SUPERHEATED STEAM IN LOCOMOTIVE SERVICE

BY

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CONTENTS.

A SUMMARY OF CONCLUSIONS.

The results of the study concerning the value of superheated steam in locomotive service, the details of which are presented in the succeeding pages, may be summarized as follows:

1. Foreign practice has proved that superheated steam may be successfully used in locomotive service without involving mechanism which is unduly complicated or difficult to maintain.

2. There is ample evidence to prove that the various details in contact with the highly heated steam, such as the superheater, piping, valves, pistons, and rod packing, as employed in German practice, give practically no trouble in maintenance; they are ordinarily not the things most in need of attention when a locomotive is held for repairs.

3. The results of tests confirm, in general terms, the statements of German engineers to the effect that superheating materially reduces the consumption of water and fuel and increases the power capacity of the locomotive.

4. The combined boiler and superheater tested contains 943 feet of water-heating surface and 193 feet of superheating surface; it delivers steam which is superheated approximately 150°. The amount of superheat diminishes when the boiler-pressure is increased, and increases when the rate of evaporation is increased, the precise relation being

$$T = 123 - 0.265P + 7.28\,H$$

where T represents the superheat in degrees Fahrenheit, P the boiler-pressure by gage, and H the equivalent evaporation per foot of water-heating surface per hour.

5. The evaporation efficiency of the combined boiler and superheater tested is

$$E = 11.706 - 0.214\,H$$

where E is the equivalent evaporation per pound of fuel and H is the equivalent evaporation per hour per foot of water-heating and superheating surface.

6. The addition of the superheater to a boiler originally designed for saturated steam involved some reduction in the total area of heat-transmitting surface, but the efficiency of the combination when developing a given amount of power was not lower than that of the original boiler.

7. The ratio of the heat absorbed per foot of superheating surface to that absorbed per foot of water-heating surface ranges from 0.34 to 0.53, the value increasing as the rate of evaporation is increased.

8. When the boiler and superheater are operated at normal maximum power, and when they are served with Pennsylvania or West Virginia coal of

good quality, the available heat supplied is accounted for approximately as follows:

	Per cent
Absorbed by water	52
Absorbed by steam in superheater	5
Utilized	57
Lost in vaporizing moisture in coal	5
Lost in CO	1
Lost through high temperature of escaping gases	14
Lost in the form of sparks and cinders	12
Lost through grate	4
Lost through radiation, leakage, and unaccounted for	7

9. The water consumption under normal conditions of running has been established as follows:

Boiler-pressure.	Corresponding steam per indicated horse-power hour.
Pounds.	*Pounds.*
120	23.8
160	22.3
200	21.6
240	22.6

The minimum steam consumption for the several pressures is materially below the values given. The least for any test was 20.29 pounds.

10. The coal consumption under normal conditions of running has been established as follows:

Boiler-pressure.	Coal consumed per indicated horse-power hour.
Pounds.	*Pounds.*
120	3.31
160	3.08
200	2.97
240	3.12

11. Neither the steam nor the coal consumption are materially affected by considerable changes in boiler-pressure, a fact which justifies the use of comparatively low pressures in connection with superheating.

12. Contrary to the usual conception, the conditions of cut-off attending maximum cylinder efficiency are substantially the same for steam superheated 150 degrees as for saturated steam. With superheated steam, when the boiler-pressure is 120, the best cut-off is approximately 50 per cent stroke, but this value should be diminished as the pressure is raised, until at 240 pounds it becomes 20 per cent.

13. Tests under low steam-pressures, for which the cut-off is later than half stroke, give evidence of superheat in the exhaust.

14. The saving in water consumption and in coal consumption per unit power developed which was effected by the superheating locomotive *Schenectady No. 3* in comparison with the saturated-steam locomotive *Schenectady No. 2* is as follows:

Saving in water consumption.				Saving in coal consumption.			
Boiler-pressure.	Locomotive.			Boiler-pressure.	Locomotive.		
	Saturated steam.	Super-heating.	Gain.		Saturated steam.	Super-heating.	Gain.
Pounds.	*Pounds.*	*Pounds.*	*Per cent.*	*Pounds.*	*Pounds.*	*Pounds.*	*Per cent.*
120	29.1	23.8	18	120	4.00	3.31	17
160	26.6	22.3	16	160	3.59	3.08	14
200	25.5	21.6	15	200	3.43	2.97	13
240	24.7	22.6	9	240	3.31	3.12	6

15. The power capacity of the superheating locomotive is greater than that of the saturated-steam locomotive.

16. Tests involving intermittent running show that the steam consumption per unit work delivered is increased when the program of operations is made to involve intervals of rest, due doubtless to the cooling of the cylinders and the connected parts. This loss increases with increase of steam-pressure. When the program of operations involves equal periods of rest and running it amounts to from 5 to 10 per cent of the consumption under constant running; adding to this the losses resulting from low efficiency when starting and the radiation and stack losses during the periods of idleness, the total loss resulting from such intermittent running, as compared with constant running, is approximately 20 per cent.

SUPERHEATED STEAM IN LOCOMOTIVE SERVICE.

I. FOREIGN PRACTICE IN THE USE OF SUPERHEATED STEAM IN LOCOMOTIVE SERVICE.*

1. The Use of Superheated Steam in Locomotive Service.—In the year 1898 the first superheating locomotives, two in number, were placed in service upon the Prussian State Railway. As might have been expected in machines of new design, a number of difficulties were encountered in their operation, but one by one these were overcome. Special forms of pistons, of piston-valves, and of rod packing, designed better to withstand exposure to steam of high temperature, were introduced. In 1899 the two original superheating locomotives were followed by two superheating express locomotives, and in 1900 by two superheating tank locomotives, the superheaters of all being of the same design. While these six trial engines were by no means perfect, they served to show that highly superheated steam might be generated and successfully employed in locomotive service. As a result of the experience thus gained, the Prussian State Railway has since 1900 made large purchases of the new type of engine. So rapidly has their use increased that in April, 1907, there were 682 in service and 467 in the process of building, or covered by orders; while in the whole Empire of Germany there were 1,320 locomotives of the new type running or on order. The locomotive builders of Germany draw their support from many different countries. While building superheating locomotives for the Empire, they have stimulated interest in and created a demand for the new type in other countries. Thus, Belgium, Russia,

*The facts presented in this chapter are based upon personal observations during the summer of 1907 and upon information supplied by engineers who are more or less intimately associated with the development of locomotive design. Among those to whom acknowledgment is especially due should be mentioned Herr Wilhelm Schmidt, of Cassel, Germany, president of Schmidt's Superheating Company, Limited, London, and his representative in Berlin, Herr S. Hoffman; Herr Geheimer Baurat Robert Garbe, of the Prussian State Railways, Berlin, and his chief assistant, Herr Smeltzer; Herr Director E. Brückmann, of the Berliner Maschinenbau-Actien-Gesellschaft (Schwartzkopf works); Herr Director F. Bukler, of the Bossig Works, Tegel, Berlin; Herr Geheimer Baurat Schäfer, of the Prussian State Railway, Hanover, and to Freiherr von Eltz Rubenacht, Regierungs baumeister, a member of his staff; Herr Buschbaum, engineer and purchasing agent of the Hannoverschen Maschinenbau-Actien-Gesellschaft (Egestorff works); Herr Ober Baurat Politzsch, director-general of the Saxony State Railways, and Herr Baurat Gustav Hultsch, of Dresden; Herr President Adelbert Hauck, of the Bavarian State Railway Direction, of Münich, and Herr Ober Regienungrat Schaller and Herr Expeditor Troeger, members of his staff; Herr Ludwig Buchler, engineer; J. A. Maffei (Maffei works); Herr von Helmholtz, engineer, Krauss & Company, Actien Gesellschaft, Münich; M. Flame, chief of motive power, Belgium State Railways, Brussels; M. Eugene Flaman, engineer in charge of equipment, Eastern Railway of France, Paris; M. Sabouret, chief engineer in charge of equipment, Western Railway of France, Paris; and Mr. Dugald Drummond, locomotive superintendent of the London and Southwestern Railway, England.

Austria, Sweden, Switzerland, Italy, France, Holland, England, Denmark, Spain, Greenland, Canada, and South America all have their German-designed and German-built superheaters, and at the time just quoted, April, 1907, the total number of superheating locomotives in service or on order for all countries approached closely to 2,000. This rapid extension of a new practice expresses the degree of confidence which many engineers have in its value. In fact, the introduction of the superheater has become a world-wide movement, and as such it is entitled to the respect and the thoughtful attention of American engineers. Of the world's 2,000 superheating locomotives but eight are credited to the United States.

2. Leaders in the Superheating Movement.—Even a brief résumé of the development of the practice of superheating in locomotive service would be incomplete did it not recognize the work of its two foremost advocates, Herr Wilhelm Schmidt, of Cassel, and Herr Robert Garbe, of Berlin.

Herr Wilhelm Schmidt, as an inventor and promoter, has devoted himself for more than twenty years to problems closely related with the generation and utilization of high-temperature steam. His first successes were in stationary practice. These were followed by results of greater significance in connection with locomotive service. The history of the development of locomotive superheating is in fact hardly more than a story of his difficulties and successes. Herr Robert Garbe, Geheimer Baurat, a high official in the Prussian railway service and skilled in the problem of locomotive design and maintenance prior to the advent of superheating, early manifested his interest in that subject. When the Ministry of the Prussian State Railway decided to undertake experiments in superheating, Herr Garbe was put in charge of them. His position made him the natural ally of Herr Schmidt, and together they worked assiduously in perfecting details of design. Besides troubles arising from parts in contact with superheated steam, they found that new conditions brought added stresses to other parts of the machine, and these were one after another redesigned and brought to a new standard of excellence.

From the beginning of the practice in Prussia, Herr Garbe has occupied the position of engineer in charge of superheating equipment, and under the Ministry he has been in supreme control of the design, purchase, and maintenance of all such equipment. The Ministry determines what proportion of an order for locomotives shall be superheating, but it does not undertake to dictate as to their design nor as to the materials to be employed in their construction. These are matters for which Herr Garbe is held responsible. Moreover, he not only determines the characteristics of new equipment, but he issues rules governing maintenance, which are to be observed in the roundhouses and shops wherever the superheating locomotives go. As German railway officials are not all enthusiastic in their support of the superheating locomotive, it is conceivable that under a less rigid organization the practical

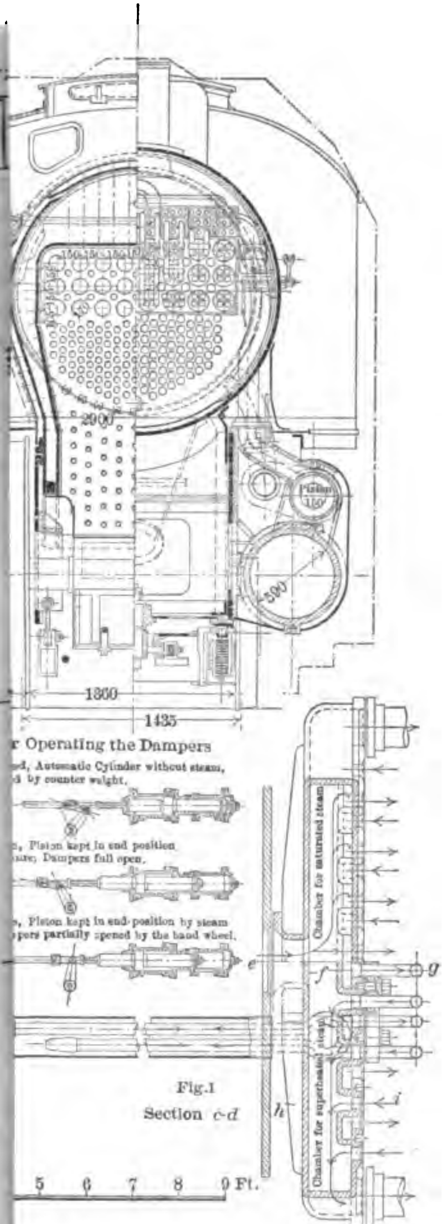


Fig.1
Section c-d

difficulties encountered in perfecting them might easily have prevented any great progress; but indifference and opposition alike have always been met by the personality of Herr Garbe, and he in turn has had the constant and unqualified support of the Ministry which appointed him.

3. Types of Superheaters.—The original Schmidt locomotive superheater was of the smoke-box type, and practically half of the superheating locomotives now in operation on the Prussian State Railway are of this design. The later introduction of the Schmidt fire-tube type of superheater has, however, proved so satisfactory that the manufacture of the earlier smoke-box type has in recent years been discontinued. All of the superheating locomotives of the Prussian State, now under construction, are to be equipped with this later type. Other forms of superheaters have been proposed and one of these has been used experimentally, but the practice of superheating in Europe as it exists to-day implies the use of the Schmidt fire-tube superheater. The introduction of this superheater (figs. 1 and 2) requires that the upper part of the boiler be fitted with from two to four rows of large smoke-tubes which are expanded into the fire-box and front tube-sheet of the boiler, in a special manner. These tubes have an inside diameter ranging from 4 to 5.25 inches, which diameter is reduced somewhat near the fire-box end. Inserted in each of these large tubes is a superheater element or section consisting of a set of pipes bent in the form of a double U and connected at the smoke-box end to a header, the whole arrangement being such as to form a continuous double-looped tube. Each particle of steam in passing from the boiler to the branch-pipes has to traverse some one of these elements, making four passes in the movement.*

The ends of each element extend into the smoke-box, where they are bent slightly upward and are expanded into a common flange which is secured to a steam-collector by a single central bolt. Two slightly different methods are employed in arranging the pipe-ends in the smoke-box. By the first method the pipes are bent upward only (fig. 2), as already described, in which case the flange-joints are horizontal, and the flanges are fastened by vertical bolts, the heads of which are movable in slots in the bottom of the collector casting. By the second method (fig. 1) the pipes are carried forward and are bent upward and backward in such a manner as to connect with vertical flanges secured by horizontal studs to the steam-collector. Both methods have been extensively used, the latter being the one which has been finally selected by the Prussian State Railway. The construction of the steam-collector and the manner in which connection is made with the steam-pipes and with the branch-pipes is best shown by the figure.

*In the original arrangement each element consisted of two separate single-loops, but it has been found that the double looping of the superheating pipes, by increasing the velocity at which the steam travels, results in the better protection of the tubes against overheating and in the more effective superheating of the steam.

