be deposited there, to flake off and leave the surface of the plate exposed to furrowing or corrosion. Although a lap joint can be made that will give as high a percentage of strength as the butt joints, yet the established fact that the butt joint lessens corrosion warrants its adoption in most cases, especially with large boilers carrying high pressures.

The fire-box end of the boiler is where the greatest danger lies, and it is this that claims the major share of attention of boiler designers. Sheets that require severe flanging, such as the throat and top connection on flat-sided wagon-top boilers, should always be made $\frac{1}{16}$ or ⅛ in. thicker than the others, so as to make up for the thinning out arising from the operation of flanging.

All portions of a locomotive boiler are subject to the pressure of the steam contained within it, and this is, of course, measured as so many pounds per square inch. The lower parts of a boiler which are covered by water must also bear the weight of the water, and these parts, therefore, sustain a slightly greater pressure than those which are only pressed upon by the steam, but the few pounds per square inch which the weight of the water may add to the internal pressure is generally disregarded, because, even in a boiler 70 inches in diameter and filled three-quarters full, there would only be a maximum increased pressure of 1.88 pounds per square inch on the area over which the water stood 52½ inches deep.

The pressure of the steam may therefore practically be said to be equal on every square inch of the internal surface and upon the outside surface of the tubes. The circular form of both the shell of the boiler and of the tubes gives them the property of resisting pressure, and, when made of material sufficiently thick, they do not require to be stayed.

The bursting strain of three-quarter-inch circular plate is usually calculated on the assumption that a circle of plate one inch wide may be taken as typical of the whole circular shell. There is, therefore, a hoop one inch wide sustaining an internal pressure of say 200 pounds per square inch. This hoop may be supposed to be divided into two arches by the diameter, and the effort of the steam to separate these two arches is resisted by two areas of metal, each one inch long by three-quarters inch thick. These two areas are together equal to 1½ square inches, and if the tensile strength of ordinary boiler plate is taken to be 60,000 pounds per square inch, a total pressure of 90,000 pounds would be required to separate the arches.

If the internal steam pressure is, say for example, 200 pounds per square inch, this pressure, as far as the tendency to burst the boiler is concerned, is exerted only upon what is called the projected areas of 1 inch wide and 70 inches long, or a total of 70 square inches; the pressure on the curved shell acting as if it were along the diameter. The total pressure on this strip is 14,000 pounds, and it tends to force the upper half up, and the lower half down, just as if each half were filled with a solid material with a flat base 1 inch wide and with a length equal to the diameter of the shell.

The internal pressure of 14,000 pounds is thus resisted by 90,000 pounds. In other words, the shell is more than 6.43 times

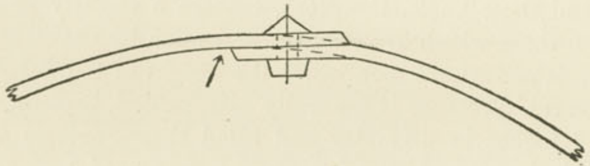


Fig. 3.

Example of Lap Joint.

stronger than the tendency to rupture it, and the circular shell is said to have a factor of safety of 6.43.

Strength of Seams. The horizontal seams of a locomotive boiler cannot have the same strength as the unbroken circular plate, for the reason that, in order to make the joint, a series of rivet holes must be punched or drilled in each edge which it is desired to unite. One form of joint which was formerly extensively used is the lap joint, Fig. 3, either double or triple-riveted; but it has now entirely disappeared in horizontal seams in modern locomotive practice. This form of seam can be made strong enough and the joint kept tight, but, on account of the fact that the lap joint cannot be made to give a perfectly circular seam, the effort of the internal pressure tends to bend the sheets slightly just beyond the lap, as indicated by the arrow, and as this tendency increases as the pressure rises, and is reduced as it falls, it introduces a sort of

hinge-like action, which causes the plates to deteriorate and weaken along a definite line close to the edge of one plate, and its ultimate failure is merely a matter of time.

The certain failure of the lap joint has forced designers to devise a safer and better joint, and, as a result, horizontal seams in locomotive boilers are made by butting the edges of the plates together and securing them by two strips of plate, called welts, usually of the same thickness as the shell. These welts are bent to the radius of the boiler, and are applied, one inside and one outside, over the butt joint, and are riveted in place. In modern practice the inside welt is wider than the outside, and the seam is made with two rows of rivets passing through three thicknesses of metal; that is to say, each rivet passes through the upper welt, the plate itself and through the lower welt. These two rows have

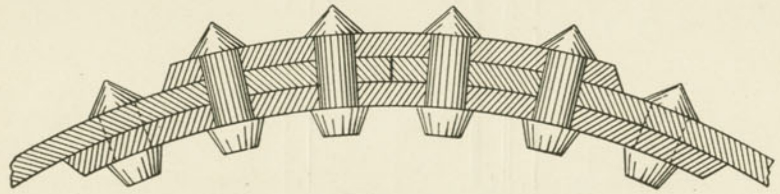


Fig. 4.

the rivets arranged in zigzag fashion. The inside welt, covering a greater area than the upper, takes an extra row of rivets along each of its edges, and these rivets pass through the inside welt and the barrel plate.

The strength of this form of double-welted triple-riveted joint is about 87 per cent of the strength of the solid plate, and has a factor of safety of 5.59. This joint, Fig. 4, has, in all, four rows of rivets in double shear and two rows in single shear. The single shear rows are each called a safety row of rivets. In calculating the strength of rivets, the tensile strength of the iron of which the rivet is composed is taken as the value for single shear. For double shear the value of the rivet is not taken as double that of single shear, but at 1.75 of the safe strength of the material of the rivet.

A form of inside welt, designed by Mr. S. M. Vauclain, Superintendent of the Baldwin Locomotive Works, gives 96 per cent of the strength of the solid plate. In this joint the outside welt is

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single-riveted; that is, there are two rows of rivets in it, one lying on each side of the butted edges of the circular sheet. The inside welt is diamond-shaped, as shown in Fig. 5, placed with its diagonal along the line of the seam. This gives a large triangular area on each side of the joint, with one rivet at the point of the triangle and a series of widely spaced rivets in widely spaced rows over the whole area, and terminating in a safety row close to the edge of the upper welt, on each side of the butt seam.

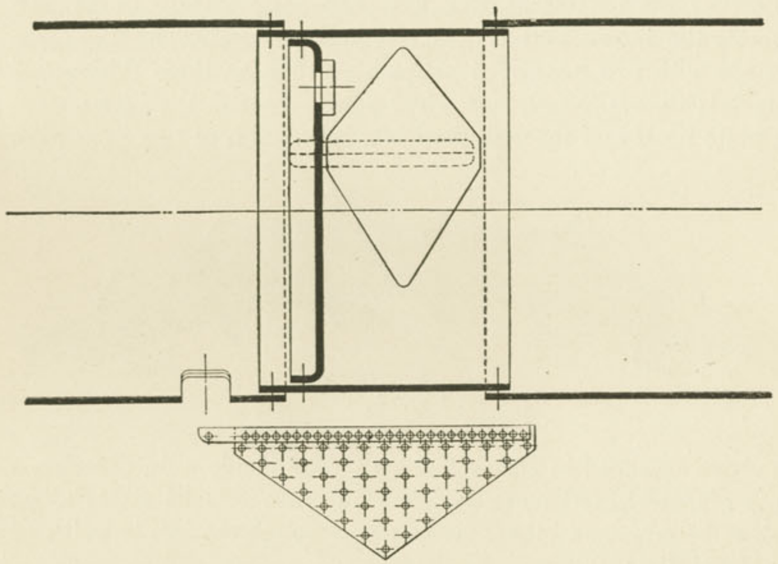


Fig. 5.

BUTT-JOINT WITH DIAMOND-SHAPED WELT.

Circumferential Seams. The circumferential seams of a locomotive boiler are lap joints double-riveted. The lapping of the plates is here quite allowable, because the seam is perfectly circular, and no distortion can take place, and although one row of rivets could be driven having a large enough factor for safety, yet such seams are usually double-riveted in order to secure as large a lap as practicable, to give the boiler the necessary stiffness when considered in the light of a tubular girder, which is called upon to withstand vibration, to carry a certain volume of hot water, and

to remain rigid when supported at each end, while experiencing what may be called the galloping motion of a locomotive traveling at a rapid rate.

Staying of Flat Surfaces. The staying of the flat sides and ends of the fire-box and the upper part of the back sheet and front flue sheet as well as of the crown sheet, is a very important consideration in boiler construction. The upper part of the back sheet is sometimes stayed by what are called gusset plates. These are pieces of boiler plates cut roughly to a triangular shape, and each secured to a pair of angle-irons placed back to back on the roof sheet and to a pair of angle-irons on the back sheet. The upper part of the back sheet is sometimes secured by long rods sloping back to the roof or sheet or barrel course and flattened for rivets, and fastened to the back sheets with crows' feet connection or with double angles, as in the gusset form. When these rods are carried through to the front flue sheet the ends are screwed into both sheets, and have a nut on the outside at each end as well as inside. The gusset stays are, however, preferable for modern boilers carrying high pressure. The flue sheets in the fire-box and at the front are sufficiently stayed by the flues which are expanded into the flue holes at both ends, and the lower rods or staybolts similar to those in the fire-box side sheets, which may be described as follows:

The fire-box sheets are stayed by bolts screwed into both sheets and riveted over on the outside at each end. These bolts pass through the water spaces between the fire-box proper and the casing sheets. They are usually spaced about four inches apart, measured vertically and horizontally, giving an area of about 16 square inches upon which the pressure is applied which the bolt is required to support. The rule for finding the strain thus imposed on such a staybolt is $16 \times 200 = 3{,}200$ pounds. The strain on the plate between the staybolts is found by the following rule:

$$P = \frac{C \times (T+1)^2}{S-6}$$

where P is the working pressure, C is a constant, taken at 60, for plates having fire on one side and water on the other, and having staybolts screwed and riveted; T is the thickness of the plate measured in $\frac{1}{16}$ths of an inch; S is the surface in square inches supported by the bolt. For a $\frac{3}{8}$-inch plate the formula becomes:

$$P=\frac{60 \times (6+1)^2}{16-6}=\frac{60 \times 46}{10}=294$$

which is the working pressure which the stayed sheet can sustain by reason of its thickness and the restricted area. The pressure on the 16 square inches supported by one stay is, as we have seen, 3,200 pounds. The rule for finding the area of the required stay is independent of the stiffness of the plate, and the fact that the stayed sheet will itself support a certain pressure is disregarded, and thus forms an addition to the factor of safety. The rule for finding the area of the required staybolt is:

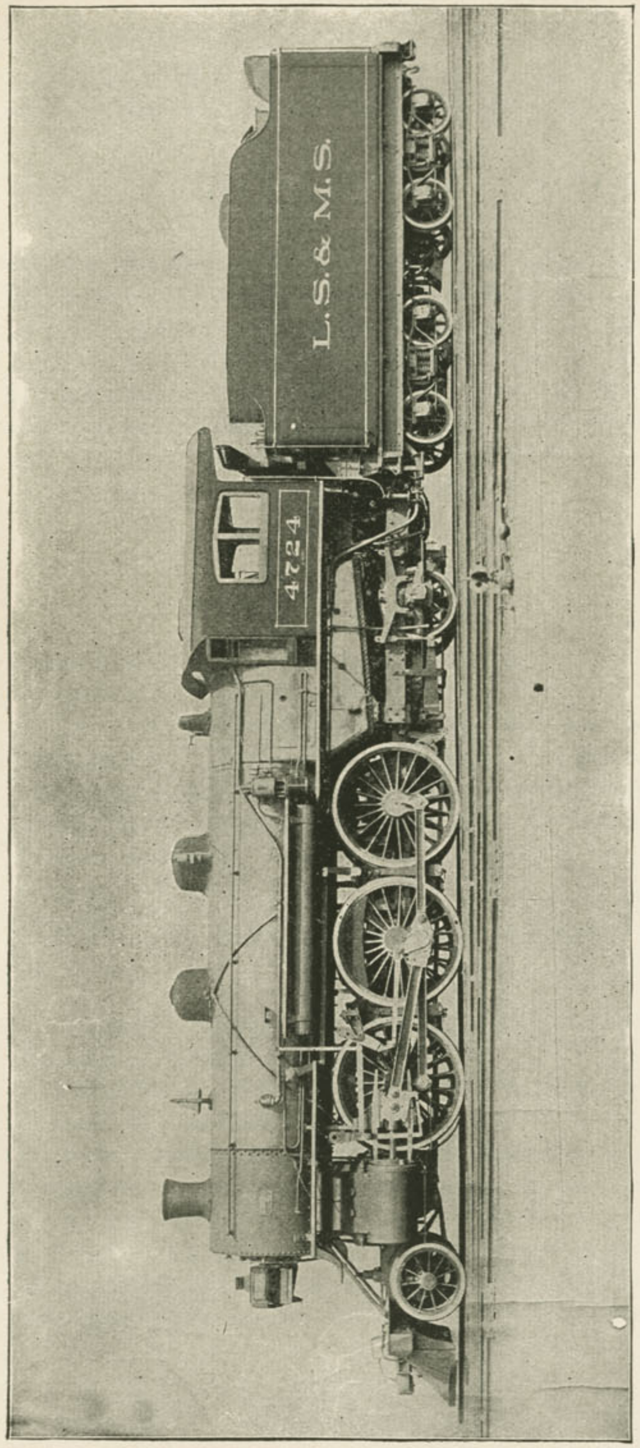
$$A=\frac{d^2 \times P}{4{,}000}$$

where A is the area of the staybolt at the bottom of the thread, d is the pitch of the bolts, P is the pressure per square inch, and 4,000 represents the tensile strain per square inch allowed on the bolt, which insures a very substantial factor of safety. According to above conditions, the staying of a $\frac{3}{8}$-inch flat sheet against 200 pounds boiler pressure and 4-inch space in both directions, the equation becomes

$$A=\frac{4^2 \times 200}{4{,}000}=0.8 \text{ square inches.}$$

A round staybolt with 0.8 square inch of area would have a diameter of very nearly one inch.

Side Sheets. The side sheets of a fire-box are usually made of sheets thinner than those of the shell of the boiler. They are in the form of flat surfaces that must be supported by the staybolts, as already described. The usual thickness of side sheets for boilers carrying a steam pressure of from 180 to 200 lbs. per square inch is $\frac{3}{8}$ inch. Experiments have shown, however, that the strength of flat-stayed surfaces does not vary exactly with the square of the thickness. The formula given by the United States Bureau of



TYPICAL FAST PASSENGER ENGINE, TYPE 2-6-2, BUILT BY THE AMERICAN LOCOMOTIVE COMPANY.

Steam Engineering for the calculation of the stress on flat-stayed surfaces is:

$$S=\frac{E\,T^2}{(D-A)^2}$$

in which

S=maximum stress in lbs. per square inch to produce permanent set;

E=elastic limit of plate, about 32,000 lbs. for steel and 29,000 lbs. for iron;

T=thickness of plate;

D=distance center to center of stays;

A=diameter of stay.

Tube Sheets. Tube sheets are usually thicker than the side sheets. The reason is, that there may be a greater width of bearing for the tubes. The tube sheet is, therefore, made about $\frac{1}{4}$ inch thicker than the side sheets. Thus, where the side sheet has a thickness of $\frac{3}{8}$ inch the tube sheet will be $\frac{5}{8}$ inch thick. Below the curve of the shell of the boiler the tube sheet is stayed in exactly the same manner as the side sheets. The portion facing the inside of the shell is stayed by the tubes. These are expanded and headed in position.

Staybolts. The locomotive fire-box of to-day, as it is stayed in the water space, differs but slightly from those used thirty years ago, notwithstanding that the heating surfaces have been greatly extended and furnace areas enlarged in order to meet the requirements of modern locomotive practice. The ordinary water space stay, known as the rigid staybolt, is shown in Fig. 6. It is simply a piece of wrought iron, threaded its entire length and screwed through the outer sheet and plate across the water space and into the inner plate or fire-box sheet. It is then riveted over on both ends, securely holding in a rigid manner the outer shell to the fire-box. Owing to the unequal expansion and contraction of the inner and outer plates, staybolts are subjected to considerable strain and frequently break. They, therefore, often have a small hole drilled into one end with a 3-16-inch drill to a depth greater than the thickness of the outside plate, so as to enable inspectors to detect ruptures or breakage by the emission of water or escape of steam through the orifice, as the break in the bolt generally occurs next to the outside plate. Fig. 7 represents a staybolt similar to Fig. 6, but is made to provide a hole through the entire length of the bar, and known as hollow staybolt iron.

In bad water sections of the country where the lime and magnesia are found in solution, incrustation forms on the outer surface of the staybolt, and at times covers a fracture, fills the telltale hole during the first stage of rupture, and prevents the escape of steam or water, regardless of breakage. In sections where the water is free from solids, this telltale hole is most advantageous,

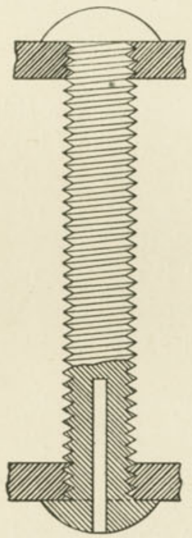


Fig. 6.

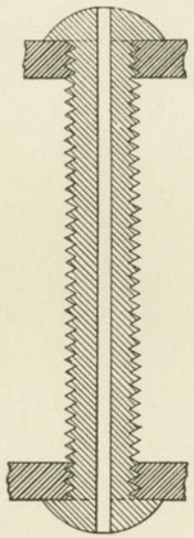


Fig. 7.

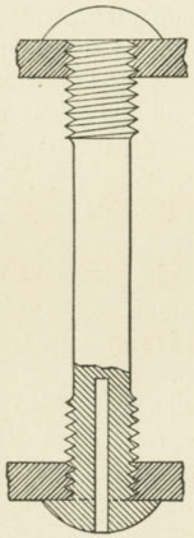


Fig. 8.

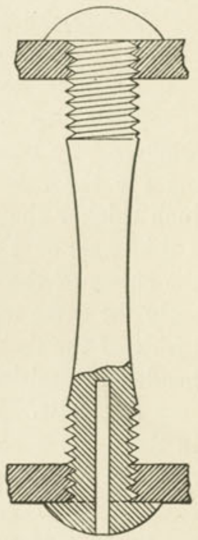


Fig. 9.

and has been recognized by State and Government supervisors of inspection as a necessary process to the proper inspection of staybolts, who have authorized its incorporation on grounds of safety.

To overcome staybolt breakages certain modifications of the original stay have been made, as shown in Figs. 8 and 9, that of simply turning off the threads in the center of the bolt exposed in the water space, followed by a greater reduction of diameter, for the purpose of giving flexibility to the bolt to more readily withstand the reversal strain due to expansion.

While it has been found that the reduction of the diameter in

the water space has not been of any material benefit to the life of the staybolt, it has the preference over the full threaded bolt to the extent that deposits, carbonates and sulphates of lime and magnesia, which precipitate from the waters used, do not adhere so closely and do not impair the quality and strength of the iron to such a marked extent as when threaded.

The Tate flexible staybolt has been widely used for the purpose of obviating staybolt troubles. Fig. 10 shows a sectional view of the bolt. The ball-shaped head of the bolt C is enclosed within a socket formed by a sleeve B that screws into the outer sheet, and a cap A that screws onto the sleeve. The other end of the bolt is screwed into and through the fire sheet a sufficient distance to

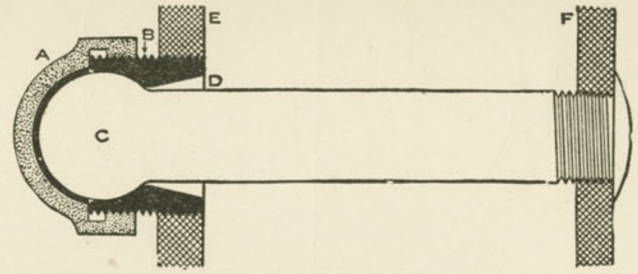


Fig. 10.

Tate Flexible Staybolt.

allow for riveting. The freedom of movement of the head of the bolt within the socket allows the fire sheet to expand and contract without subjecting the bolt to transversed stresses. Sometimes sling stays are used instead of flexible stays. This construction is shown in Fig. 11.

Breakage of Staybolts. The greatest and most constantly recurring trouble with locomotive boilers is caused by the breakage of staybolts. Broken staybolts, after low water and hot crowns, are the most usual cause of explosions that there is. When fireboxes were small, broken staybolts were not so frequent as they are at this day of large boilers and high pressures. As is well-known, staybolts usually break close to the outer sheet, and may generally be found broken in the two or three upper rows along the sides, except toward the ends of the box, where they extend down as far as the sixth or eighth row from the crown. They are very rarely found broken near the mud ring. This is brought about by the fact that, the inside and outside fire-box sheets being tied together, the expansion of the inside plates by becoming hot first, when the boiler is fired up, causes their upward movement,

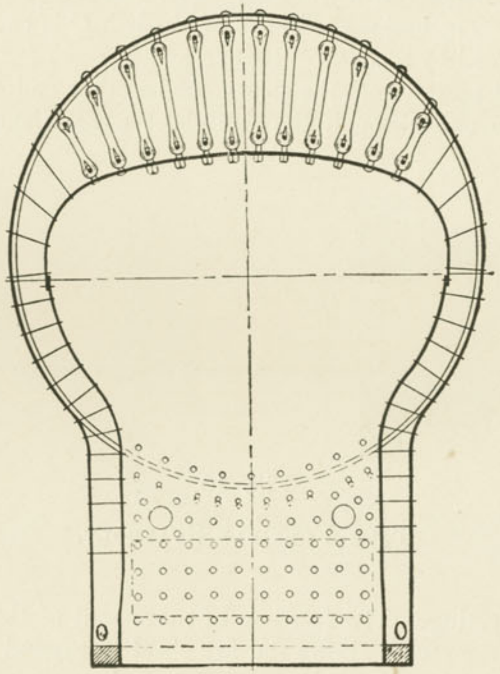


Fig. 11.

Crown Sheet Supported with Sling Stays.

and carries the inside ends of all the staybolts up a greater distance than that produced by the lesser movement of the outside sheets.

In course of time the staybolts, which are subjected to the maximum movement, that is usually along the ogee curve of the box and toward the top, are broken. The breakage occurs in the water space close to the outer or casing sheet. In order to cause

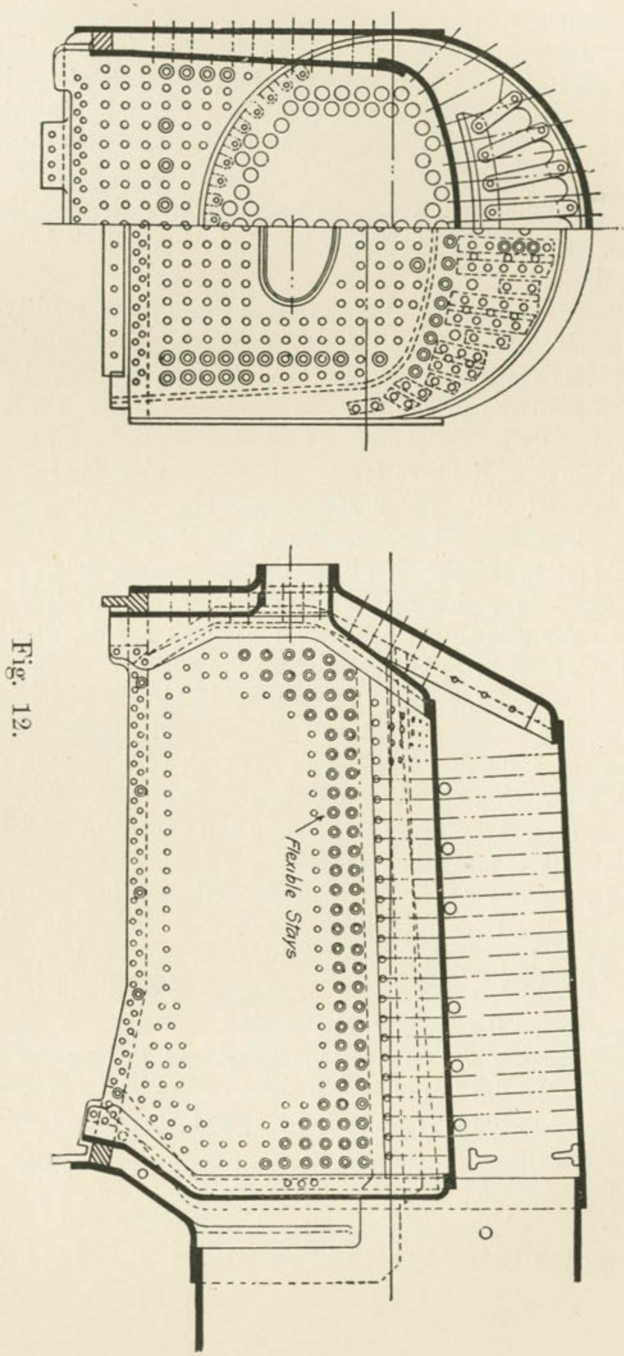


Fig. 12.

Fire-box Used on Prairie Type of Locomotive on the Wabash Railroad.

a broken staybolt to automatically indicate its presence, it is customary to drill a small hole about 3-16 of an inch in diameter and about an inch deep in the center of the staybolt along its axle, as shown in Figs. 6, 8 and 9. When a staybolt having this telltale hole breaks, water passes through the fracture and into the small hole in the center of the bolt, and causes a sputter of water and steam on the outside from the broken bolt, thus revealing its condition. Care must be taken to see that these telltale holes are clean at all times.

The breakage of staybolts takes place more readily when the outside sheet is made of thick material than it does when the outside plates are comparatively thin. The outer or shell sheet being thicker than the inner, is more rigid, and consequently the staybolt naturally breaks there. Increasing the diameter of those bolts which are most liable to fracture is a good plan for remedying this trouble, and wide water spaces are also advantageous, as they make a long staybolt necessary, and the longer the staybolt the less will its angle of deflection be as the fire-box expands.

Absolute rigidity in staybolts is to be avoided, and many designs for allowing the staybolt a slight movement at its outer end have been brought out. These are called flexible staybolts, as shown in Fig. 10, the idea being to maintain the bolt itself without flexure, and strong enough to fully support the sheets, while providing for a slight movement at one end. The length of the fire-box has a noticeable effect on staybolt breakage. The longer the fire-box the greater the variation in the expansion and the greater the liability to staybolt breakage.

In the application of flexible staybolts, they are put in only where the breakage is most likely to occur, while the ordinary form of staybolt is used for the remainder of the fire-box, as shown in Fig. 12, which represents a fire-box used on the Prairie type of locomotive on the Wabash Railroad.

Supporting Crown Sheets. There are three general methods by which the flat top or crown sheet of the boiler is strengthened: first, by crown bars; second, by radial stays, and third, by the Belpaire system.

Crown Bars. The commonest method of staying crown sheets was formerly by the use of crown bars, as shown in Fig. 13. These had various forms, but were practically iron beams placed across

the crown sheet, about an inch or two above it, their ends resting on the edges of the fire-box where the side sheets and the crown sheet joined. The crown stays are screwed into the crown sheet

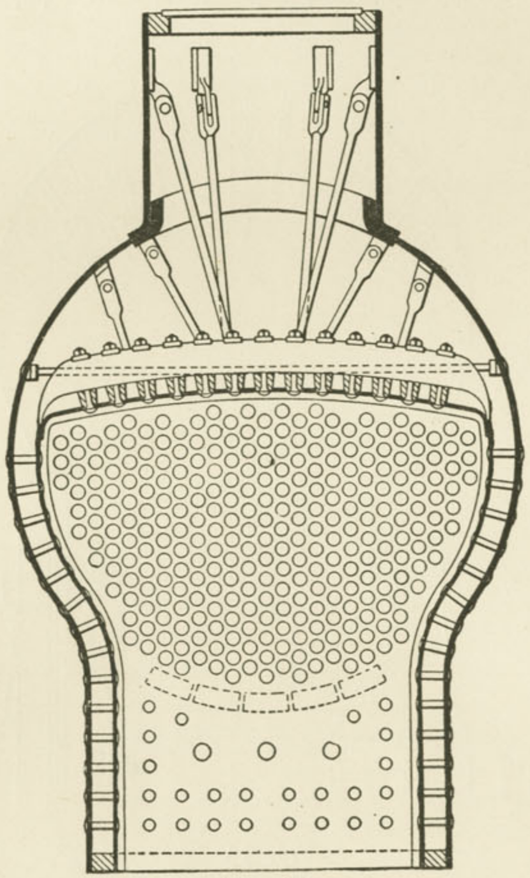


Fig. 13.

CROWN BAR METHOD OF SUPPORTING CROWN SHEETS.

and riveted, the body of the bolt passing up between a pair of crown bars and through a washer wide enough to cover the upper edges of the bars, and upon the upper end of the bolt a nut is screwed down on the washer. In order to still further increase the holding power of the crown bars, the bars are united to the roof sheet by a series of sling stays. In this way the crown sheet is directly supported by staybolts fastened to a pair of rigid beams, and indirectly by sling stays to the roof sheet.

The crown bar boiler has long enjoyed a wide popularity, and

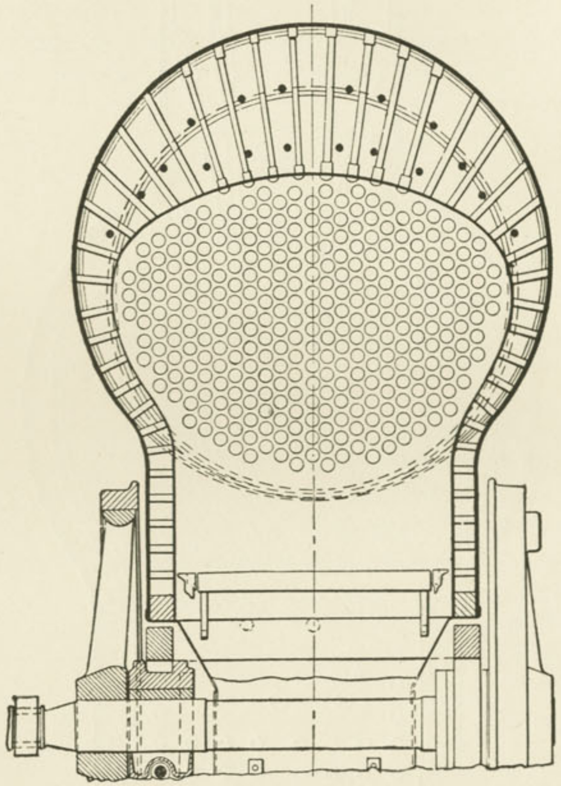


Fig. 14.

Radial Stay Method of Supporting Boilers.

when a boiler is small, the pressure comparatively low, say 140 lbs. per square inch, and the water fairly free from scale, there is probably no better method of staying a crown sheet used.

When water containing a large number of impurities that are precipitated freely has to be used, then the difficulty experienced in keeping the crown free from sediment is much increased by the

obstruction that the crown bars offer, and on that account alone many roads have abandoned the crown bar in favor of the radial stay. With large boilers, having wide crown sheets and carrying high pressures, the crown bar is insufficient to carry the load without the assistance of a large number of sling stays.

Radial Stays. The second method of supporting the crown sheet is by the use of radial stays, which are long staybolts screwed into the outer shell and into the crown sheet. The radial stay method is shown in Fig. 14. It is the method in general use, especially since the advent of the extended wagon-top boiler. Its principal objection is the lack of security, which is due to the angle at which many of the stays must necessarily pass through the sheets, although when the stay is put in properly there has been little trouble from this source. The center six rows of stays should be fitted with button heads under the crown sheet, so that in case of low water the stays will prevent the crown from dropping down.

A radially stayed crown sheet has stays screwed into it and riveted. The stays pass directly to the roof sheet, into which they are screwed and riveted like those in the side water spaces. With this method of staying, the crown is usually arched to have a general approximation of form to that of the roof sheet, and the stays slope outward at the top something like the joint lines between the stones of an arch. The center row of stays along the longitudinal center line of the crown sheet is the only row of truly radial stays.

The crown sheet, with a lesser degree of curvature than that of the roof sheet, prevents the placing of the stays so that they are truly radial to both the surface of the crown sheet and the roof sheet. The stays are, however, placed so as to be radial as far as the crown sheet is concerned, and so that several full threads are secured in the thinner sheet, and the number of full threads in the roof sheet are consequently sacrificed. The stays are, however, made larger in diameter than those on the sides, and the wider spaces between them on the roof sheet are compensated for by the circular form of the sheet and its increased thickness.