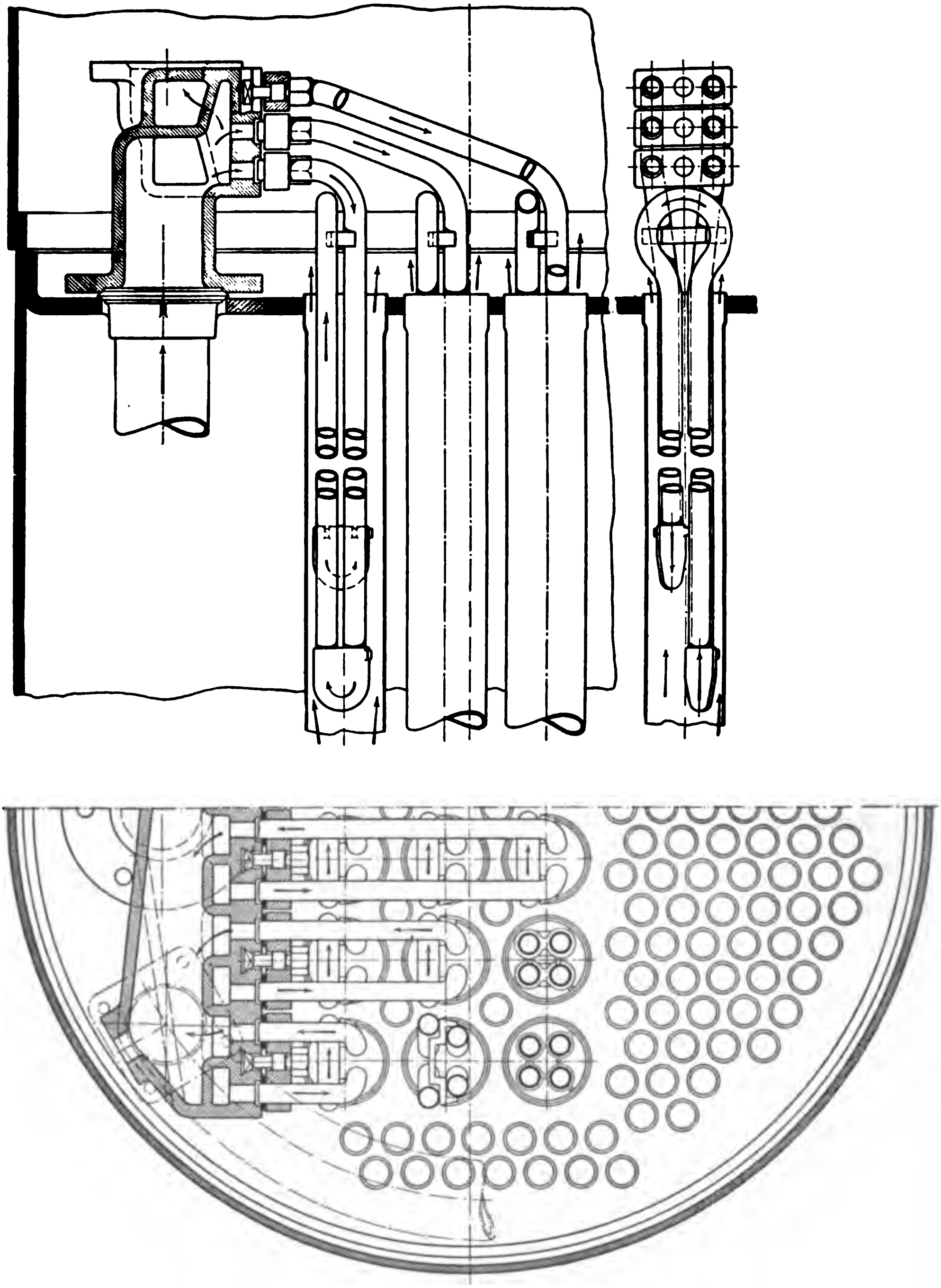


FIG. 2.—Smoke-tube superheater, Wilhelm Schmidt's patent.

By the construction which was adopted the gases of combustion are divided, one part passing through the ordinary boiler-tubes and the other through the larger tubes. In the larger tubes a portion of the heat is given up to the water surrounding the tubes and a portion to the steam contained in the superheating elements inclosed. The flow of heat through the large tubes is controlled by dampers hinged or pivoted below the steam-collector in the smoke-box. As long as the throttle of the locomotive is closed these dampers are kept closed, either by a counterweight or by a spring, but as soon as the throttle is opened they are opened simultaneously by means of a piston working in a small automatic steam-cylinder. Thus, while getting up steam or while standing at stations, under any conditions in fact for which no steam is passing the loops of the superheater to keep them cool, no gases of combustion can pass through the large smoke-tubes to heat them. This arrangement provides against the overheating of the superheating pipes. It is only when the throttle is open and when, as a consequence, steam is passing through the superheating pipes, that the dampers which control the circulation of the heated gases open and permit them to have contact with the superheating elements.

The limited number of the superheating elements and their small diameter provides a comparatively small area through which the steam must pass from the boiler to the engine-cylinders. The degree of restriction constitutes one of the important elements in the design of the Schmidt superheater. It has been found that the superheating surface is made more effective as the flow of the circulating steam is made more rapid; the statement by a German authority being that for constant-temperature differences the rate of heat transmission varies as the square root of the velocity of the steam. By maintaining high velocities through the superheating pipes, therefore, two important results are accomplished: first, a higher degree of superheat is obtained than would otherwise be possible; and, second, the protection of the superheating elements against overheating is made more complete. The degree of restriction employed in the Schmidt superheaters is such that when the engine is working at full power with the throttle wide open, the drop in pressure between the boiler and the valve-box is approximately 15 pounds. It is stated that under these conditions the velocity through the superheating tubes varies from 325 to 400 feet per second.

The superheaters thus described have an abundant capacity. Locomotives fitted with them are provided with a dial thermometer showing the temperature of the steam in the valve-box. After starting, this temperature steadily rises until it exceeds 300° C. (572° F.), after which the dampers controlling the circulation of heat through the superheater-tubes are partially closed by means of mechanism which connects with a hand-wheel in the cab. This manipulation of the dampers is such as will check the rising temperature before the maximum safe limit of 350° C. (662° F.) is reached.

It is said that there is now no difficulty in designing, for any locomotive, a superheater which will give with certainty any desired degree of superheat within limits which are practicable. Rules governing all portions of the design have been formulated and are strictly adhered to by the Wilhelm Schmidt Company, Limited, in working out the details of their design. Such rules have not yet been published.

4. The German Superheating Locomotive.—The Schmidt superheater as described in the preceding paragraph is in European practice applied to locomotives in which valves, piston-packing, and similar details are widely diversified. The purpose of the present chapter will, however, be served by a description of a single machine, namely, a superheating steam express locomotive of the Prussian State Railway. The details of this locomotive, so far as they affect the production and utilization of superheated steam, are common to all superheating locomotives of the Prussian State Railway and hence to a large percentage of all existing superheating locomotives (fig. 1). In the design of these locomotives Herr Garbe has sought to take advantage of every possible chance to avoid incidental losses of heat and power. He has not hesitated to redesign details nor to introduce new features, and as a consequence the superheating locomotives of the Prussian State Railway are worthy of careful study with reference to many matters quite apart from the superheater. Certain cab-fittings, differing from those on American locomotives, or not found on them at all, will best be understood from a description of their use as observed on an 8-wheeled superheating locomotive at the head of a fast passenger train between Berlin and Halle, 102 miles on a schedule of 110 minutes.

Having received the signal to start, the engineer with both hands pulls down on the throttle lever, which moves in a vertical plane, until it is more than half-way open, and now that the engine is starting he gives the throttle no further attention, but stands with his hands on the reverse-wheel, watching the struggle of the locomotive for the mastery of its train. When the drivers slip he catches them with a quick turn of the reverse-wheel before they have made a single revolution. If they hold well, he slowly turns the reverse-wheel to lengthen the cut-off, feeling with a fine sensitiveness of touch the adhesion of drivers upon the rail, and with one hand and little effort holds his engine to the hardest work it is capable of doing. The train is now moving out through the yard with steadily increasing speed, the danger of slipping wheels is past, and the engineer is busy in perfecting adjustments which will bring all parts of the mechanism into a condition of most efficient working. High up on the side of the cab at his right is a speed indicator, which shows him at a glance the rate at which he is running. In front of him, besides the usual boiler-gage, is another gage which gives the pressure of steam in the valve-box. The maximum boiler-pressure is 180 pounds, and it is explained that the purpose of the engineer is to keep the valve-box pressure at approximately 150 pounds.

As the speed increases, the engineer adjusts, by small increments, first the cut-off, then the throttle, until the output of power and the conditions of pressure are to his liking. Another dial before him is that of a thermometer indicating the temperature of the steam in the valve-box. This at the instant of starting was but little above 400° F., but has since risen steadily. It is desirable that it should not go above 660° F. By the time the train is at speed it has passed the 550 mark, and the engineer, crossing over to the fireman's side, turns a wheel attached to a light shaft running out forward over the boiler, thus partially closing the damper and thereby diminishing the flow of furnace gases through the superheater. A permanently attached dial draft-gage discloses the reduction of pressure within the smoke-box, and a ratchet-driven pump, the plunger of which, with one stroke for each filling of the lubricator, forces oil to the valves and cylinders. If it is desired to augment the rate of flow beyond the normal, the fireman works a lever which gives motion to the rachet in excess of that which is automatically given by the motion of the locomotive. By attention to all these devices the engineer is able to operate his machine with a delicacy of adjustment that insures high efficiency in action.

The train moves forward past stations, through cities, always at a speed of from 55 to 65 miles an hour. The engineer stands at his post, generally keeping a lookout ahead, but occasionally moving about the cab that he may better scrutinize the adjustment of his machine. The fireman, at intervals varying from 2 to 4 minutes, fires from 4 to 10 scoopfuls of a free-burning mixture of fine coal and lumps. From the tenth to the fortieth minute of the run the average rate of firing was 2.8 scoopfuls a minute, but the scoops are smaller than those commonly used in America. Each time before putting in coal he shut off the injector, and after he had finished firing he started it again. Thus the journey proceeded, the speed on favorable grade rising to 68 miles per hour and falling on adverse grade below 55. The track was always clear. At Wittenberg, where the track crosses the Elbe, 63 miles from Berlin, the throttle was closed for the first time during the run, the by-pass valves, devices to be hereafter described, were opened, and the brakes applied for slower running at the bridge. There was no stop, and in an instant the by-pass valves were closed, the throttle opened, and, as the reverse-lever had not been moved, normal conditions of operation were quickly re-established. Approaching its destination, the train was several times slowed and once stopped on signal, being ahead of its time. At the station at Halle the locomotive gave up its train, went to the cinder-pit, and thence on to the round-house, there to await a train for the return trip on the morrow.

The superheating locomotives of the Prussian State Railway are balanced for revolving parts only. They have no balance for their reciprocating parts.* The opinion among German engineers is divided as to the wisdom of this practice. The engines, when in good condition, ride well, but it is commonly reported that the absence of balance for the reciprocating parts makes it difficult to keep them in this condition. The adoption of the practice evidently grew out of certain restrictions which limit wheel-loads. The maximum static load which may be carried per driving-axle upon the Prussian State Railway is 16 tons, but the law provides for an allowance in excess of this limit of approximately 12 per cent for the dynamic forces resulting from the vertical action of the counterbalance in the wheels, the whole provision of the law being such as to limit the total maximum loads due to static and dynamic influences combined to approximately 18 tons.

When some years ago the Prussian State Railway, under the inspiration and guidance of Herr von Borries, entered upon the construction of four-cylinder balanced compound locomotives, the dynamic effect of which was assumed to be nil, it permitted a static load equal to the maximum combined load provided by the law. The von Borries balanced compounds, therefore, began operation carrying 18 tons per driving-axle, and thus designed they possessed an advantage over previously existing locomotives which was an important factor in securing for them the good opinion of all concerned. Later, when Herr Garbe began to shape his designs for superheating locomotives, he was required to compete not with simple engines, but with balanced compounds. He realized that to achieve permanent success his superheating engines must do as much work as the compounds, and hence must carry as much weight per axle as the compound; to secure this without violation of the law he was required to omit all excess balance in the drive-wheels.

The boiler-pressure in the superheating locomotives is normally 180 pounds. The authorized method of operation permits some withdrawing of steam at the throttle and more results from its passage of the superheater, so that the pressure in the valve-box under running conditions is normally from 150 to 160 pounds. To meet this condition the cylinders are proportioned to give maximum traction power on the assumption of a mean effective pressure which is one-half the boiler-pressure. This process of calculation results in cylinder volumes which are from one-fourth to one-third greater than those commonly used in American practice. It is said that the purpose of this increased cylinder volume is to permit operation under shorter cut-offs, which, in the presence of superheated steam, will, it is assumed, promote economy. But in the actual operation of the superheating locomotives practice with reference to cut-off seems to differ but little from that common upon non-superheating locomotives of this country. At speed the cut-off is normally from 25 to 40 per cent and the throttle from two-thirds to three-quarters open; a cut-off of 30 per cent is assumed to be that for maximum efficiency.

*The rule of the American Railway Master Mechanics' Association provides that in balancing locomotive drive-wheels the counterweights shall be sufficient to balance all revolving parts and a considerable percentage of the reciprocating parts, the amount of balance for reciprocating parts depending upon the total weight of the locomotive.

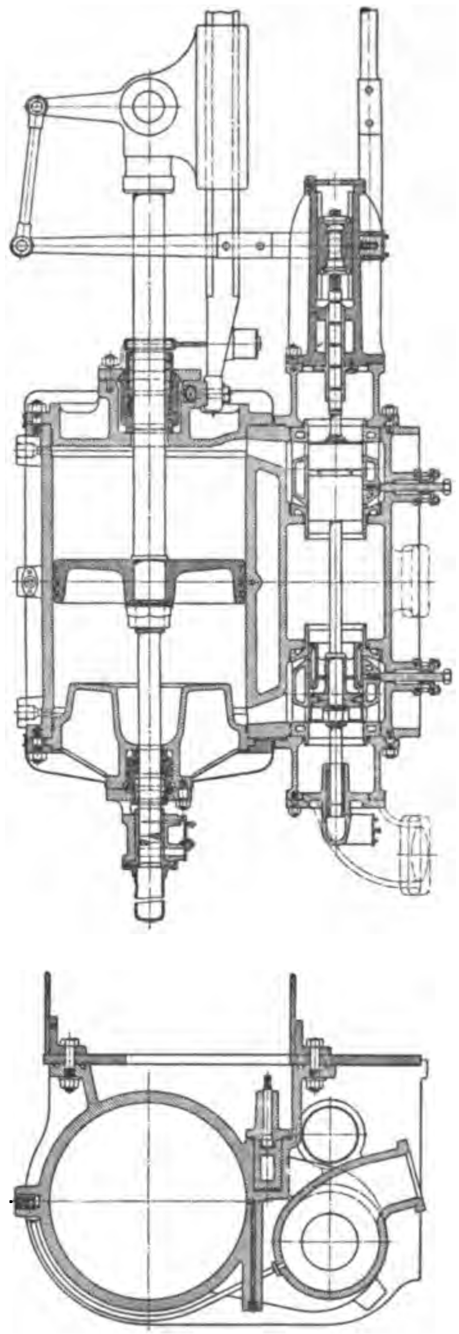


FIG. 3.—Cylinder details for superheated-steam locomotives, Wilhelm Schmidt's system.

The valves of the superheating locomotives of the Prussian State Railway are shown in their general arrangement by accompanying fig. 3. There are practically two valves for each cylinder, the function of each being to distribute the steam to one cylinder-end. The two valves together make up in effect an internal admission mechanism not different in its general character from the internal admission-valves used in this country. The ends are, however, more widely separated and the ports are shorter than those commonly used in America. To provide for these proportions, bonnets are added at either end of the valve-case, from which the exhaust is led away. The details of valve are well shown by fig. 4.