The Belpaire Method. The third method of supporting the crown sheet in Fig. 15 is known as the Belpaire method, first in-

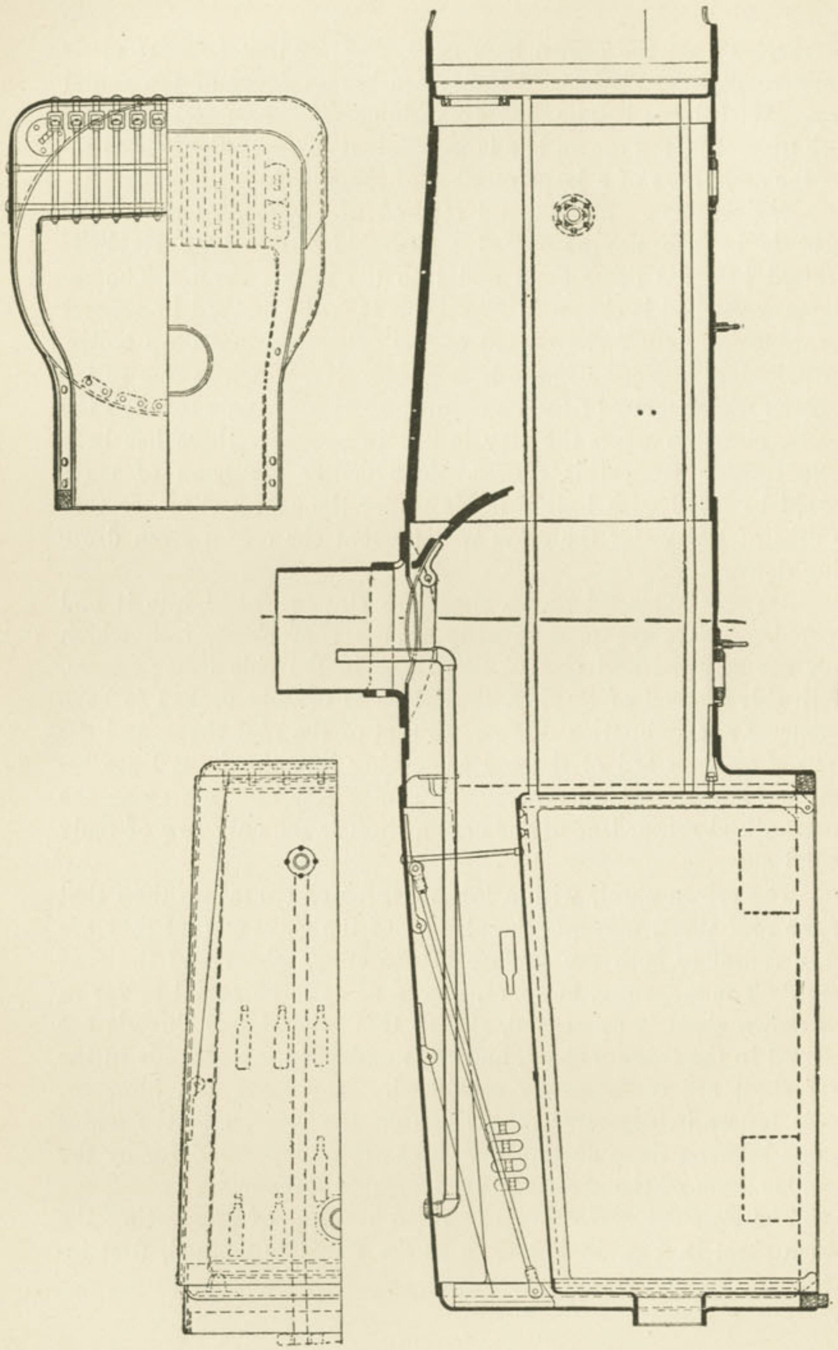


Fig. 15.

Type of Belpaire Locomotive Boiler as Used on the Canadian Pacific Railway.

troduced by, and taking the name of, M. Belpaire, one time head of the motive power department of the Belgian state railways.

It consists of a box having a flat crown sheet and a flat roof sheet. The staying between these two flat surfaces is carried out in the same way as that of the staying of the side sheets of the fire-box. The staybolts are screwed directly into each sheet and riveted. The area supported by each stay is the same in both sheets. The bolts form a direct and positive stay, with several full threads in each sheet. The side sheets of this fire-box above the crown sheet are stayed to each other by large cross stays screwed into each side casing sheet, usually with nuts on the outside. Gusset stays are used from roof to back sheet, and the whole surfaces of box inside and out are thus securely united to each other by staybolts, and the strain can be accurately calculated and provided for. When properly designed and well constructed, this style represents the best solution of the problem of crown staying yet brought forward. The crown sheet is comparatively unobstructed, and may readily be kept clear of sediment. The staying is positive, all the stays having good bearings in and on the sheets. All the strains may be accurately calculated and provided for, and all the stays may, if desired, be made of one length, an advantage that is appreciable.

The form of throat sheet used with the Belpaire fire-box was at first an objection, owing to the difficulty of keeping the upper corners tight; but modern methods of manufacture and an allowance for the upward thrust of the fire-box flue sheet, caused by its expansion when becoming hot, have now practically overcome this objection.

Another objection has been the difficulty of keeping the crown stays tight in the neighborhood of the ends of braces running from the back head to the top of the fire-box shell, owing to the constant downward pull of these braces. This trouble has been overcome by dispensing with the round back-head braces, and substituting in their places gussets or plate braces attached to the roof sheet by long angle irons; by running the braces forward to the waist of the boiler; by running the braces clear forward and attaching them to the front flue sheet; or by riveting heavy angle irons crosswise of the roof sheets as close as possible to where the brace ends take hold, thereby stiffening the sheet.

When a fire is started in a boiler filled with cold water, the inside sheets become hot before the casing sheets do, and, as a result of their being all tied to the mud ring, the side, back and flue sheets expand in an upward direction. The crown staybolts are usually placed as far from these vertical sheets as may be done with safety, and as a certain amount of spring at the edges of the crown sheet is possible, the slight premature upward movement of these sheets does not produce any excessive strain in the stays near the side or back sheets. The point where the expansion of the fire-box flue sheet is felt is in the stays near the line where the

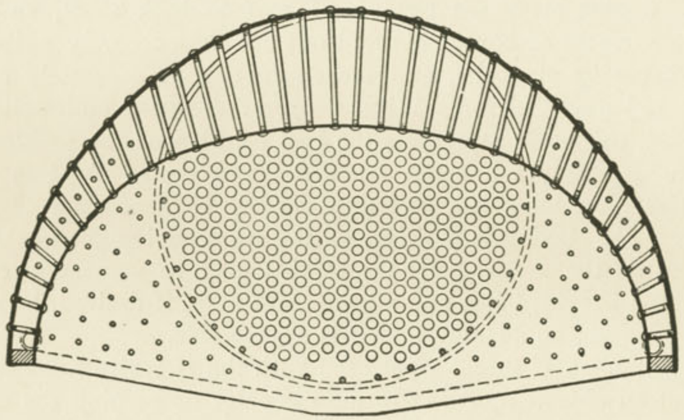


Fig. 16.

Type of Wide Fire-box Used on the Pennsylvania Railroad.

fire-box flue sheet and the crown sheet join. This condition is met by the use of two rows of staybolts, which are practically sling stays, and which, while they are capable of adequately resisting the pull which comes upon them in service, are yet able to allow for the slight upward motion of the flue sheet.

Fire-box. The fire-box is usually a rectangular box constructed of steel or copper plates from ⅜ to 9-16 inches in thickness. The inner shell is surrounded by an outside shell, also constructed of steel plates, usually of about the same thickness as the inner plates. The outside shell is large enough to allow a space of 2½ to 4½ inches between the inner and outer plates. This

space is called the water space, and entirely surrounds the fire-box on the four sides, the water occupying it being in free communication with the main body of water in the boiler. The top and sides of the fire-box being flat, they will bulge from the pressure of the steam unless they are properly stayed.

The locomotive fire-box is limited in size by the other portions of the boiler, the machinery of the engine and the clearance spaces along the side of the road. For many years the fire-box was placed between the frames. As these frames were at least

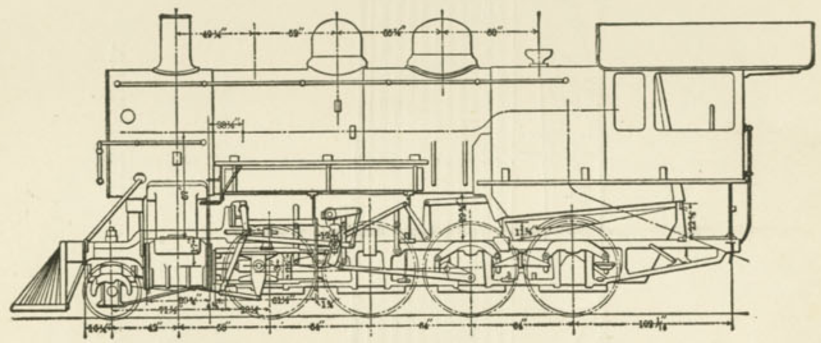


Fig. 18.

Straight-top Boiler as Used on Consolidation Locomotive of the Colorado Southern, New Orleans & Pacific Railroad.

3½ inches wide, and an allowance for clearance of ⅜ inch on each side was made, to which 3½ inches on each side was to be added for the water leg, the total width of the inside of the fire-box was reduced to about 2 feet 10 inches, as shown in Fig. 13, which represents a narrow fire-box.

Wide Fire-boxes. Placing the fire-box over the top of the driving wheels added to the possible width. The width of this type of box is only limited by the space available for the total width of the engine. It may be made 8½ feet or more wide over all and about 8 inches less on the inside. Such a box is shown in section in Figs. 16 and 17, the former representing a type used on

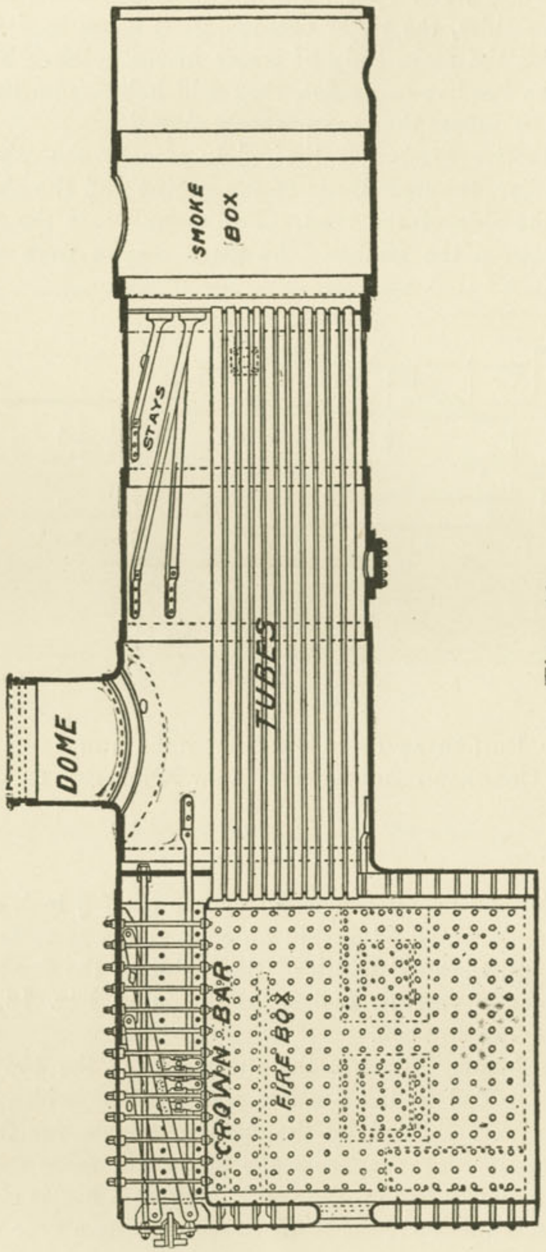


Fig. 19.

Flat-top Type of Locomotive Boiler.

the Pennsylvania R. R., and the latter a type used on the Lake Shore & Michigan Southern R. R.

When the fire-box was placed between the axles, the length of the fire-box was limited by the distance between the driving wheel centers, and was rarely made more than 6 feet 9 inches long, from which the front and back water legs were deducted, leaving about 6 feet for the length on the grates. Placing the

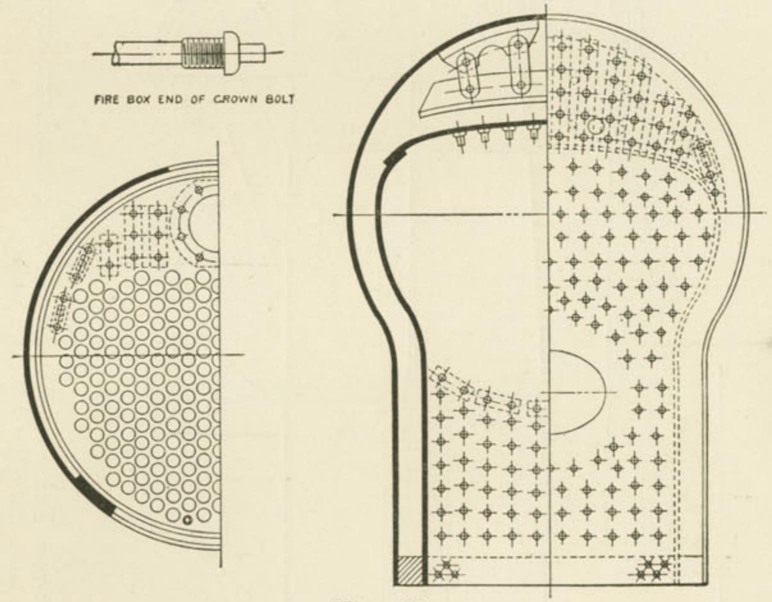


Fig. 20.

Wagon-top Type of Boiler.

fire-box on top of the frames has made any length possible, and the limit is imposed by the capability of the fireman to throw coal to the front end of the box. These fire-boxes are now made from 11 feet to 12 feet in length.

Corrugated Fire-box Side Sheets. In some types of boilers the fire-box is fitted with side sheets, having vertical corrugations extending nearly to the edge of the sheets, top and bottom. It is claimed that a sheet of this type will outlast the usual straight sheet from one to two years. Its advantage lies in its flexibility

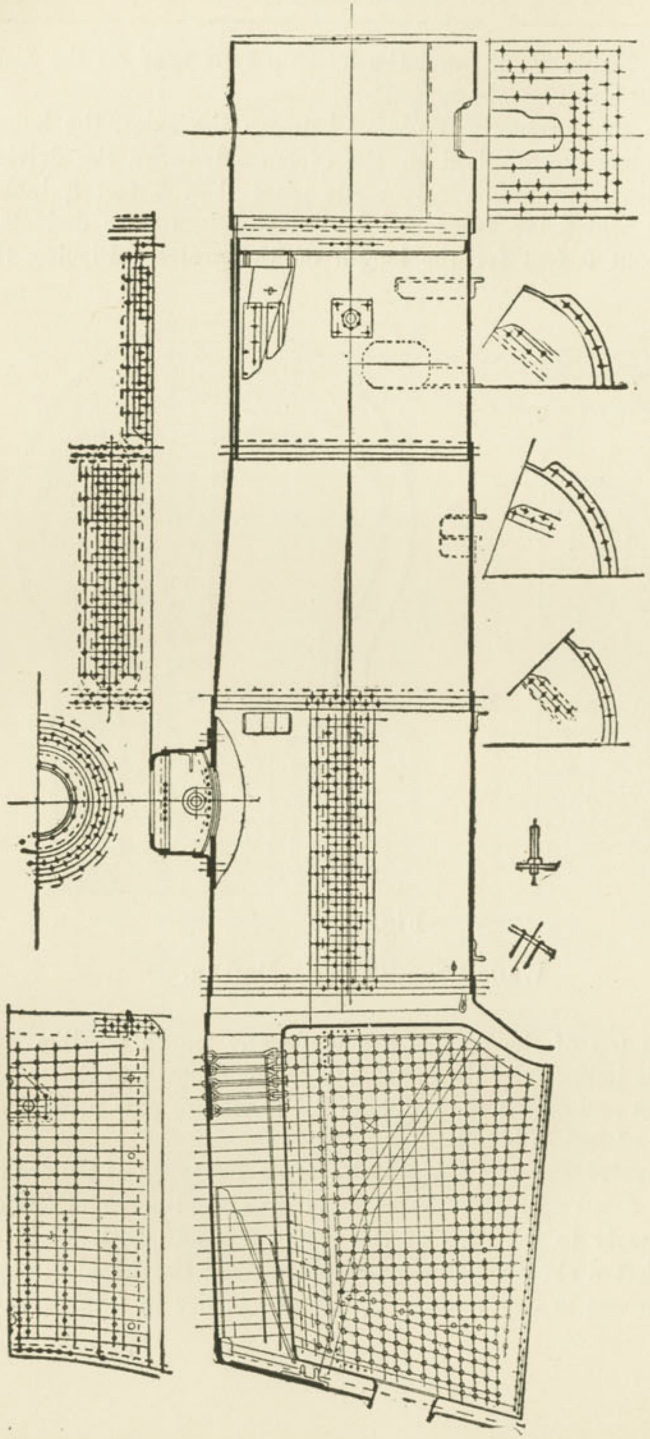


Fig. 21.

RADIAL STAYED EXTENSION WAGON-TOP TYPE OF BOILER USED ON THE LAKE SHORE & MICHIGAN SOUTHERN 2-6-2 LOCOMOTIVES.

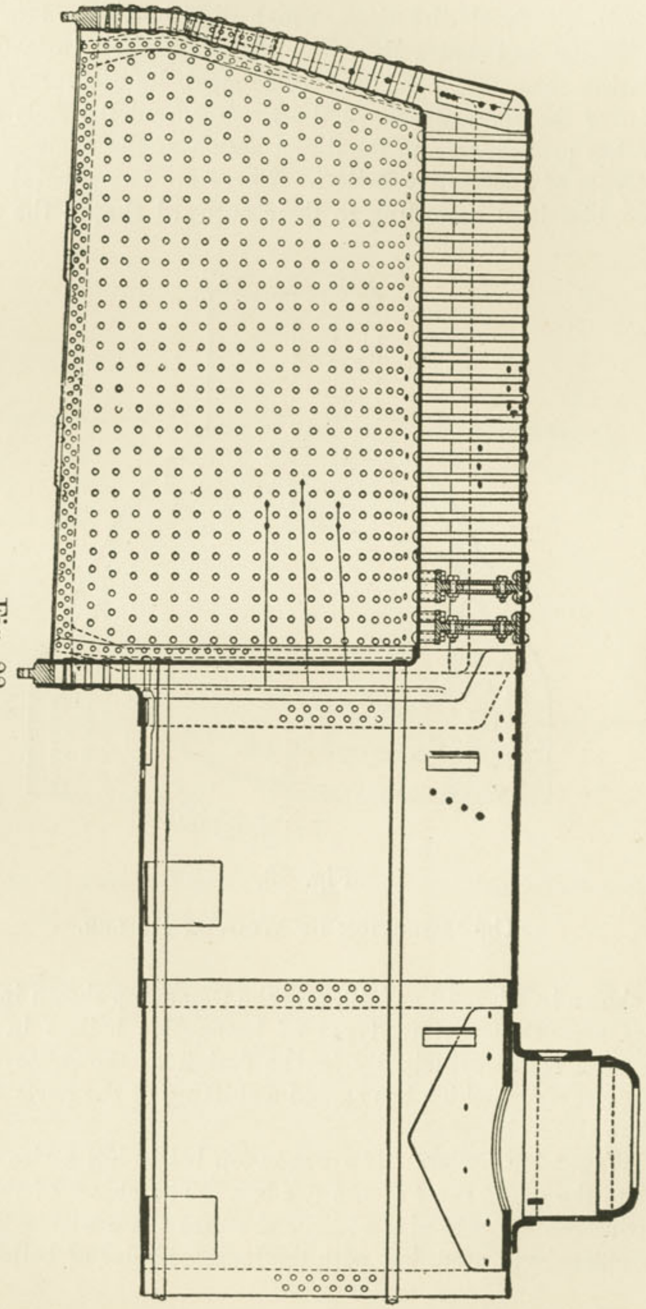


Fig. 22.

LONGITUDINAL SECTION OF A WOOTEN TYPE BOILER.

in the longitudinal directions, which distributes the strains, due to expansion and contraction, over the whole sheet instead of concentrating them at the flanges. The staybolts are secured to the bottom of the corrugations in the fire-box, and the ends are thus somewhat protected from the direct action of the flames.

Types of Locomotive Boilers. There are two general types of boilers, classified according to their outward shape; the straight-

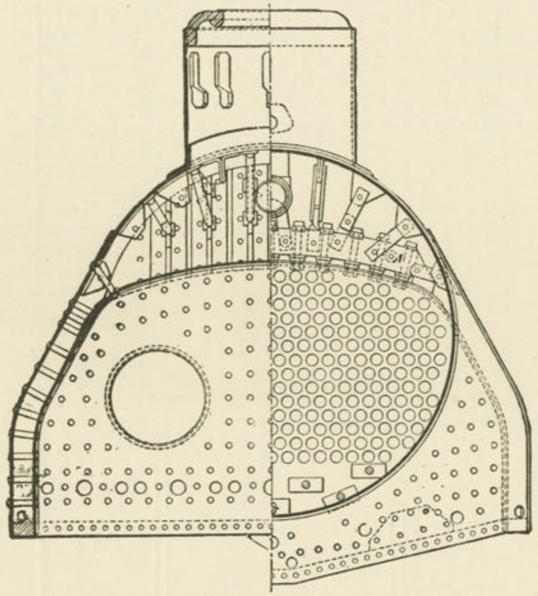


Fig. 23.

CROSS-SECTION OF WOOTEN BOILER.

top, shown in Figs. 18 and 19, and the wagon-top shown in Fig. 20. There are other various types of locomotive boilers in use, the difference being principally in the design of the grate area and heating surface, which has caused a shifting of the parts to accommodate these changes.

Wagon-top Boiler. The wagon-top boiler has a rise from the shell to the outer sheet of the fire-box. The object of the wagon-top construction is to give additional steam space within the boiler. It is extensively used, but with the increased size of boilers, which

has raised them high above the rails, there has not been headroom enough in tunnels and bridges to use this type of construction. The straight-top is, therefore, now extensively used.

The fire-box of a wagon-top boiler passes down between the frames and the crown sheet, and has a slight radius to accommodate the radial staybolts that support the crown sheet. The crown stays are attached to the crown bars and crown sheet with sling

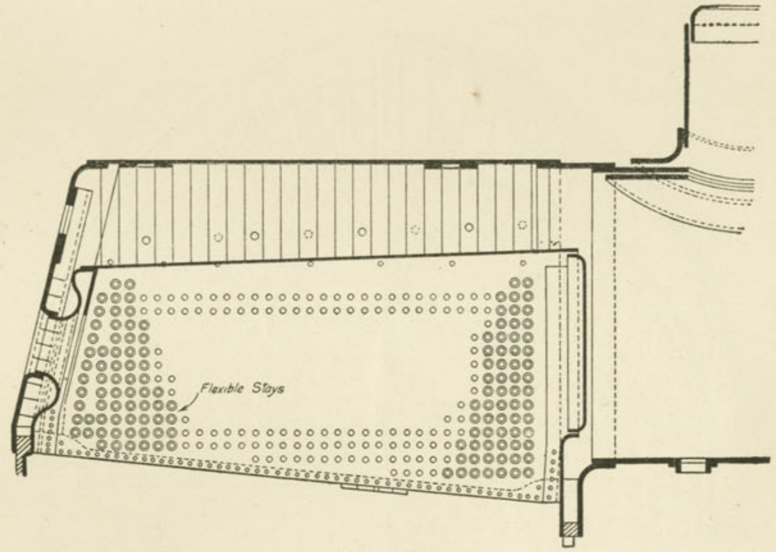


Fig. 24.

SECTION OF FIRE-BOX USED ON THE TEN-WHEEL LOCOMOTIVES OF THE DELAWARE & HUDSON RAILROAD.

stays supporting the crown bars to the outer sheet, as shown in Fig. 21. The back head is stayed by gusset stays from the top sheet by longitudinal stay-rods. The deep fire-box boiler of this type is used for burning bituminous coal, and the shallow fire-box, which sets over and above the frames, is used for anthracite coal.

The Wooten Boiler. In the design of the Wooten boiler the construction necessitates the cab being placed forward of the fire-box, with the steam-dome either in the cab or back of it over the crown. This type was first used in 1877, and is especially adapted for burning poor grades of coal. When fine anthracite coal is burned, a much larger fire-box is required than in the case of bituminous coal. The fire-box need not, however, be as deep. The Wooten fire-box is very wide and very shallow. The boiler is raised so that the grates are above the tops of the driving-wheels. The fire-box can, therefore, be made as wide as the clearance spaces of the roadway will permit, as shown in Figs. 22 and 23.

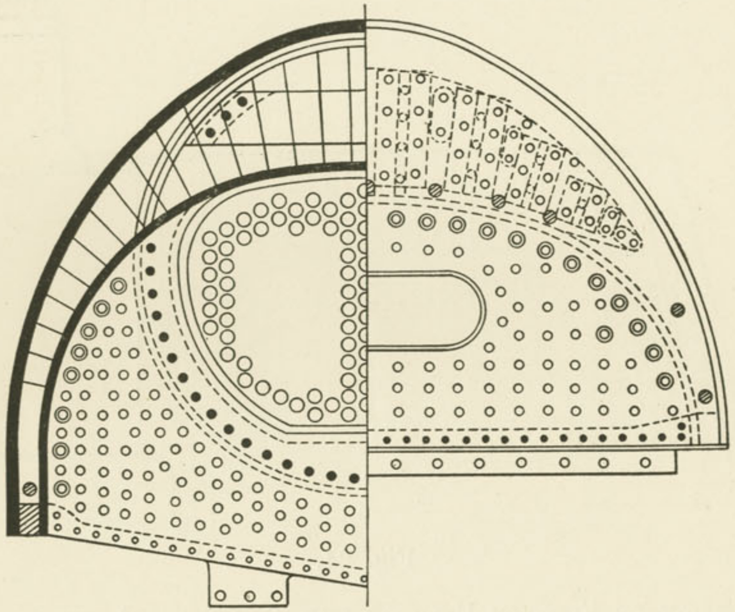


Fig. 25.

WOOTEN TYPE OF BOILER USED ON THE 4-6-0 ENGINES ON THE DELAWARE & HUDSON RAILROAD.

It has undergone numerous changes from its first design, one of the later designs used on the Delaware & Hudson R. R. being shown in Figs. 24 and 25. The fire-box is spread out to a maximum limit on each side of the cylindrical part of the boiler. In the older types a combustion chamber was provided in the forward end, a bridge-wall of fire-bricks being placed between this chamber and the fire-box. In its original form, the top sheet over

the crown was made to slope down to the back end. As this allowed only a small quantity of water over the crown sheet, the design is now made straight instead of sloping, the combustion chamber is also omitted and the height from the grate-bars to the crown-sheet is increased. When fire-brick arches are used for burning soft coal, water-tubes are used supporting them.

The Belpaire Boiler. The Belpaire boiler, the fire-box of which is shown in Fig. 26, is similar to the Wooten boiler. This style of boiler necessitates a trailer-wheel back of the drivers to

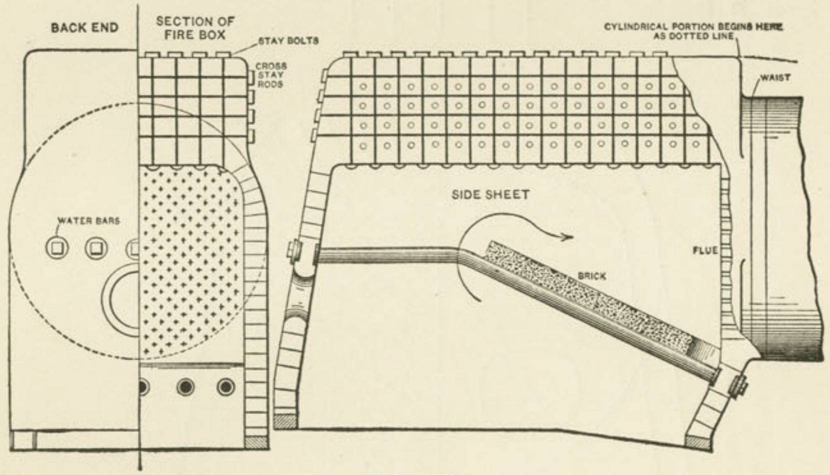


Fig. 26.

BELPAIRE TYPE OF WIDE FIRE-BOX.

carry part of the weight of the engine when using a large driving-wheel, the trailer-wheel being small enough in diameter to clear the bottom of the fire-box. The back end of the boiler and the front end under the cylindrical portion slope from the top of the boiler to the bottom of the fire-box, the back and forward sheets following the same slope. The outer sheets around the fire-box have a flat crown and top sheet. There is one objection to the Belpaire boiler, and indeed any straight boiler, apart from any question of boiler-making, to be found more especially in the case of eight- and ten-wheel engines, and that is the large percentage of the total weight of the boiler that is thrown on the leading truck.

With the ordinary wagon-top, crown bar, or radial stay boiler, with the fire-box down between the main and back axles, the drivers of an eight-wheeler get on an average about 64 per cent, and of a ten-wheeler about 74 per cent, of the total weight; but if the Belpaire

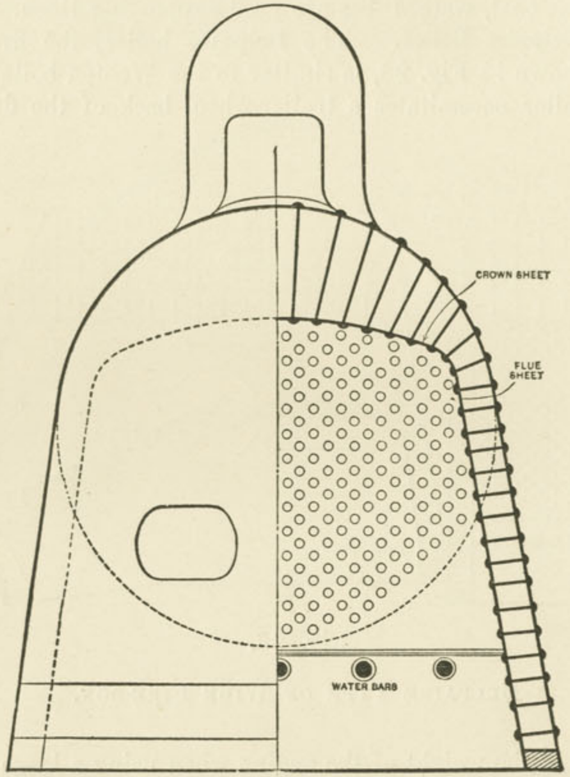


Fig. 27.

PRAIRIE TYPE BOILER.

boiler is used, this percentage is only about 61 for an eight-wheel engine and about 68 for a ten-wheel locomotive. The reason of this is that with the wagon-top boiler a sufficiently large space can be obtained for steam room over the crown sheet, while keeping the waist of the boiler tolerably small in diameter, but, with the Belpaire boiler, which is straight on top in the great majority of

cases, that is to say, without any rise at the back end, the waist must be increased at least four inches in diameter in order to obtain the necessary steam room. The larger the waist the larger the smoke-box and front must be, the branch and exhaust pipes must be longer and heavier, and altogether the weight of the front part of the boiler, which comes directly on the truck, is materially increased.

Prairie Type. The Prairie type of boiler has a wide fire-box extending over the frame to the fullest width possible, and, when used on locomotives having large driving-wheels, requires a trailer-

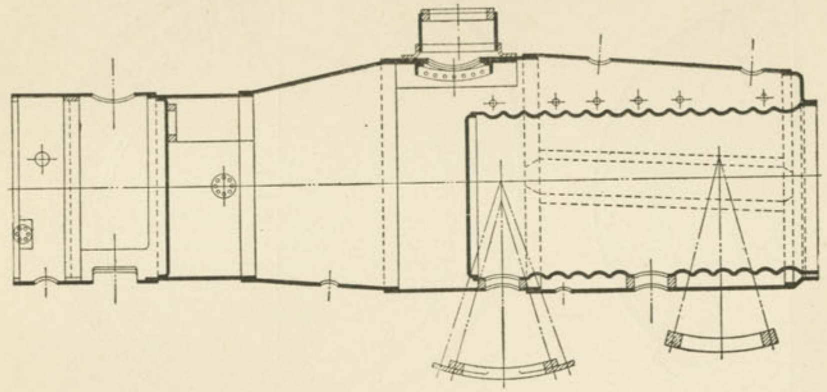


Fig. 28.

MORRISON SUSPENSION TUBE AS USED ON VANDERBILT BOILERS.

wheel. This form of boiler is generally straight and long, and generally has a large diameter. The fire-box is wider at the bottom than at the crown sheet, the crown sheet having a curve and being stayed with radial stays. A large radius is given to where the side sheets join the crown sheet, as shown in Fig. 27, thus preventing sharp corners. When used on freight engines, the forward portion of the fire-box has a drop, the forward end being deeper than the back end. The back end of the boiler and the front leg under the waist slope downwards. The flue sheet is straight, while that portion under the flues conforms to the slope of the outside sheet.

The Vanderbilt Boiler. A type of boiler which differs materially from those already described is the Vanderbilt boiler shown in Fig. 28. The fire-box is cylindrical, there being no staybolts to support it as in the usual construction. The fire-box is a corrugated tube of the Morrison suspension type, as shown in Fig. 29. The grate is carried by a half-round iron in one of the grooves, there being a brick arch on top of this. The space in front of this forms a combustion chamber, and permits the gases to flow into the

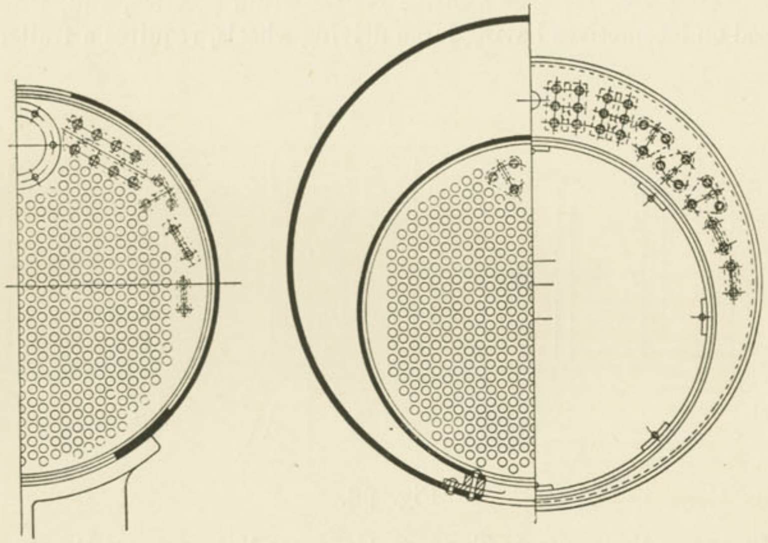


Fig. 29.

END VIEW OF MORRISON SUSPENSION FIRE-BOX USED ON VANDERBILT BOILERS.

lower tubes. The back end of the fire-box is generally brick-lined, the fire door being in the back end. The front and back tube sheets are not set vertical, but are inclined. The lower portions of the fire-box and the combustion chamber are provided with outlets for cleaning purposes, these openings being closed by manhole plates. The outlet from the ash-chamber has a chute attached to dump the ash. No staybolts are required.

Brick Arches. On some roads it is the practice to use brick arches in the fire-box. A brick arch is an arrangement placed in

the fire-box to effect a better combustion and secure a more even distribution of the hot gases in their passage through the tubes. Fig. 30 represents a longitudinal section of a fire-box fitted with a brick arch. The bricks are made specially for locomotive use.

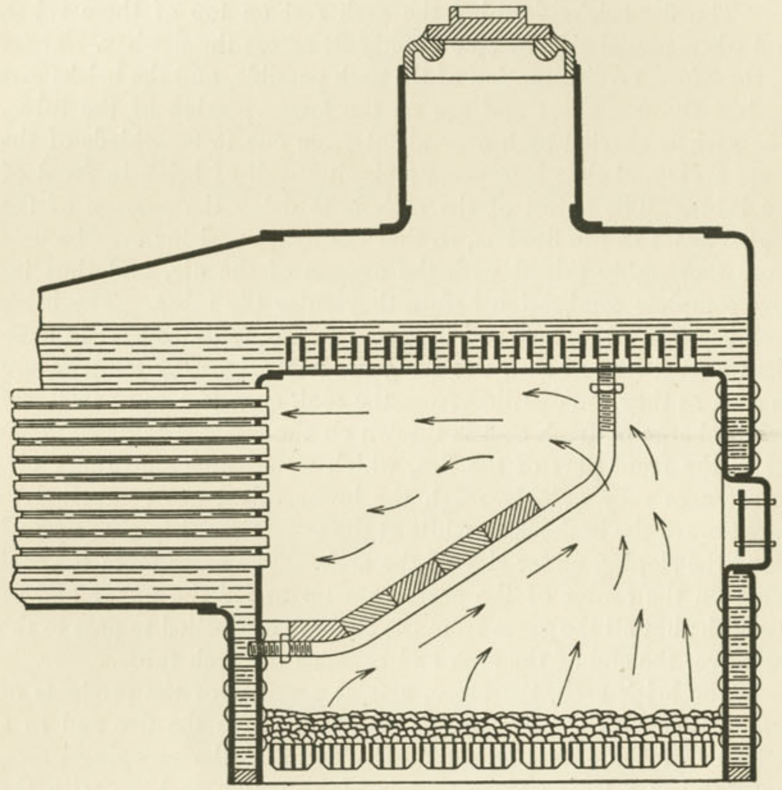


Fig. 30.

FIRE-BOX WITH BRICK ARCH.

They are usually supported upon four or five water tubes which are set in the back sheet of the fire-box above the fire door, or from the back end of the crown sheet, and pass down in a diagonal direction to the fire-box flue sheets, in which they are also set, below the tubes. The tubes themselves are therefore able to promote the circulation of water. In the back sheet, when the tubes terminate in it, and in the throat sheet, opposite to the ends of the arch tubes, holes are cut which are closed by washout plugs. The interior of these tubes can be cleaned out and their ends made accessible by the removal of the plugs, in case repairs are necessary.

The fire-bricks forming the arch rest on top of these tubes, and when placed side by side exactly fit across the fire-box. There is, therefore, no side motion of the arch possible, and the bricks rest against the flue sheet and are on the lower portion of the tubes. The arch is carried back over about from one to two-thirds of the grate area, and thus interposes a sloping wall of brick in front of the tubes. The object of the arch is to delay the passage of the heated gases in the fire-box, so that the hydro-carbons may become more thoroughly mixed with the oxygen of the air, and thus insure complete combustion before they enter the tubes. The brick arch becomes white-hot, and thus continually radiates heat in sufficient quantities to help raise the gases to the igniting temperature as soon as they are distilled from the coal, even if a comparatively heavy charge of fresh coal is thrown on the fire. The gases given off in the front part of the fire, which would under ordinary circumstances very quickly reach the lower tubes, are compelled to pass toward the back sheet, while at the same time they pass up and along the sloping under side of the arch. The gases from the coal lying on the center of the grate pass up under the upper end of the arch; but all the gases from the coal are compelled to pass to the flues over the end of the arch and between the arch tubes.

The brick arch, therefore, acts as a mixer of the products of combustion with the air that is admitted above the fire and as a reflector of the radiant heat of the fire and the escaping gases, maintaining a temperature that is high enough to burn with the smallest possible quantity of air all of the carbonic oxide and the hydro-carbons that arise from the coal.

The principal advantages of the brick arch are saving in fuel, elimination of the smoke nuisance to a large extent, and consequently it develops a high calorific power in the fire-box. The principal disadvantage of the use of fire-brick is that it is expensive to maintain, owing to the rapid deterioration and the burning out of the brick.

Water Tables. Water tables are intended as a substitute for

the brick arch. They have been made and applied in various forms, one of which is shown in Fig. 31, and is known as the Buchanan fire-box. The upper and lower portions are connected, and the products of combustion pass from the fire-box through a

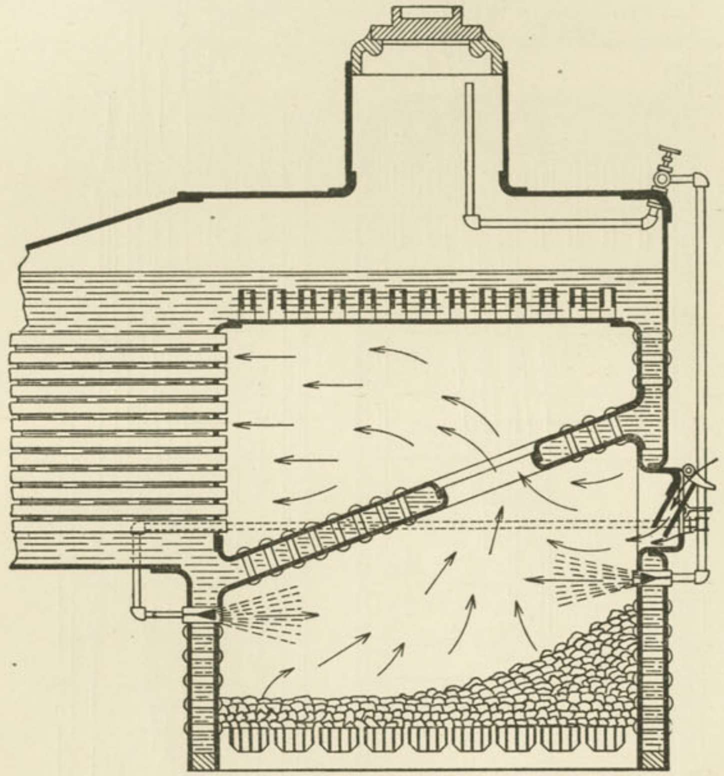


Fig. 31.

FIRE-BOX EQUIPPED WITH WATER-TABLE.

hole in the table to the chamber. Tubes are also expanded in the sheets opposite the foot of the table for the cleaning of the combustion chamber. This table gives no trouble with burning out, and the violent circulation keeps it from scale and sediment; but it has the disadvantage that it places a large cooling surface in the fire-box at a point where it is desirable that the heat should be

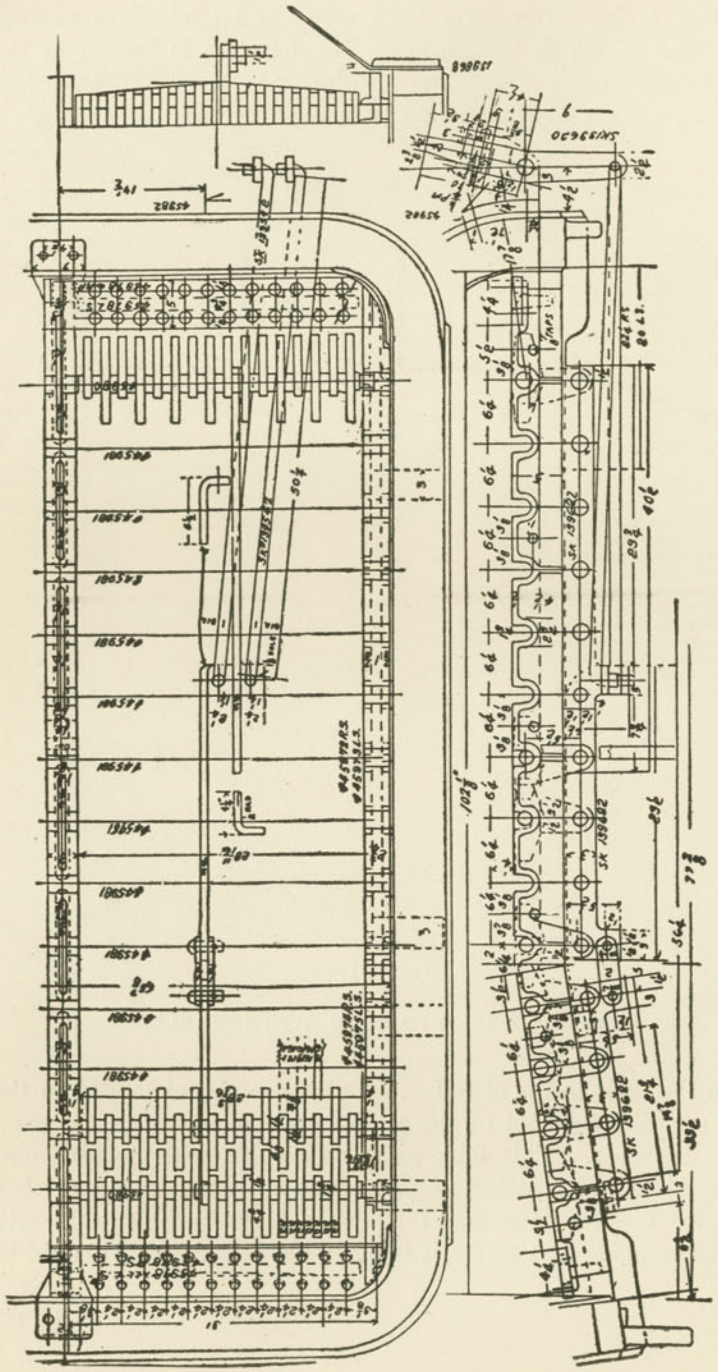


Fig. 32.

Rocking Grate-bars in Locomotive Fire-box.

the most intense, and, owing to its rigidity, it is very difficult to keep tight. This surface acts as a cooling one on the fire, leads to the production of smoke and cuts down the completeness of combustion, and on the whole it increases the evil it is intended to avoid.

Grates. There are four general types of grates used on locomotives, their construction depending upon the kind of fuel to be burnt.

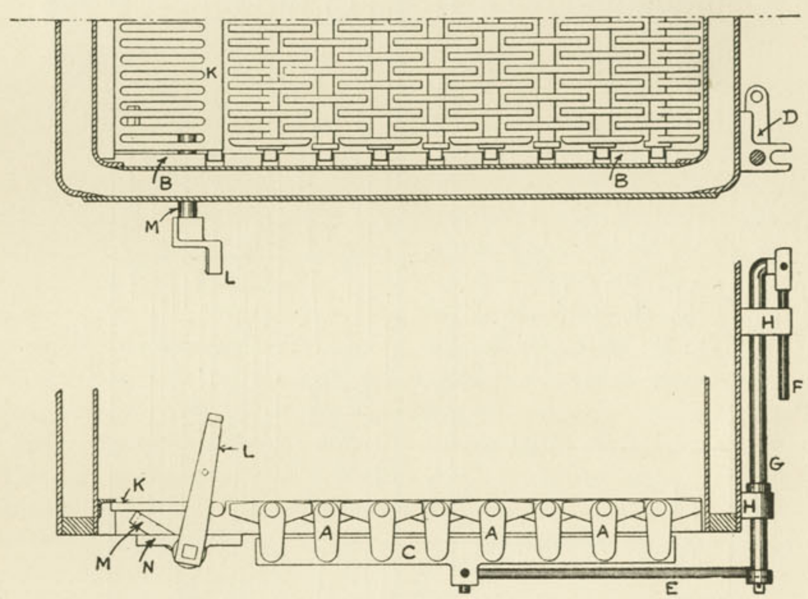


Fig. 33.

General Arrangement of Rocking Grate.

They are usually made of cast iron bars, which are made wider at the top than at the bottom, so that cinders and ashes will fall through easily, and also to give free access to the air from below.

Soft Coal or Rocking Grates. The soft coal grate, as it is called, consists of a series of cast iron bars, which rock on trunnions, and which are carried in a series of pockets in two cast iron frames, one on each side, bolted to the mud ring as shown in Fig

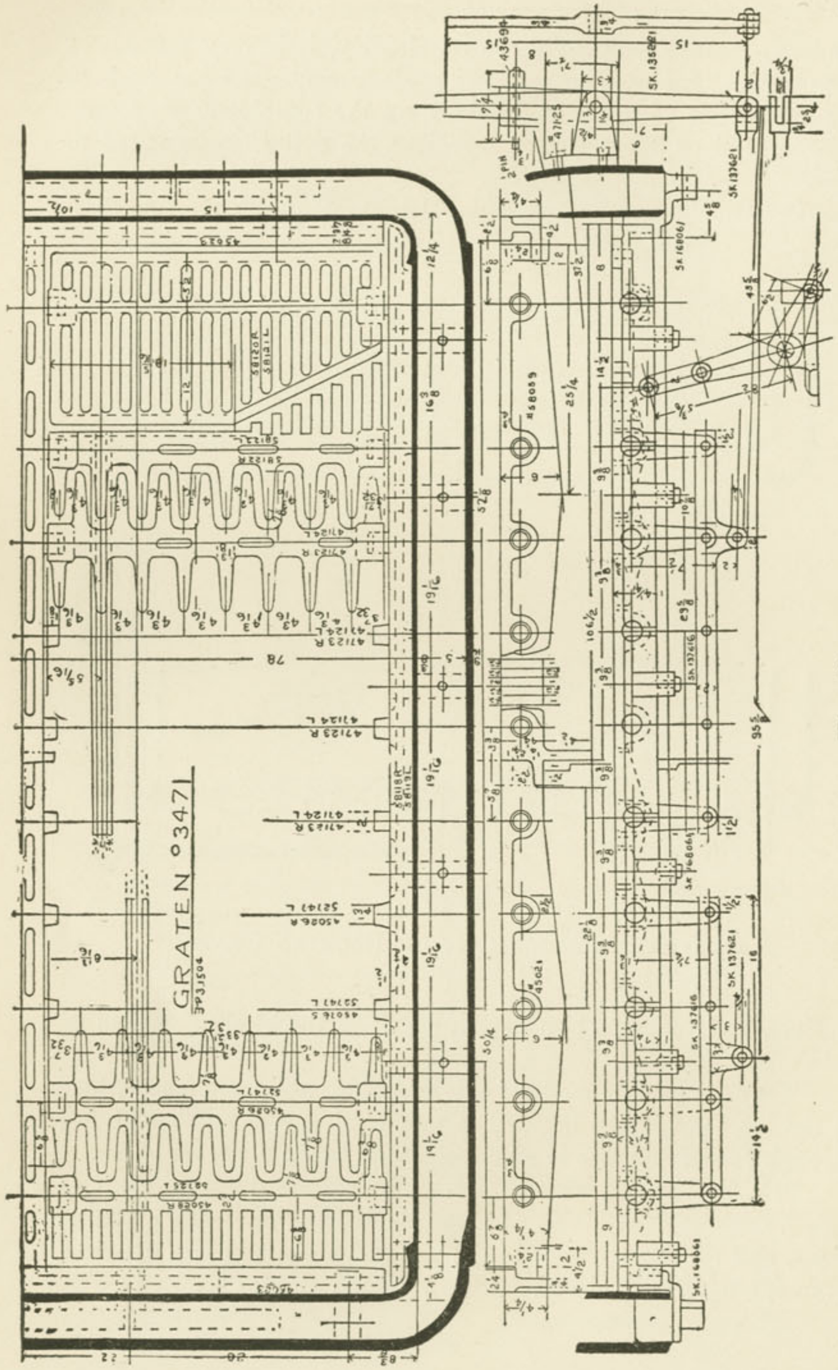


Fig. 34. Grate-bars Showing Dump-bar at Front End.

32. From the central bar, which terminates in trunnions, a series of short fingers, placed at right-angles, extend both ways. A great variety of these shaking and rocking grates are now used, the general arrangement of all of them being shown in Fig. 33. The grate bar is shown at A; the frame at B; the connecting bar at C; the arm rod and the handle at D, E and F; shaft and shaft bearings at G and H; the drop plate at K, and the drop plate handle shaft and bearing at L, M and N.

This form of grate is arranged so that the fingers of the first bar pass in between the spaces of the second, with ample clearance, and so on. The spaces between these bars are made from ½ to 1¼ inches wide. The floor of the fire-box is thus covered with a series of bars and fingers which support the coal, and at the same time allow air to pass up between them. All the grate bars are made to rock through an angle of about 45 degrees upon the trunnions of each end, so that the fire may be easily cleaned or shaken out when required. At the flue sheet end of the fire-box a grate bar is generally placed which has all its fingers on one side, and is made to swing through 90 degrees. This style is called a dump grate, illustrated in Fig. 34, and it facilitates the removal of clinkers or lumps of coal which will not drop through the tilted grate bars. These grates consist of a central bar carrying the fingers, which interlock with each other, forming the air spaces. The grates can be moved by a bar beneath, connecting the downwardly projecting arms of the several bars. For dumping they are turned to an inclined position. At the front end of the fire-box there is usually an independent grate, consisting of a perforated flat plate. This can be operated separately from the remainder of the grates. It is used when it is desired to clean the fire without dumping the whole. This plate is opened, and the clinkers contained in the bed of coals can be pushed through the opening thus formed into the ash-pan beneath.

In the construction of fire-boxes special care is often taken to close all openings around the sides of the fire-box, so as to prevent cold air from entering at such places. The object of this is twofold: to keep the cold air away from the fire-box plates, and to keep the fire away from them, as contact with the cold plates always has the effect of checking combustion. In order to close the openings which are left between the bearing bars and side of fire-box, cast iron blocks are made which fit in between the bars and the plates, with a flange or head which laps over the top of the bar. In some cases inclined plates are fastened to the mud-ring and bear against the sides of the fire-box, and have joints formed by grooves in the plates filled with asbestos. This makes them almost air-tight.

While the vast majority of soft coal grates are rocking or shaking grates, there are some soft coal grates used on small engines

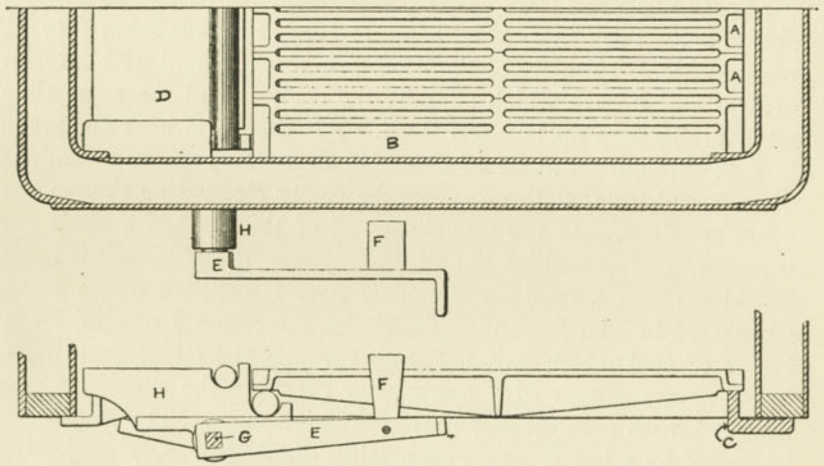


Fig. 35.

Type of Soft Coal Grate Used on Small Locomotives.

which do not have the rocking feature. One of this type is shown in Fig. 35, where A is the grate bar; B, the dead plate; C, the end holder; D, the drop plate; E, the drop plate handle; F, the drop plate handle support; G, the drop handle shaft, and H, the drop plate shaft bearing.

Hard Coal Grates. The hard coal grate consists of a series of round water tubes, shown at B in Fig. 36. The tubes are made of wrought iron, two inches outside diameter, and are fastened in the front and back plates of the fire-box, and are inclined from the front end, so that there will be a continuous circulation of water through them to keep them cool, and thus prevent them from being

burned out by the intense heat of the fire. These water tubes are screwed into the flue sheet just above the mud-ring, and are secured in the inside back sheet by being expanded. These water tube grate bars are usually spaced some distance apart, the space between them being occupied by solid round iron bars, C, which rest on a bearing strip, D, on the flue sheet, and pass through short tubes in the water space, E, between the outer and inner back sheets. These bars can be drawn out by means of eyes, F, and the

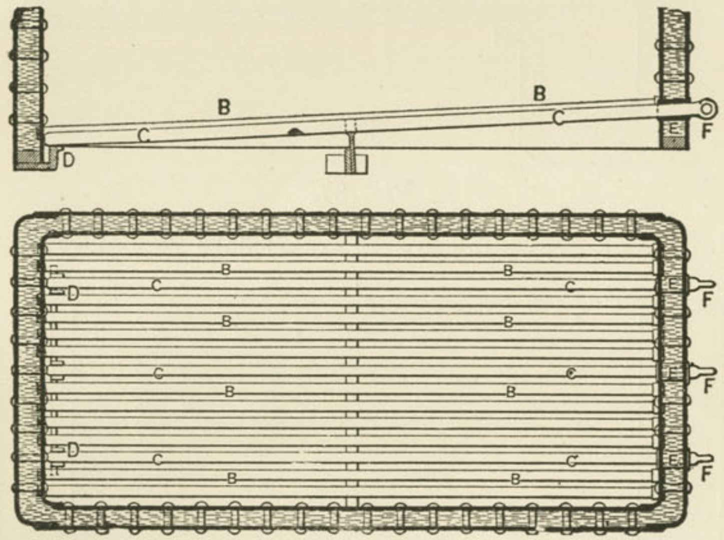


Fig. 36.

Water Grate Used for Antracite Coal.

fire dumped out through the spaces thus left between the water tube bars. Hard coal grates run longitudinally with the fire-box, while the soft coal grate bars cross the box from side to side. The usual method of fastening the water grate bars to the back sheet is shown in Fig. 37. The grate is formed of a tube A that is expanded into a ferrule in the back sheets of the fire-box. It is inclined from the back down to the front so as to insure a circulation of water. Opposite the back opening a plug B is screwed into the outer sheet. The hole for this plug affords a means for cleaning the tube and also for inserting it in position. At the front end the tube is usually screwed into the tube sheet.

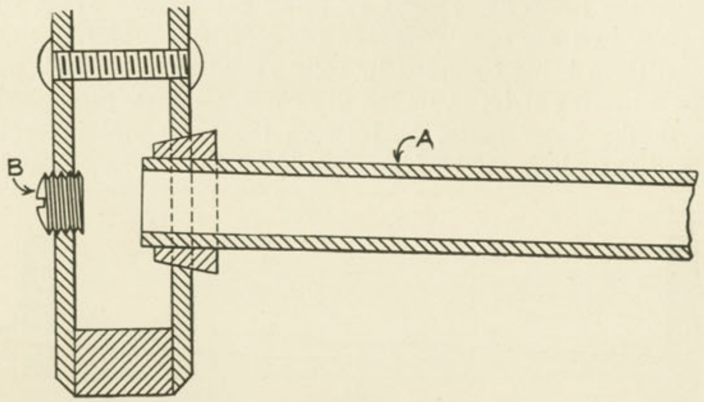


Fig. 37.

Method of Fastening Water Grate-bars to Back Sheet.

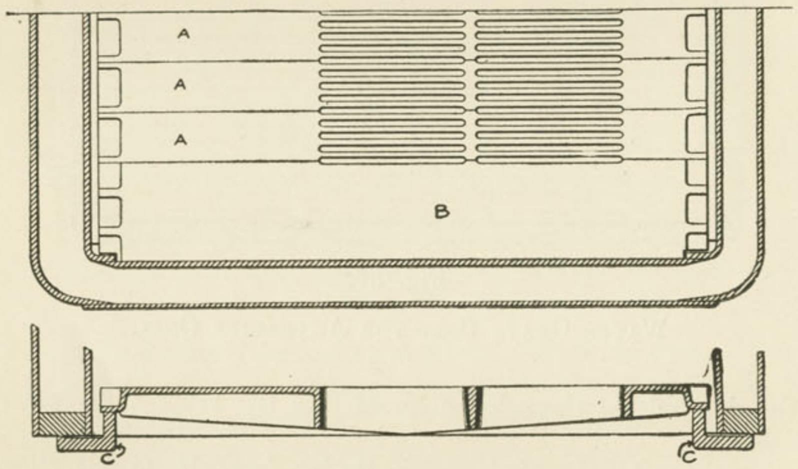


Fig. 38.

Wood Burning Grate.

Wood Grates. In wood-burning locomotives the grates are stationary, and are supported by brackets bolted to the mud-ring. One form of grate for wood-burning locomotives is shown in Fig. 38, where A represents the grate bar; B, the dead plate, and C, the grate support. The air spaces and the bars are of about the same width and vary from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch. The ends, which are generally sloping, act like a wedge when the grate expands, and push up the ashes that may have accumulated at the ends.

Coke Grates. The burning of coke, which is being used on

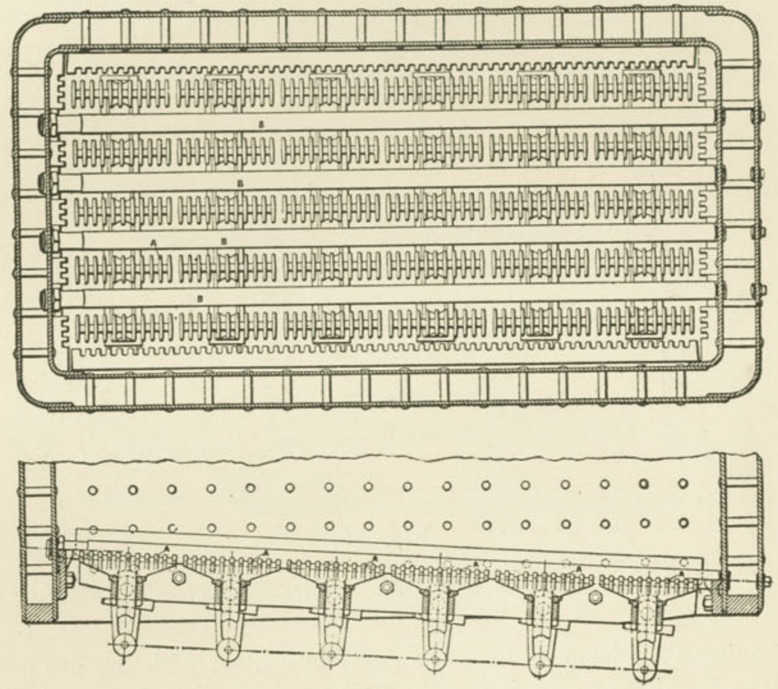


Fig. 39.

Coke Burning Grate.

some roads in this country, demands a grate which is more or less a combination of the hard and soft coal grates. One arrangement which is being used successfully is shown in Fig. 39. This grate is formed by the use of water bars B running lengthwise the fire-box. These water tubes may be horizontal when the construction of the fire-box demands it, but it is preferred that they should be on an incline from the front up to the back. They have an outside diameter of two inches, are screwed into the front tube sheet, and are held by a bushing screwed into the back sheet of the fire-box.

Between the tubes there is a series of rocking grates A, so arranged that each short section can be removed and replaced in case it is injured. The rockers are provided with pockets, into which the short grates are dropped. These rockers lie below the water bars, where they are well away from the fire, and the fingers are so designed that the maximum of air space is obtained where there are no heavy sections of metal to become heated, the circulation of air

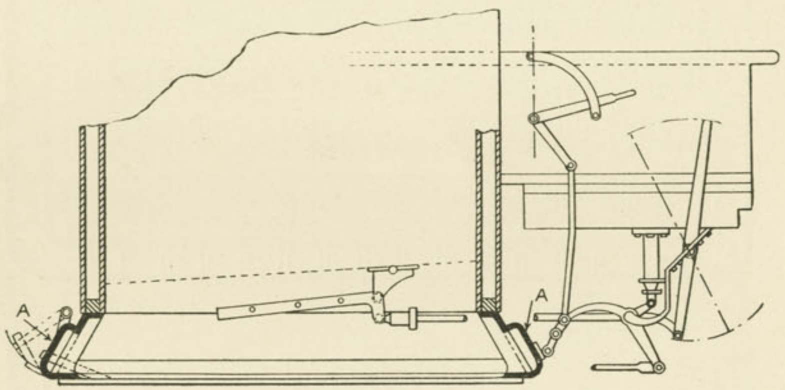


Fig. 40.

Ash-pans Located Between Axles.

having a tendency to keep the parts in contact with the fire cool. The burning of coke is greatly facilitated if a jet of steam be introduced into the ash-pan beneath. This cools the grates, thus preventing clinkers from adhering and protecting the grates from melting.

Ash-pans. In every locomotive the ash-pans are suspended beneath the fire-box for the purpose of catching and carrying the ashes and coals that may drop between the grate bars. They are made of sheet steel. Fig. 40 represents a type of ash-pan that is ordinarily used on fire-boxes that lie between the axles of the engine. It is provided at each end with a damper A hinged at the top, and which may be opened and set in any desired position

in order to regulate the flow of air to the fire. When the fire-box lies above the axles the ash-pan must be cut away from them, as shown in Fig. 41.

Dampers. The ash-pan is supplied with dampers where soft coal is used, and the opening of the dampers is controlled from the cab. The air necessary for combustion enters through the damper openings, and goes up through the spaces between the grate bars to the fuel. It is quite important that the dampers of locomotive

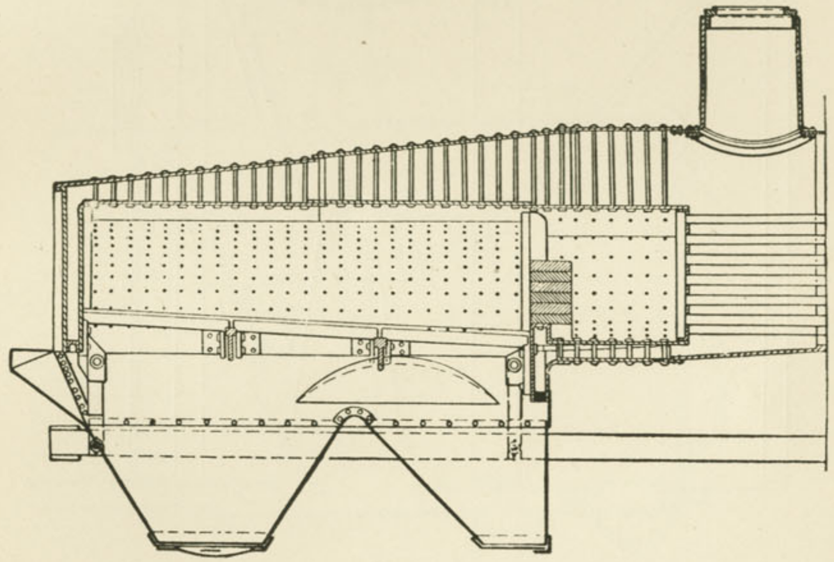


Fig. 41.

Ash-pan Cut Away for Axle.

ash-pans should be in good condition and capable of regulating the flow of air. Dampers are not used when hard coal is burned.

Front End. The front end of the locomotive includes the diaphragm, the exhaust nozzle, the exhaust stand, the stack, the petticoat pipe and the netting. These with the exhaust jet constitute an arrangement designed to produce the maximum amount of draft through the fire with the minimum of back pressure in the cylinders. One arrangement as used on the older types of boilers is shown in Fig. 42. The deflector plate is shown at A, the netting is shown at B, the deflecting plate or diaphragm is shown at C, the deflecting plate slide is shown at D, the spark ejector is shown at E, the cleaning hole is shown at F, and the exhaust nozzle at G.

Extension Front. The more recent type of locomotives all use some form of smoke-box known as the extension front end, shown in Fig. 43. The gases issuing from the tubes either strike against

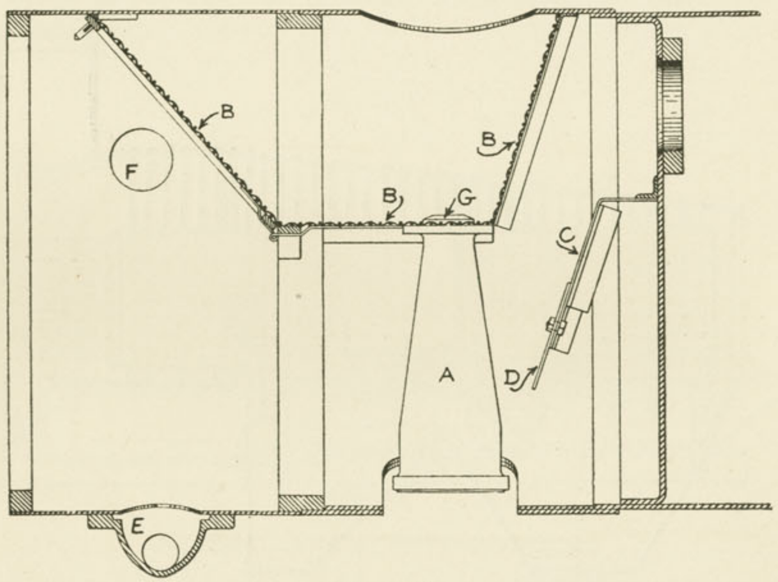


Fig. 42.