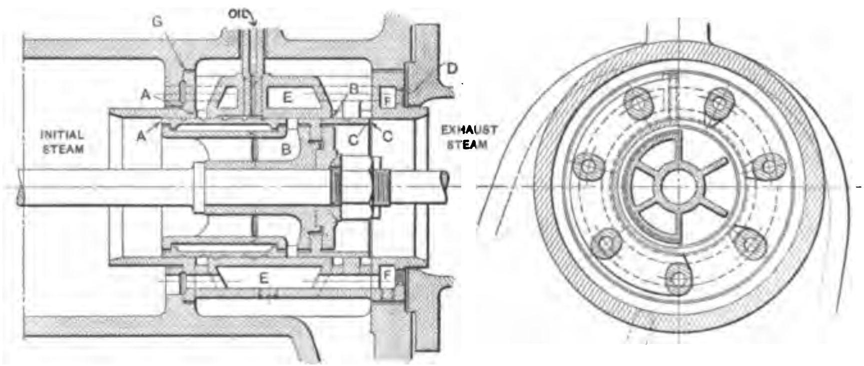


FIG. 4.—Piston-valve with steam-jacketed bushing, double admission, and solid rings, Wilhelm Schmidt's patent.

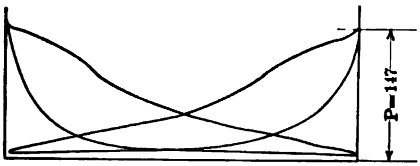
It is assumed by the designer that the use of superheated steam requires the steam-distributing valves to work with as little friction as possible in order that the natural difficulties in lubrication may be reduced to a minimum. The design in question seeks to meet this condition by the use of broad, solid rings which constitute in effect a plug-valve, the elements of which are incapable of exerting pressure against the walls of the bushing. It is safeguarded against difficulties which might otherwise arise from differences in the expansion of valve and bushing by the small diameter of the valve itself and by providing a bushing which is completely jacketed with steam at a pressure equal to that to which the valve is exposed.

The provision for double admission may be understood by reference to fig. 4. Thus, when the line *A* of the valve opens into the port *A* of the bushing, the line *B* of the valve opens into port *B* of the bushing. The exhaust is always single and occurs when the line *C* of the valve opens the port *C* of the bushing. The bridges which cross the ports in the bushing are so designed as to offer no obstructions to the passage of steam through the ports; the port edges constitute complete and uninterrupted circles. The diameter of this valve is 150 mm., or 6 inches, and it serves a cylinder of more than 21 inches in diameter in high-speed service. The two rings which constitute its outside surface are of cast iron and they work in cast-iron bushings. The rings are carried by the body of the valve between scraped surfaces, insuring a steam-tight joint between ring and body and at the same time giving the body of the valve perfect freedom to move radially in all directions for a distance of about an eighth of an inch. This radial movement permits the ring to follow the bore of the bushing, even though the valve-spindle may not travel directly through its center. The exterior surface of the rings is ground accurately to a standard size, determined by a ring-gage, and the interiors of the bushings are ground to fit a standard plug-gage. The difference in diameter between the ring and the bushing when both have the same temperature is said to be 0.045 mm., that is, about 0.0001 inch. Around the exterior of the rings light grooves are formed, which assist in retaining the lubrication and in preventing leakage past the valve. The valve-rings, when mounted upon their spindle ready for their bushings, appear as light-rimmed pulleys fitting loosely upon a shaft.

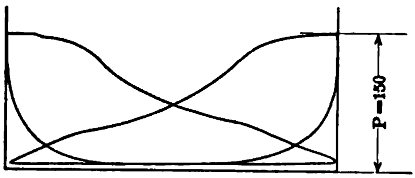
The bushings of the valves (fig. 4) are not forced to their place, as is the practice in America, but are secured by means of long bolts in such a manner as to make a steam-tight joint along the line *G*. The joint against the exhaust steam at the opposite end *D* is made by use of a soft gasket inserted between the exhaust-bonnet, the end of the bushing, and the end of the cylinder casting. The inner end of the bushing is entirely immersed in initial steam. Steam for the main jacket of the bushing *E* passes through small ports which open through the several bridges crossing the steam-port *A*, as shown in the lower part of fig. 4. In a similar manner initial steam for the jacket *F* passes ports in bridges which span the second port *B*, so that the interior walls of the bushing are everywhere backed by steam at initial pressures. The effectiveness of this thorough system of jacketing will at once be seen. No preliminary warming of valves or cylinders is necessary, for the temperature of the steam which reaches the valve exists also behind the walls of the bushing, so that the metallic surfaces in contact are always exposed to the same degree of heat.

Lubrication is supplied from a pump in the cab which delivers oil through pipes connecting with an oil-plug passing through the valve casing and into the bushing, as shown by fig. 4. There is one plug for each end of each cylinder.

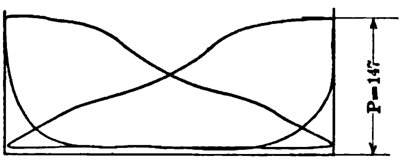
The valve and bushing as described is made in one size only. It is always 6 inches in diameter, whether employed upon suburban, freight, or passenger locomotives. Its dimensions as well as its general design are regarded as standards. It is admitted that slight changes in dimension would in some cases be desirable, but it is urged that the practical advantage of having a single standard more than compensates for any loss involved. As a means for securing the distribution of steam this valve is entirely satisfactory. A study of indicator-cards (fig. 5) taken from a freight locomotive having wheels 53 inches in diameter will show that the exhaust line runs a little higher than is desirable, but that in all other respects the cards are the equal of those obtained in normal American practice. The facts that the valve is employed in distributing highly superheated steam which flows with great rapidity; that since the cylinder condensation is less, the volume required to be admitted is less than when saturated steam is used; that there is double admission; and that the steam-passages are short, direct, and unobstructed, account for the excellent showing made by so small a valve.



CUT-OFF 25 PER CENT, SPEED 26 M.P.H.



CUT-OFF 30 PER CENT, SPEED 18 M.P.H.



CUT-OFF 85 PER CENT, SPEED 11.2 M.P.H.

FIG. 5.—Typical indicator-cards.

The fact is worthy of record that from an operating point of view these valves and bushings satisfactorily perform the service for which they were designed. An inspection in the roundhouse of valves and bushings which had been in service for a year and a half, during which time no attention had been bestowed upon them beyond that of cleaning, showed practically no signs of wear. It is stated that valves still running, which have been in service for from 2 to 3 years, have not yet come to a point where it is necessary to touch them with a tool, though they require frequent cleaning. In the presence of superheated steam the lubricant gums and in some cases cakes upon them, filling the joints and preventing the radial motion of the valves for which the design provides. When this occurs it is necessary to remove the valves and to take them apart for thorough cleaning.

A rule of the Prussian State Railway provides that the valves and their spindles shall be removed and cleaned at intervals not longer than two weeks. This rule, however, is not strictly enforced, the practice in several roundhouses being to try the valves by admitting steam with the brakes set. If it appears that there is no blow of steam past the valves, no attention is paid them, whereas if any leakage is discovered the valves are cleaned at once. The process of cleaning is a comparatively simple one, two men having no difficulty in taking care of both sides of a locomotive in from 2 to 4 hours' time. It only rarely becomes necessary to remove the bushing, and when this must be done there are no machine parts to be handled which one man can not lift. The lightness of the valve and its spindle and the consequent low value of all inertia effects contribute to its accuracy of movement. The fact that the rings exert no measurable pressure upon their bushings reduces the frictional resistance of the valve and its gear to a minimum. A locomotive at its regular work on the road was stopped and the long lever of the valve-motion was disconnected from the cross-head, whereupon the valve was readily moved back and forth through its course by one's little finger inserted in the bolt-hole of the long lever.

While this valve is standard upon the Prussian State Railway, German manufacturers do not favor its use in locomotives which are to be sent to other parts of the Empire or to other countries. The accurate work which is involved in its construction makes the matter of its maintenance a difficult one for the average railway-shop. As a consequence, many superheating locomotives are being constructed in Germany which are equipped with piston-valves of larger diameter and of more ordinary design. The presumption is, therefore, that whatever of merit there may be in the valve arrangement described, its employment is not absolutely essential to the use of superheated steam. Herr Garbe, however, is distinctly of the opinion that the success of his superheating locomotive is the result of many small increments of gain, brought about by the attention given to the design of many details, among which, of course, the valve must have an important place.

Another interesting detail of the superheating locomotives of the Prussian State Railway is a self-adjusting air-cooled stuffing-box with spherically seated packing-rings (fig. 6). It is reported that rigid stuffing-boxes having no provision for cooling, such as are commonly used, were not satisfactory when highly superheated steam was employed. For such steam only metallic packing can be used, and this must be so designed that the packing-rings will be continually cooled by air. The design used upon the superheating locomotive of the Prussian State Railway meets these conditions. Each stuffing-box is fitted with movable spherically-seated rings. The sleeve containing the rings is cored out to permit cooling by air throughout its entire length. The packing-rings are held in position by the steam itself, aided by a spring, which prevents the rings from being carried along by the returning rod. The valve-spindle, which is required to be packed against exhaust pressure, only passes through a long metal bushing. It has no gland or stuffing-box.

The by-pass, which constitutes a feature of all superheating locomotives of the Prussian State Railway, is shown by fig. 7. Its function has already been briefly described. Its significance will be appreciated if one considers that in American practice, where such a device is unknown, excessive compression in the cylinders while the locomotive is drifting is prevented by the presence of air or relief valves on the valve-boxes and by dropping the reverse-lever to the end of its quadrant. Under these conditions, however, air is drawn into the cylinder and forced out of the exhaust with each movement of the piston, and in its passage it cools the metallic parts with which it has contact, with the result that when the throttle is again opened the heat thus

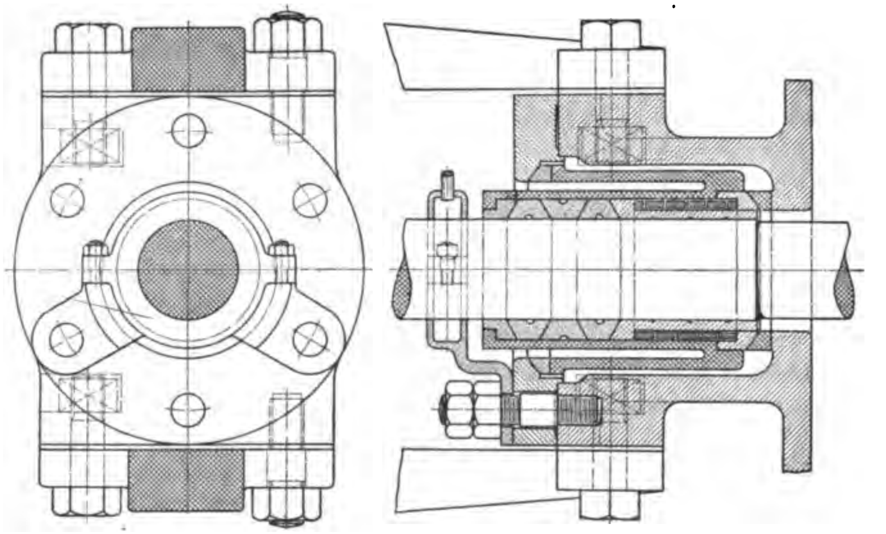


FIG. 6.—Stuffing-box for piston-rod. Wilhelm Schmidt's patent.

lost must be restored. The by-pass prevents the waste of heat occasioned by the cooling of the cylinder and at the same time avoids unnecessary loss of power when drifting. It consists of a steam-passage which connects both cylinder-ends, which passage may be closed by a cylindrical cock in the middle. So long as the engine is running under steam the cock is kept closed. The

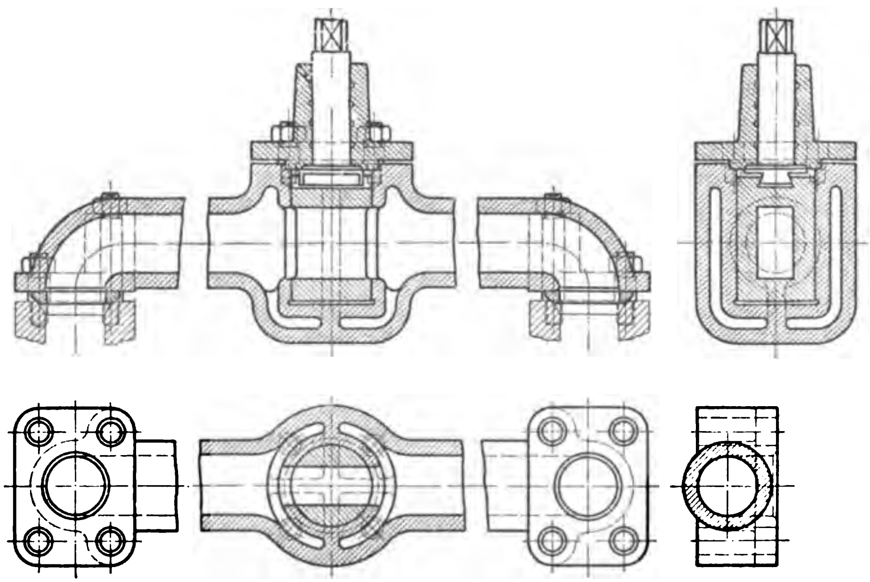


FIG. 7.—By-pass valve arrangement for superheated-steam locomotives.

moment the throttle is closed the engineer opens the by-pass. Thus the spaces before and behind the piston are connected with each other, the pressures on either side of the piston approach equalization, and the action of the piston merely discharges low-tension steam from one end of the cylinder to the other. As there is no circulation between the cylinder and the outside atmosphere, no heat is conveyed away. Indicator-cards taken while the engine is drifting (fig. 8) show that the loss of power resulting from this arrangement is small.

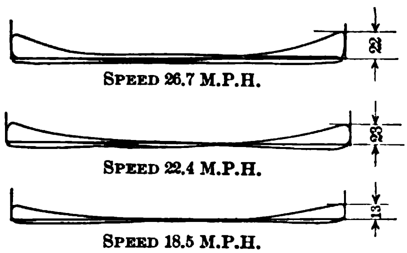


FIG. 8.—Typical indicator-cards. By-pass open.

5. The Maintenance of Superheating Locomotives.—From such inspection in shops and roundhouses as could be had, and from the testimony of those concerned in the handling of locomotives at terminals, it appears reasonably certain that no special difficulty is experienced in the maintenance of those details which are peculiar to a superheating locomotive. This statement applies especially to the superheater itself. In a repair-shop, a boiler was inspected from which the superheater had been drawn bodily and laid upon blocking beyond the boiler. All of the ordinary small tubes of the boiler were being cut out in preparation for retubing. The superheater, meanwhile, had been judged to be in good condition and it was to go directly back to its place without having any work done upon it. Even those German engineers who are not friendly to the superheating locomotive frankly say that there is no difficulty in maintaining the present type of fire-tube superheater.