Front End Arrangement.

the diaphragm plate, and are deflected downward, or pass beneath it from the lower rows of tubes. They then turn up and pass through the netting and out at the stack, which is located directly above the exhaust nozzle.

Exhaust Nozzle. This is a device placed on the end of the exhaust pipe in the smoke-box for the purpose of causing the exhaust steam to create the proper draft in the fire-box. When the engine is running, the exhaust produces a draft by inducing the flue gases to mingle with the steam issuing from the jet, so that con-

siderable velocity of the gases is obtained. When the engine is at rest, a jet of steam flowing from the exhaust nozzle produces a draft similar to that obtained when the engine is running. The steam jet, by virtue of its high velocity, creates a partial vacuum in the smoke-box, which decreases toward the top of the stack. This induces the flow of gases through the boiler tubes and ejects them at a high velocity from the stack.

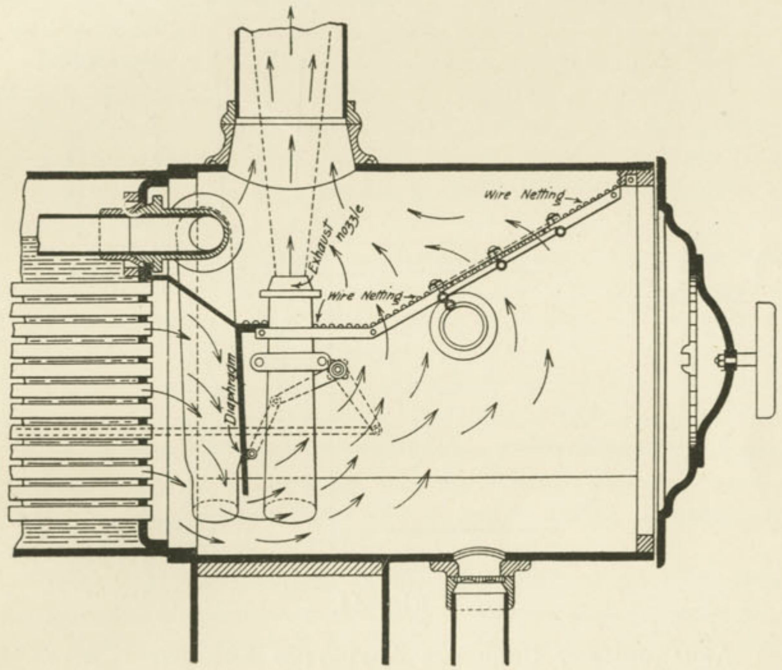


Fig. 43.

Extended Smoke-box, Front End.

Sometimes a single exhaust nozzle is used, and in other cases two nozzles which are cast together. Rings or bushings are fitted to the outlet openings of these nozzles for the purpose of reducing their area and increasing the draft. These bushings are made of various diameters, and are easily removable in order to substitute others with larger or smaller openings as they may be required. Various devices, such as the ones shown in Fig. 44, have been invented for adjusting the exhaust nozzles, fitted on the upper end of the exhaust pipe C. In this arrangement the plate is provided with apertures, the same size as the apertures at the upper end of the exhaust pipe C, so that when the plate is in a central or normal position the exhaust steam can pass freely out of the exhaust pipe through the smoke-box and smoke-stack of the locomotive. When it is desirable to increase the amount of draft in

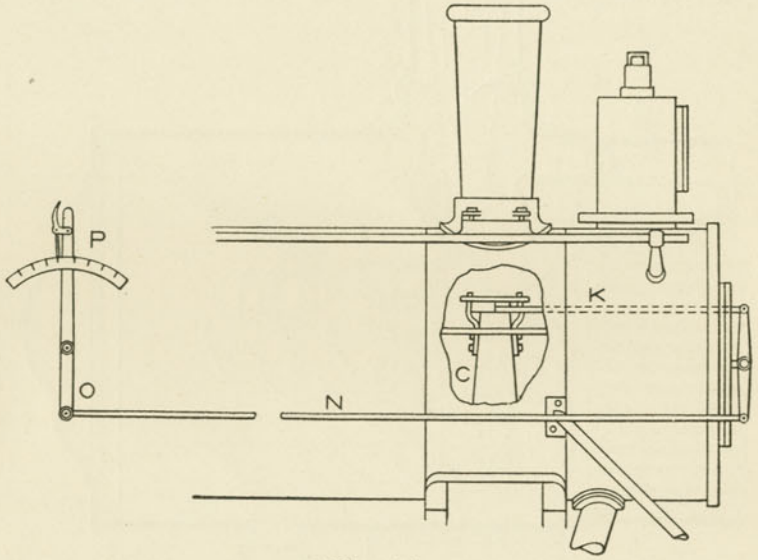


Fig. 44.

Arrangement Used for Adjusting Exhaust Nozzles.

the fire-box of the locomotive, the engineer operates the lever, O, either forward or backward, so that the lever L, through the link K, moves the plate across the top of the exhaust pipe C. The opening is thus diminished in size, so that the exhaust of the engine is retarded, and consequently the draft in the smoke-box and smoke-stack is increased, which increases the draft in the fire-box. There are a large number of these draft regulators patented, all of which work on practically the same principle. As to the shape of the nozzle, it has been pretty definitely determined that that shape

of nozzle which keeps the jet in the densest and most compact form will be the most efficient.

Cleaning Exhaust Nozzles. The exhaust nozzles become coated, from time to time, with a hard, grimy substance on the inside, due to the hydro-carbons from the oil in the exhaust steam. The result of this is that the fire becomes torn and cut to pieces on account of the draft becoming too strong. The remedy for this is to ream out the nozzles by means of a reamer having a long handle, so that it can be introduced through the stack.

Diaphragm. This is an arrangement used for regulating the draft in the extended smoke-box. It is placed at an angle of 20 or 30 degrees to the front sheet, so that the flue gases, after passing through the tubes, impinge against the diaphragm, and are thus impeded in their passage to the stack, the flow being regulated by a diaphragm damper.

Adjusting the Diaphragm. There is no exact rule or method of adjusting the deflector or diaphragm sheet in the smoke-box. After the smoke-stack and exhaust pipe are exactly in line and of the proper size, the rest is largely experimental. Many costly experiments have been made in the design of a smoke-box, all of which have been based upon the fact that a deflector sheet extending at least half-way over the flues, and an adjustable apron, which may extend the covering still farther, are necessary conditions in the matter of economy of fuel and in aiding the steaming qualities of the engine.

The proper adjustment of the apparatus in the smoke-box depends upon the condition of the fire. If the fire burns particularly hard at the front of the fire-box, it shows conclusively that the movable apron is too low, and that there is a sharp draft passing through the lower flues. Under this condition it will be found that the upper flues will become choked more rapidly than in the lower section.

When moving the adjustable apron, it is better to make a very small change and note the effect until the ideal condition is obtained, namely, the evenness of the condition of the fire in burning. This is the condition aimed at in all smoke-box adjustments.

There is a tendency in the construction and repair departments of railroad shops to fix certain specific dimensions in the opening of deflector sheets, the space from the bottom of the smoke arch and distance from the flue sheets being set down as absolute in certain kinds of engines. This, however, is considered among the best engineers as entirely wrong, as it has been repeatedly demonstrated that the kind of fuel and climatic conditions materially affect the steaming qualities of locomotives. The style of road and the traffic conditions are also of material consequence, and the varying amount of load to be drawn by the locomotive also affects the draft upon the fire, and renders the adjustment of the deflector sheet a more or less constant care to the engineer.

When the vacuum occurs after each succeeding blast from the exhaust pipe, the gases from the fire-box rush instantly through the flues to the point where the greatest vacuum exists. This, of course, is on the lower edge of the deflector sheet, and it is the position of this edge that regulates the evenness of the draft from the fire-box to the flues.

Petticoat or Draft Pipe. Petticoat pipes are used for the purpose of equalizing the draft between the several rows of tubes in the boiler. They are invariably used in the old style type of smoke-box, but with the extension front they are only used in connection with boilers of large diameter.

The petticoat pipe in some form has for years been a feature of American locomotive practice, and is more or less of a necessity, in view of the limited dimensions of the smoke-stack on the modern locomotive. It serves in a great measure the same purpose as the tubes of an injector do in inducing the flow of water. The draught of air passing through the flues is led into the bell mouth of the petticoat pipe by the action of the exhaust, and it is essential that in the event of the petticoat pipe being separate from the smoke-stack its size at the upper end should be proportionate to the size of the smoke-stack, and it should be set exactly central with the exhaust nozzle and smoke-stack. The effect of the petticoat pipe in regulating the draught in the smoke-box is coincident with the deflector sheet, and both are intended to create a uniformity of draught through the flues, so that the heat should be equally distributed over the entire area occupied by the flues.

When used, they are located above the exhaust nozzle in the smoke-stack, as shown in Fig. 45. By raising or lowering the draft pipe, the proper draft may be secured. A and C represent the petticoats arranged with lugs D on the sides with slides E E,

having slots and set-screws F F, by which they are adjusted to the space required between them, thereby enabling the engineer to equalize the draft in the fire-box. Experience has shown that when the draft is nearest to the bottom of the smoke jacket the draft is strongest on the back end of the fire next the flue, and by decreasing it there and increasing it in the top flues the draft is made stronger in the front part of the fire-box. By pulling or

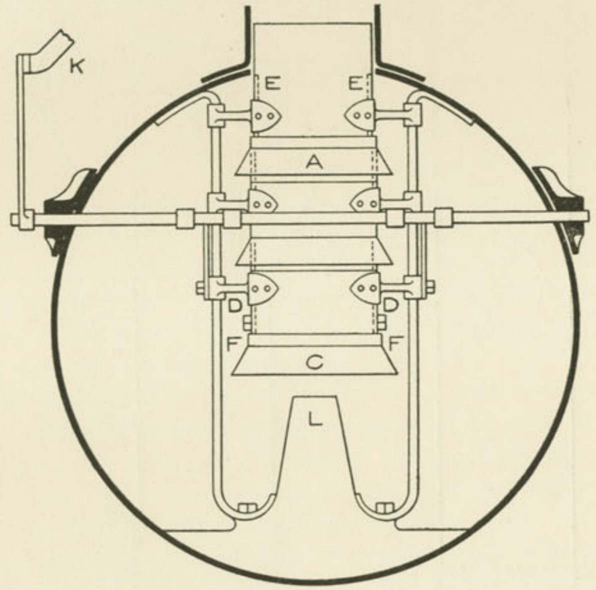


Fig. 45.

ARANGEMENT USED FOR ADJUSTING PETTICOAT PIPE.

pushing the rod K, the petticoats are raised or lowered, thus increasing and decreasing the distance from the exhaust nozzle, L.

Setting Petticoat Pipes. Exact rules cannot be laid down for the location of the petticoat pipe. The distance from the top of the exhaust pipe to the lower edge of the petticoat pipe is usually made about equal to the diameter of the smoke-stack. A slight change of the height of the pipe has often a considerable effect on the draught, and consequently on the steaming qualities of the engine. The uniform appearance of the flues is the best test of the uniformity of draught. Where the draught is strongest the flues are the cleanest, and if flues are partially choked with soot or ashes, it is conclusive proof that the draught has not been sufficiently strong in that locality to keep them clean. Generally speaking, if the petticoat pipe is set too high, the draught will be strongest in the lower flues, and if the pipe is set too low the upper

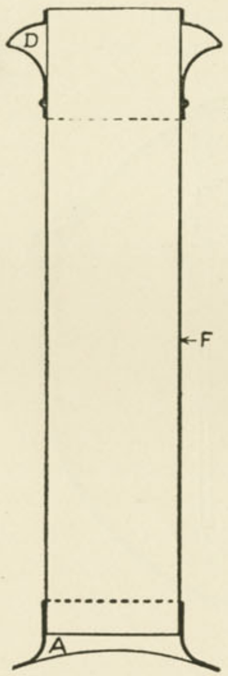


Fig. 46.

STRAIGHT STACK.

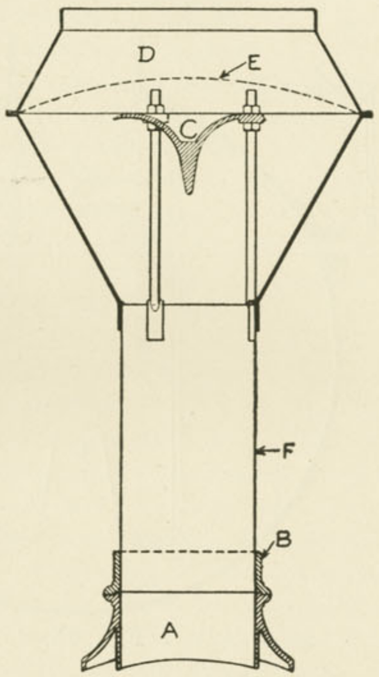


Fig. 47.

DIAMOND STACK.

flues will receive the strongest amount of draught. In view of these facts, very little experimenting should be necessary to obtain the best working height at which the petticoat pipe should be kept.

Badly proportioned or badly set petticoat pipes have a very bad effect on the fire. In cases where the fire is burned rapidly out in some portion of the fire-box, it is safe to assume that the

cause of the trouble is in the petticoat pipe, and a slight change of position in the pipe will show some variation in the fire-box. The tendency on American locomotives is to make the petticoat pipe a mere extension of the smoke-stack projecting towards the center of the smoke-box, and doubtless this method will eventually become standard.

Stack. The stack is that portion of the engine which conveys the gases and exhaust steam to the atmosphere. The form of smoke-stack is now made straight, although formerly they were made in shapes known as the diamond stack, shown in Fig. 47, which was intended to deflect the motion of the sparks and cinders which are carried up with the ascending current of smoke and air in the pipe. As shown in Figs. 46, 47 and 48, A represents the base of the stack; B, the base flange; C, the cone; D, the top; E, the netting; F, the stack body; G, the stack chamber; H, inside pipe; and J, the hand-hole and plate. For burning wood, locomotives are equipped with a wide stack at the top and a straight interior pipe within, so arranged that the sparks are deflected from going out of the top, and are collected in the space outside of the straight pipe, as shown in Fig. 58.

The stack used in connection with the extension front is invariably of the open type, as shown in Figs. 44 and 46. It may be straight as in Fig. 46, or provided with a choke or contraction as in Fig. 44. Various other forms are used, dependent upon the form of jet issuing from the exhaust nozzles.

The diameter of the stack is usually made about the same diameter as the cylinders, and the height of the top of the stack above the rail varies from 14 to 15 feet.

Netting. To prevent the locomotive stack from emitting sparks, netting is used in the front end, as shown in Fig. 43. It is so located that the sparks in the smoke-box will strike it at right-angles to its face. The total area of the netting should be as great and its mesh as large as conditions will with safety permit. Double-crimped steel wire or perforated steel plate is used.

The netting used in stack shown in Fig. 48 is made of iron or steel wire, about 1-10 inch in diameter. The meshes are three or four to the inch. It is sometimes replaced by plates of sheet metal perforated so as to present the same obstruction to the passage of cinders, and yet allow as much freedom for the escape of the gases.

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As the wire netting on the smoke-stack often has holes worn into it by the action of the sparks, it should be frequently examined to see whether it is in good condition. As soon as holes are cut into the netting there is danger that the sparks will escape into the atmosphere. When the engine throws fire from this cause, the netting should be renewed. If there is much water in the ex-

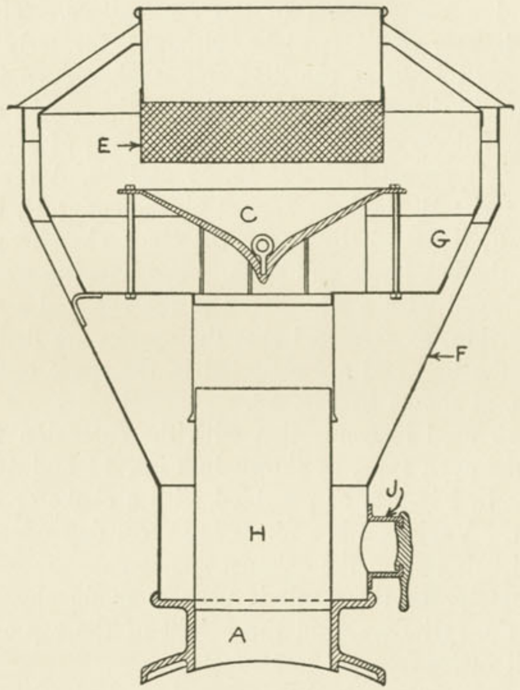


Fig. 48.

Wood Burning Stack.

haust steam the netting is liable to get clogged; it may also become gummed up, due to the use of too much oil in lubricating the cylinders and valves. Should the netting become obstructed, the action of the exhaust is liable to blow the fire out of the furnace door and burn the fireman.

Cinder Trap. As cinders will collect in the front end of the extension front, a trap is placed in the bottom, so that they can be

removed from time to time. This should be closed by a slide that should fit air-tight in its casing, so as to prevent fresh air from entering the smoke-box, as fresh air not only lowers the vacuum in the smoke-box, but supplies oxygen for the combustion of the hot cinders that may have accumulated therein.

Boiler Covering. The loss of heat by radiation and convection is prevented by covering the boiler and dome with lagging, which is a poor conductor of heat, and then covering the outside with Russia iron, the smooth, polished surface of which is a poor conductor of heat. Any form of non-conducting substance, such as asbestos, felt, etc., may be used between the boiler and the iron covering.

Feed Domes. Locomotives are generally equipped with a feed-dome, into which is discharged the feed-water from the choke valves, and which is often located on the first ring of the boiler barrel. Water enters the boiler from this dome through a large number of holes drilled through the shell, and strikes a deflector plate, which delivers it on either side of the dry pipe. The feed-dome may be filled with a series of horizontal baffle plates, placed one above the other, on which is deposited a large part of the impurities in the feed-water. These plates can be easily removed when necessary and replaced with cleaner ones.

Steam Dome. The steam dome is used for the purpose of providing a reservoir for dry steam, and in it the throttle valve is placed as high as possible above the water line, in order that the steam which is supplied to the cylinders may be as dry as possible. It is a cylindrical chamber made of boiler plate and riveted to the top of the boiler.

Tube Setting. In spacing the tubes in a boiler they should not be brought closer together than 11-16 in. in the clear; $\frac{3}{4}$ in. is better. Placing them closer weakens the tube sheets, retards circulation and affords sediment a better lodgment. With regard to whether tubes should be placed in vertical or horizontal rows, there is a very little little difference in the results obtained with either plan. When setting tubes in a boiler, it is preferable to use a copper ferrule at each end instead of at the fire-box end only, as is often done, the advantage being that when the flues have to be taken out of the boiler for renewal it is a much easier job to get them and their coating of scale through the slightly larger holes in the front flue sheet that the use of the copper ferrules entail than it is if the holes are nominally the same diameter as the flues themselves. When about to put a set of tubes into a boiler, care should be taken that the holes are quite clean and free from dirt of any description, so that a perfect metallic contact may be obtained, otherwise there is sure to be trouble from leakage.

Causes of Leaky Tubes. There are two general causes of leaks in locomotive boiler tubes: those due to mechanical causes and those due to variations in temperature. Among the reasons for leaks due to mechanical causes are defective work at the time of

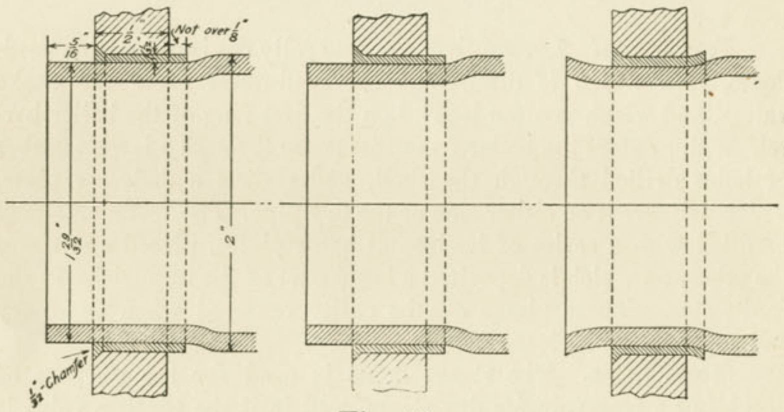


Fig. 49.

METHOD OF EXPANDING TUBES.

first setting the tubes, poor work in making running repairs, excessive vibration of the tubes and wearing out of the tube ends by the abrasive action of the cinders.

Leaks due to variation of temperature are caused either by cold air entering the fire-box, cold feed-water entering the boiler, or deposits of incrustation. These are vastly more important than those due to mechanical causes, as the latter can invariably be better guarded against. The two main causes for boiler leakage are those due to deposits of incrustation and to the changes of water temperature caused by the injection of feed-water.

Methods of Setting Tubes. The method of setting tubes used by the different railways is now very uniform, the process used by

the Union Pacific, and shown in Figs. 49 and 50, being practically the standard used in the United States.

The method of setting tubes is as follows:

1. All scale must be removed from the tube hole by small air drill, with small emery wheel on shaft of drill.

2. All scale must be removed from end of tube. This can be done by holding a square file on end of tube while being cut to length and tube is revolving.

3. Copper of proper thickness should be inserted and ex-

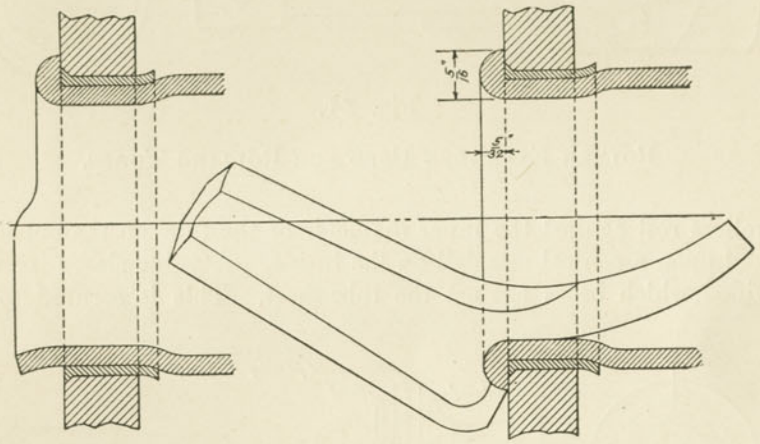


Fig. 50.

METHOD OF BEADING TUBES.

panded in tube hole. Edge of copper should be $\frac{1}{32}$ in. from face of tube sheet.

4. The tube should be inserted and pinned out, as shown in Fig. 49.

5. It should then be either rolled with a roller expander, as shown in Fig. 51, or it should be expanded with a Prosser sectional expander, as shown in Fig. 52.

6. The end of the tube should then be beaded with the standard beading tool, as shown in Fig. 50.

Tube Expanders. Two forms of expanders are in general use for making the joint around tube steam and water-tight, the roller expander, shown in Fig. 51, and the Prosser expander, shown in Fig. 52.

The roller expander is designed to expand a tube by means of a continuous rotary pressure. It consists of a hollow cylinder provided with openings to receive three or more steel rollers. These

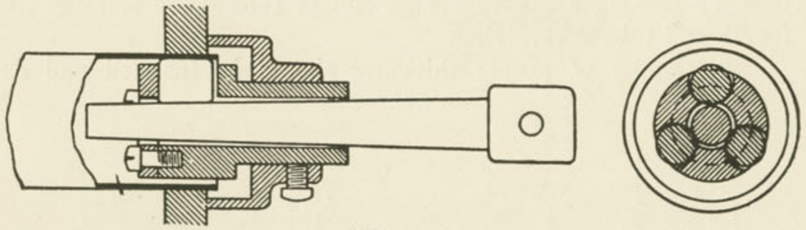


Fig. 51.

Roller Expander Used for Rolling Tubes.

rollers rest against the inner diameter of the tube on the outside, and upon a conical mandril on the inside. A guide sleeve is provided which bears against the tube-sheet. This is secured to a

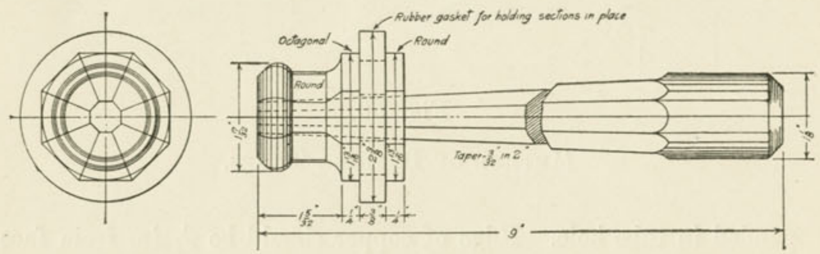


Fig. 52.

Prosser Sectional Flue Expander.

hollow cylinder by means of a set-screw. By shifting the position of this guide sleeve, the different thicknesses of the tube sheet are provided for. By revolving the expander, and at the same time gently forcing in the conical mandril, the rollers are forced outward against the inner circumference of the tube, thus enlarging its diameter until it completely fills the bored hole.

The Prosser expander consists of a number of steel segments with radial joints held together by an external band, the whole being so arranged that the expander when collapsed is of less diameter than the tube into which it is to be inserted. A tapered steel pin passes through the center of these steel pieces, and by driving on the end of this pin these segments are forced out ra-

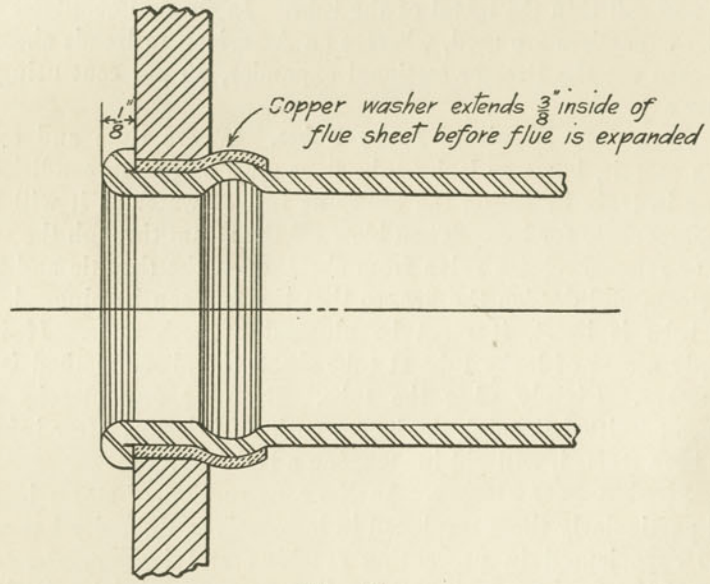


Fig. 53.

Section Through Expanded Flue as Used on the Minneapolis & St. Louis Railroad.

dially against the tube. By successive operations of driving and slacking, and by turning the expander slightly after each such expansion, the end of the tube is stretched until it accurately fills the hole. The expander is made with a convex projection, so that when the tube is expanded, as shown in Fig. 53, it tends to act as a brace for the tube sheet. The expanded tube, shown in Fig. 53, is the method used on the Minneapolis & St. Louis Railway. In this method the tubes are rolled first, and expanded with the Prosser expander afterwards.

There is some difference of opinion among the railroads as to when the roller should be used, whether before or after the Prosser sectional expander is used. Some roads do not use rollers in either first setting or in running repairs, while some use them in first setting, but never in running repairs. The roller expander should be used to tighten the tube in the tube sheet, and for all such purposes it may be used; but it should never be used to wear out and roll thin the metal of the tube. In foreign countries only roller expanders are used, whereas on American railroads about 60 per cent use the Prosser sectional expander, 40 per cent using the roller expander.

Temporary Repair of Leaky Tubes. Where time and conditions permit, burst or leaky tube flues may be put in condition to bring in train by filling the boiler as full of water as it will hold to compensate for loss. Then blow off the steam through the whistle, or remove release valve from chest, open the throttle and blow off steam and deaden the fire, so that the flue can be plugged. If the tube is burst, it must be plugged at both ends. If it is simply a case of leaky tube at tube sheet, the above method is not necessary. Simply plug the tube. Bran or any starchy substance admitted through the heater cock on injector, after injector has been started, will aid in stopping a bad leak.

Fire-box Door Flanges. In the construction of steam boilers, and particularly those employed in locomotives, difficulty has often been experienced in preventing cracking and leakage about the door of the fire-box. The outstanding flange carried by the inner sheet, and the connection of the flange with the sheet, is in the form of a sharp bend in the metal. It is with this portion of the structure that the difficulty is experienced, as the cracks occur along the inner bend. There are several reasons which cause this damage. The inner door sheet and flange are highly heated by the fire, but as soon as the door is opened by the fireman a large volume of cold air rushes in through the door; as a result the fire door flange is suddenly cooled, causing unequal contraction of the metal, thus setting up strains which tear the flange away from the sheet. Another reason which causes the fire-box door flange to leak is the limited amount of water which surrounds the doorway. The space is generally so contracted by overlapping flanges at the heads of rivets that very little water can come into direct contact

with the flange extending outward, and, besides, in this small space incrustation and deposits of foreign matter soon collect, thus separating the water entirely from the sheet and permitting the metal to become overheated.

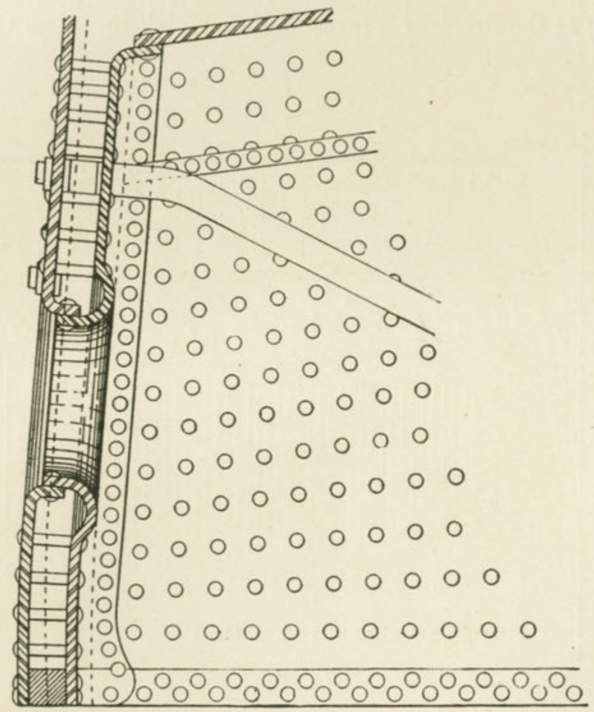


Fig. 54.

O'Connor Fire-door Flange.

The O'Connor Fire-door Flange. With the O'Connor fire-box door flange shown in Fig. 54, the portion of the metal connecting the flange sheet is inwardly swelled, thus forming an enlarged water chamber around the entire opening. This prevents the usual sharp bend between the flange and the inner sheet, and allows a much greater quantity of water to flow around it. The larger body of water tends to maintain a more even temperature of the metal, thus preventing, to a great extent, overheating and the rapid cooling of the flanges. It also provides more room for the inner heads of the rings, and with the larger space there is not so much danger of scale accumulating and separating the water from the metal sheets.

The O'Connor fire-door flange is simply a design which gives the flange at the fire-door a large radius, which increases the space

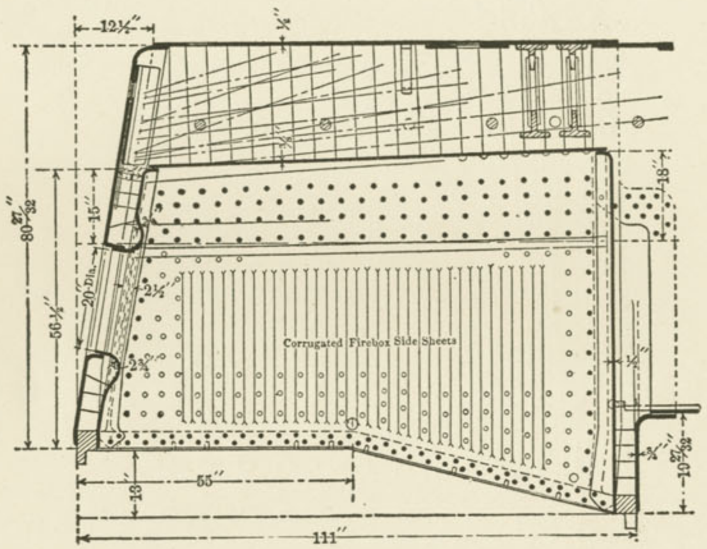


Fig. 55.

FIRE-BOX, SHOWING CORRUGATED FIRE-BOX SIDE SHEETS.

around the fire-door ring or joint. The outer radius acts in a manner similar to the corrugated fire sheets which are used in boilers by an increasing flexibility of the sheet, and preventing the concentration of the stresses at the joint or sharp flange. The strain at this point is particularly severe, due to the rapid cooling of the sheets whenever the door is opened. The increased water space around the door largely prevents the collection of mud and scale by allowing room for better circulation, which thus prolongs

the life of the sheets and joint. This type of fire-door flange has been in use upon the Chicago & Northwestern Railway for several years, and is shown in Fig. 55. It has greatly reduced the trouble formerly experienced in the corroding and burning of the sheets at the door ring. This same design of flange is also used on the large Consolidation locomotives used by the Delaware & Hudson Company.

Pneumatic Door Openers. In order to lessen the labors of the

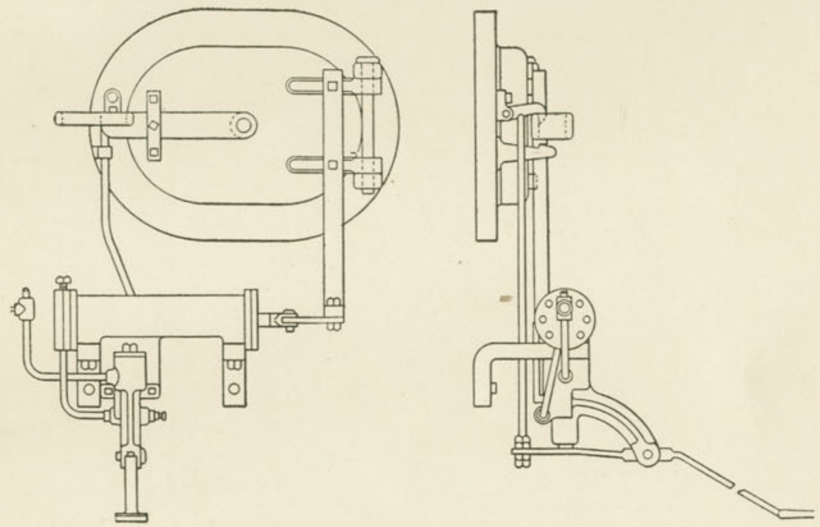


Fig. 56.

PNEUMATIC DOOR OPENER.

fireman, and at the same time prevent any large amount of cold air from rushing into the boiler when the boiler is being fired, various arrangements are used for opening and closing the fire-door quickly. One of these arrangements in use is the Brewer pneumatic door opener, shown in Fig. 56. By its action in opening and closing the fire-door almost instantaneously it also protects the flues, as it prevents a large volume of cold air from entering the fire-box with each firing. It consists of a small horizontal air cylinder located underneath the floor. This cylinder is fitted with a piston, the rod of which is connected by means of a link and crank to the pivot upon which the door swings. The door is opened by simply placing the foot upon the treadle or trip, which is located on the deck. This action opens the air valve, admitting air to the cylinder, thus forcing the piston to move and the door to open. The door is closed by removing the foot from the trip, which allows the air behind the piston to swing it shut. Only a very small amount of air is required for each operation.

REVIEW QUESTIONS.

THE LOCOMOTIVE BOILER.

1. Name the different requirements of a locomotive boiler.
2. Why is it that the boiler limits the power that a locomotive is capable of exerting?
3. Name the principal parts of a locomotive boiler.
4. How is the heating surface of the fire-box calculated?
5. How do you calculate the flue-heating surface of a boiler?
6. In what way does the grate area affect the design of a boiler?
7. What kind of a fire-box is required for burning wood?
8. How does the hard coal fire-box differ from one burning soft coal?
9. About how many pounds of coal can be burned economically per square foot of grate area per hour?
10. What is the general relation which exists between piston displacement and grate area?
11. Acording to best practice, how many square feet of heating surface is allowed per square foot of grate area?
12. What are the principal materials used in the construction of a locomotive boiler.
13. Name a few specifications required for fire-box steel.
14. Give four physical tests which are required by the American Railway Master Mechanics' Association for iron locomotive tubes and cold-drawn steel locomotive tubes.
15. If you had a lot of 10,000 tubes, how many of these would you test to find out if they complied with the specifications?
16. Why are butt joints used for longitudinal seams rather than lap joints?
17. Why are lap joints used for a circumferential seam?
18. In making a butt strap joint with inside and outside welts, which is the best practice, to make the inside or outside welt the widest?

19. What are gusset stays and for what purpose are they used?

20. Give the rule required for finding the area of a staybolt to support a given surface.

21. How are the side sheets of a fire-box generally supported?

22. Are the tube sheets thicker or thinner than the side sheets?

23. What is the reason for boring a hole through the center of a staybolt?

24. Describe the flexible staybolt and explain the purposes for which it is used.

25. When rigid staybolts are used, what is sometimes done to give more flexibility to the bolt?

26. In connecting up staybolts, is absolute rigidity necessary?

27. Name three general methods for supporting crown sheets.

28. Describe a crown bar and explain how it is used.

29. What are the difficulties experienced in keeping the crown free from sediment when crown bars are used?

30. Why has the radial stay supplanted the crown bar in many types of boilers?

31. What are the principal objections to radial stays for supporting the crown sheets?

32. Explain the Belpaire method of supporting the crown sheets.

33. What are the principal advantages and disadvantages of the Belpaire fire-box?

34. What is the usual thickness of a fire-box and out of what material is it usually made?

35. Explain the difference between a narrow and wide fire-box, and explain the use of each.

36. Explain the advantages of using corrugated side sheets for fire-boxes.

37. What is the difference between a straight-top and a wagon-top type of boiler?

38. What is a Wooten boiler and for what purposes is it generally used?

39. Explain the construction of the Vanderbilt boiler. How does the fire-box differ in this type of boiler from those of any other?

40. Explain the construction of a fire-box containing a brick arch.

41. How are the fire bricks supported in a locomotive fire-box?

42. Explain the action of the fire bricks in the fire-box, and what are the principal reasons for using them?

43. What is the principal disadvantage in using brick arches?

44. What are water tables and for what purposes are they used in the fire-box?

45. What are the advantages and disadvantages of water tables?

46. Describe briefly the construction of a soft coal grate.

47. How do the grates allow the fire to be cleaned?

48. How does a hard coal grate differ from a soft coal grate?

49. Of what use are the water tubes in a hard coal grate?

50. What kind of grate is used in wood-burning locomotives?

51. Would you use a rocking grate or a stationary grate when burning coke?

52. What is meant by the front end of a locomotive?

53. Name five different parts contained in the front end.

54. What is meant by an extension front of a locomotive?

55. What is the exhaust nozzle, where is it placed, and why is it used?

56. How are exhaust nozzles cleaned, and why do they become dirty?

57. Is it necessary to adjust the opening in exhaust nozzles, and, if so, why?

58. What is the diaphragm and why is it used?

59. Should the diaphragm be adjusted; and, if so, how can it best be opened?

60. What is the petticoat or draft pipe, and is it necessary for a boiler to have these pipes?

61. With what types of boilers are petticoat pipes mostly used?

62. Describe three different kinds of stacks used on locomotives.

63. What effect has a badly set petticoat pipe on a boiler?

64. Of what use is the netting in the front end of a locomotive?

65. When should the netting be examined and for what reasons?

66. Where is the cinder trap of a locomotive located, and why is it used?

67. Describe the construction of a stack for a wood-burning locomotive.

68. Why are steam domes used on locomotive boilers?

69. What are the principal causes of leaky boiler tubes?

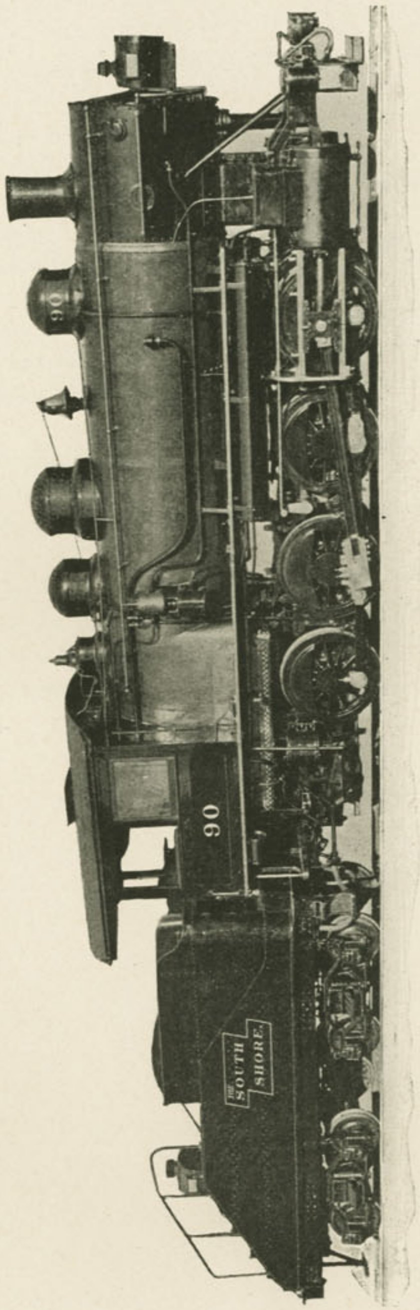
70. Describe the difference between a roller and a Prosser expander.

71. Explain the use of a tube expander and tell for what purposes it is used.

72. How would you go about making a temporary repair of a leaky tube?

73. Describe a type of fire-box door flange which is supposed to overcome the difficulty of leakage about the door.

74. Of what use are pneumatic door openers, and how do they help the fireman?



EIGHT-WHEEL SWITCHING LOCOMOTIVE—DULUTH, SOUTH SHORE AND ATLANTIC RAILROAD
(Baldwin Locomotive Works)

Boiler Fittings and Attachments

There are a certain number of fittings that must be used on the locomotive boiler in order to enable the engineer to operate it successfully and economically. These fittings consist of the safety valves, whistle, steam gauge, water gauges, blower, throttle valve, dry pipe, injectors, etc.

Dry Pipe. The dry pipe is used for conducting the steam from the steam dome to the cylinders. The pipe runs through the steam space to the front flue sheet or head of boiler. When the throttle valve is closed, the dry pipe is subjected to the pressure of steam upon the outside, and must be strong enough to withstand

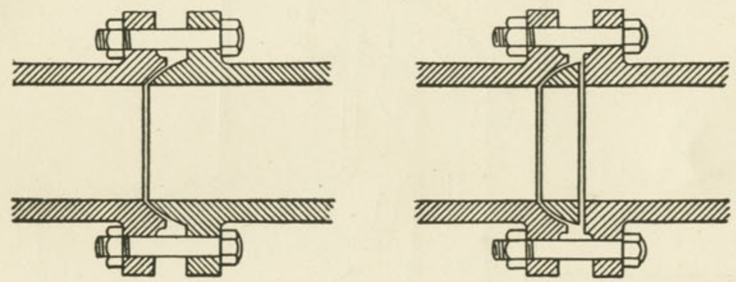


Fig. 1. Fig. 2.

FLEXIBLE STEAM PIPE JOINTS.

it. It is made of wrought or cast iron. Since the introduction of high steam pressure wrought iron is generally used. The diameter of the dry pipe depends upon that of the cylinders. It should be of such a diameter that the area of its cross-section is equal to at least one-twelfth the combined sectional areas of the two cylinders.

Steam Pipes. The steam pipes are connected to the front end of the dry pipe inside the smoke-box, and carry the steam to the steam chest and valve chests. The steam pipes are exposed to great changes of temperature as a result of their being within the smoke-box, and consequently some special form of joint must be used to keep the pipe joints tight. One kind of flexible joint used is shown in Fig. 1. It is called a ball joint, the end of one of the pipes being turned into the form of a sphere, the end of the other pipe being a corresponding concave shape. Another form of flexible joints is shown in Fig. 2. A ring is interposed between the ends of the pipe, one side of the ring being spherical and the other side flat, the ends of pipe being made to correspond. These joints accommodate themselves to any motion caused by contraction and expansion.

Throttle Valve. This valve is generally located at the top end of the throttle pipe near the top of the dome, although it is

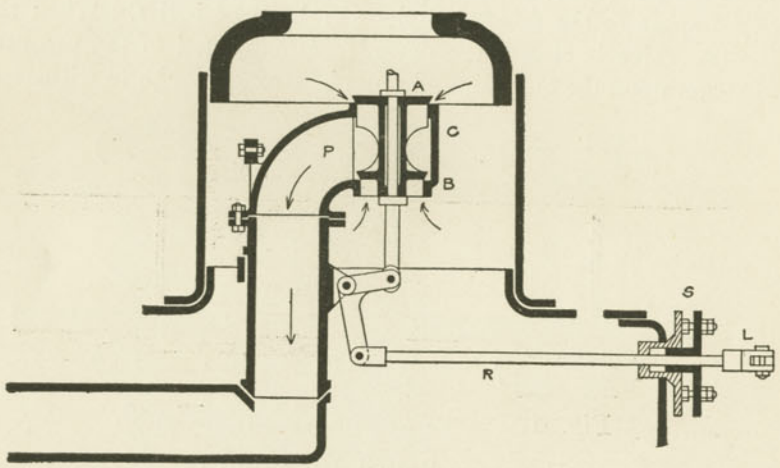


Fig. 3.

Double-Seated Poppet Throttle Valve.

sometimes placed in the smoke-box at the front end of the dry pipe. In former years, the throttle valve was a plain slide valve that moved upon a seat, in which were ports similar in form to the steam ports in the valve chests, the objection in this type being that the pressure of steam upon it made it difficult to open the throttle gradually, or to regulate or adjust it while open—two very important points in the operation of a locomotive, as every engineer knows. The type now most generally used is

the double-seated poppet type, shown in Fig. 3, the discs being of different diameters, the top one being slightly larger. The valve consists of two circular discs, A and B, which cover the two valve seats in the valve case, C. When the valve is raised and the discs are off their seat the steam flows from the steam chamber into the pipe P. The steam pressure in the boiler acts

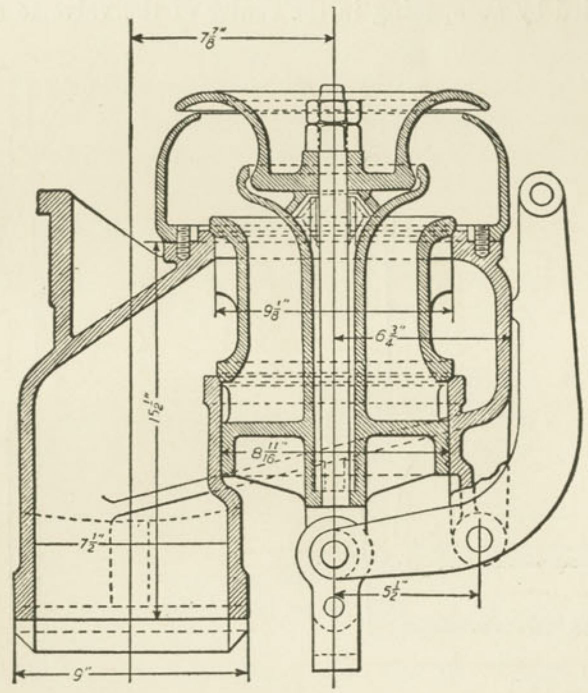


Fig. 4.

Throttle Valve Used on Erie Mallet Compound Engines.

upon the top of disc A, and upon the bottom of disc B. If the two discs were of the same diameter, the valve would be balanced, but this, for several reasons, is not desirable. The top disc, being larger, tends to keep the valve closed on account of the larger pressure on it, and the top opening being larger, permits the valve to enter the case. The throttle is opened and closed by the rod R, called the throttle stem. The throttle lever is connected to the throttle stem at L. The throttle rod passes through the stuffing-box S, which keeps the sliding joint steam-tight.

A type of throttle valve used on large engines is shown in Fig. 4. It differs from the ordinary throttle valve, as it takes steam at the top only, and acts as a steam separator. The entering steam strikes against the curved surface of the upper part of the valve, upon which the moisture in the steam will be deposited and carried by an opening in the center of the valve to an outlet

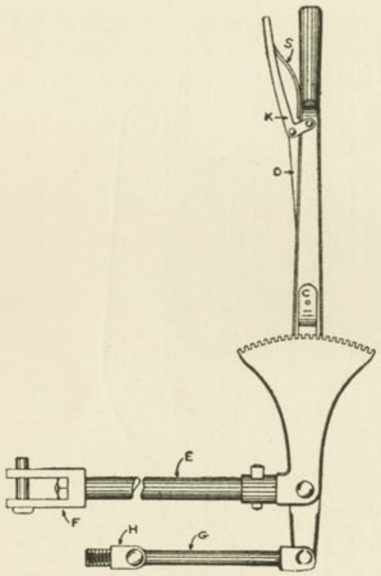


Fig. 5.

THROTTLE LEVER.

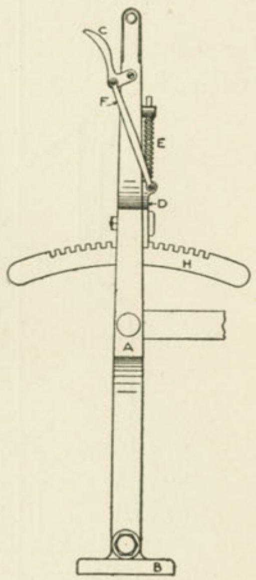


Fig. 6.

REVERSE LEVER.

below. This curved top of the valve does not take bearing, and hence does not act as a valve, the valve being shown on its seat below it. This particular type of valve is used on one of the 409,000-pound Mallet compounds used on the Erie Railroad.

Throttle Valve Stem. This is the rod which extends through a steam-tight stuffing-box in the boiler head, and connects with the bell-crank lever, which is fastened to the lower end of the valve stem and the throttle lever, as shown in Fig. 3.

Throttle Lever. The throttle lever shown in Fig. 5 is connected to the throttle stem. It is fitted with a latch C, that gears into the curved rack in order to hold the throttle in any desired position. The latch C is operated by a trigger K, connected by a rod. The latch link is shown at D, the throttle rod at E, the jaw that connects with the throttle valve stem at F, the link at G, the link stud at H, and the handle spring at S.

Reverse Lever. The arrangement which is used for shifting the link, and thereby changing the cut-off in the cylinder of the engine, is called the reverse lever, and is shown in Fig. 6, where A is the lever; B, the lever fulcrum; C, the lever handle; D, the latch; E, the latch spring; F, the latch rod; G, the catch.

INJECTORS.

Injectors are now universally employed for delivering the feed water to the boiler. Two injectors are always used, either one of

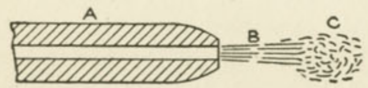


Fig. 7.

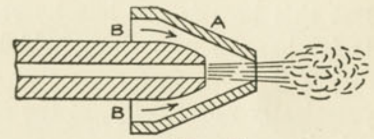


Fig. 8.

which should have a capacity sufficient to supply the boiler with water under ordinary working conditions. They are located one on either side of the boiler.

The Principle of Operation of the Injector. Despite the fact that it has been in use for almost half a century, the injector is still a subject of much misunderstanding and discussion. There is no mystery surrounding the action of the injector, its operation being based on simple, natural laws, which can readily be stated and understood. The mere fact that it has no moving parts need cause no confusion.

In Fig. 7, suppose that the tube A is connected with the steam space of a boiler, so that the steam, under pressure, is free to escape through the tube. It will emerge in the form of a jet, as shown, moving at a great speed. Just beyond the end of the tube, as at B, the jet of escaping steam has a slightly conical form, while at a still greater distance, as at C, the jet expands, and is broken up by the resistance of the surrounding atmosphere.

A tube like that shown in Fig. 7 is usually called a nozzle. When steam from a boiler flows through a nozzle of this kind, and escapes into the air, velocity of the steam outside the nozzle may be from 1500 to 3000 feet per second, depending on the boiler pressure. This issuing steam has weight, and to give it such a high velocity requires that work be done upon it, just as it requires work on the part of a horse to move the weight on a truck. Now, work is produced by heat energy. Therefore, since the column of steam has had work done upon it in order to give it this high velocity, it is necessary to look for a source of the heat which is transformed into work.

This source of heat is in the steam itself. When the steam leaves the boiler it has a high pressure and temperature, and when it issues from the nozzle its pressure and temperature are both much lower. Evidently the steam loses heat in its passage. But this heat is not lost by radiation from the pipe and nozzle. It is changed into work, which work, expended upon the steam, makes it move faster, so that while the steam in the boiler has practically no velocity, at the end of the nozzle it has a very high velocity.

But heat cannot be taken away from ordinary steam without causing some steam to condense into water. Consequently the steam that emerges from the nozzle is not dry steam, but contains moisture in the shape of very fine drops. Under different boiler pressures this moisture may amount to from 10 to 20 per cent of the weight of the steam.

Hence, as the steam passes through the nozzle, three things take place: (1) The pressure and the temperature both decrease. (2) The velocity of flow increases enormously. (3) The steam condenses to a greater or less extent. Then, for every pound of steam that passes through the nozzle there is found to be a mixture of about .8 or .9 pounds of steam, and from .1 to .2 pounds of water at the mouth of the nozzle.

Now, suppose that the nozzle of Fig. 7 is so placed as to discharge through a cone-shaped ring, as in Fig. 8. The small end of the cone, A, is of such size that the expanded jet of steam,

when the latter is turned on, will be carried along and forced through the cone by the moving jet. Air will then rush in at B, B, and, meeting the jet, will be drawn along with it in the direction of the small end of the cone. The continued friction of the steam with the air inside the cone will then set up a continuous current flowing through the cone in the direction indicated by the arrows. The mingling of the air and steam will cause still more of the steam to condense, while the velocity of the steam jet will decrease somewhat, owing to the fact that a part of its energy is used in giving velocity to the air.

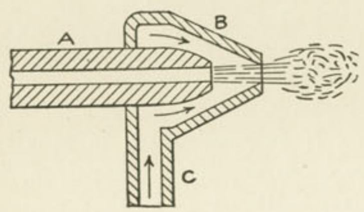


Fig. 9.

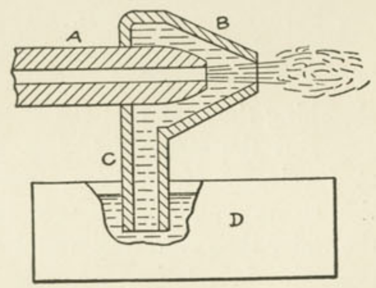


Fig. 10.

Instead of a simple cone, open at both ends, let the device in Fig. 8 be changed to that shown in Fig. 9. In the latter figure the nozzle A is inserted through the back wall of the cone B, which is closed at the large end, with the exception of the opening C. The action does not differ in any way from the action of the device in Fig. 8. The air is driven and drawn out of the closed cone by the jet, causing a partial vacuum inside it, and to fill this space air rushes in at C, and a continuous current is established, entering at C, and emerging at the small end of the cone.

The devices shown in Figs. 8 and 9 will be recognized by many engineers as being the typical forms of various boiler appliances, such as tube cleaners, soot suckers and blowers for producing draft, all of which depend on the production of a rapid current by the escape of steam through one or more openings.

It has just been shown that the flow of air upward through the pipe C, Fig. 9, is due to the fact that the pressure inside the cone B is reduced somewhat below that of the atmosphere. Suppose, then, that the pipe C is lengthened, and that its lower end is placed beneath the surface of the water contained in a tank, according to the arrangement shown in Fig. 10.

When the steam is turned on, it forms a partial vacuum in the cone B, as already explained. But air cannot rush in to fill the space thus left vacant, since the pipe C is submerged in the tank D. However, the pressure of the atmosphere acts just as before, and it forces water from the tank up into the cone surrounding the nozzle A, completely filling that portion of the space not already occupied by the jet of moist steam. This action, of course, brings the water and the steam into contact, which can have but one result. The steam is condensed by the cool water, and the heat thus set free is taken up by the water. That is, the steam is cooled and the water is heated, the latter simply absorbing the heat that the steam gives up.

But the steam jet, just before it is condensed, is moving at a velocity of, perhaps, 2000 feet per second. Therefore, if this steam could be changed to water without any other action, the water thus resulting would have the same high velocity. However, this is not the case. Besides being condensed, the jet mingles with the water that is forced up from the tank. Consequently, owing to the resistance thus offered, the velocity of the condensed jet is very greatly reduced.

Instead of a jet of steam, there is now a jet of water particles moving toward the small end of the cone. This jet is surrounded by the water inside the cone. As a result, the friction between the jet and the water causes the latter to be drawn along, at an increasing speed, toward the outlet, the jet meanwhile decreasing in velocity. At the mouth of the cone the mingled jet emerges, now an almost solid column of water, which, though it has not the velocity of the original steam jet, is nevertheless moving at a fairly rapid rate, say 400 to 500 feet per second.

The condensation of the steam inside the cone produces another important effect. When a volume of steam condenses to water, the space occupied by the water is only about 1-1000 as great as that originally occupied by the steam. Hence, in condensing in the cone, a partial vacuum is formed, to fill which the water of the tank D has been forced up into the cone. As the condensation in the cone is continuous, the flow of water up through C is likewise continuous, and a steady stream is delivered at the mouth of the cone.

This issuing stream is not a solid column of water, it is rather a mingled spray, composed of water and vapor, the greater part, however, being water. Now, such a jet, moving at a velocity of several hundred feet a second, has considerable energy stored in it. And if the jet be allowed to impinge against a flat surface, it will exert a pressure upon that surface. For example, if the velocity of the jet is 400 feet per second, and the weight of the mixture of water and vapor is 50 pounds per cubic foot, the pressure exerted by such a jet impinging upon a stationary flat surface will be several hundred pounds per square inch. A pressure like this is capable of overcoming considerable resistance.

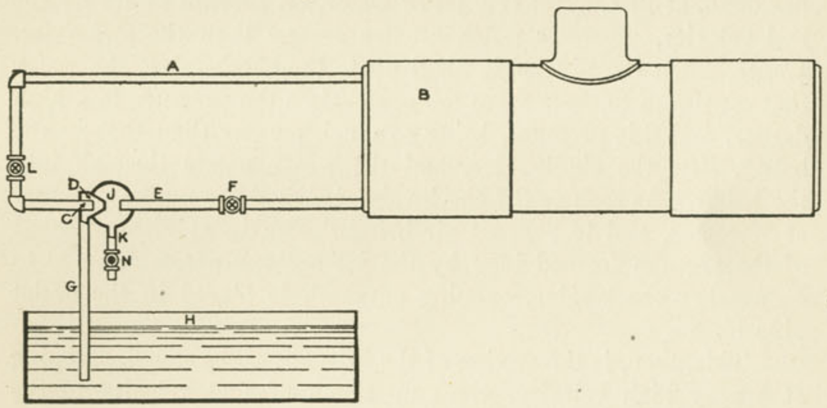


Fig. 11.

Suppose, now, that the apparatus shown in Fig. 10 is attached to a steam boiler in the manner shown in Fig. 11. A pipe A leads from the steam space of the boiler B to the nozzle C inside the cone D. Just beyond the edge of the cone is another pipe E, containing a swing check-valve F, by which the water in the boiler is prevented from running out. A pipe G connects the cone D with a tank of water H, and a chamber J, having an outlet K, surrounds the mouth of the cone and the end of the pipe E. A valve L controls the flow of steam through the pipe A. This apparatus contains the elements of the steam injector as commonly built. The action is precisely like that of the cone, as already described in connection with Fig. 10.

When the valve L is opened steam issues from the nozzle C, escapes through the mouth of the cone D, and leaps across the narrow opening in the pipe E. Here, however, it meets the closed check-valve F, which it cannot lift, owing to its slight pressure. Consequently, as soon as the steam fills the pipe C it is forced out into the chamber J, whence it escapes through the overflow K to the atmosphere.

But the rush of steam from the nozzle forms a vacuum inside the cone, and water is forced up into the cone, where it mingles with the steam, is heated and condenses the steam. The combined current, on leaving the mouth of the cone at a high velocity, leaps across the gap into the pipe E, just as the steam has done, at first. But this jet of water, on account of its weight and velocity, possesses much greater energy than the steam jet. Hence, when the pipe E is filled up to the check-valve, the water that continues to come from the cone raises the pressure to a high degree, and this pressure, being so much greater than that in the boiler, lifts the check-valve, and the water passes through into the boiler. As soon as the check-valve is lifted the escape of water at K ceases, and to prevent air being drawn in at K on account of the vacuum formed in J by the jet rushing across from D to E, another check-valve, opening outward, is placed in the outlet pipe K.

This, then, is the section of the injector. The steam, escaping at a very high velocity, gives up much of that velocity to the water, and the pressure of the swiftly-moving column of water is sufficiently great to overcome the boiler pressure, which it does.

Types of Injectors. There are two general classes of injectors, known as "Single-Tube" injectors, when they have a single set of nozzles; and as "Double-Tube" injectors, when they have two sets of nozzles. One of the latter kind has the function of lifting the feed water and delivering it to the forcing set, which latter imparts to the water sufficient velocity to cause it to enter the boiler.

Lifting and Non-lifting Injectors. A lifting injector is placed above the highest water level of the tank from which the feed water supply is taken, so that the injector has to lift the water up to its own level. A non-lifting injector is placed below the lowest level of the water of the tank from which the feed water is taken, and it flows to the injector by gravity.

The Essential Parts of an Injector. The essential parts of injectors are, in the first place, the nozzles, which perform the function of delivering or forcing the water into the boiler, and, in the second place, the operating mechanism, such as the lifting-valve, steam-valve, water-valve, etc.

Sizes of Injectors for Locomotives. In determining the size of injectors required for locomotives, the size of the cylinder is usually taken as the standard, although the diameter of the boiler and the kind of service for which the locomotive is intended have a modifying influence.

Types in General Use. There are a large number of different types of injectors in general use, some of which are shown in Figs. 12 to 19. Fig. 12 represents a Sellers injector; Fig. 19 represents the interior arrangement of the Koerting injector; Fig. 14 represents the Monitor injector; Fig. 18 the Eclipse injector; Figs. 15 and 16 two types of the "Little Giant" locomotive injectors; Fig. 17 represents the Hancock inspirator, and Fig. 13 the Metropolitan injector.

The Sellers Improved Self-Acting Injector. This injector is simply constructed, and contains few operating parts, as shown in Fig. 12. The lever is used in starting only, and the water valve for regulation of the delivery. It is self-adjusting, with fixed nozzle, and restarts automatically. All the valve seats that may need refacing can be removed; the body is not subject to wear, and will last a lifetime.

The action is as follows: Steam from the boiler is admitted to the lifting nozzle by drawing the starting lever (33) about one inch, without withdrawing the plug on the end of the spindle (7) from the central part of the steam nozzle (3). Steam then passes through the small diagonal-drilled holes and discharges by the outside nozzle, through the upper part of the combining tube (2) and into the overflow chamber, lifts the overflow valve (30), and issues from the waste pipe (29). When water is lifted the starting lever (33) is drawn back, opening the forcing steam nozzle (3), and the full supply of steam discharges into the combining tube, forcing the water through the delivery tube into the boiler pipe.

At high steam pressure there is a tendency in all injectors having an overflow to produce a vacuum in the chamber (25). In the self-acting injector this is utilized to draw an additional supply of water into the combining tube by opening the inlet valve (42); the water is forced by the jet into the boiler, increasing the capacity about 20 per cent. The water-regulating valve (40) is used only to adjust the capacity to suit the needs of the boiler.

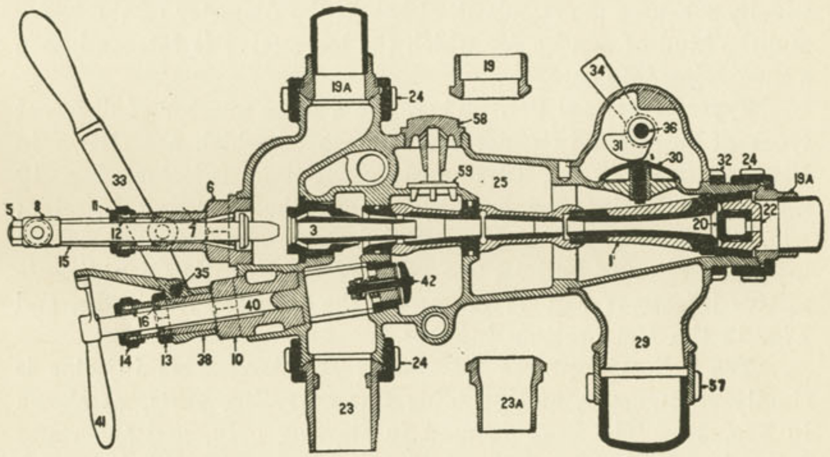


Fig. 12.

SELLERS SELF-STARTING INJECTOR.

The cam lever (34) is turned toward the steam pipe to prevent the opening of the overflow valve when it is desired to use the injector as a heater or to clean the strainer. The joint between the body (25) and the waste-pipe (29) is not subject to other pressure than that due to the discharging steam and water during starting; the metal faces should be kept clean, and the retaining nut (32) screwed up tight.

To tighten up the gland of the steam spindle, push in the starting lever (33) to end of stroke, remove the little nut (5), and draw back the lever (33). This frees the crosshead (8) and

links (15), which can be swung out of the way, and the follower (12) tightened on the packing to make the gland steam-tight.

The Sellers self-acting injector is especially adapted to railroad service, as its efficient, positive action and wide range of capacities at 200 pounds steam render its application to high-pressure locomotive boilers very advantageous. It will work from the highest steam pressures used on locomotives down to 35 pounds steam without adjustment, and without wasting at the overflow, and by regulating the water-supply valve on the injector

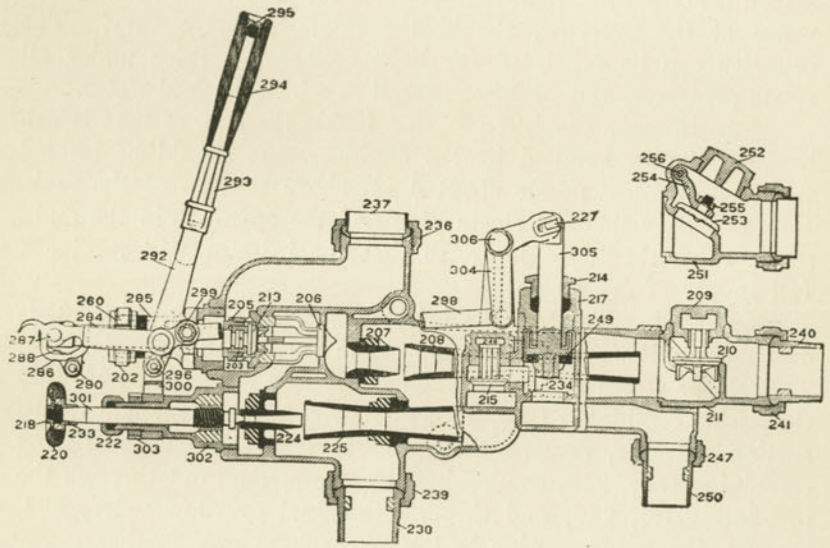


Fig. 13.