With respect to the care bestowed in freeing the large flues containing the superheating tubes from deposits of fuel and ash, the superheating locomotive requires additional labor. The extent of this depends, however, upon the nature of the fuel used. The fact that solid matter entering the large tubes from the fire-box comes upon the ends of the loops of the superheater as upon an obstacle set in their path naturally leads to such a result. With some grades of fuel little or no difficulty arises, while with other fuels it is difficult to get a locomotive over its division. Roundhouses, therefore, which handle superheating engines are equipped with long pipe-nozzles through which a blast of air is delivered for the purpose of clearing the large flues. Upon at least one division inspected an equipment of these nozzles was carried upon locomotives. In certain roundhouses a set of small tools from 3 to 6 feet long, with sharp cutting-edges, usually at right angles to the axis, which could be inserted from the fire-box, was in use for the purpose of cutting out the deposits in the tubes. A round of inspection gives abundant evidence that the stopping-up of flues is a serious matter. Engineers friendly to the use of superheating locomotives admitted that there are coals which are serviceable in other classes of locomotives which can not be used by the superheating locomotives.

In the matter of maintaining valves and valve-gears much has already been said. There appears to be no difficulty in maintaining lubrication in the presence of superheated steam, and it is repeatedly asserted that the wear of piston-rings and of valve-parts in the superheating locomotive is of less consequence than the similar wear which occurs in compound and simple engines using saturated steam. Reference has already been made to the necessity for removing valves for cleaning.

It will be remembered that in Germany the natural competitor of the superheating locomotive is the compound, and that in passenger service the compound is of the four-cylinder type. This fact is often mentioned as important from a roundhouse point of view, since it is easier to wipe the superheating locomotives after a run than the compounds, a statement which, of course, grows out of the fact that there are fewer parts to receive attention. Whether the superheating passenger engines are on the whole easier to maintain than the balanced compounds is a matter concerning which little definite information can be obtained. It is admitted everywhere that the absence of balance for reciprocating parts in the superheating engines tends to increase the cost of maintenance, and it is not unlikely that the newness of the type also operates to its disadvantage. The compounds, on the other hand, with their duplication of parts and their higher boiler-pressures, demand attentions which are peculiar to their type. In Berlin, where superheating is in the ascendancy, it is generally agreed that the problems of maintaining the superheating engine are far more simple than those of maintaining the compound, while in Hanover, which is the home of the balanced compound, opinions are likely to be the reverse of this.

6. The Economy Resulting from the Use of Superheating Locomotive.— The degree of economy attending the operation of the superheating locomotive is probably not definitely understood in Germany. There are as yet no locomotive-testing plants in the Empire, and while the results of many road tests are reported, they are upon a comparative rather than upon an absolute basis. As the superheating locomotives are all of recent design, there are no simple locomotives using saturated steam whose performance can fairly be compared with them. Partisan advocates of the superheating locomotive not infrequently claim for it a saving in water of from 30 to 40 per cent and in coal from 25 to 35 per cent when compared with the simple locomotive, and some data are presented in support of such claims. It is also claimed that the superheating locomotives consume 25 per cent less water and 10 per cent less coal than the four-cylinder balanced compounds. Such statements of course reflect partisan opinions. One who is a close student of these matters and whose position is such as to make him quite independent in opinion believes that the saving in water could be taken at from 20 to 25 per cent and in coal at from 15 to 20 per cent, as compared with the consumption of simple locomotives.

When comparisons are made between the performance of a superheating locomotive and that of the compound, partisan advocates of the superheating claim an advantage for their type of machine. Conservative experts give the opinion that the performance of the superheating locomotives is without question equal to that of the compound. Others, whose opinions are perhaps entitled to equal attention, affirm that it is better, but how much better they are not willing to say. The performance sheet of a division operating balanced compounds and also superheating locomotives in the same service shows that the coal used per 1,000 kilometers run by superheating locomotives varied from 12.1 tons to 14.4 tons and for the balanced compounds from 8.9 to 14.2 tons. Upon the basis of these statements it would appear safe for the American engineer to assume that the superheating locomotives are as economical in their use of water and fuel as are the highest types of compounds. This applies to a practice which involves locomotives using a high degree of superheat on the one hand and a well-perfected type of compound on the other.

7. Concerning the Trend of Foreign Practice with Reference to Superheating in Locomotive Service.—In the development of this chapter attention has been given thus far to the single type of locomotive which may properly be referred to as the Garbe type. Taking now a more general view of the tendency manifested in Europe with reference to superheating, mention may be made of several significant facts. First, it should be noted that while it is the opinion of the officials of the Prussian State Railway that success in superheating depends in large measure upon the adoption of those details in the design of machine parts which are peculiar to their special type, this view is not shared by the locomotive builders of Germany nor by engineers not connected with railway service. While, therefore, the high character of the details of the Garbe engine from the designer's point of view is unquestioned, it is probably true that the superheater may enter as a detail into the design of any well-considered locomotive without disturbing other details.

Among certain foreign engineers the plan of combining the superheater with the compound engine has been favored and a considerable number of locomotives have been constructed on this plan. In favor of such an arrangement it is urged that the presence of the superheater will serve to reduce the coal consumption of the compound to the extent of approximately 7 per cent. Against it are urged the objections that the two systems are in the main antagonistic; that the compound, to work effectively, must be supplied with steam at high pressure, whereas it is counted as one of the advantages of the superheating locomotive that without sacrifice of its efficiency it may employ much more moderate pressures. The American engineer is likely to concur in the opinion that the saving which can result from the combination is too small to justify the complication incident to the presence of both systems.

It is an interesting fact that in France, the birthplace of the balanced compound, there is to-day an extremely active interest in the practice of superheating as developed in Germany. A commission representing the leading railways of France has, after a careful investigation, made a report most favorable to the new practice. While it is not likely that superheating locomotives will in France be allowed to take the place of the highly developed types of balanced compound common in that country, and while it is not likely that superheating will be employed to any considerable extent in connection with the compounds, there are still in the freight and switching service of France many simple engines, and the hope is expressed that the superheater may be the means of improving them. Meantime, in Belgium, where the advantage of the balanced locomotive is well understood and the objections of combining the superheater with the balanced compound engine are appreciated, practice is involving a four-cylinder balanced simple engine with the superheater, an arrangement which gives promise of very great success.

These manifestations of interest in the problem of superheating are giving rise to great activity on the part of German locomotive builders, who are supplying superheating locomotives to many different countries. The railroads of England and of the United States, meantime, while watching the development with interest, are proceeding with great deliberation.

8. Arguments Favoring the Adoption of Superheating.—These, as based upon results derived from German experience, may be set forth as follows:

1. The advantages of superheated steam may be had in practice without involving undue complication in mechanism and without involving a degree of attention in maintenance in excess of that demanded by a simple engine.

2. The superheating locomotive will perform its service efficiently while employing a comparatively low steam-pressure, a condition which tends to reduce cost in maintenance. The presence of the superheater does not necessitate any qualification of this statement.

3. Superheating will materially reduce the consumption of water, which in bad-water districts constitutes a matter of importance.

4. The superheating locomotive will reduce the fuel consumption probably to that required by a first-class compound engine.

5. As to power and capacity, the superheating locomotive is to be compared with the compound rather than with the simple engine. It may be forced to limits of power far beyond those possible with simple engines.

6. In operation the degree of superheat increases with increased rate of power, which tends to conserve the steam-supply as the demand for power is increased.

II. AMERICAN ATTITUDE TOWARD THE USE OF SUPERHEATED STEAM IN LOCOMOTIVE SERVICE.

9. During the past few years, while a new practice in locomotive design has been developing in Germany, American railroads have been occupied with the task of meeting urgent demands for ordinary service. It has frequently happened that the railroads of this country have had more freight to move than their facilities would permit them to handle, and that there have been more passengers wishing to travel than could easily be accommodated. Under these conditions a theory has grown up which assumes that the efficiency of a railroad as a whole is best promoted by increasing the weight of individual trains and the mileage of individual locomotives. Under the stimulus of this conception locomotives have steadily become heavier and more powerful, that greater loads may be carried. Every pound of metal entering into the construction of the locomotive has been scrutinized with reference to its effect upon the power capacity of the machine; its efficiency has been regarded as of secondary importance. The locomotive has in fact been looked upon merely as one of many details in the great fabric which makes up a railroad, and the efficiency of the railroad as a whole is believed to be more dependent upon the amount of power which can be delivered at the tender draw-bar than upon the degree of efficiency with which the power is developed. Again, the capacity of a given line of railway is dependent upon the regularity with which trains may be moved over it. Regularity of movement demands certainty of action, and the details of mechanism entering into the design of locomotives which can fail in service have been reduced to the smallest possible number. New devices of recognized value in their effect upon the thermodynamic efficiency of the machine have in many cases been avoided through fear that their presence might increase the liability to failure on the road. Again, since the locomotive is effective only when it is pulling at the head of a train, the value of a given type of locomotive has been judged largely by its ability to keep the road. No embellishment of design has long been tolerated the presence of which has operated to prolong the periods during which the locomotive must be held for attention at terminals or make more frequent the periods during which it must be shopped for general repairs.

These statements will serve to show that the ideal underlying practice in the development of the modern American locomotive has placed power-capacity and continuity of service upon a higher plane than thermodynamic efficiency. This ideal has on the whole not been misleading. It has produced locomotives of unprecedented power; it has satisfied a legitimate demand for service; and it has resulted in the development of a machine which must always be regarded as a mechanism of remarkable quality. This in itself has been a great achievement. It is, therefore, not discreditable to the railroads of America that their interest in superheating has thus far been hardly more than academic, for the advent of the superheater brings complications of mechanism with it and introduces new problems in maintenance. Thus far only a few of the railway companies of the United States have supplied themselves with this new type of machine, and these have in most cases been content with trial orders. In Canada, however, where fuel is more expensive and where perhaps there is a greater willingness to contribute the time which must be given to the development of new details, many superheating locomotives of various types are in regular serivce. The time is approaching when, in the natural order of development, the railroads of the United States will leave no stone unturned in their efforts to increase the thermodynamic efficiency of the American locomotive. Such an attitude involves no abandonment, but merely an enlargement of existing ideals. Progress in this direction means, in its ultimate analysis, the sacrifice of nothing already possessed, but the addition thereto of greater economy in the use of fuel and an extension in the amount of power developed. If, as time goes on, it appears that superheating offers a safe road to such progress, American practice will ultimately embrace it. For the present it must be recognized that there are many points of view from which the question must be considered, and there are many individuals who must be concerned in its development. It is not unlikely that where there is so much that is debatable the facts presented by the chapters which follow will have some permanent value.

III. TESTS TO DETERMINE THE VALUE OF SUPERHEATING IN LOCOMOTIVE SERVICE.

10. Conditions Suggesting Tests.—The fact that the efficiency of a steam-engine may be improved by superheating the steam supplied it is a matter which has long been understood and appreciated, and the effect of such highly heated steam upon the process of heat interchange, which goes on in the engine cylinder, has been so carefully traced that the precise manner in which the improvement is brought about has been made a part of the common knowledge of the engineer. But the process of producing superheated steam is one which consumes heat and involves apparatus which has been expensive in first cost and difficult to maintain. Against the thermodynamic gain, therefore, which may be secured by the use of superheated steam is to be set the cost of fuel necessary to produce the superheating and the interest and maintenance charges arising from the presence of the superheater. Costs resulting from these accounts are in large measure functions of the design of the superheater and of the materials which enter into its construction, so that the wisdom of adopting the superheater in any branch of steam-engine practice is a matter which involves very much more than the fundamental thermodynamic theory—a fact which greatly complicates the task of the present-day student in this particular field of research. In recent years the problem of superheater design has received generous attention and materials possessing qualities hitherto unobtainable have been made available to the designer, so that a practice which a quarter of a century ago was generally regarded as of doubtful expediency has gradually been advanced to a position of great promise.

Attention has been called to the extensive use of superheated steam in the locomotive practice of Germany and to the influence of this practice upon that of other European countries and of America. In America, especially, there are evidences of a strong professional interest which is doing much to secure for our country a more general introduction of superheating locomotives. Under the stimulus of these developing conditions it was natural that the energies of the locomotive-testing laboratory of Purdue University should have been turned in the direction of superheated steam. The University's locomotive, designed originally for work under high steam-pressure, was converted into a superheating locomotive, and with the aid of many friendly influences has since been subjected to an elaborate series of tests, the results of which define the performance which is to be expected from such a machine. This performance, when compared with that of a normal locomotive using saturated steam, should aid in making up an estimate of the gain to be secured by the use of the superheater in locomotive service.

11. The Means Employed.—The locomotive laboratory of Purdue University, established in 1891 for the instruction of students and for research, has been many times described.* The locomotive which for a number of years had been operated upon this plant is of the single-expansion American type, having a boiler designed to carry working pressures as high as 250 pounds per square inch.† In preparation for a new program of tests, this locomotive was fitted with a Cole superheater, the boiler and other parts being rebuilt, so far as was necessary, to make the reconstructed machine a normal superheating locomotive which, from the time of reconstruction, has been known as *Schenectady No. 3*. By this process the laboratory not only gained a machine suited to its needs, but all data previously obtained from the locomotive while using saturated steam (*Schenectady No. 2*) at once became available as a basis from which to measure the performance of the new locomotive working with superheated steam.

12. The Tests were begun in November, 1906, and were completed, so far as the series at present under consideration is concerned, in July, 1907. During this period of 8 months the experimental locomotive ran 1,417,995 revolutions, which is equivalent to 4,851 miles. The tests were arranged in two series: first those in which the speed and the position of the reverse lever and throttle remained constant throughout each run, hereafter referred to as tests under constant conditions; second, those involving the alternate running and resting of the locomotive in obedience to a fixed program, hereafter referred to as intermittent tests.

The tests under constant conditions were run at pressures of 240, 200, 160, and 120 pounds, respectively, the number of tests under each pressure being sufficient to disclose the performance when running at several different speeds and cut-offs. The exhibit is especially full for a pressure of 160 pounds, a pressure which is a close approach to that commonly used in connection with superheating locomotives. Altogether, 38 tests were run under constant conditions. A concise statement of the pressure, speed, and cut-off represented is set forth by figs. 9 to 12, in which each circle represents the general conditions of one test. Concentric circles represent conditions for which duplicate tests were run, and the numeral within each circle is the serial number of the tests. Corresponding numbers will be found in column 1 of the tables (7 to 27) of Appendix II, which include all observed and calculated

*"The Purdue University Locomotive Testing Plant;" "Locomotive Testing Plants" (A. S. M. E.).

†For complete description with drawings of this locomotive, see High Steam-Pressures in Locomotive Service, Publication No. 66, Carnegie Institution of Washington.

data. All results thus presented are directly comparable with corresponding results obtained when using saturated steam, which are set forth in the published account of a previous research.*

The intermittent tests were designed to disclose the effect upon its efficiency of certain conditions which enter into the normal operation of a locomotive. The writer long ago called attention to the fact that not less than 20 per cent of the total fuel used by the average locomotive of this country was not utilized in advancing trains over the road, but was consumed in starting fires,

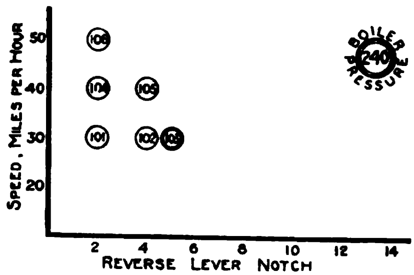


FIG. 9.—Tests at 240 pounds pressure.

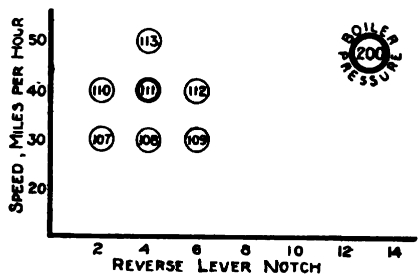


FIG. 10.—Tests at 200 pounds pressure.

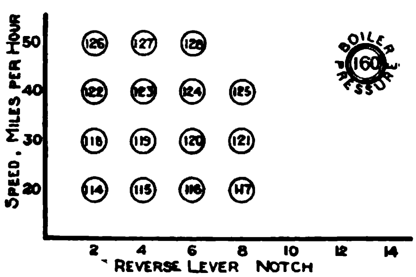


FIG. 11.—Tests at 160 pounds pressure.

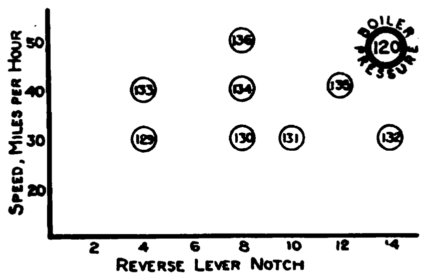


FIG. 12.—Tests at 120 pounds pressure.

in raising steam, in keeping the locomotive hot while waiting for its trains while stopping at stations and at passing points, or remained in the fire-box at the end of the run. Obviously, no embellishment in the design of a locomotive can effect a saving in that portion of the total fuel supply which is thus accounted for. The advantage to be derived from such an embellishment as a superheater must, therefore, be judged by the effect it can produce upon not more than 80 per cent of the coal consumed. If, for example, it were shown that the superheater can effect a saving of 20 per cent in the amount of fuel used, the saving in total fuel which it will be necessary to supply will be 20 per cent of 80, or 16 per cent only.

In undertaking to secure a measure of the advantages to be derived from the use of superheated steam in locomotive service, it was thought that some

*High Steam-Pressures in Locomotive Service, Publication No. 66, Carnegie Institution of Washington.

attempt should be made to replace the rather crude conception of the facts just outlined by figures which would supply a more definite measure. To this end the intermittent tests were planned. Nine such tests were made, two each, respectively, at pressures of 240, 200, 160, and 120 pounds, and one duplicate. In one test under each pressure there were six periods of running and five intervals of standing. The running time equaled one-half the total duration of the tests, in view of which fact tests upon this schedule will be referred to as the half-time tests.

The second tests under each pressure involved four periods of running and three intervals of standing, the sum of the running periods equaling one-fourth the total duration of the tests. These, therefore, will be referred to as the quarter-time tests. In all tests a period of 120 minutes at the beginning was utilized in starting the fire and the bringing the steam to the running pressure. A more elaborate statement of the conditions maintained and of the rate of acceleration in starting is set forth by the graphic schedules showing the exact program of running (figs. 61 and 62). The program described gave a schedule which could be faithfully followed, the running conditions being duplicated without difficulty from day to day. As the records began with the starting of the fire and did not end until the fire was out at the end of the day, the results show well the losses incidental to the intermittent running.

13. Data.—While the discussions presented by the pages immediately following deal with such phases of the problem of superheating in locomotive service as will best show the degree of advantage to be derived from the practice, the data presented are sufficiently complete to serve in a much more general study. The student is therefore urged to make direct use of the data of the tests, which will be found presented as Appendixes II and III. Referring to the tests at constant speed (Appendix II), it should be noted that heat-balances have been calculated for 18 of the 38 tests. The data of the intermittent tests (Appendix III) require no special mention.

14. Acknowledgments.—The research as a whole is the outgrowth of many influences. The American Locomotive Company, at its own expense, made all designs and performed all work necessary to the complete conversion of the saturated-steam locomotive, *Schenectady No. 2*, into the superheated-steam locomotive *Schenectady No. 3*. Thanks are especially due to Mr. W. H. Marshall, president of the company, and Mr. F. J. Cole, chief of its designing department, for this and other courtesies. Purdue University, expressing the interest of its president and board of trustees, has contributed for a considerable period all of the resources of a well-equipped laboratory, has furnished all supplies excepting those of coal, and has given the time of the experts and attendants who are regularly attached to the testing-plant.

Thanks are due many members of the university faculty for the kindly spirit of cooperation shown on many occasions, and especially to Prof. L. E. Endsley, who, as the university's representative in immediate charge of the laboratory, was at all times untiring in his efforts.

The United States Geological Survey, as represented in its technologic branch, by Mr. J. A. Holmes, director, maintained at the laboratory, for a period of a year, a detail of two experts, who were intrusted with the work of taking samples for all chemical analyses, the analysis of gases at the laboratory, and the working up of all computations based on chemical and calorific data. The Survey also generously provided for the handling of all samples of coal, cinders, and ash at its extensive chemical laboratories at St. Louis, Missouri, and at Columbus, Ohio, operating under the direction of Professor Lord. As a result of cooperation thus extended, it is now possible to present for the first time from the Purdue laboratory a considerable array of satisfactory data covering the furnace-action of a locomotive. Credit for the successful issue of this phase of the undertaking is chiefly due Messrs. M. Stack and M. A. Charavay, the Government experts at the laboratory.

All costs in addition to those already specified have been drawn unstintingly from the grant of the Carnegie Institution of Washington. By reason of this grant it has been possible to increase the staff of attendants at the laboratory and to provide supplies of fuel necessary to maintain, for a considerable period, the continuous operation of the plant. Assistants have been employed to work up the observed data of the tests and to summarize results. Acknowledgment is especially due the efficient part rendered by Mr. Paul Diserens, who throughout the progress of the research has supervised all work of computation and the preparation of all data for publication.

IV. PERFORMANCE OF BOILER AND SUPERHEATER.

15. The Observed and Derived Data pertaining to the performance of the boiler and superheater are given in detail by columns 13 to 112, Appendix II. Graphic representation of much of the data, grouped with reference to boiler-pressure, is presented by figs. 13 to 16. Attention should early be called to the fact that because of threatened interruptions in the running of the tests it was thought expedient to use two grades of coal and to rely upon the results disclosed by the heat-balance of the several tests as a basis for final comparisons. Of the two fuels used the Youghiogheny coal has been accepted as standard, and where results obtained from the Pocahontas coal have been needed in formulating conclusions they have been reduced to equivalent results which would have been obtained had the standard coal been used throughout the work. The manner of making such reductions is described in Appendix II. One man served as fireman for all tests.

A study of the process of combustion, as it is presented in locomotive service, involves many difficulties. In the previous work of the Purdue locomotive-testing plant, attempts to secure such information as would permit the assignment of a definite cause to such irregularities in the evaporative efficiency of the boiler as commonly appear in the data of any series of tests have not been altogether successful. Prompted, therefore, by past experiences, unusual care was taken in the organization of this phase of the work, and as a result it is now possible to present a satisfactory heat-balance for 18 tests. The process has involved, for each test, a proximate analysis, an ultimate analysis, and a calorific test of a sample of the fuel used; a determination of the amount of combustible materials and a calorific test of samples of sparks delivered from the stack and of cinders collecting in the front-end; a determination of the amount of combustible material in the refuse collecting in the ash-pan before and after as well as during the test; and the constant sampling and frequent analysis of the smoke-box gases. Numerical values resulting from this work are included in the exhibit of data, columns 65 to 91, Appendix II, in connection with which will be found a detailed description of methods employed. Values which enter as factors directly into the heat-balance are included in columns 92 to 112, Appendix II.

In the paragraphs which follow an attempt will be made to state briefly some of the more significant facts which may be developed from the data, and in some cases graphic methods are employed to emphasize their importance, but the reader who has time to do so will find greater satisfaction in drawing his information directly from the more complete presentation supplied by the tabulated results.

16. Superheating.—The observed temperature of the steam delivered from the superheater, as measured by a high-grade mercurial thermometer placed in the header at a point near its opening into the left-hand branch-pipe, point *A*, fig. 80, Appendix I, is given for each test as column 20, Appendix II, and the degrees of superheating represented by these temperatures as column 21, Appendix II. The effect of the conditions of running upon the degree of superheating developed is better shown by the diagrams, figs. 13 to 16. These diagrams are interesting and significant, though it is perhaps fair to assume that changes of speed and cut-off affect the quality of steam only in so far as they produce changes in the rate of evaporation. For this reason a more logical basis for study is shown in figs. 17 to 20, which present the extent of the superheating effect for the different rates of power to which the boiler was worked (equivalent evaporation per square foot of water-heating surface per hour), each diagram representing some one of the several pressures under which the boiler was operated. The ordinates and the abscissæ of all points in each diagram have been averaged and from values

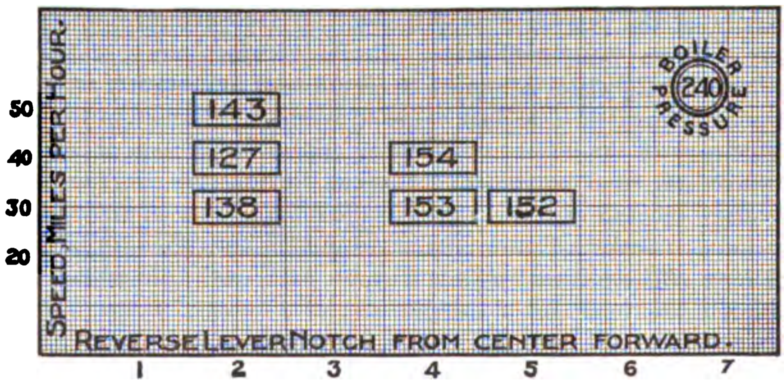


FIG. 13.—Superheating effects, degrees F., boiler-pressure 240 pounds.

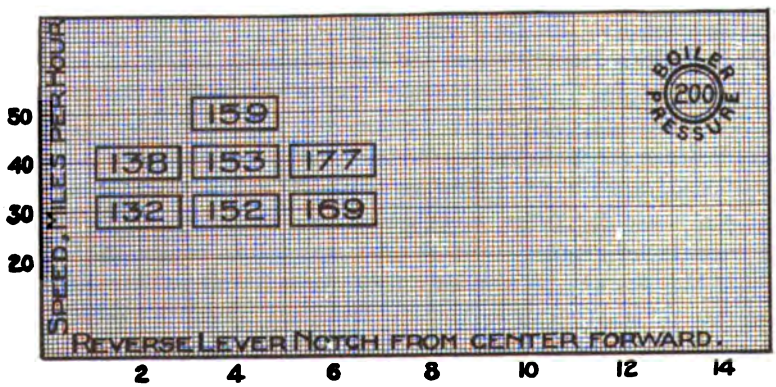


FIG. 14.—Superheating effects, degrees F., boiler-pressure 200 pounds.

thus obtained an average point, designated as a cross in a circle, has been located. Through this a straight line has been drawn which represents, with a fair degree of accuracy, all of the experimental points involved. It happens that the slope of these lines is the same for all of the diagrams under consideration. They define the change in the degree of superheat attending changes in the rate of evaporation when the boiler-pressure has the value stated.

A comparison of the several diagrams will show that if the boiler were operated under a constant rate of evaporation for each of the several boiler-pressures the degree of superheat would be different in each case. For example, if a comparison is based upon a rate of evaporation of 11 pounds of water per foot of water-heating surface per hour, the degree of superheat will be:

170	degrees	when	the	boiler	pressure	is	120	pounds.
165	"	"	"	"	"	"	160	"
154	"	"	"	"	"	"	200	"
135	"	"	"	"	"	"	240	"

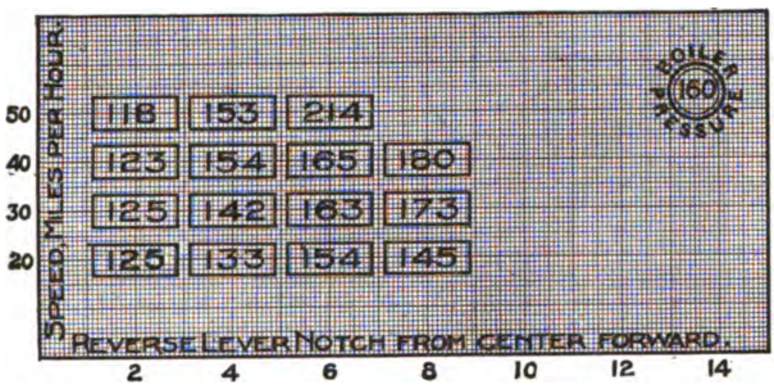


Fig. 15.—Superheating effects, degrees F., boiler-pressure 160 pounds.

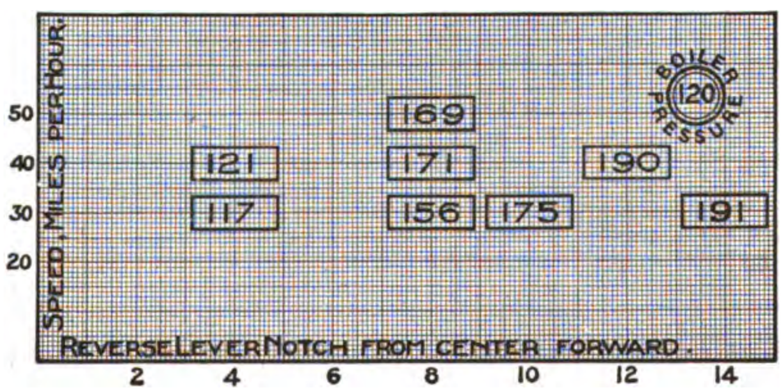


Fig. 16.—Superheating effects, degrees F., boiler-pressure 120 pounds.