METROPOLITAN INJECTOR.

it can be operated at 15 pounds. As it restarts instantly under all conditions of service, it can always be depended upon to force all the water into the boiler, so that the engineer can give his whole attention to his other duties.

The Metropolitan Locomotive Injector. Fig. 13 represents a Metropolitan double-tube injector, composed of a lifting set of tubes, which lifts the water and delivers it to the forcing set of tubes under pressure, which in turn forces the water into the boiler.

The lifting set of tubes acts as a governor to the forcing tubes, delivering the proper amount of water required for the condensation of the steam, thus enabling the injector to work without any adjustment under a great range of steam pressure, handle very hot water, and admit of the capacity being regulated for light or heavy service under all conditions.

This injector will start with 30 to 35 lbs. steam pressure, and without any adjustment of any kind will work at all steam pressures up to 300 lbs. When working, all the water must be forced into the boiler. It is impossible for part or all the water to waste at the overflow, should the steam pressure vary. The capacity can be regulated for light or heavy service under all steam pressures, and with hot as well as with cold feed water.

The injector should be located inside the cab, so that it can be conveniently handled by the engineer. It should be located with the overflow nozzle about 4 in. above the top of the tank. It is necessary that the steam pipe and the openings in the main steam valve should be large, so that the injector will receive a full supply of dry steam.

Operation. To start the injector, the lever, 292, Fig. 13, is drawn back, lifting the auxiliary steam valve, 213, from its seat. This allows steam to flow through the lifting steam jet, 224, into the lifting combining tube, 225, thereby creating a vacuum in the suction chamber, causing the water to flow through the lifting combining tube, 225, condensing the steam, then out through the overflow valve, 215, and through the final overflow valve, 234, through the overflow pipe to the atmosphere. A further movement of the lever, 292, opens the steam valve, 206, which admits steam to the forcing steam jet, 207, which is condensed by the water which is in the intermediate chamber, and in the forcing combining tube, 208, creating a pressure in the delivery chamber of the injector, which is sufficient to close the overflow valve, part 215; and a further movement of the lever, 292, closes the final overthrow valve, thereby turning the water from the overflow into the boiler, thus opening the check valve, 210. When the injector is working, the overflow valve is closed and held to its seat by pressure equal to the boiler pressure.

The capacity of the Metropolitan injector is regulated by increasing or decreasing the amount of steam to the lifting

steam jet, 224, by means of the regulating valve, 301. When this valve is wide open, the lifting steam jet, 224, receives a full amount of steam, which enables the lifting apparatus of the injector to lift the greatest quantity of water and deliver it to the forcing apparatus. When this regulating valve, 301, is partially closed, it will partially close the opening into the lifting steam jet, 224, decreasing the flow of steam, which will decrease the amount of water lifted by the lifting apparatus. This arrangement has been found to be far better than the old method of throttling the water supply. It enables the injector to run steadier when working at its minimum capacity, and also enables the capacity to be reduced more.

To use the injector as a heater, lift the side links, 286, by means of the small handle on same, and pull the links back until the pin, 287, drops into the notch. This operation causes the final overflow to be closed and a small amount of steam can be admitted, enough to heat the injector. When it is desired to operate the injector after using it as a heater, the lever is simply pushed in, which will place the injector in position to be operated.

If the injector breaks or will not start promptly, see if there is a leak in the suction connection. If the openings into the tank are too small, or the hose strainer clogged, or the hose kinked, or the hose lining is collapsed, the injector will not get a sufficient supply of water. If the injector will lift the water, but will not deliver it into the boiler, see that the intermediate or line check-valve, or the main boiler check-valve, is in proper working order; also examine the suction pipe for leaks. A leak in the suction pipe, while it may not prevent the injector from lifting, will prevent the water being forced into the boiler. If the main steam pipe, or the main steam valve, is not of sufficient size, or if there is a leak in the dry pipe, the injector will not receive a supply of steam sufficient to force the water into the boiler. If the overflow pipe is smaller than the overflow nozzle, there will be a back pressure, which will prevent the injector from lifting the water promptly. The overflow nozzle and overflow pipe should be kept free from lime or scale. This is very important.

Repairing. When the tubes become worn they should be renewed. The forcing tubes are removed by removing the check-valve casing, part 211, by breaking the flanged joint. The lifting tubes are removed by removing the regulating center piece, part 302. Should the steam valves leak they should be reground. Overflow valve, part 215, must seat tightly. If this valve leaks it will cause the hot water from the delivery chamber of the injector to be forced into the intermediate chamber and drawn into the combining tube, part 208, causing the injector to break. This is very important.

The final overflow valve has a soft disc, part 249. This disc is made soft, so that in case the valve should close on to any hard substance it will not injure the valve seat. These discs can be removed very easily.

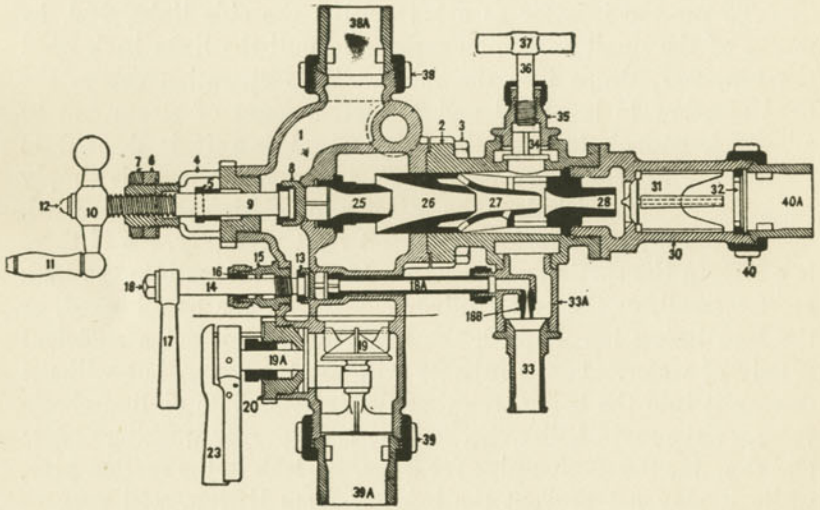


Fig. 14.

MONITOR INJECTOR.

The Monitor Injector. The proper position of this injector is in the cab above the level of the water in tender, convenient to engineer. If it is placed outside, it must be provided with connecting rods extending into the cab. Steam should be taken from dome or highest part of boiler to insure best effects. It does not waste water at overflow by ordinary variation of working steam pressure, whether the water-valve is wide open or throttled

down until almost shut. It works steadily, whether the engine is running fast or slow; while reversing, applying brakes, and during ordinary stoppages. It is also capable of running heavy as well as light trains, the quantity of water needed being regulated by the water-valve attached. It is provided with an independent lifting jet, which enables the injector to start promptly at all times.

The body of the injector, as shown in Fig. 14, has been divided into two parts, which are firmly held together by a double flange, securely bolted. This enables the interior parts to be taken out for cleaning or renewal, when necessary, without injury to the injector.

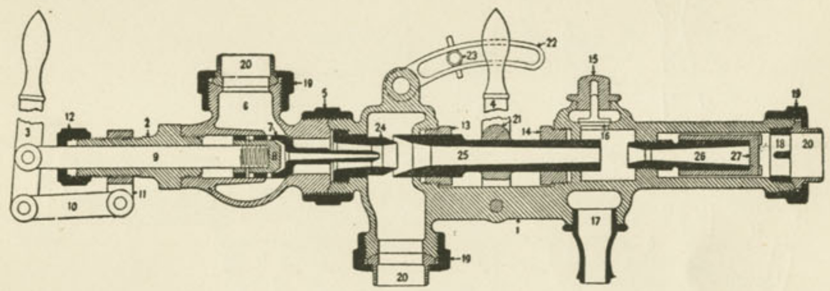


Fig. 15.

LITTLE GIANT INJECTOR.

The steam-valve spindle is provided with a yoke stuffing-box, which makes it possible to place the threaded part of the spindle outside the steam chamber, diminishing its wear. The packing can be adjusted and tightened by means of a large central nut, still preserving the simplicity and convenience of an ordinary stuffing-box.

The water-valve has been provided with a double handle, with index pin, which engages with notches cut into the stuffing-box cap, thereby keeping the water-valve steady in any position against any jar or vibration of the engine..

The Little Giant Locomotive Injector. These injectors, shown in Figs. 15 and 16, are fitted with a movable combining tube, operated by a lever, which allows them to be adjusted to work correctly at different pressures of steam, and under the many conditions which injectors are required to work.

To operate the injector, have the combining tube in position to allow a sufficient quantity of water to condense the steam when the starting valve is full open, then open the starting valve slightly; when water shows at overflow, open full. Regulate the water by moving the combining tube. To use a heater, close overflow by moving the combining tube up against the discharge, then open starting valve enough to admit the quantity of steam required.

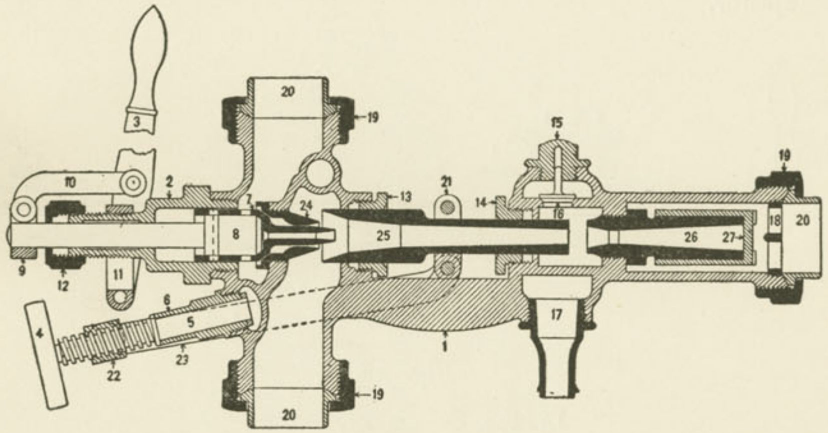


Fig. 16.

LITTLE GIANT INJECTOR.

The Hancock Locomotive Inspirator. The Hancock inspirator consists of one apparatus for lifting and one for forcing. It works with high or low steam pressure on all lifts up to 25 feet, when taking feed water under a head, with hot feed water as well as cold. For all steam pressures and for all conditions its operation is the same, and it requires no adjustment for varying steam pressures.

The Hancock locomotive inspirator, Fig. 17, is operated by a single lever, and is made in different types to suit different connections, and will work successfully with pressures of steam from

35 lbs. to 350 lbs. without any adjustment of either steam or water, and the proportions are such as to increase its quantity of water from 35 lbs. to 200 lbs., this being about the average pressure carried on locomotives; and while its maximum capacity is at 200 lbs., the percentage of decrease from 200 lbs. down to 160 lbs. is not enough to interfere with the requirements of the locomotive. It will lift water on the highest lifts encountered in locomotive practice, even if the suction becomes heated or filled with hot water.

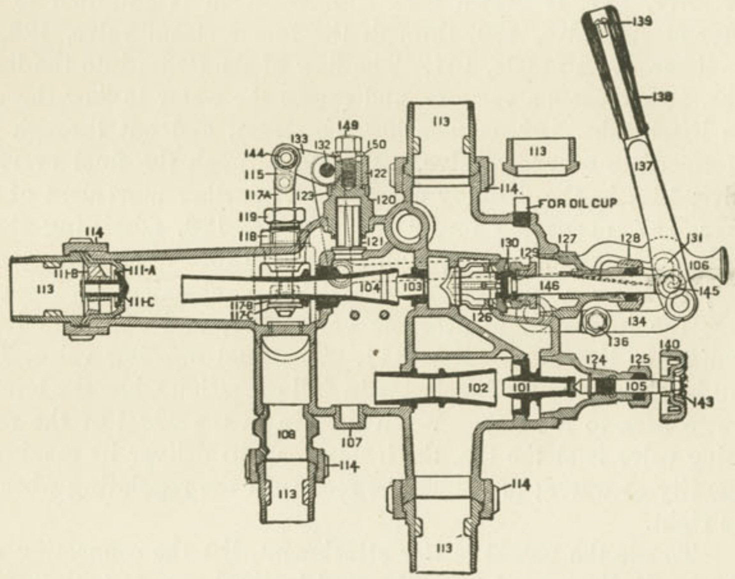


Fig. 17.

HANCOCK INSPIRATOR.

The regulation from maximum to minimum is accomplished by simply reducing the amount of steam supplied to the lifting apparatus. The combining tube has no openings between its mouth and delivery end, and it admits of a positively closed overflow; hence all water passing through the combining tube must go to the boiler, and cannot escape at the overflow. This condition is possible on account of the two sets of tubes, the lifting tube acting as a regulator and governor for the forcer, hence requiring no adjustment from the lowest to the highest steam pressures within its entire range.

The intermediate overflow valve operates automatically, its only function being to give direct relief to the lifter steam nozzle when lifting or priming, and it comes to its seat when the force of steam is applied, and is held there by the pressure exerted by the force.

To start the Hancock inspirator, draw the lever, 137, Fig. 17, back to lift the water, then draw it back to the stop. When the lever, 137, is drawn back slightly steam is admitted to the lifter steam valve, 130, through the forcer steam valve, 126, to the lifter steam nozzle, 101. The flow of the steam into the lifter tube, 102, creates a vacuum, and causes the water to flow through the lifter tube, 102, condensing the steam, and out through the intermediate overflow valve, 121, and through the final overflow valve, 117, in the delivery chamber. A further movement of the lever, 137, opens the forcer steam valve, 126, admitting steam to the forcer steam nozzle, 103, and to the forcer combining tube, 104, creating a pressure in the delivery chamber sufficient to close the intermediate overflow valve, 121, and open the intermediate or line check-valve, 111. The final overflow valve, 117, will be closed and the inspirator in full operation when the lever is drawn back to the stop. When the pin in the wheel of the regulating valve is at the top, the inspirator will deliver its maximum quantity of water; to reduce the feed turn the regulating wheel to the right.

To use the patent heater attachment, lift the connecting rod, 106, until disengaged from the stud in the lever, 131, then draw back the connecting rod to close the overflow valve, 117. Draw the lever back to the point used in lifting. This will usually give all the steam that is required for a heater. If the amount going back is too large, regulate it by the regulating wheel to give just the amount required, as with the lever in the position described all the steam blowing back would pass through the lifter nozzle. Thereby the closing of the main steam-valve at the boiler becomes unnecessary.

To obtain the best results, the inspirator should be located with the overflow nozzle about 4 in. above the water in the tank. The steam should be taken through a dry pipe from the dome.

Connections from the inspirator to the dome and the openings in the suction or feed pipe connections from the inspirator to the tank must not be smaller than those called for by the manufacturer.

The Hancock inspirator of the composite type consists of two separate and individual inspirators within one body or casing, which can be operated separately or simultaneously, as desired. Where it may be desired to locate both injectors on one side of the locomotive, convenient to either the engineer or fireman who has charge of pumping the engine, or on the boiler butt, available to both, the advantages of the composite are apparent. Owing to

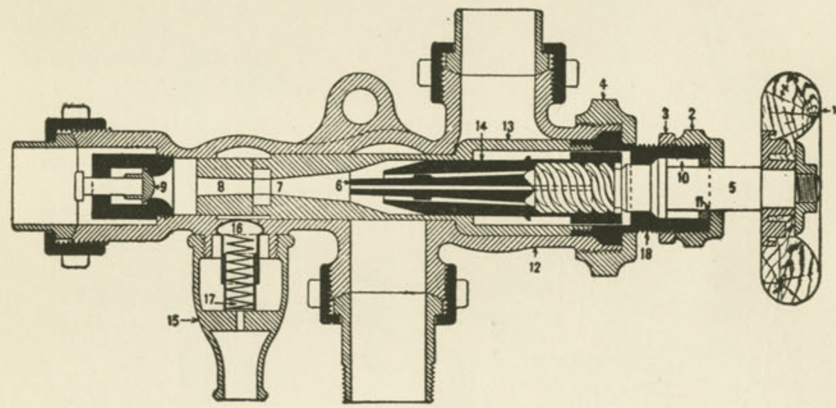


Fig. 18.

ECLIPSE INJECTOR.

the limited room in the cab, it is generally difficult to locate both instruments so that they can both be operated by the engineer and be equally convenient.

The composite type occupies but little more space than a single inspirator or injector, and, owing to its compactness, it has been found that it can be located in positions where in the past it has not been possible to locate two separate instruments. It places both instruments directly under control of the engineer, and both are equally convenient to operate, the result being that both instruments are operated and kept in good order. Each instrument has an independent suction pipe, delivery pipe and line check-valve, thus enabling each to be operated independent of the other.

In attaching the composite inspirator (either to back head or side of boiler), one steam valve, one steam pipe, one overflow pipe and one opening into the boiler are dispensed with, thus effecting a very considerable saving of material and labor, which would be required with two separate instruments. It is desirable to use a double check-valve in connection with the composite inspirator.

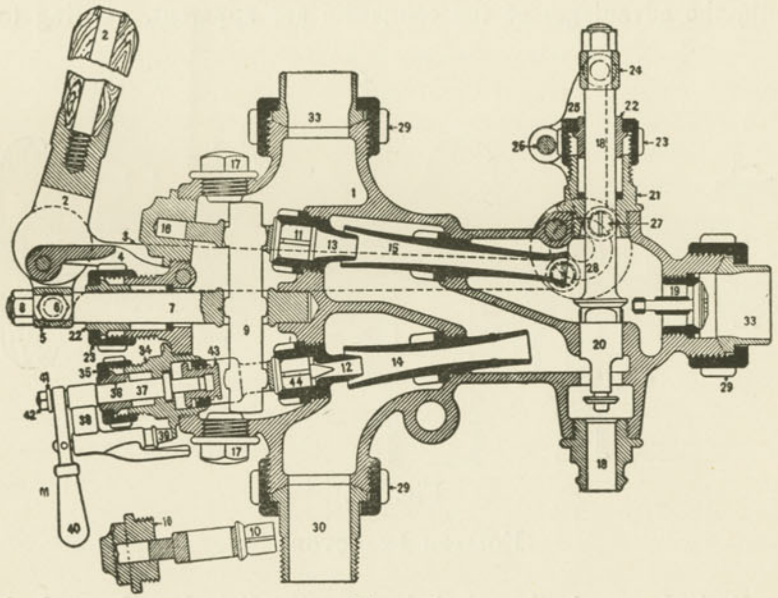


Fig. 19.

KOERTING INJECTOR.

There are a considerable number of other types of injectors in general use, among which are the Lunkenheimer, the Eclipse, Fig. 18, and Koerting, Fig. 19.

Care of Overflow Pipes. An ordinary source of annoyance very often occurs from the overflow nozzle or overflow pipe becoming filled up, contracting the openings so that the injector will not lift or prime promptly. Sometimes it occurs, when the overflow

nozzle is all free and clear, that the overflow pipe is apt to escape the attention of the person doing the repairs or overhauling the injector, and are reported not working satisfactorily. It is almost impossible to ascertain this without removing the pipe. These pipes should always be looked over and kept free.

Care of Check-Valves. The intermediate or line check-valve in the delivery pipe should receive attention. The line check-

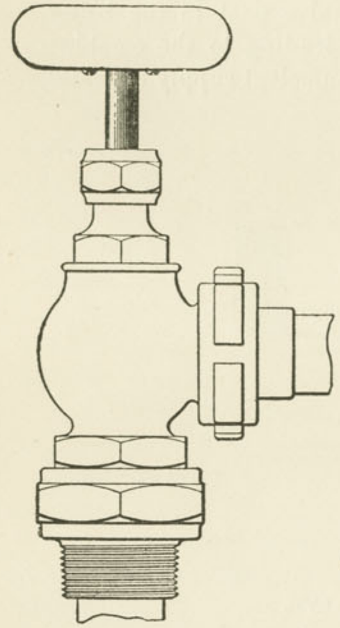


Fig. 20.

INJECTOR STEAM VALVE.

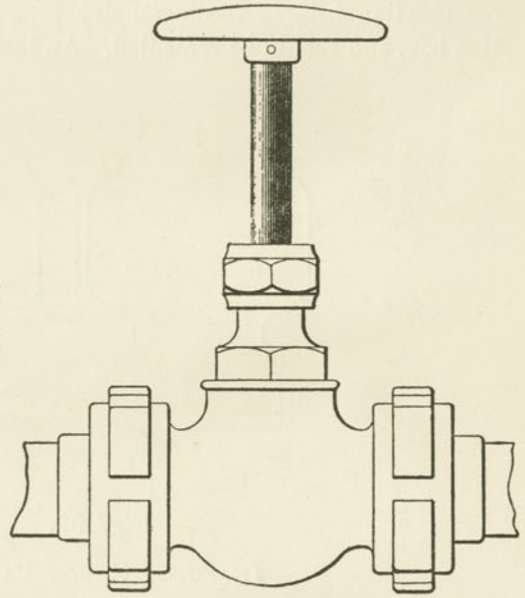


Fig. 21.

INJECTOR FEED VALVE.

valve in the delivery end of the injector, in case of impure water, should be looked after frequently. When the injector is provided with a swing check-valve, care should be taken to keep this valve clear from deposits resulting from impurities in the water.

Care of the Suction Pipe. Where iron suction pipes are used, especially if the pipe is in two pieces and connected by unions, they should be carefully watched to see that they are absolutely tight and well supported, as a very slight leakage of air will materially reduce the capacity of the injector, and if too large a quantity of air is admitted it will cause the injector to break.

Points on Operation. It is very important that there should be ample steam and water supply to all types of injectors. It sometimes occurs that the injector will not work satisfactorily with the regulating valve wide open or at its maximum, but will work when this valve is partially closed or when at its minimum. This indicates clearly an insufficient steam supply. It may be due to the contracted openings in the valve next to the boiler, combination box, or too small dry pipe leading to the combination box, and should be remedied. An insufficient supply of water,

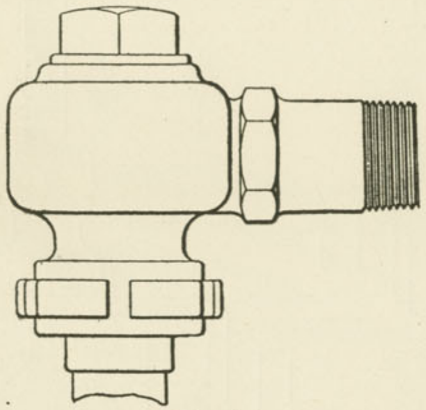


Fig. 22.

INJECTOR CHECK VALVE.

caused by too small size or restricted opening in the tank valve, too small opening in the goose-neck leading to the tank, too small area in the strainer, a kinked or partially collapsed hose, or leaks in the suction pipe, would cause the inspirator to break.

Injector Valves. For controlling the steam flowing through the steam pipe leading to the injector, a steam valve, shown in Fig. 20, is used. The steam pipe for supplying the injector is placed inside the boiler, and the steam valve on the outside, near where the pipe leaves the boiler to run to injector. This valve is closed only when the injector is disconnected or the engine not in use. The feed pipe is connected directly to the boiler, and is carried

forward inside of it to its front end. The feed-valve, Fig. 21, is placed in this line, as is also the check-valve shown in Fig. 22. The check-valve may be placed either inside or outside the boiler, which prevents the boiler from being emptied in case of accident.

Starting an Injector. In starting an injector, if it is a lifting one, the lifting valve should be opened first, and when the water appears at the overflow the forcing valve of the injector should be opened gradually to its full extent. In starting a non-lifting injector the water should be admitted to the injector first, and when it appears at the overflow the steam valve should be opened gradually to its full extent.

Stopping an Injector. In stopping an injector, the steam valve should be pressed firmly and gradually on its seat, avoiding (more particularly in the case of a lever mechanism) the closing of the valve with a sudden shock, which injures the valve and its seat, and has a tendency to loosen these seats where they are inserted in the body of the valve.

Hints to be Followed Before Connecting the Injector. 1. Blow out all pipes carefully with steam before attaching the injector, tapping the pipe with a hammer in order to loosen all the scale.

2. When drip pipe is attached close to overflow of injector, it must be same size as given in table.

3. Always use a dry pipe attachment to insure perfectly dry steam.

4. The diameter of the strainer should be large enough to give an ample supply of water even when some of the holes are choked.

5. Keep all valves steam-tight. All leaks tend to increase rapidly, owing to the velocity with which steam passes through the smallest opening.

6. Keep the steam pipe and chamber free from dirt and chips from the threads on the pipes, and the steam nozzles perfectly clean. The steam nozzle is the life of an injector, and should be maintained in best condition. If the injector is new and the lifting nozzle should fill up, remove from body as described.

7. When grinding the steam-valve, place a rubber washer over the holes leading to the lifting nozzle to prevent the sand from working into the lifting jet; this washer should, of course,

be provided with a hole large enough to admit the plug on the end of the spindle; then screw the steam stuffing-box rather tightly against its shoulder to insure its proper alignment. Keep the steam-valve perfectly tight.

8. To remove lime and scale, immerse the tubes or the whole injector in a bath composed of ten parts of water to one part muriatic acid. Remove as soon as scale is dissolved.

Things to be Remembered About Injectors. Set the injector just above the top water level of the tank. At 8 feet lift, 200 pounds, the capacity is about 10 per cent. less than its rated capacity.

Cold water is best for the injector. Hot water reduces its life and efficiency. At 120 deg. the capacity is about one-third below its rated capacity.

Use large suction pipe and tank-valve connections. If the diameter is increased one size, the gain in capacity is from 5 to 10 per cent.

Use large strainer with small holes. Small strainers require frequent cleaning. If the holes are large, cinders and coal pass through and wear the tubes. If the strainer is too small, the injector does not give full capacity. Be sure that the gasket between hose and section pipe is not squeezed so as to close opening.

Suction pipe must be absolutely tight. Any leak of air reduces the capacity and makes the overflow-valve jump.

Delivery pipe and main check-valve must be of ample area. If an injector gives high back pressure, it is using too much steam. If the delivery opening is too small, the power of the injector is wasted in increased friction in the pipes.

Take good care of the injector. Keep all glands steam-tight, and watch carefully for leaks in the suction pipe. Do not force the steam-valve against its seat; close the valve gently. Start the injector in the same way; at very high pressure the delivery pipe is liable to burst if the lever-starting valve is jerked open. Keep the injector clean, and report at once if not working properly. Do not run with the water-regulating valve wide open all the time.

Failures of Injectors. If an injector stops working while on the road, first ascertain the cause before applying the remedy. It

may be due to a disconnected and closed tank-valve, clogged strainers, loose coupling in feed pipe, which destroys the vacuum necessary to raise the water when starting a lifting injector, stuck check, etc.

Causes of Injector Failures. The most common causes for failures of injectors are the following: Leak in the suction pipe; obstructed strainer or strainer of insufficient size; lining up of the nozzles; loose hose lining; obstructions in the nozzles, such as pieces of coal, or other foreign matter washed in from the tank; obstructions in the delivery pipe, such as a sticking boiler check, which will not open properly; leaky steam-valve and boiler check, which will affect the starting of the injector by heating the suction pipe and the feed water.

Remedy for Injector Troubes. In case the check-valve is stuck open, and is not provided with a stop-valve, it will be necessary to close the heater-cock and water-valve of the injector. In this case reliance for feeding the boiler must be had on the other injector, the check of which must be in good condition. If the boiler check has a stop-valve, this can be closed down to shut off the boiler pressure from the check, in which case the check can be taken out for cleaning, or for the removal of the causes which made the valve stick open.

To determine whether the check-valve is leaking, the frost-cock, with which all delivery pipes and most check-valves are provided, should be opened. If water continues to issue from this first frost-cock, the indication is that the check-valve is leaking. To determine whether the steam-valve is leaking, the cap of the heater-cock and the heater-cock should be removed. If the steam-valve is leaking, steam will issue through the opening. In such cases the check-valve and the injector must be reported for repair, and the leaky valves ground in.

In case the combining tube is obstructed, it must be removed, the nozzles thoroughly cleaned, and all obstructions removed.

When the suction pipe leaks the injector works with a hoarse, rumbling sound, caused by the air drawn in through the leaks. A leak in the suction pipe may also be determined by closing the tank-valve and opening the steam-valve of the injector slightly, with the heater-cock closed. If there is a leak anywhere in the suction line, the steam under such circumstances will issue through the leak.

In case of an obstructed hose or strainer, the connection between the hose and strainer should be broken, and, with the heater-cock closed, steam should be blown back through the strainer. The water allowed to flow through the open hose will usually wash out the obstruction. In most cases it will be sufficient to remove the waste cap of the strainer, and allow water from the tank to flow through to wash out the obstruction.

Leaky Throttle, Steam Pipes or Dry Pipe. If the throttle were closed and steam came out of the cylinder cocks, the cause would probably be a leaky throttle or dry pipe. A leaky throttle will show dry steam only, while with a leaky dry pipe more or less water will pass out of the cylinder cocks with the steam when the engine is standing, and when the engine is working she appears to be working water all the time. Leaky steam pipes interfere with the draft on the fire, and prevent the engine from making steam. They should be tested by placing the lever in the center, setting the air brake, opening throttle and watching the joints of steam pipes top and bottom. If the test is made in the shop, it should be done with hydraulic pressure.

A leaky exhaust pipe joint or a leaky nozzle joint may be tested by placing the lever forward or back, and moving the engine slowly with brakes set and watching the joints. Cinders never accumulate around such leaks, and are always driven away from them.

STEAM GAUGES.

Steam gauges are instruments used for indicating the pressure in the boiler or pipes. The gauge really belongs among the safety appliances of the boiler, as it is consulted very frequently, and its indications taken as representing the actual conditions in the boiler. The gauge should, therefore, be of the most approved pattern, and every effort should be made to have it reliable. It should always be placed in some convenient position so that it may be read at a glance, usually in front of the steam drum. If it is practicable, it is always a good plan to have two gauges, for one would then be a check upon the other. A steam gauge never should be attached to the steam pipe, but always to the top of the drum or boiler; it should stand at zero when the pressure

is off, and it should show the same pressure as the safety-valve when that is blowing off. If not, then one is wrong, and the gauge should be compared with one known to be correct. Every gauge should be calibrated and the needle reset every month. The cost of a calibrating apparatus is very small, and a gauge can be tested and returned to its place on the boiler in less than a half hour. It is a gross neglect to have gauge readings several pounds off, and, with a little care, it can be kept in first-class condition.

There are at present two kinds of gauges in most general use, namely, the Bourdon gauge and the Diaphragm gauge.

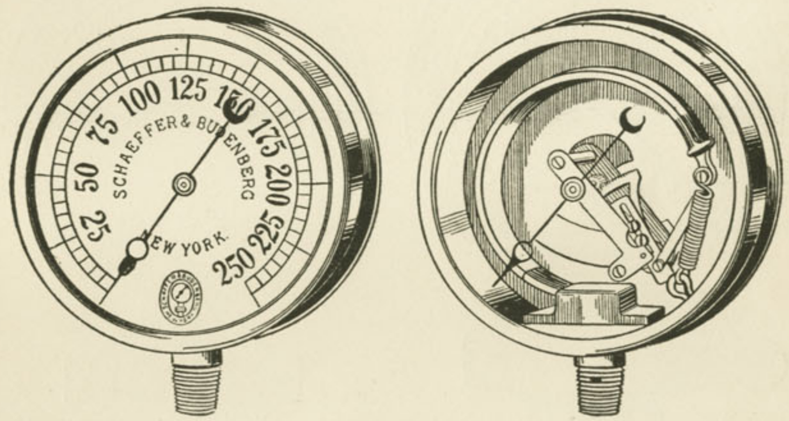


Fig. 23.

Bourdon Gauge.

The Bourdon Gauge. The Bourdon gauge, sometimes called the spring gauge, is represented in Fig. 23. It consists of a curved tube, usually of brass, having an elliptical cross-section. One end of this tube is rigidly fastened at the point where the connection is made to the steam pipe. The other end is closed and left free to be influenced by the pressure within the tube. The pressure in the tube has a tendency to change the cross-section from an ellipse to a circle. This change of section affects the metal differently in the tube, and tends to straighten it. One end being fastened, the other moves outward under the influence of pressure, and operates a gear which meshes with a pinion, upon which the needle is mounted. The needle is thus moved around a circular dial, and readings at known pressure recorded.

The range of the gauge is governed only by the tube, and by varying the thickness of this tube the gauge can be made to read very low pressures or the highest hydraulic pressures. The action of heat on the tube will tend to expand it and change its readings appreciably, so that a siphon is usually attached to the gauge. This siphon collects a quantity of condensed steam, and the steam

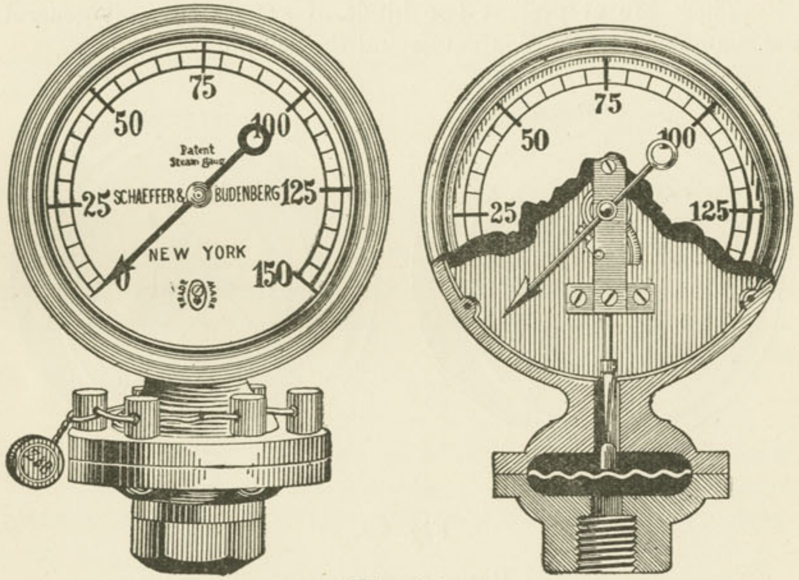


Fig. 24.