These values are shown graphically in fig. 21. Referring to this figure, it will be noticed that the superheat varies more rapidly for a given increment at the higher pressures than at the lower pressures, and that the line connecting the experimental points is a curve. A straight line may, however, be drawn which will represent all the experimental points with an error which in no case will be greater than 2 per cent. By plotting similar points for the degrees of superheat representing the vertical intercept, as shown by figs. 17, 18, 19, and 20, and by drawing a straight line through them, an equation of this line can be written and therefore employed as a substitute for the intercept in the equation of the curve at any given pressure. The result defines the performance of the superheater for any pressure between 120 and 240 pounds

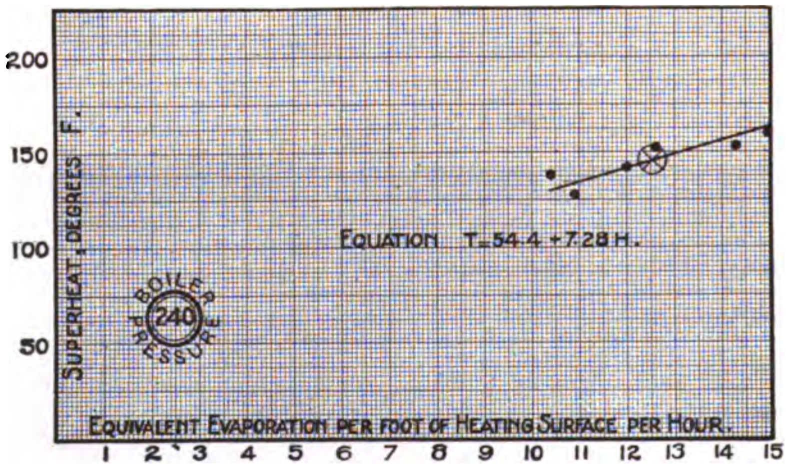


FIG. 17.—**Superheating as affected by rate of evaporation, boiler-pressure 240 pounds.**

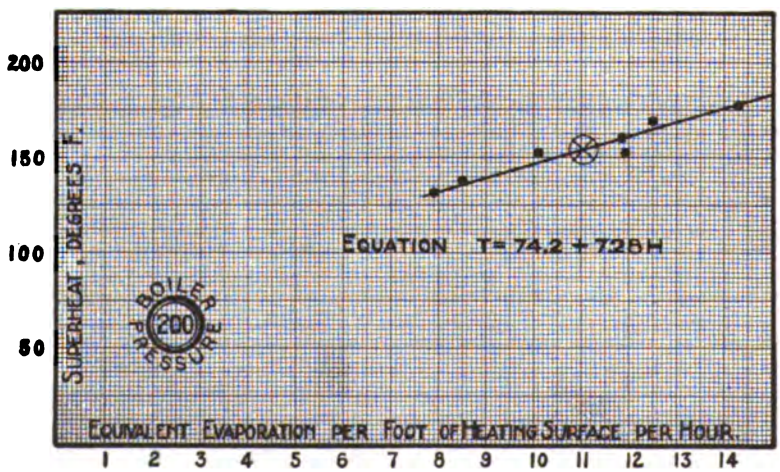


FIG 18.—**Superheating as affected by rate of evaporation, boiler-pressure 200 pounds.**

gage, with a maximum error of less than 2 per cent. The equation thus determined is

$$T = 123 - 0.265\,P + 7.28\,H$$

where T equals the number of degrees superheat; P the boiler-pressure by gage, and H the equivalent evaporation per square foot of water-heating surface in the boiler.

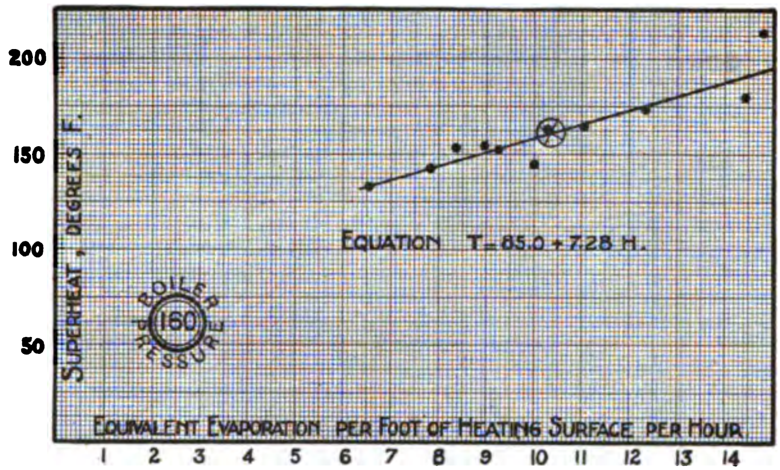


FIG. 19.—Superheating as affected by rate of evaporation, boiler-pressure 160 pounds.

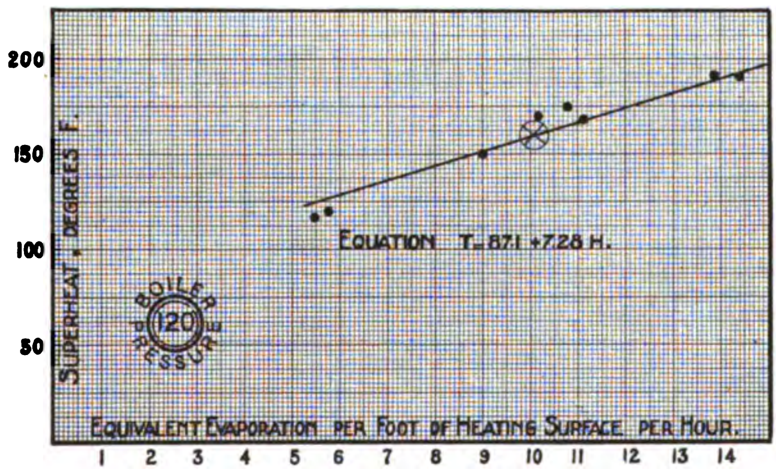


FIG. 20.—Superheating as affected by rate of evaporation, boiler-pressure 120 pounds.

17. Draft.—The draft produced in the front-end of the locomotive was measured at a point directly in front of the diaphragm. Values thus determined expressed in inches of water are given in column 39, Appendix II. The rate of increase in draft values with increased rates of evaporation is well shown by fig. 22. This figure gives the results of tests at 160 pounds only. Curves representing points obtained at other pressures are practically identical with those shown, the fact being that changes in boiler-pressure, within the limits of the experiments, have practically no influence upon draft values. As would be expected, these depend entirely upon the rate of evaporation required.

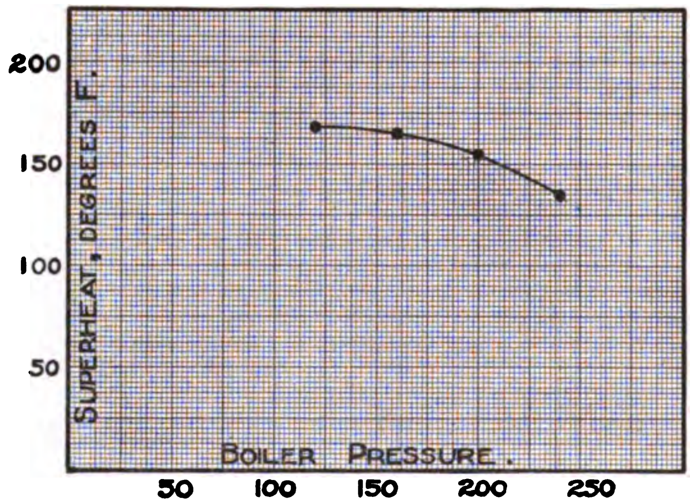


FIG. 21.—Degrees of superheat under all conditions of pressure when rate of evaporation is 11 pounds per foot of heating-surface per hour.

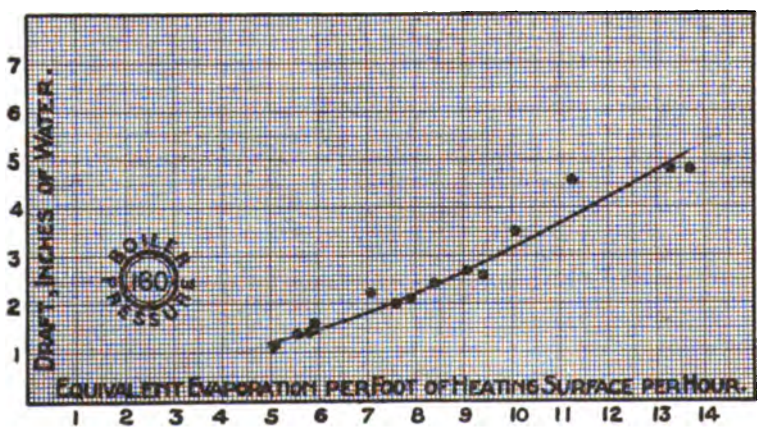


FIG. 22.—Draft in front of diaphragm.

18. Smoke-Box Temperatures.—The temperatures of the smoke-box gases were read by a mercurial thermometer placed midway between the diaphragm and the front tube-sheet. Values for this quantity will be found in column

40, Appendix II. These values, plotted with the rate of evaporation (figs. 23 to 26), show the effect upon the smoke-box temperature of changes in the rate of power. It will be seen that the smoke-box temperature increases as the rate of evaporation is increased, an effect the significance of which is well understood. For example, when the rate of evaporation equals 6 pounds of water per foot of heating-surface, the smoke-box temperature is approximately 600° F. When the rate of evaporation is increased to 12, the temperature of the smoke-box approaches 800° F. It is not far from the truth to say that a change of 1 pound in the rate of evaporation produces a change

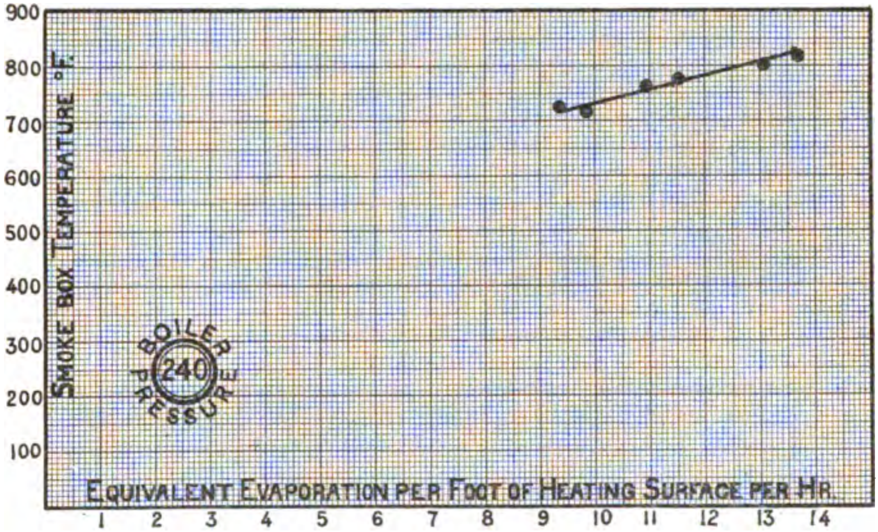


FIG. 23.—Smoke-box temperature, boiler-pressure 240 pounds.

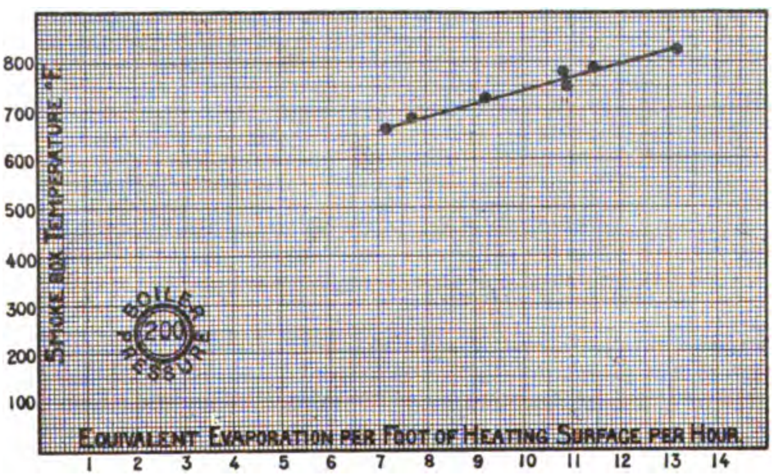


FIG. 24.—Smoke-box temperature, boiler-pressure 200 pounds.

of 20° in the temperature of the smoke-box. Comparing the results of the several diagrams, the smoke-box temperature shows a slight tendency to increase with increase of pressure, other things being the same, but the differences are too slight to be accepted as material.

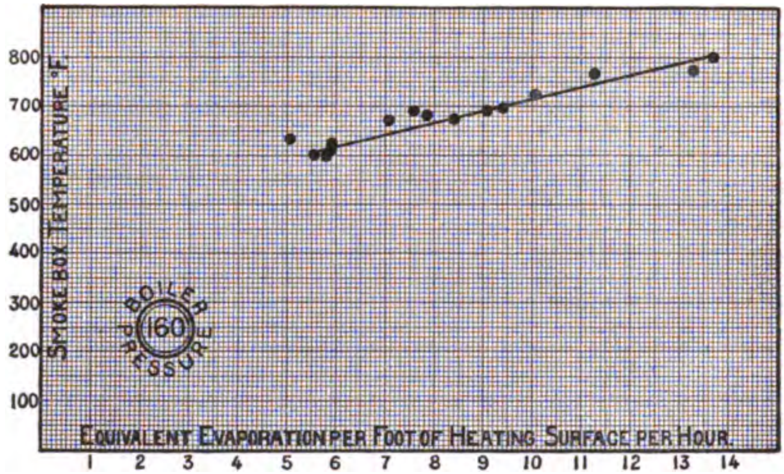


FIG. 25.—Smoke-box temperature, boiler-pressure 160 pounds.

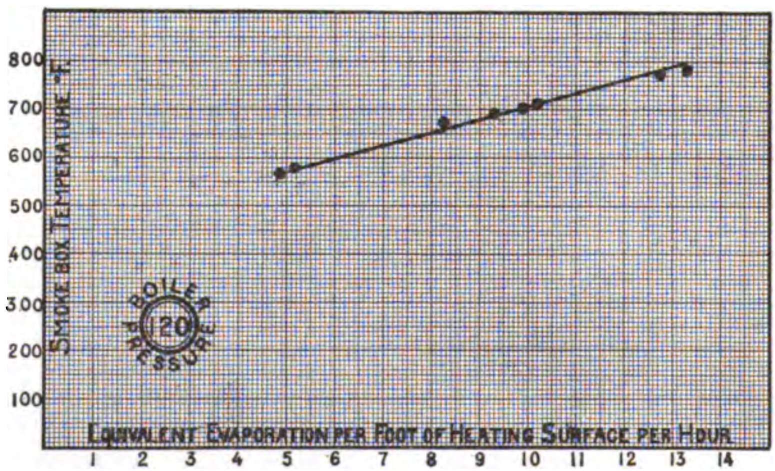


FIG. 26.—Smoke-box temperature, boiler-pressure 120 pounds.

19. Evaporative Efficiency of the Combined Boiler and Superheater, as expressed by the pounds of water evaporated from and at 212°, equivalent to the weight of superheated steam delivered per pound of dry coal, is given for each test by column 53, Appendix II. These values, plotted with the equivalent evaporation per square foot of surface in the boiler and super-

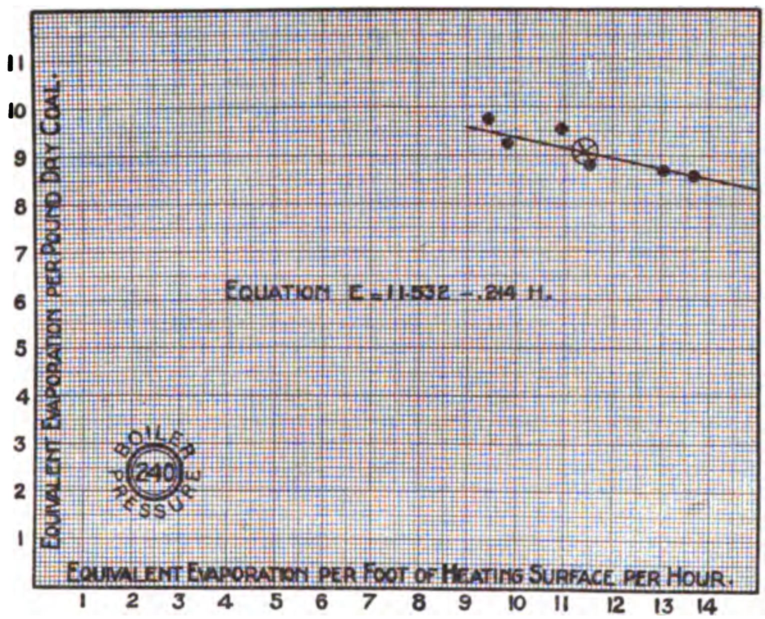


FIG. 27.—Equivalent evaporation, combined boiler and superheater; boiler-pressure 240 pounds.