Diaphragm Gauge.

pressure is communicated through this water to the tube. If a gauge should become heated while in use, a piece of wet waste put upon the siphon will usually condense enough steam to cool off the gauge and prevent any further trouble. After heating, a gauge should always be checked to make sure that it is not affected.

Diaphragm Gauges. Diaphragm gauges are those in which there is a chamber, usually immediately below the case, as in Fig. 24, or just back of the case. A disc or diaphragm is placed in

this chamber, and the pressure, acting on one side of it, causes it to sag at the center. This force is opposed on the other side by some devices which transmit the movement of vibration of the diaphragm to the needle which moves about the dial. Known pressures are applied and the position of the needle marked on the dial. The scale is thus constructed, and the needle will indicate the pressure of the steam.

The principal difficulty with this form of guage is that the diaphragm will lose its elasticity after a time and become unreliable. This is especially true where metal diaphragms are used. Experiment has shown, however, that the corrugation shown

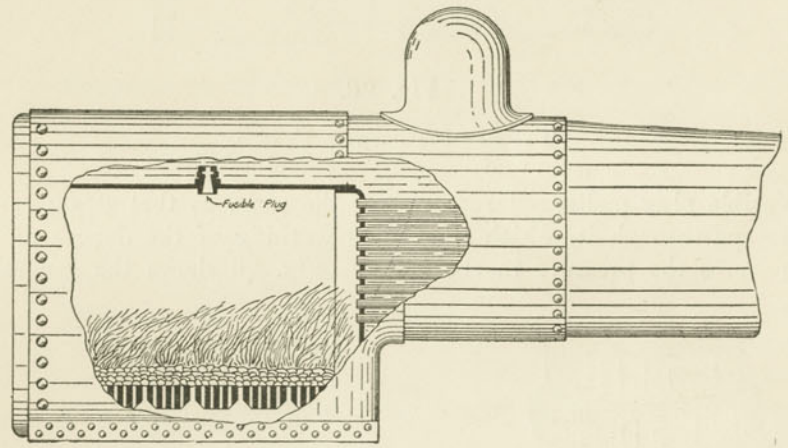


Fig. 25.

Location of Fusible Plug.

in Fig. 24 gives the most durable diaphragm, and is very efficient. The pressure is applied to the diaphragm and acts through it on the plunger, which then transmits the motion through the intermediate mechanism shown in the middle of the diagram. The spring is used to hold the needle firm, and to prevent it from sticking.

FUSIBLE PLUGS.

Fusible plugs are inserted in the highest part of the crown sheet of locomotive boilers, as shown in Fig. 25, as a safeguard against collapse of the furnace crown due to low water. Fusible plugs are made of brass, and are provided with a core of fusible metal composed of an alloy of tin, lead and bismuth. In case the water gets low and the plate dangerously overheated, the

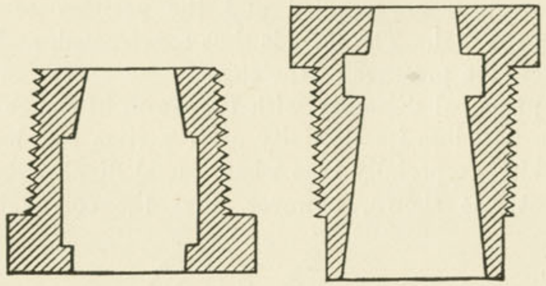


Fig. 26.

TYPES OF FUSIBLE PLUGS.

fusible plug melts and runs out of the plug, so that steam can escape through it, which thus gives warning of the danger and relieves the pressure in the boiler. Fig. 26 shows the general

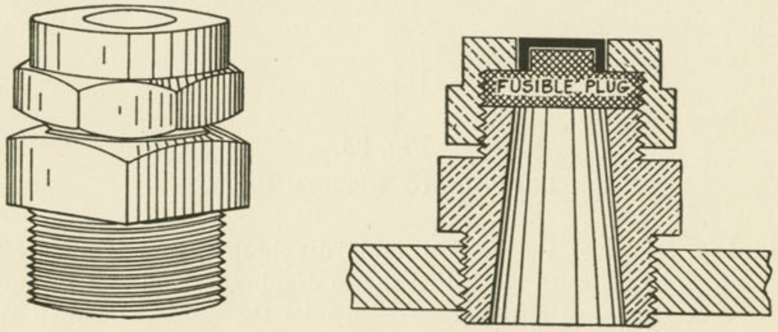


Fig. 27.

COVERED FUSIBLE PLUGS.

form of a fusible plug, with the fusible composition in a conical form to prevent the steam from blowing it out.

The fusible plug should be made in such a shape that when screwed into the crown-sheet it projects one and a half to two

inches above the plate, so that when the alloy melts there will still be sufficient depth of water over the exposed plate to prevent injury from heat. Sometimes the core is covered with a thin copper cap, as shown in Fig. 27, which protects the alloy from contact with the water, thus preventing chemical change and the formation of scale.

Fusible plugs should be examined when the boiler is cleaned, and very carefully scraped clean, on both the fire and water sides. If they are not kept clean, they may not act when they are most needed.

SAFETY VALVES.

The most important safety device used on the boiler is the safety-valve, as it governs the amount of pressure that can be carried by the boiler; it forms an outlet for any pressure in excess of that which should be carried, and it prevents boiler explosions due to high pressure. The universal practice at present is to use at least two safety-valves of the pop type upon every locomotive boiler, these valves being placed upon the dome.

The requisites of a good safety-valve for locomotive work are: The area for the escape of steam should be sufficient to allow it to escape as rapidly as it is formed; its construction should be such that it will close as soon as the pressure has fallen a predetermined amount; it should be so designed that it can neither be tampered with nor get out of order; it must act promptly and efficiently; it must not be affected by the motion of the locomotive.

Richardson Safety-valve. In order to answer all these requisites, special forms of safety-valves are used on locomotive boilers, one of which is the Richardson safety-valve, shown in Fig. 28. In this type the valve A rests upon the seat B. The valve is held down by a spindle C, the lower end of which rests upon the bottom of a hole in the valve A. A helical spring, D, rests on a collar on the spindle. The pressure on the spindle is regulated by screwing the collar E up or down in the muffler casing. The valve seat B may be rounded or straight. Outside of the valve seat there is a projection F, beneath which a groove, C, is cut

20

in the casing. When the valve lifts, this groove is filled with steam, which presses against that portion of the valve outside of the seat, which, by thus increasing the effective area of the valve, causes it to rise higher and remain open longer than it would without this device. The adjustment of the valve is usually

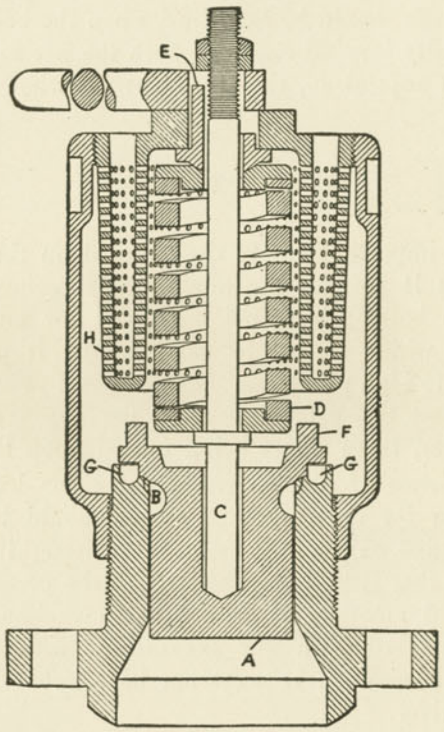


Fig. 28.

RICHARDSON SAFETY VALVE.

made so that, after opening, it will allow steam to escape until the pressure in the boiler is about 4 lbs. per square inch below the normal. The U-shaped, perforated casing H serves as a muffler to decrease the noise caused by the escaping steam. It does this by breaking up the large flow of steam issuing from the main valve into a number of small jets.

American Pop Safety-valves. Other types of safety-valves in general use are shown in Figs. 29, 30, 31 and 32. Fig. 29 represents the American muffled pop safety-valve, the adjustment of which is located directly beneath the cap at top of valve. To adjust the valve, the cap is removed from the top of the valve, and lock nut B is loosened. The pressure at which the valve should blow off is then regulated by bolt A. The blow-back is

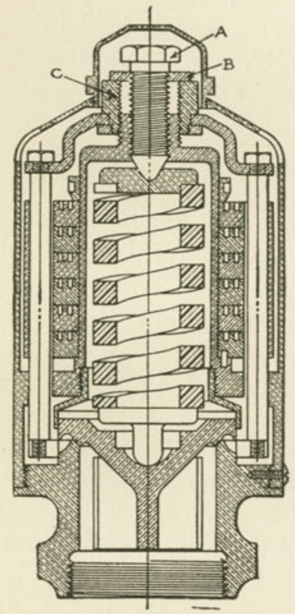


Fig. 29.

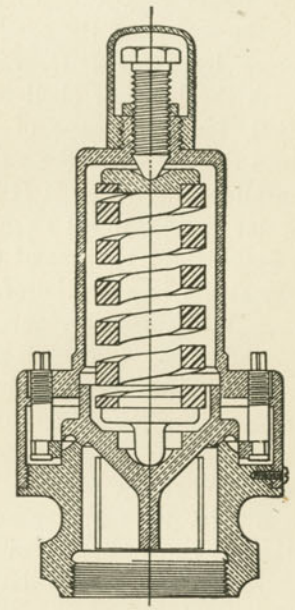


Fig. 30.

AMERICAN POP-SAFETY VALVE.

regulated by the large hexagon nut C, located below the lock nut B. The American open pop safety-valve is shown in Fig. 30. The blowing-off point is adjusted by means of the two square-head relief nuts projecting through the valve casing.

The Crosby Locomotive Pop Safety-valve. Fig. 31 represents the Crosby locomotive pop safety-valve. The valve proper, B, rests upon two flat annular seats, M M and N N, on the same plane, and is held down against the pressure of steam by the steel spiral spring S. The tension of this spring is obtained by screwing down the threaded bolt T at the top of the cylinder R. The area contained between the seats M M and N N is what the steam pressure acts upon ordinarily to overcome the resistance of the spring. The area contained within the smaller seat N N is not acted upon until the valve opens.

The larger seat M M is formed on the upper edge of the shell or body of the valve. The smaller seat N N is formed on the upper edge of a cylindrical chamber C C, which is situated in the center of the shell or body of the valve, and is held in its place by arms D D, radiating horizontally, and connecting it with the body or shell of the valve. These arms have passages, E E, for the escape of the steam or other fluid from the well into the air when the valve is open. This well is deepened so as to allow the wings H H of the valve proper to project down into it far enough to act as guides, and the flange G is for the purpose of modifying the size of the passages E E, and for turning upward the steam issuing therefrom.

When the pressure under the valve is within about one pound of the maximum pressure required, the valve opens slightly, and the steam escapes through the outer seat into the cylinder and thence into the air; the steam also enters through the inner seat into the well, and thence through the passages in the arms to the air. When the pressure in the boiler strains the maximum point, the valve rises higher and steam is admitted into the well faster than it can escape through the passages in the arms, and its pressure rapidly accumulates under the inner seat; this pressure, thus acting upon an additional area, overcomes the increasing resistance of the spring, and forces the valve wide open, thereby quickly relieving the boiler. When the pressure within the boiler is lessened the flow of steam into the well is also lessened, and the pressure therein diminishing, the valve gradually settles down; this action continues until the area of the opening into the well is less than the area of the apertures in the arms, and the valve promptly closes.

The point of opening can be changed while under steam by screwing the threaded bolt at the top of the cylinder. To adjust the valve, screw the head-bolt until the valve opens at the pressure desired, as indicated by the steam gauge; secure the head-bolt

in this position by means of the lock-nut. For regulating the loss of escaping steam, turn the screw ring G up or down for increasing or decreasing it.

Care should be taken that no red lead, chips, or any hard substance be left in the pipes or couplings when connecting the valve with the boiler. Never make a direct connection by screwing a taper thread into the valve, but make the joint with the valve by the shoulder.

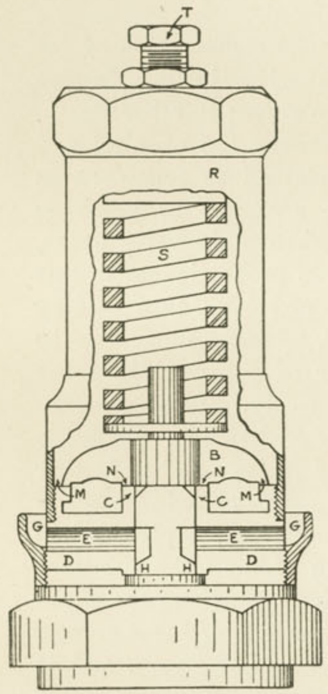


Fig. 31.

Crosby Pop-Safety Valve.

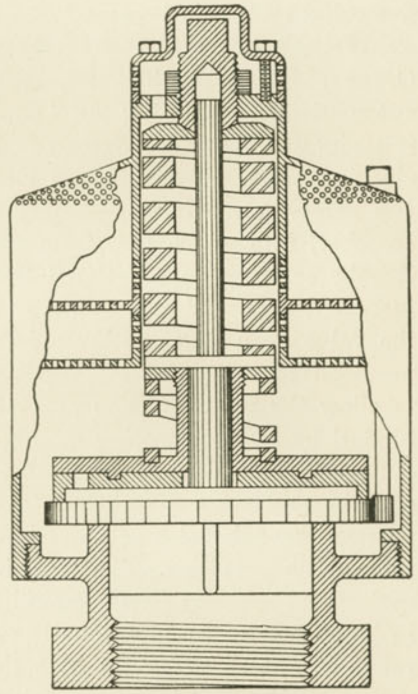


Fig. 32.

Crane Pop-Safety Valve.

To Repair Leaky Valve. The Crosby valve, having flat seats on the same plane, is very easily made tight if it leaks by following these directions, viz.: With an ordinary lathe slightly turn off the two eccentric seats of the valve and valve-shell, or base, respectively, being careful that this is done in the same plane and perpendicular to the axis of the valve. The valve will then fit tightly on the valve shell. If no lathe is at hand, then grind the valve proper on a perfectly flat surface of iron or steel until its two bearings are exactly on a plane, and with good, smooth surfaces; then take the shell and grind its seat in precisely the same manner; rinse both parts in water and put together, and the valve will be found to be tight; to ascertain when the bearings are on the same plane, use a good steel straight-edge. Do not grind the valve to its seat on the shell by grinding them together, but grind each part separately, as above stated.

Crane's Improved Pop Safety Valve. The construction of the Crane safety-valve, Fig. 32, embodies a self-adjusting feature automatically regulating the " pop " of the valve; in other words, it maintains the least waste of steam between the opening and closing points. This is more clearly explained as follows: In pop safety-valves it is necessary to have a "pop," or huddling chamber, into which the steam expands when main valve opens, thereby creating an additional lifting force proportionate to this increased area, and greater than the force of spring, thus holding the valve open until pressure is relieved. Means must also be provided to relieve this " pop " chamber of pressure, in order to allow the valve to close promptly and easily. This is accomplished by a self-adjusting auxiliary valve and spring, which are entirely independent of the main valve and spring; and to further explain their operation, the steam in " pop " chamber finds a passage through holes or ports into an annular space provided in the auxiliary valve or disc, and by reason of the light auxiliary spring this pressure lifts the auxiliary valve and allows the steam in " pop " chamber to gradually escape, thus permitting a greater range in setting pressures with the least waste of steam, and at the same time supplying a cushion or balancing medium, thereby preventing any chattering or hammering, and affording the easiest possible action in closing.

To change pressure, unscrew the top bolts and remove the cap, slacken lock-nut; to increase pressure, turn screw plug down (to the right); to decrease pressure, turn screw plug up (to the left), then tighten lock-nut.

Should the valve waste too much steam between the opening and closing point, turn the outside pop regulator to the left until

the desired waste is obtained. Should it work too close, turn regulator to the right for greater waste.

Size of Safety-valves. No uniform practice has prevailed in the past in proportioning safety-valves for various sizes of locomotives. The locomotive builders follow specifications of the railroads, and it has been the practice of the railroad companies to base their specifications on what has been done before on similar locomotives. During the year 1908, however, the Master Mechanics' Association collected data from the various railroad companies, valve manufacturers and locomotive builders, in order to determine some rule which should prevail in existing practice. Based upon this data, the committee of the Master Mechanics' Association found that the lift of safety-valves varied from 1-32 to 1-10 of an inch, and that the following empirical rule for the size of safety-valves represented the best practice as it exists to-day.

Taking the mean effective area of the opening of the valve as one square inch per 500 square feet of heating surface, this value being based on the existing average practice of twelve railroads, the formula becomes

$$A = \frac{.10266 \times S}{P}$$

in which

A=the effective area of the opening of the valve in square inches.

S=the heating surface of the boiler in square feet.

P=the gauge pressure plus fifteen pounds.

The formula is based on an evaporation of 5.28 pounds of water per square foot of heating surface per hour, and the committee of the Master Mechanics' Association recommends it for use in the application of safety-valves until such a time as it has been shown to be in error, or upon future investigation a better one shall have been devised.

The practice of builders is, however, to use two or three valves, whose combined area shall be equal to 1 square inch to 2 square feet of grate area, with a tendency to make the ratio of grate to valve more rather than less. This is especially true on boilers of the Wooten type, where the ratio may be as high as 1 square inch of valve area to 5 square feet of grate. The usual practice is to use $2\frac{1}{2}$-inch or 3-inch valves.

Whistle. The whistle is used for signal purposes, and consists of a thin cylindrical bell, A, Fig. 33, closed at the top and sharpened at the lower edge. Steam is allowed to escape from a narrow circular orifice B, directly beneath the edge of the bell.

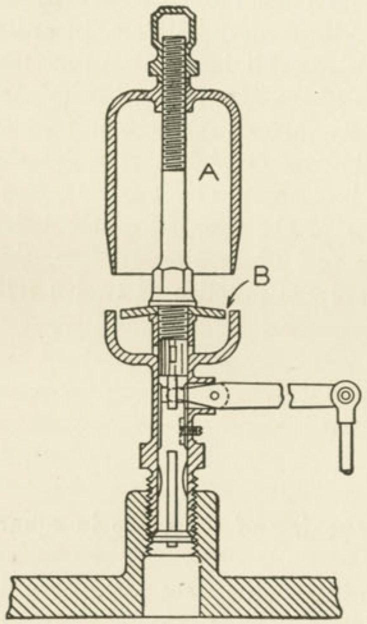


Fig. 33.

WHISTLE.

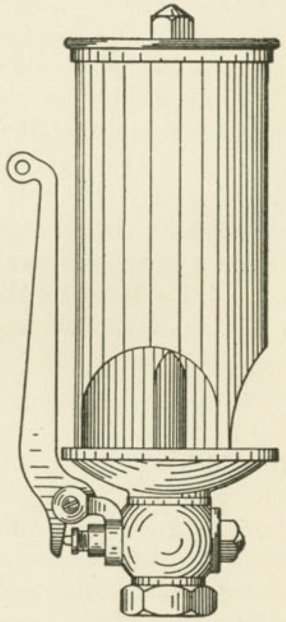


Fig. 34.

CHIME WHISTLE.

Part of this steam enters the interior, and sets up a series of vibrations therein. The more rapid these vibrations, the higher the tone of the whistle. The tone is affected by the size of the bell and the pressure of steam. The larger the bell the lower will be the tone; the higher the steam pressure the higher the tone. In order to avoid the shrill noise of the common whistle, chime whistles are used, as shown in Fig. 34. In these the bell is

divided into three compartments, tuned respectively to the first, third and fifth of the common musical scale, which harmonize and give an agreeable chord.

Blow-off Cocks. One or two large cocks, called blow-off cocks, are generally placed on the side of the boiler or near the bottom of the fire-box, either in front or back, for the purpose of allowing the boiler to be cleaned by blowing out considerable loose mud and dirt with the water.

A blow-off cock may be either a globe-valve operated by a screw; a taper plug-valve, operated by a lever; a sliding disc-valve, operated by a lever, or a plunger-valve, upon whose upper end either steam or air may be forced to unseat it. As the object of any of these valves when open is to permit the escape of sediment and impurities from the boiler, they are located at the bottom of the boiler.

Blower. Another valve found in the cab is the blower-cock, which controls the blower.

The blower consists merely of a steam pipe leading from and fitted with a valve in the cab to the stack, where it is turned upward. The escaping steam gives motion to the air therein, the same as the exhaust steam, and thus induces a draft through the fire-box. It is used when the fire is to be forced while the engine is standing.

Gauge Cocks. Every locomotive is provided with three or more gauge cocks, which are placed in the back end of the boiler, where they are easily accessible. The positions of these cocks on the boiler are shown at C, C, C, in Fig. 35. The upper cock is placed above the point where the surface of the water should be when the engine is working. The middle cock is placed in line with what should be the normal water level in the boiler, and the lower cock is placed below the normal water level. They are placed about 3 or 4 inches apart, and when opened the upper cock should always show steam and the lower one water. Whether the middle cock shows steam or water depends upon the position of the water level between the upper and lower cock. A receptacle D is usually placed below the cocks, so as to catch the water and steam which are discharged from the cocks, and the pipe P carries the water away.

Gauge cocks must under all conditions be kept clean, so that they will operate accurately at all times.

Water Gauge. A water gauge is an instrument used for indicating the level of the water in a boiler. A common form of water gauge is shown in Fig. 36. It consists of two attachments fitted with valves, one for water and one for steam. The water-valve is provided with a pet cock, so as to clean the water glass

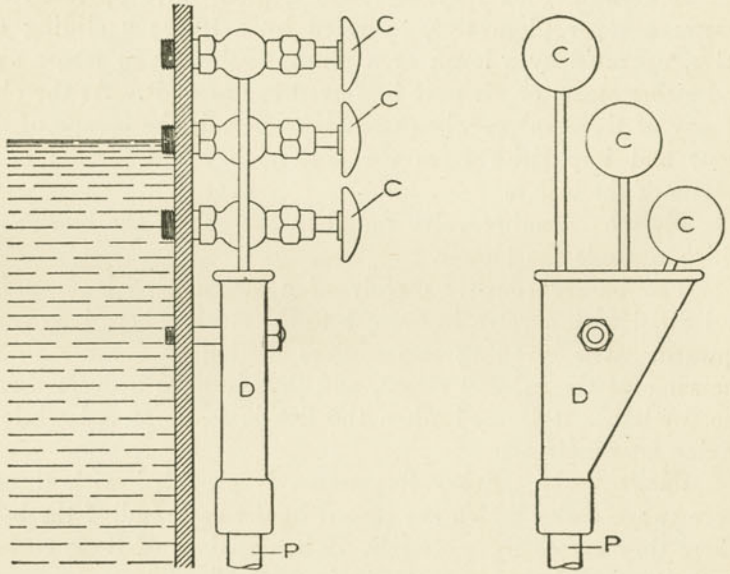


Fig. 35.

LOCOMOTIVE GAUGE COCKS.

and test the lower opening. The glass tube is secured in a stuffing-box at each end. In placing the water gauge on the boiler, it should be at least one inch above the crown sheet, or in line with the lower gauge cock. It is very important that the water gauge should record the proper level in the boiler, so that it should always be attached to indicate the true level, and it should be blown out frequently, and the glass and valve passages kept clean.

Hand-holes. In order to clean out the mud and scale in a boiler, hand-holes are generally placed in the fire-box near the bottom. They are usually oval-shaped holes, about 4½ inches long and 2½ inches wide, and covered with a metal plate, which is

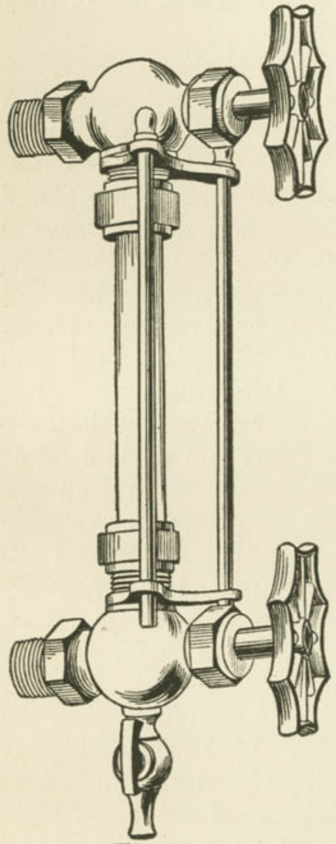


Fig. 36.

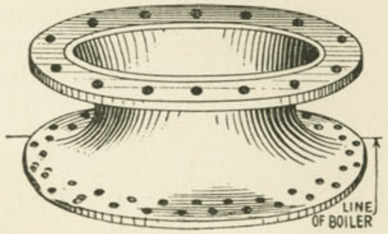


Fig. 37.

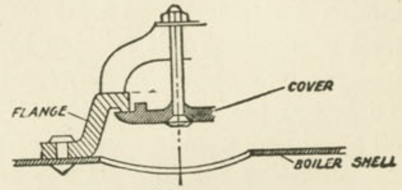


Fig. 38.

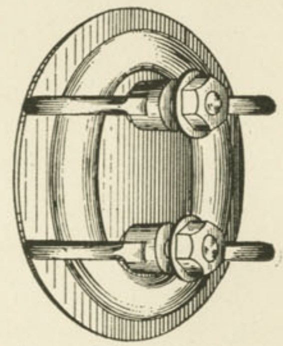


Fig. 39.

fastened by bolts, as shown in Figs. 38 and 39. The cover should have its seat on the inside, in which case a rubber gasket will be sufficient to make a steam-tight joint. Before removing hand-holes all safety-valves should be opened, and the pressure in the boiler reduced to atmospheric pressure.

SIGHT-FEED LUBRICATORS.

Next to the injector, the sight-feed lubricator, with which all locomotives are equipped, is one of the most important locomotive accessories. Generally speaking, every engineer understands how to operate a lubricator, but there are many men who do not fully understand the principles of its operation.

Object of Lubrication. The object of lubrication is the reduction of friction between two surfaces which slide together. A perfectly smooth surface exists only in theory. With the most modern appliances it is possible to produce at the best only a comparatively smooth surface, so that when two surfaces are placed together in sliding contact there will always be some resistance to motion and consequent wear on the surfaces. Oil is, therefore, used to diminish this friction by filling up the irregularities and interposing a thin film between the sliding or revolving surfaces. To insure perfect lubrication the surfaces must be coated with oil at all times, and under all pressures and velocities.

Selecting the Oil. It has been found, however, by long experience, that the best lubricant for cylinders is a mineral oil of good body, with a high flashing point, because a mineral oil possesses a greater number of qualities which go to make up a valuable cylinder lubricant than any other oil. Vegetable and animal oils are not suitable in a cylinder, as they decompose easily, especially at high temperatures, and tallow decomposes to a certain extent, forming stearic acid, which attacks and eats the surfaces of the piston and cylinder.

In selecting an oil for the cylinder of a steam engine, the viscosity of the oil is an important factor. If the engine belongs to the slow-speed type, an oil with high viscosity is necessary, but with high-speed engines the viscosity need not be so high. In either case, however, the viscosity should not be any higher than necessary, since excessive viscosity tends to increase the friction between the molecules in the oil itself. The flashing point is another important consideration. If the steam pressure is high, the oil should have a correspondingly high fire test. The flashing point should never fall below 400 degrees F. in any case, while a range of between 500 and 600 degrees is often demanded by

careful purchasers. It is very difficult to get an oil that will stand a higher temperature than 600 degrees without flashing.

Graphite. A good cylinder lubricant, which is coming into use more and more, is graphite. It is a mineral substance, and gives an exceedingly smooth surface to the interior of the cylinder. Its principal objection has been the difficulty of feeding it into the cylinder. This difficulty has now been overcome by mixing the graphite with oils. Two oils are used of about the same specific gravity, but of such a nature that they will not mix together. The graphite is then mixed with one of the oils very thoroughly, after which the mixture is added to the other oil, and the distribution of graphite is complete throughout the mixture. It has been found that this compound feeds well without clogging the lubricator, while the graphite will not settle, and is always held in suspension.

Principles of Lubrication. The system of lubrication used for oiling the cylinders and valves of locomotive engines is based upon the principle of hydrostatic displacement. The difference in the specific gravity of the oil and water presses the oil from the oil reservoir into the tallow pipe by means of the weight of water entering in the condenser, with which all lubricators are equipped. In other words, the lubricator depends on the action of natural laws, which have to be complied with, or failure is the result. The positive steam pressure in the lubricator and pipes being the same as the back pressure, these soon neutralize each other, and this leaves the positive pressure of the column of water extending through the pipe leading from the condenser, the condenser itself, and the part of the pipe above it; against this is opposed the back pressure of the column of water in the sight-feed glass. As the latter is much less than the positive pressures, the drops of oil are forced through the nozzle.

Changes in Construction. From the time that Nicholas Seibert applied, in 1869, the hydrostatic system of oiling the valves of steam engines, the principal change in the construction of lubricators has consisted in increasing the size of the steam supply pipes and equalizing pipes, producing a more complete equalization of pressure within the lubricator, and in providing steam chest arrangements for the purpose of enabling the lubricator to deliver the oil into the steam chest or cylinder of the engine under even the most unfavorable conditions. These steam chest arrangements are of different types, some consisting merely of an opening of a certain size in the steam chest oil plug; others of valve arrangements, which are supposed to be in continuous vibration, opening and closing in response to the pulsations of pressure in the steam chest.

It was not until 1884, however, that a general attempt was made to apply the hydrostatic displacement principle to oiling the valves and cylinders of locomotive engines. Considerations of convenience and accessibility made it desirable to take the steam supply direct from the boiler, and to connect the oil pipes to the top of the steam chest. This mode of connecting up to the lubricator resulted in the condition that full boiler pressure prevailed at all times at the inlet end to the lubricator, while at the outlet end the pressure was variable, according as to whether the engine was running under steam or with throttle closed, as when drifting on a down-grade or running into a station.

Equalizing Feature. This condition necessitated the use, and resulted in the invention of what is termed the equalizing feature. This feature consists of a steam chamber, located near the delivery end of the lubricator, which chamber is at all times subjected to direct boiler pressure, and from which the steam and oil is permitted to escape through a passage of such small size that the pressure at the outlet end is maintained at practically boiler pressure. By this means the pressure at the inlet to and the outlet from the lubricator is practically balanced or equalized, irrespective of the pressure in the steam chest and in the oil pipes. In some types of lubricators the equalization of pressures is accomplished by using a reduced opening in the steam chest oil plug in connection with or without automatic valves, with full open tallow pipes from the chest to the outlet end of the lubricator, with no choke plug in the lubricator. In these cases the tallow pipes become part of the equalizing steam chamber just referred to.

Proper Size of Choke Plugs. The plan of providing a choke plug in the lubricator and a reduced opening in the oil plug on steam chest, so that there are no living parts or check-valves in connection with the lubricator, which would be liable to wear and necessitate frequent repairs or renewals, has worked successfully.

Maintaining the proper size of choke plugs is one of the prime conditions for the proper operation of the lubricator. This can best be done by having two gauges, one to fit snugly a new and unused choke plug, which has been provided with the proper

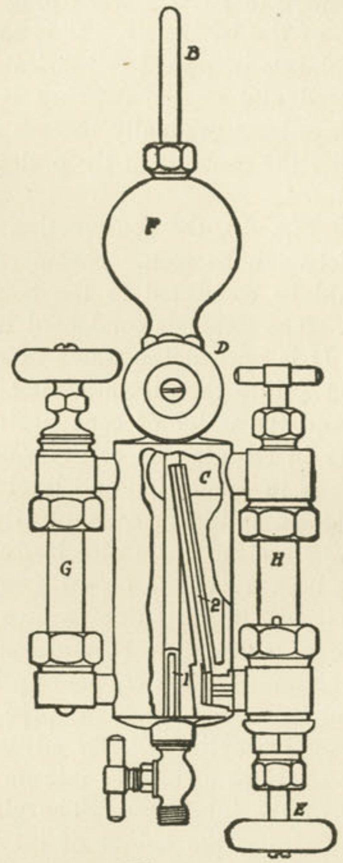


Fig. 40.

Single Feed Lubricator.

opening by the manufacturer, and is to be considered the standard for a certain type of lubricator, and a second one, which might be termed the "rejecting gauge," and which fits snugly a choke plug, which has worn just enough to begin causing the lubricator to feed noticeably faster with steam shut off the cylinder than it does with steam on. Choke plugs through which the rejecting gauge passes should be thrown out of service. Choke plugs may be procured from the manufacturer at such slight expense that it is unwise to allow a worn plug to interfere with the proper operation of the lubricator. It is safe to say that 90 per cent. of the complaints in regard to lubricators feeding faster when throttle is closed and engine drifting is due to the fact that the choke openings have gradually become worn from usage, irrespective of whether the choke is at the outlet of the lubricator or at the steam chest.