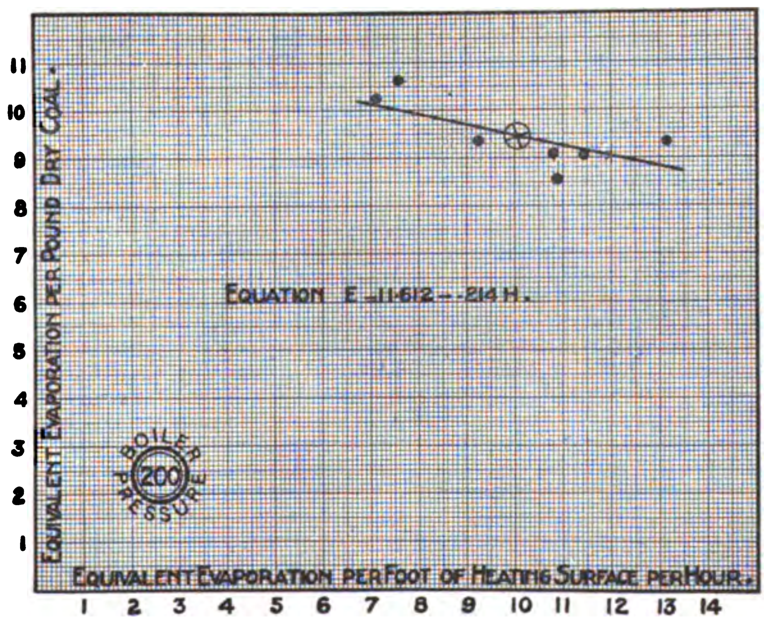


FIG. 28.—Equivalent evaporation, combined boiler and superheater; boiler-pressure 200 pounds.

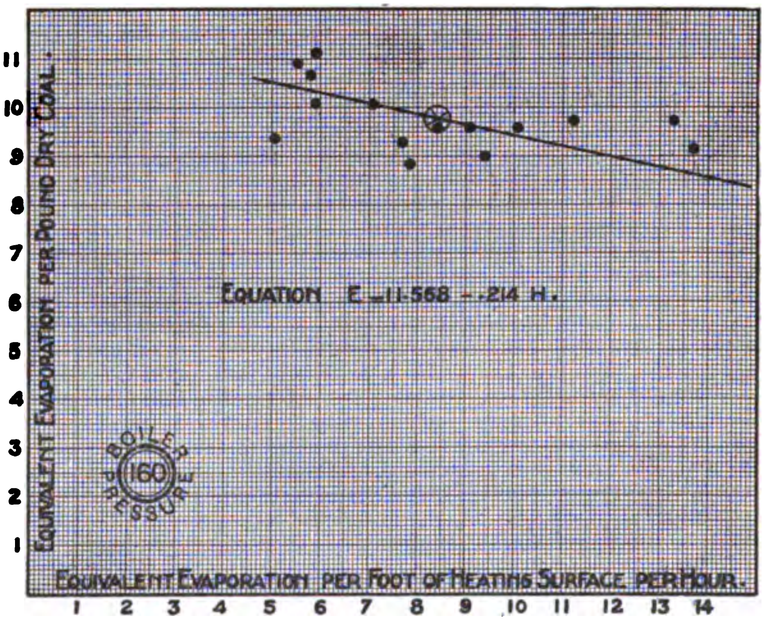


Fig. 29.—Equivalent evaporation, combined boiler and superheater; boiler-pressure 160 pounds.

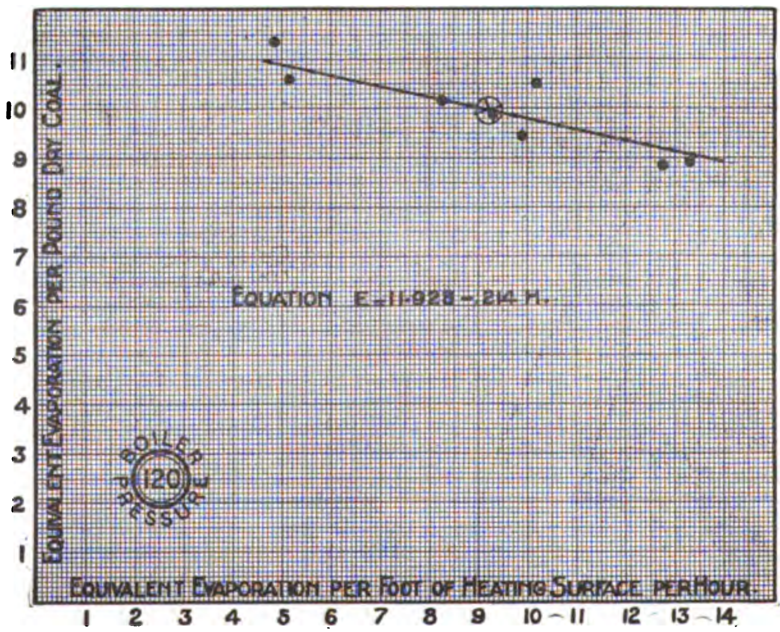


Fig. 30.—Equivalent evaporation, combined boiler and superheater; boiler-pressure 120 pounds.

heater per hour (column 48, Appendix II), are given as figs. 27 to 30, inclusive. Through the plotted points of each diagram a mean line has been drawn, the equation of which appears on the diagram. The slope of the average lines of the diagrams, figs. 27 to 30, was determined by plotting on a single sheet the results of all 240-pound tests, 6 in number, together with those of 6 representative tests from each of the other series. These were divided into two groups, the averages of which determined two points which were assumed to define the slope required. The diagram thus developed is shown by fig. 31. The lines drawn on the diagrams, figs. 27 to 30, have this slope and pass through a derived point which is the average of all points plotted. On all diagrams the derived or average point is represented by a cross inclosed by a circle.

The individual diagrams (figs. 27 to 30) show clearly the effect upon boiler efficiency of changes in the output of power, while a comparison of the several diagrams, one with another, will show that, within limits covered by the experiments, the effect upon boiler efficiency of changes in boiler-pressure is slight. Basing a statement upon the facts thus presented, it appears that if the discussion is allowed to concern itself with very small differences, the highest efficiency is obtained when the boiler-pressure is lowest; conversely, the lowest efficiency results when the boiler-pressure is highest. But, except in the case of tests at 120 pounds, the results of which do not compare closely

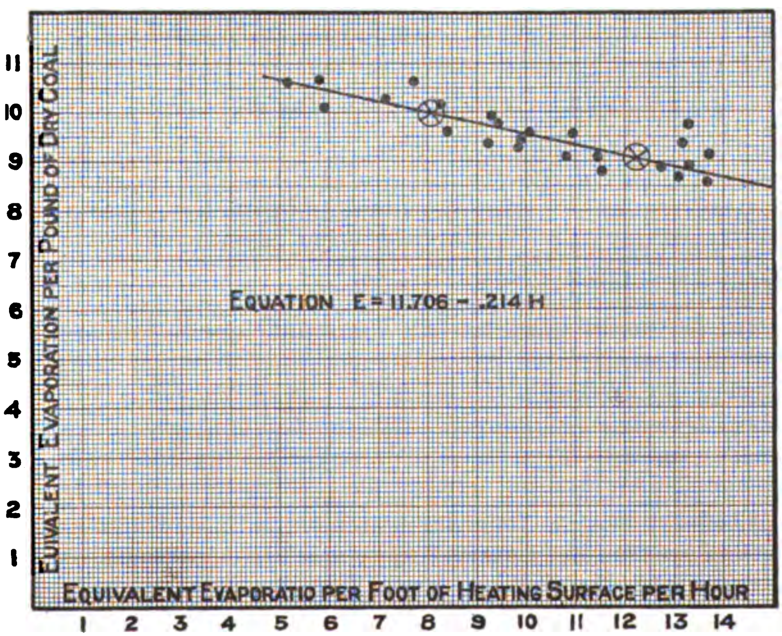


FIG. 31.—Equivalent evaporation per pound of coal, under all conditions of pressure; combined boiler and superheater.

with those for other pressures, the differences are hardly more than measurable. In a larger sense, it seems to be true that changes in boiler-pressure between the limits of 120 pounds and 240 pounds have practically no effect upon the evaporative efficiency of the boiler. It has already been shown that the temperature of the smoke-box gases is substantially the same, whatever may be the boiler-pressure, provided, of course, the output of power remains unchanged, which may be accepted as further confirmation of this statement. These general conclusions are in agreement with those already established for locomotives using saturated steam.* Proceeding on this basis, it is clear that a general expression for the evaporative efficiency of the combined boiler and superheater may be based upon the results of all tests, regardless of the pressure at which they were run. Such expression is represented by the line drawn through the plotted points of fig. 31. The equation for this line, and consequently one which defines in general terms the performance of the combined boiler and superheater, is

$$E = 11.706 - 0.214\,H$$

where E is the equivalent evaporation from and at 212° F. per pound of dry coal and H is the equivalent evaporation per square foot of water and superheating surface.

20. Evaporative Efficiency of the Boiler, Exclusive of the Superheater.—The equivalent evaporation of the boiler per pound of dry coal (column 51, Appendix II), in terms of the equivalent evaporation per square foot of water-heating surface in the boiler per hour (column 46, Appendix II), is shown in fig. 32. The equation for the mean line drawn through these points is

$$E = 11.105 - 0.2087\,H$$

This curve is substantially of the same slope as that which represents the performance of the combined boiler and superheater (fig. 31), but it represents values which are lower, a result due to the fact that the basis of the comparison practically assumed that the heat which is normally absorbed by the superheater is in this case lost.

21. The Division of Work between Water and Superheating Surface.—The ratio of the heat absorbed per square foot of superheating surface to that absorbed per square foot of water-heating surface (column 49, Appendix II) may be accepted as an expression of the relative efficiency of the water and superheater surface. Figs. 33 to 36 represent this quantity plotted against equivalent evaporation per square foot of water-heating surface for the several boiler-pressures. Referring to these figures, it will be seen that as the rate of evaporation increases, there is a corresponding increase in the ratio of the heat absorbed per square foot of superheater surface to that

*High Steam-Pressures in Locomotive Service, Publication No. 66, Carnegie Institution of Washington.

absorbed per square foot of boiler surface. Thus, when the boiler-pressure is 160 pounds, the ratio has a value of 34 per cent when the rate of evaporation is 6 pounds of water per square foot of water-heating surface and 53 per cent when the rate of evaporation is increased to 14 pounds. Comparing the lines of the diagrams for the several different pressures, it appears that if these lines were superimposed they would very nearly coincide; that is, the value of the ratio is independent of the boiler-pressure.

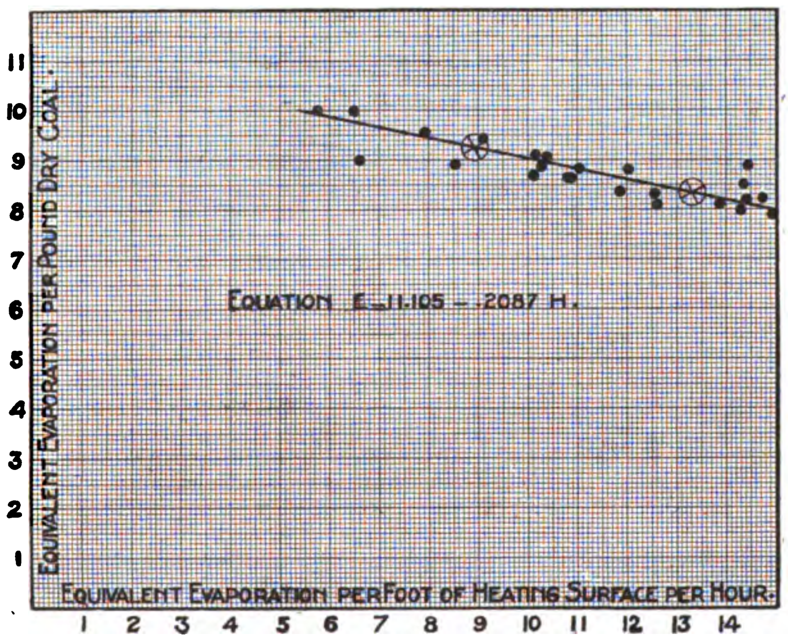


FIG. 32.—Equivalent evaporation per pound of coal under all conditions of pressure, exclusive of the superheater.

22. Smoke-Box Gases.—The percentage of excess air in terms of equivalent evaporation per foot of heating-surface per hour, as obtained in tests at the several different boiler-pressures, is shown by figs. 37 to 40. No attempt has been made to draw curves through the plotted points. The points serve to show, however, that the amount of excess air is in all cases small and that it distinctly tends to diminish as the rate of evaporation is increased. The reason for this is to be found in the fact that in locomotive service higher rates of evaporation necessarily involve the use of thicker fires, which offer greater resistance to the admission of air.

The percentage of carbon dioxide (CO_2) present in the smoke-box gases ranges from 10.8 to 14.6. The significance of these results as factors in any general comparison is impaired by the variable quality of the fuel used. Taken as they stand, they do not disclose any well-defined law governing the changes in their value with changes in the rate of combustion. The

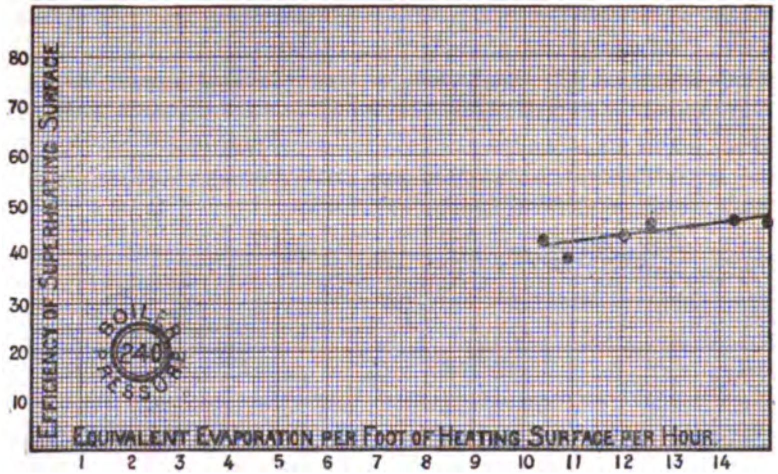


Fig. 33.—Relative efficiency of the superheating surface, that of the water-heating surface being 100; boiler-pressure 240 pounds.