By referring to Fig. 40, the construction and operation of the single feed variety can be seen. Steam comes through the pipe B, which should be connected to the boiler some distance above the lubricator. The steam is condensed in the reservoir F, and when the valve D is opened the water of condensation runs through pipe marked I into the oil-containing chamber. Steam also enters pipe C, and the water of condensation fills the sight-feed glass H. Water in the glass H can rise no higher than the pipe C, for this pipe is in connection and level with the delivery pipe leading to the steam cylinder; consequently any more water would simply run over into the steam pipe leading to the cylinder. Water, however, can back up in the pipe B; consequently, if the valve E is opened, oil will be forced down pipe 2 by the hydrostatic pressure of the water in pipe B, and the oil will rise out of the nozzle at the bottom of glass H, pass up through the water in the glass, and find its way through the pipe C into the steam pipe leading to the engine cylinder. By adjusting the valve E, any desired number of drops of oil per minute may be delivered within the capacity of the lubricator. The glass G is used for the purpose of determining the height of oil in the lubricator. The lubricator is known as the "single-connection" type, to distinguish it from the type having two pipes connecting it with the steam pipe.

Two types of sight-feed lubricator which are in general use are the Nathan sight-feed lubricator, shown in Fig. 41, and the Detroit sight-feed lubricator, shown in Fig. 42. In Fig. 41 A is the condenser; B, the filling plug; C, the auxiliary oiler; D, the safety valve; E, the reducing plug; F, the delivery nut and

coupling; G, the water valve; 4, the jam nut; J, sight-feed glass; K, upper sight bracket and nut; L, lower bracket and nut; M, body of lubricator; N, gauge glass plug; O, gauge glass; P, upper

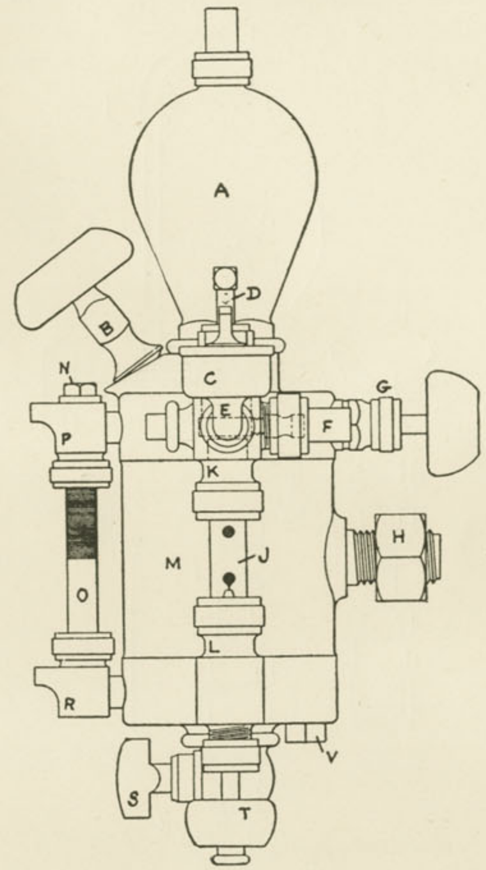


Fig. 41.

Nathan Sight-Feed Lubricator.

gauge bracket and nut; R, lower gauge bracket and nut; S, waste cock; T, regulating valve, and V, bottom plug.

The different parts of a Detroit sight-feed lubricator, shown in Fig. 42, are A, the condenser; B, filling plug; C, auxiliary oiler; D, connection for boiler pressure; E, plugs to fill glasses with water when lubricator is first attached; F, tail pipe; G, water valve; H, jam nut; J, sight-feed glass; K, drain valve; L, the regulating valve.

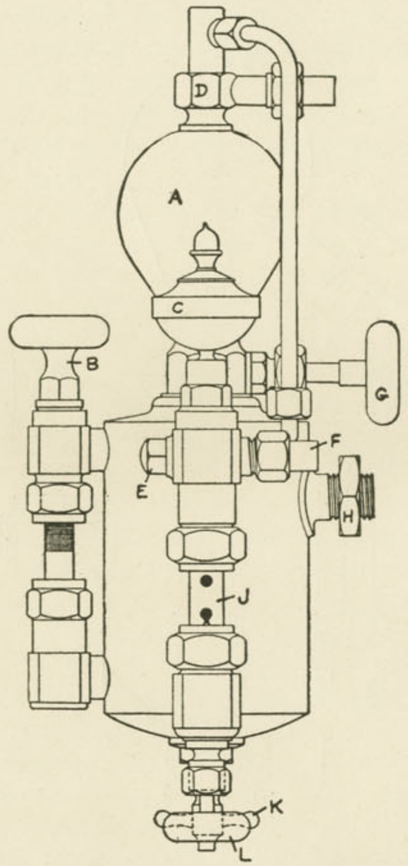


Fig. 42.

DETROIT SIGHT-FEED LUBRICATOR.

Bull's-eye Lubricators. A constructive change of vital importance in the design of locomotive lubricators consists in replacing the tubular sight-feed and gauge glasses by a form of glass best known by the designation, "Bull's-eye." These glasses have

the form of a thick, round disç. The chances of their breaking are reduced to a minimum, and even if they do break or crack they will not fly around, but will remain imbedded in their casings, so that the enginemen are safeguarded against injuries which may result from broken glasses. The fact that these glasses are safe under high pressure also resulted in the elimination of

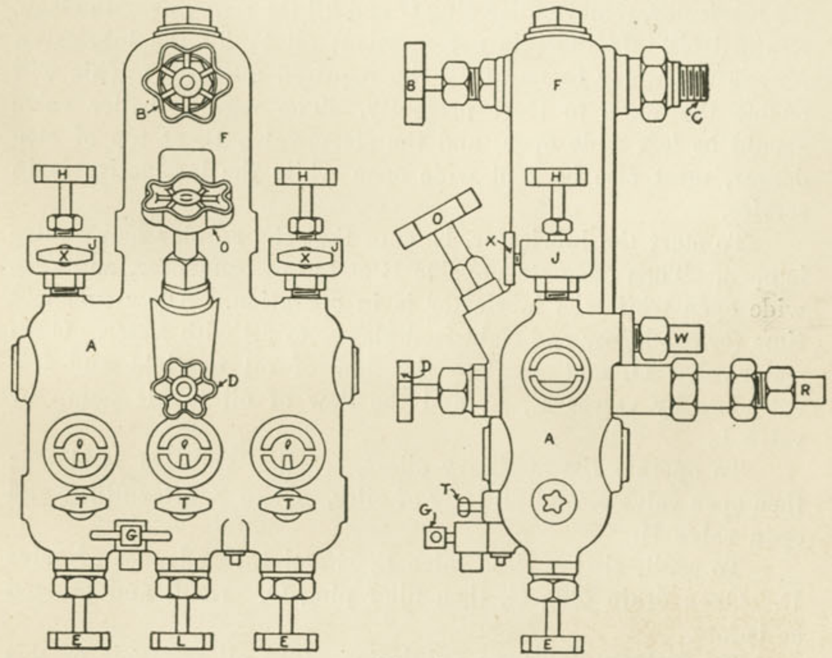


Fig. 43.

DETROIT BULL'S EYE LUBRICATOR.

parts which otherwise would have been necessary, making the lubricator simpler and more compact, reducing the number of parts, and, therefore, also the cost of maintenance.

The Detroit Bull's-eye Lubricator. This type of lubricator is shown in Fig. 43, and, as will be noticed, the sight-feed glasses take the form of a "bull's eye." By referring to Fig. 43 the designation of the different parts are shown. A is the oil reservoir; F, the condenser; B, steam valve; E, E, feed-regulating valves to right and left-hand cylinders; D, water feed-valve; G, drain-valve; C, steam connection; J, J, auxiliary oilers; L, feed-regulating valve to air pump; O, filler plug; R, coupling to air pump; T, T, T, sight-feed drain stems; W, W, coupling to right and left-hand cylinders; X, valve on auxiliary oiler.

In the operation of this lubricator, steam is taken from the turret or from dome through an independent dry pipe. To fill the lubricator, remove filler plug O and fill the reservoir with clean, strained oil. If there is not sufficient oil to fill the lubricator, always use water to make up the required quantity. This will enable the feeds to start promptly. The regular boiler valve should be left wide open, and the steam-valve B, at top of condenser, must also be kept wide open while the locomotive is in service.

To start the lubricator, be sure that the regular boiler-valve is open. Then open steam-valve B at top of condenser, and keep wide open while the lubricator is in operation. Allow sufficient time for condenser and sight-feed glasses to fill with water. Open water-valve D, and regulate the flow of oil to right and left cylinders by valves E, E, and the flow of oil to air pump by valve L.

To operate the auxiliary oilers, see that valve H is closed; then open valve X and fill body of oiler. Close X after filling and open valve H.

To refill, always close valve E, E and L in advance of valve D. Open drain plug G, then filler plug O. Refill and proceed as before.

The Nathan Bull's-eye Lubricator. The oil reservoir of this lubricator is of cylindrical form, which is the most suitable form for high pressures. Fig. 44 represents a Nathan triple sight-feed cylinder lubricator of the bull's-eye type, in which 1 is the condenser; 2, the filling plug; E, hand oiler; 6, delivery nut and tail-piece; 7, water valve; 9, sight-feed glass and casing; 9a, feed nozzle; 11, body of lubricator; 13, gauge glass and casing; 14, waste cock; 15, regulating valve; 16, top connection; 20, sight-feed drain valve; 21, reserve glass and casing; 22, cleaning plug; 23, body plug; 24, oil-pipe plug; 25, gauge glass bracket; 29, cleaning plug for gauge glass; 30, gauge glass cap.

As shown in Fig. 44, the lubricator is provided with hand oilers for the cylinder feeds, and with gauge glasses, which indicate when the reservoir is nearly empty. The lubricator carries a reserve glass, packed in its casing, ready for use whenever occasion requires. All glasses are packed in casings which screw into

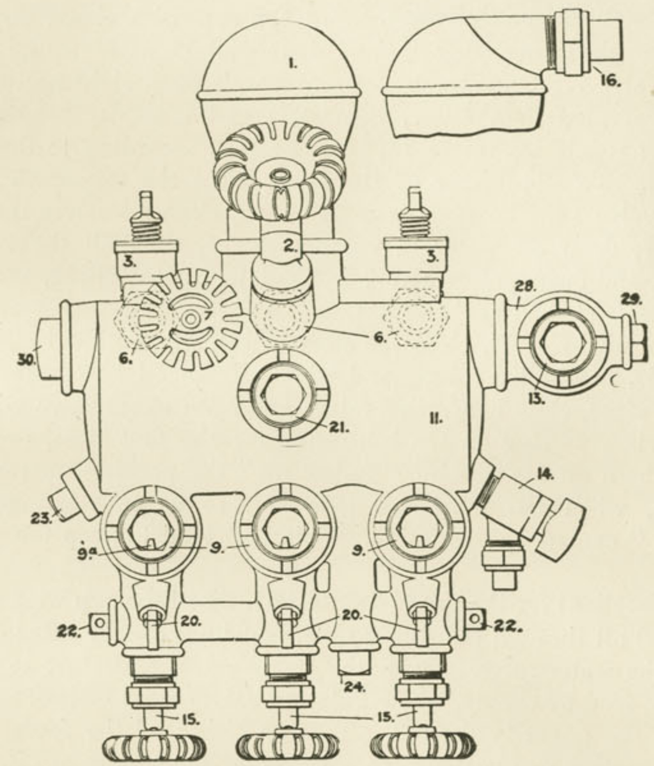


Fig. 44.

Nathan Triple Sight-Feed Cylinder Lubricator.

the body, making their removal for inspection or repairs very convenient.

Directions for Application. 1. Secure the lubricator to boiler head or top of boiler in the usual manner.

2. Connect for steam to fountain or turret, if large enough, otherwise direct to boiler. The steam pipe must not have less

than ⅝-in. inside diameter when iron pipe is used, and not less than ⅜-in. inside diameter when copper pipe is used. Steam-valves and their shanks must have openings fully in accordance with these dimensions.

3. Oil pipes must have a continuous fall towards the steam chest, without any "pockets" in them.

Directions for Operation. Fill the cup with clean, strained oil through filling plug 2, and immediately after filling open water-valve 7. Open steam-valve and wait until sight-feed chambers are filled with water, then start and regulate the feed by opening regulating-valves 15, more or less, according to the feed desired. To stop either of the feeds, close the respective regulating-valve 15. To renew supply of oil, close all valves, 15 and valve 7, draw off water at waste cock 14, then fill the cup as before, and open water-valve 7 immediately after filling, whether the feed is started again or not.

To oil by hand, close the steam-valve, fill the hand oilers 3, open the hand-oiler valves, and when all the oil has entered the tallow pipes, close hand-oiler valves and open steam-valve wide.

When putting on the lubricator for the first time, or after it has been off for repairs, "follow up" the packing nuts of the glasses, when the lubricator gets hot, so as to take up any "slack" caused by expansion. This will tend to keep the joints tight.

Directions for the Use of Lubricators. Fill the cup with clean, strained oil through the filling plug, and immediately after filling open the water-valve. Open the steam-valve, and start to regulate the feed by opening the regulating valves more or less, according to the quantity desired. To stop either of the feeds, close the respective regulating-valve. To renew the supply of oil, close the regulating and water-valves, draw off the water at the waste-cock, then fill the cup as before, and open the water-valve immediately after filling, whether the feed is started again or not.

Gauge glass-valves must be always kept open, except when one of the glasses breaks. In such case close valves belonging to the broken glass, and use the auxiliary oiler on that glass on down grades as a common cab oiler. In a multiple-feed lubricator the breaking of one glass does not interfere with the proper function of the others.

Always open the steam-valve before the engine begins to do any work whatever, whether the feed is started right away or not, and keep it open as long as the engine is doing service of any kind.

Keep the water-valve always open except during the period of filling.

Once in two weeks, at least, blow out the cup with steam; open the valves wide, with the exception of the filling plug, which should remain closed.

Care of Lubricators. Since the lubrication of valves and cylinders is very important in maintaining the running condition of the engine, the lubricator should always be kept in the best of condition. Leaky valves should be attended to and ground to make them tight, as a small leak may continue to grow until the valve seat is cut so deeply that it cannot be repaired. Rubber washers of the glass packing should be kept in good repair. Pure rubber is not recommended for this purpose; but a good quality of rubber, interlaced with canvas, will be found to be the most serviceable. The lubricator should be blown out occasionally by steam, in order to open up the steam and air passages. Under ordinary conditions about once in two weeks will be sufficient, but should soda ash or other scale preventative be used, the lubricator will have to be blown out more frequently.

The equalizing oil and water tubes should be inspected occasionally, to see that they are tight and sound; in fact, the whole lubricating system should be inspected periodically for any small defects.

Lubricating Engines with Superheated Steam. Hydrostatic lubricators will work successfully to lubricate the valves and cylinders of engines using superheated steam, but in some cases a mechanically operated oiler may be used. When a hydrostatic lubricator is used on a locomotive using superheated steam, there should be one oil pipe from the lubricator leading direct to the cylinders, at about the center of them, so that the oil fed from the lubricator to the cylinders may be properly distributed. This pipe should be added in addition to the oil pipe, and connected to the valve chest.

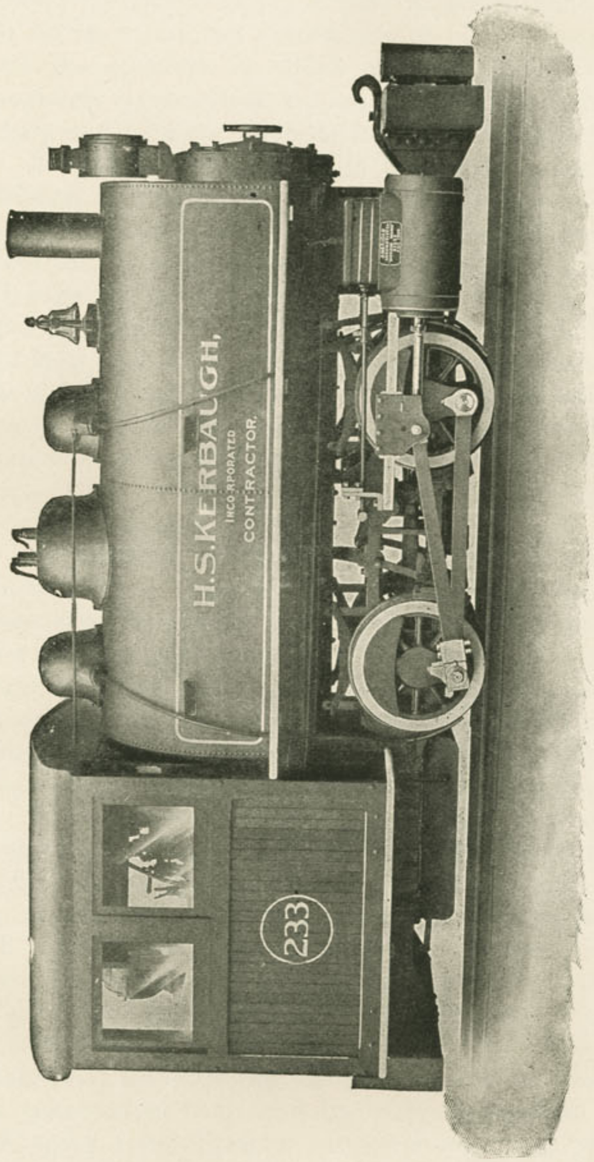
In order that the lubricator should properly operate, it is of utmost importance that the recommendations of manufacturers should be carried out to the letter, as to sizes of pipes as well as the directions for manipulating the lubricator. If a manufacturer specifies for steam supply a pipe of ⅜-inch inside diameter, it will not do to use this correct size of pipe in connection with a valve the openings in which are only half that size. Such thoughtless combinations are not infrequent, and for the unsatisfactory results in operation the lubricator is undeservedly blamed.

Cleaning Feed Stems. With high steam pressures there is a tendency, even with good valve oil, to deposit a gummy substance resembling vaseline around the feed stems and cones. This substance can be removed, and the glasses cleaned and filled by the following method: After the oil is all fed from the lubricator, leave the pressure turned on and close all feeds but one; open vent stem to this one, which will allow the condensation to circulate and thoroughly cleanse the feed stem, cone and glass. Close vent stem. The glass immediately fills with condensation from lubricator. Close feed stem. Repeat same operation with other feeds. Close the water feed-valve, blow out body and fill with oil in the usual manner.

Arrangement of Piping. It is of the greatest importance that there be no traps in the oil pipes between the lubricator and steam chest, otherwise the oil will trap. The time required to fill a trap depends largely upon the diameter of pipe, and form or length of a trap, as well as the rate of feed per minute. It must be remembered that the oil pipes are filled with steam at boiler pressure and temperature; that circulation or draw of steam is equal to the diameter of the choke at the steam chest.

It must be evident that the practice of locating the oil pipes on top of the boiler head of the Belpaire or whale type of boilers, or running the oil pipes on a level the full length on the side of the fixe-box before the oil pipes incline towards the steam chest, will cause a trap when the locomotive is ascending grades; in other words, the locomotive and the grade form a trap, unless the oil pipes have a gradual descent from lubricator to steam chest.

Shuttting Off a Lubricator Before Filling. When shutting off a lubricator before filling, the feed-valves should be shut off first, the water-valves next, and the steam-valves last. Bad results will ensue from filling a lubricator full with cold oil if the lubricator is not provided with an expansion chamber, because oil



FOUR WHEEL SADDLE TANK 0-4-0-T-TYPE LOCOMOTIVE
(American Locomotive Company)

expands about $\frac{1}{5}$ in volume while being heated from about 70 degrees to the temperature of steam at 200 lbs. pressure, which is 387.7 degrees F.

Care of Lubricator on Sidings. While waiting on sidings, the better practice is to close the water-valve instead of the regulating-valve. By so doing the hydrostatic pressure is cut off from the body of the lubricator, and the pressure within the body of the lubricator equalizes with that in the feed-glass chamber. Then, by opening the water-valve, the feeds will start off at the same number of drops per minute as originally, as the adjustment has not been interfered with. It is not generally understood that if it becomes necessary to do any switching, or if the engineer wishes, for any reason, to feed less oil, he can slow down the number of drops per minute by simply throttling the water-valve. This will give the same effect as adjusting the feeds to a slower rate. The only objection that can be made to closing the water-valve in these cases is that the air pump does not receive oil while the water-valve is thus closed.

Lubricator-valves should be opened in the following order: First, the steam-valve. Next, the water-valve. Last, the regulating stems. Under no circumstances should the water-valve be opened first.

Causes of Irregularity of the Feed. Irregularity of the feed may be caused by throttling the steam to the lubricator down to that point where it becomes wire-drawn, in which case the combined steam chest pressures would overcome the lubricator pressure, and the feed would slow down; also, if sediment should gather in the water passage to such an extent that the openings would be closed up, this condition would be similar to throttling the water-valve, and would reduce the number of drops per minute. When the opening through the small choke in the automatic steam chest plug becomes enlarged beyond 7-64 in., the rate of feed will also vary. The same will happen when the opening through the chokes at the lubricator end of the oil pipe in some type of lubricators becomes enlarged.

If the feeds should stop while running, the best plan to follow is to shut feed valve, blow out glass thoroughly, permit it to fill with water, and start feed. If this does not give the desired result, at first opportunity disconnect tallow pipe from steam chest valve and blow out the tallow pipe. Put the reverse lever on center and give engine steam. This will clean out the chest-valves and oil plug.

Cleaning Sight Feeds. If the sight feeds get stopped up, they should be cleaned by either of the following methods: First, open the feed-regulating valve wide to the feed in question, and open the sight-feed drain stem. The result will be a lessened pressure in the sight-feed chamber, which will force the clogging matter out of the cone. If the obstruction is too great to be forced out in this way, try closing the other regulating feed stems, and also the water-valve. Open the drain-valve to the body of the lubricator. This will allow the pressure to escape through the body of the lubricator, and at the same time the steam pressure will blow down through the feed cone, and will dislodge the obstruction and force it into the body of the lubricator.

Cleaning Choke Plugs. To clean the choke plugs, take them out and examine them. Run a small wire through the opening. They should be renewed when the opening is larger than 7-64 in. in diameter.

The main object of the equalizing tubes is to overcome the back pressure from the steam chest. At the same time it furnishes condensation to the sight-feed chambers. By the use of these tubes the same pressure exists on top of the water in the sight-feed chamber as on the surface of the water in the condenser, and this steadies the feed.

Impurities in the Oil. Straining of the oil before it is placed in the lubricator is a precaution, the importance of which is frequently overlooked. Floating particles of foreign substances in the oil may easily find their way to the choked openings wherever located; close the small openings, and eventually stop the operation of the lubricator altogether. It is much easier to prevent than it is to cure this trouble.

The rubber washers of the glass packing should be kept in good repair. Pure rubber should not be used. A good quality of rubber, interlaced with canvas, is found to be the most serviceable.

Blowing Out Lubricators. Steam and oil passages should not be allowed to be obstructed by corrosion. This can be prevented by blowing out the lubricator occasionally by steam, which should be done at least once in two weeks. If soda ash, or other such scale preventative, is used, the lubricator will have to be blown out more frequently, and if water works over into the lubricator when the boiler is foaming, the sight-feed chambers ought to be blown out at once, and allowed to fill up with condensed water which is pure and clean.

The equalizing oil and water tubes should be looked after occasionally, to see that they are sound and tight, as the breaking or looseness of any of these will offset the proper operation of the lubrication.

When Lubricator Should be Started. As it takes from twelve to twenty minutes to get the first drop of oil from the lubricator to the steam chest, the lubricator should always be started at least twenty minutes before leaving the terminal or yard, because in the interval during which the engine is left standing the cylinders and chests are washed completely clean of all lubrication by the condensation that accumulates in the steam chest, and the oil escapes through the cylinder cocks. When the engine is ready to start out on a trip, the valves and cylinders are entirely free from lubrication, so that unless the engineer turns on the lubricator some time before starting his run, he will run a considerable distance with a dry engine.

Lubricator Pointers. DON'T FORGET that a lubricator will give better results if it is cared for intelligently.

DON'T FORGET that the water passage will close up with sediment and cut off the water between condenser and oil reservoir as completely as if the water-valves be closed.

DON'T FORGET that a lubricator should be blown out at least once a week, and in bad water districts oftener.

DON'T FORGET that a piece of soap put in the reservoir about once a week will keep it clean, also the glasses.

DON'T FORGET that valve oil and engine oil should never be mixed and put in a lubricator. The temperature of the lubricator is too great for engine oil; besides, the engine oil will carbonize. As soon as it passes up and out of sight-feed chamber it comes in contact with the high steam temperature, and all lubricating properties have been destroyed.

DON'T FORGET that particles of carbonized engine oil have no more lubricating properties than powdered charcoal would have.

DON'T FORGET that if your valve-oil supply is not sufficient to reach a terminal point at the regular rate of feed, feed the lubricator slower, carry less water. Don't wet the valves; run with a lighter throttle, a longer cut-off, and do not allow your engine to drift into town or down hill, but work a very light throttle.

DON'T FORGET that the chokes at the steam chest are constantly cutting away by the action of the steam.

DON'T FORGET that the chokes balance a lubricator.

DON'T FORGET that the steam valve on a boiler, and the one on top of the condenser, must be opened wide in order to counteract the two steam chest pressures.

DON'T FORGET that the quantity of oil per mile increases as the speed of a train decreases, and it correspondingly decreases as the speed of the train increases.

DON'T FORGET that as the engine is running very slowly on the hill, the lubricator is increasing the quantity of oil per mile in proportion to the speed.

DON'T FORGET that salt water is more buoyant than fresh water, and for that reason it will force the drop of oil off the feed cone sooner. There would be more drops of oil in a minute than when the water in the sight-feed chamber was fresh, but the quantity of oil would not be any less.

DON'T FORGET that the water in the sight-feed chamber becomes salty, and it is carried over from the boiler by the mechanical action of the steam.

DON'T FORGET that there is a constant evaporation taking place in the condenser of any kind of locomotive lubricator. The same is true in the outlet of the sight-feed chamber.

DON'T FORGET that there are two principles involved in a locomotive lubricator. First: Hydrostatic. The hydrostatic pressure ends on the point of the feed cone. From that point to the surface of the water in the sight-feed chamber the oil travels at the rate of 30 feet per minute. Second: The oil coming in contact with the steam is carried to the steam chest by the laws of gravity, heat and motion.

DON'T FORGET that the chokes at the steam chest give better results. That the boiler pressure reaches down to the steam chest, chokes and prevents back pressure from backing up into

the oil pipe, also the lubricator is feeding against a constant boiler pressure, and not against a fluctuating oil-pipe pressure, as when the chokes were located at the lubricator.

DON'T FORGET that the oil should be strained. Lubricators are not guaranteed to feed sawdust, coal, waste or any such substances.

Force Feed Lubricators. A great deal of discussion has taken place among engineers, especially since the introduction of superheated engines, as to whether the hydrostatic lubricator will suc-

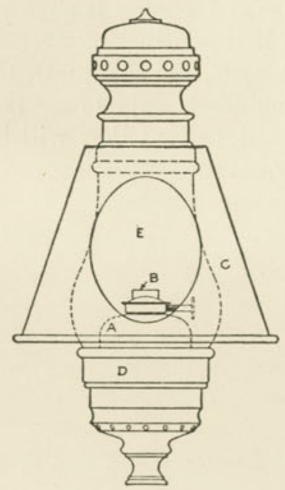


Fig. 44.

STEAM GAUGE LAMP.

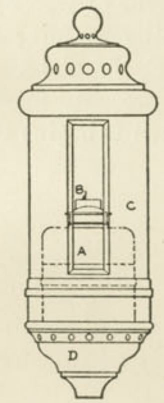


Fig. 45.

WATER GAUGE LAMP.

cessfully lubricate such engines, or whether the use of forced feed lubricators, operated mechanically from some moving part of the engine, becomes a necessity. Tests have shown, however, that hydrostatic lubricators will successfully and effectively lubricate the valves and cylinders of superheated engines, and that the use of mechanically operated lubricating pumps becomes a matter of preference rather than necessity.

The advantages of a positive oil feed have led to the development of the force feed lubricator driven by some part of the engine gear. They are all small mechanical oil pumps, and the amount of feed can be easily regulated. They are made with single or multiple feed, depending on the service. The force feed lubricator consists of a closed oil chamber, to which are attached one or more pumps, and they can feed oil of any viscosity, for they are not subjected to any of the difficulties of the hydrostatic sight-feed lubricator.

Steam Gauge Lamp and Water Gauge Lamp. To enable the engineer to notice quickly the reading of the steam gauge and the level of the water gauge, special types of lamps are used which throw the light upon the gauges without lighting up any other portions of the cab. A type of steam gauge lamp is shown in Fig. 44, and a type of water gauge lamp is shown in Fig. 45. A represents the oil reservoir; B, the burner; C, the shade; D, the lamp base, and E, the globe. It is the engineer's duty to see that these lamps are properly filled and trimmed, so that they will be ready for use when it begins to grow dark.

REVIEW QUESTIONS.

BOILER FITTINGS AND ATTACHMENTS.

1. Explain the use of the dry pipe, and the method of connecting it to the boiler.
2. Explain why the steam pipe must be connected with flexible joints.
3. Explain two kinds of flexible joints in general use.
4. What is the throttle-valve, and where is it generally located?
5. Explain the advantages of the poppet type of throttle-valve over the slide-valve.
6. Sketch a simple form of throttle lever, naming its different parts.
7. State briefly what are the fundamental principles of the operation of an injector.
8. Name the essential parts of an injector.
9. What is the difference between a lifting and a non-lifting injector?
10. Explain how the capacity of a Metropolitan injector is regulated.
11. Explain how you use a Metropolitan injector as a heater.
12. Explain briefly the general arrangement of the different parts of a Sellers injector.
13. Explain the general method of operating a Little Giant locomotive injector.
14. How is the regulation from maximum to minimum accomplished when using the Hancock locomotive inspirator?
15. Where should the Hancock inspirator be located so as to obtain the best results?
16. How does the composite type of Hancock inspirator differ from the usual type?
17. When an injector is provided with a swing check-valve, what care should this check-valve have?

18. What precautions are necessary in the care of overflow pipes?

19. If the suction pipe of an injector is made of iron pipe, and the injector breaks, where would you look for the trouble?

20. If the injector will not work satisfactorily with the regulating valve wide open, but will work when this valve is partially closed, what does it indicate, and where would you look for the trouble?

21. Explain the method of starting a lifting injector.

22. Give at least six precautions which should be taken before connecting up an injector.

23. Name half a dozen reasons why injectors fail to pump water into a boiler.

24. How would you discover whether the check-valve is leaking?

25. If you had a leaky exhaust pipe or a leaky nozzle joint, how would you discover it?

26. If the throttle was closed, and steam came out of the cylinder cocks, what would be the probable cause?

27. Name two kinds of steam gauges in general use.

28. Explain the general construction of the Bourdon gauge.

29. Explain why it is necessary never to let a gauge of this kind become heated while in use.

30. Explain the construction of a Diaphragm gauge.

31. Of what use are fusible plugs in a locomotive boiler, and of what material are they made?

32. Where are fusible plugs located in a locomotive boiler?

33. What care should be taken of fusible plugs, so that they will operate when they are most needed?

34. Name several requisites of a good safety-valve.

35. How many safety-valves are generally used upon locomotives?

36. Where are the safety-valves of a locomotive generally placed?

37. Explain the operation of a Crosby locomotive pop safety-valve.

38. Explain the method of adjusting the Crosby valve, so that it will blow off at the proper pressure.

39. Describe briefly the general construction of the Richardson safety-valve, and explain how the spring can be adjusted to blow off at the required pressure.

40. What is meant by a muffler safety-valve, and explain how the sound of the escaping steam is muffled?

41. Explain what determines the size of safety-valve for a given boiler.

42. Of what use is a blow-off cock, and name several different types in general use?

43. Where is the blow-off cock located, and why is it used?

44. Explain the general construction of a gauge cock, and explain where they should be located in reference to the water level.

45. Explain the general construction of a water gauge, and explain how it should be located on a boiler so as to give the proper water level.

46. Of what use are hand-holes, and where are they generally placed?

47. Explain the general construction of a single-feed sight-feed lubricator.

48. What kind of oil should be used in the cylinder of a locomotive?

49. Explain the general principle upon which all hydrostatic lubricators operate.

50. What is the equalizing feature as applied to a sight-feed lubricator?

51. What are the choke plugs of a lubricator, and why are they used?

52. If a lubricator is feeding faster when the throttle is closed and the engine drifting than when the throttle is open, what is the usual cause?

53. Describe the difference between an ordinary sight-feed lubricator and the bull's-eye lubricator.

54. Of what advantage is the bull's-eye lubricator over the ordinary form of sight-feed lubricator?

55. Describe briefly the construction of the Detroit bull's-eye lubricator.

56. Explain the methods of connecting a Nathan bull's-eye lubricator to the boiler.

57. Will hydrostatic lubricators operate successfully on engines using superheated steam?

58. When connecting up lubricators, what particular precaution should be taken as to the proper sizes of pipes?

59. Should a gummy substance be deposited around the feed stems and cones, what method may be used for removing it?

60. When shutting off a lubricator preparatory to filling, explain the methods of shutting and opening the valves.

61. When the engine is waiting on sidings, is it better practice to close the water-valve or the regulating-valve?

62. After the lubricator has been filled, explain the order of opening the different valves.

63. If the sight feeds get stopped up, explain a method for cleaning them.

64. How would you clean the choke plugs of a lubricator?

65. What precaution should be taken to prevent impurities from entering the oil?

66. How long before starting an engine should the lubricator be turned on?

67. If the feeds of a lubricator should stop while running, what would you do?

68. What are the advantages of a forced-feed lubricator over an ordinary side-feed lubricator?