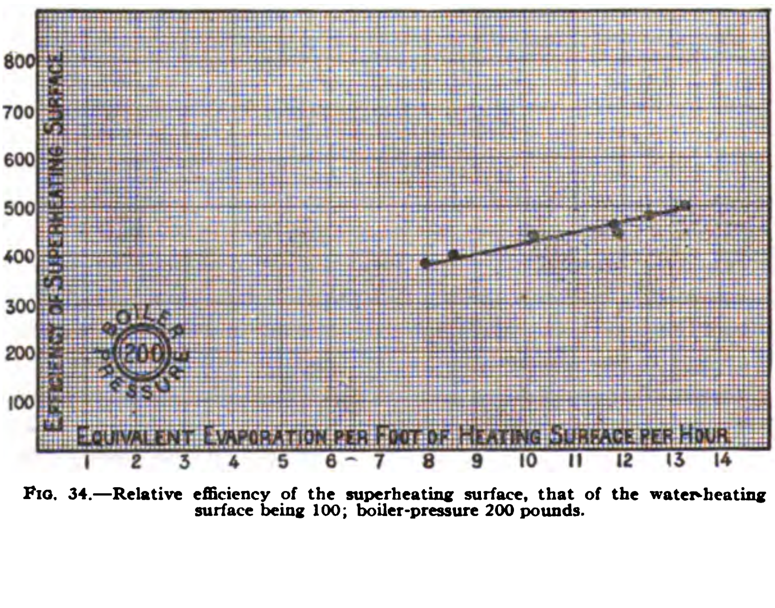


Fig. 34.—Relative efficiency of the superheating surface, that of the water-heating surface being 100; boiler-pressure 200 pounds.

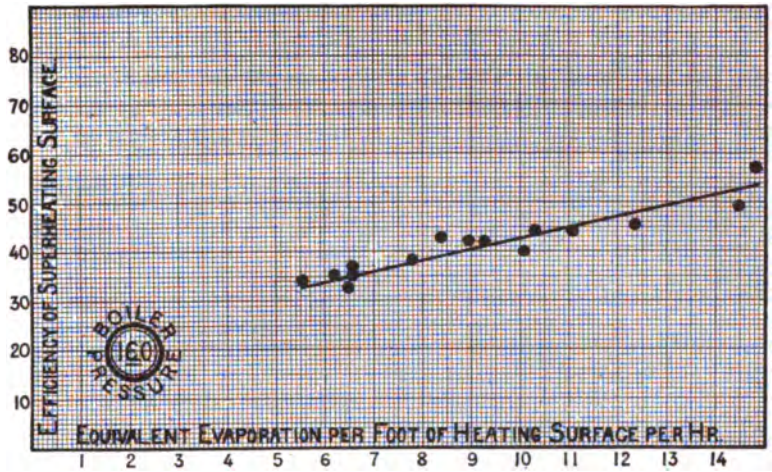


FIG. 35.—Relative efficiency of the superheating surface, that of the water-heating surface being 100; boiler-pressure 160 pounds.

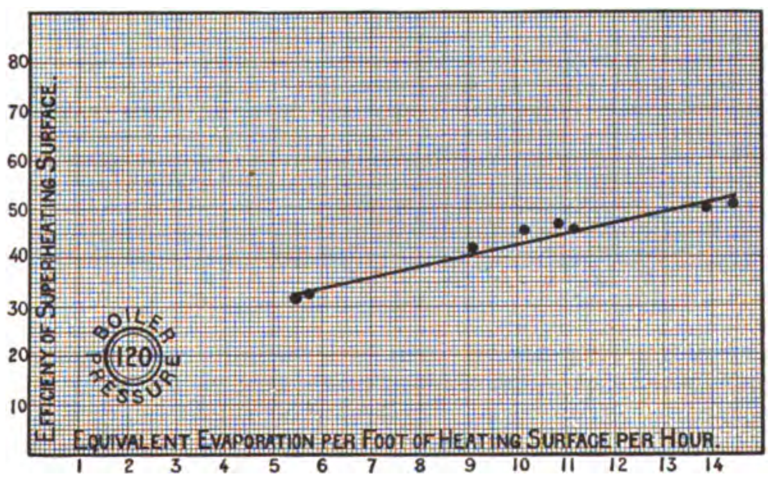


FIG. 36.—Relative efficiency of the superheating surface, that of the water-heating surface being 100; boiler-pressure 120 pounds.

highest values are, however, those which were obtained in tests under the higher pressures, the average value for all tests at 240 pounds being 14.25, while the average value for all tests at 120 pounds is but 11.70. This may be accepted as evidence that, for some reason not defined, the fire was maintained in a more efficient condition during the tests under high pressure than

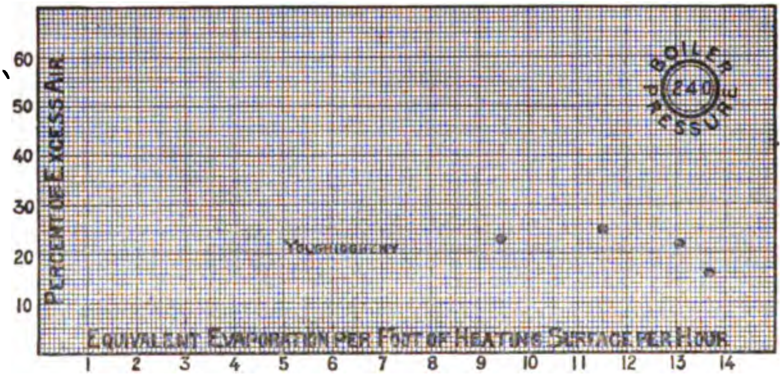


FIG. 37.—Excess air in the smoke-box; boiler-pressure 240 pounds.

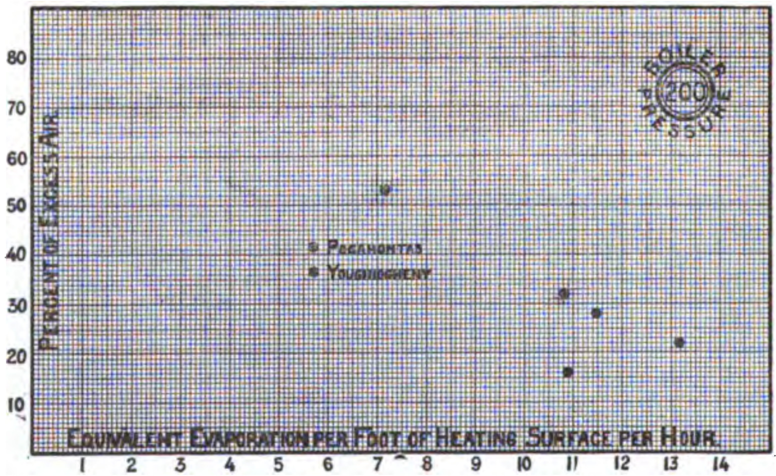


FIG. 38.—Excess air in the smoke-box; boiler-pressure 200 pounds.

during those at lower pressures. It is in fact well understood in the laboratory that the development of a given power with higher-pressure steam is more exacting upon the fireman than the development of the same power with steam at a lower pressure.

The percentage of carbon monoxide (CO) present in the smoke-box gases is never great (column 67, Appendix II), notwithstanding the low percentage of excess air present. At the same time, there are no tests that do not show the presence of a trace or more than a trace of this gas. Its tendency to increase as the percentage of excess air diminishes is well shown by fig. 41. This figure shows also that under similar conditions the combustion of the Pocahontas coal is less perfect than that of the Youghiogheny, a result which is more likely to be due to the presence of a greater percentage of fine coal in the Pocahontas than to differences in composition. The ten-

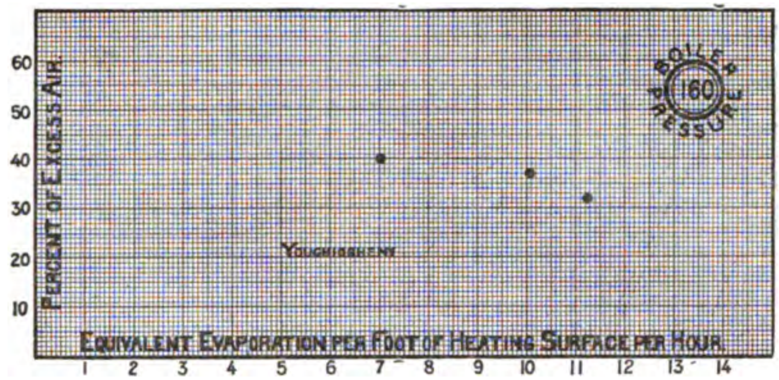


FIG. 39.—Excess air in the smoke-box; boiler-pressure 160 pounds.

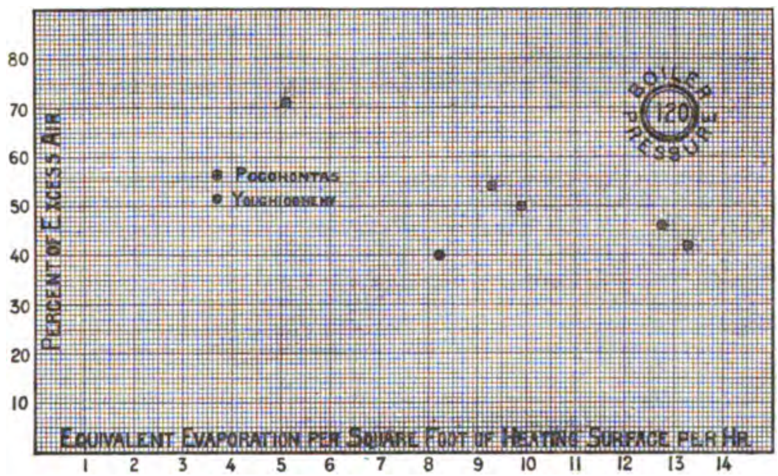


FIG. 40.—Excess air in the smoke-box; boiler-pressure 120 pounds.

dency of carbon monoxide to increase with increased rates of evaporation is shown by fig. 42. This tendency is doubtless due to mechanical conditions. It may be accepted also as a function of that tendency to which attention has already been called. Thus, increased rates of evaporation demand higher rates of combustion, and these in turn require more air, which must be supplied by an increase in the strength of the draft-action. In the presence of a stronger draft the bed of the fire must be thickened, and the thicker fire throttles the passage of air into the fire-box to such an extent that the supply is not commensurate with the increase in the draft-action; hence a reduction in the amount of excess air, and this, as has already been shown, leads to an increase in the percentage of unconsumed gas.

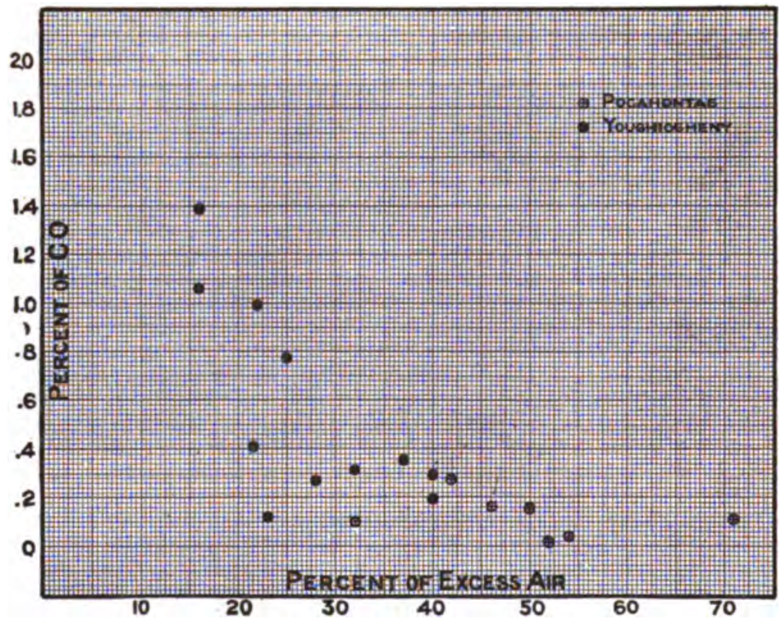


Fig. 41.—Carbon monoxide and excess air.

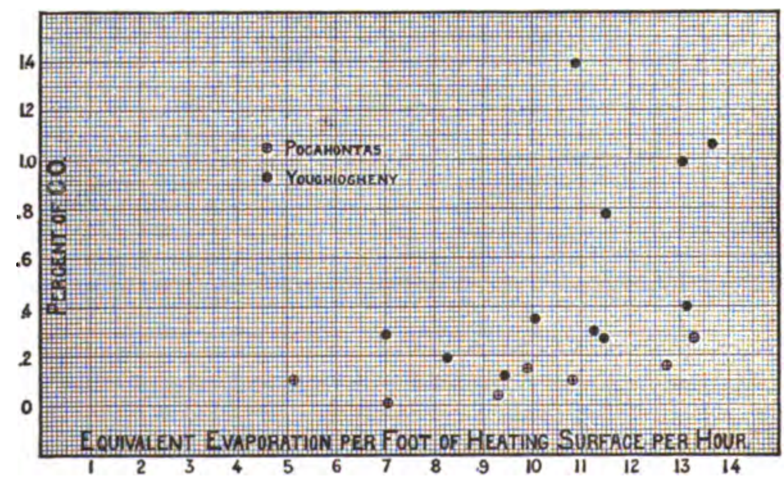


Fig. 42.—Carbon monoxide and rate of evaporation.

23. Heat-Balance.—From data obtained, it has been possible to complete a heat-balance for 18 tests. The results appear as columns 92 to 112, Appendix II. Graphic representations of the heat absorbed and of the heat lost, plotted in terms of the rate of evaporation, are presented by figs. 43 and 44. The necessity for two diagrams is to be regretted. It has been no part of the purpose of the present work to make tests of coals, and thus far in the discussion it has been possible to avoid bringing into direct comparison the results obtained from the two varieties employed. The process of making up a heat-balance, however, admits of no compromise, and the discussion which follows necessarily defines the behavior of the coals. In the consideration given this portion of the work it will be well to remember that the commercial grading of the two coals was not the same. This is well brought out by the following summarized facts concerning them:

The Pocahontas coal used was run-of-mine, and as such it contained a considerable amount of slack. It was fairly uniform throughout.

The Youghiogheny coal was obtained from two different sources and was less uniform in quality. All tests involving this fuel, run prior to April 12, were fired with a so-called Virginia lump, while tests run after this date were fired with fuel delivered as run-of-mine, but which was screened at the laboratory before being used. Averages of all results obtained from samples of the Pocahontas and Youghiogheny coal is shown in the following statement.

The facts concerning the proximate and ultimate analyses of the coal used in each test are given as columns 74 to 86, and its calorific values as columns 87 to 91, Appendix II.

	Pocahontas.	Youghiogheny.
Moisture (per cent)	3.10	1.89
Volatile matter (per cent)	15.23	31.94
Fixed carbon (per cent)	72.75	57.71
Ash (per cent)	8.92	8.46
Heating value per pound of dry coal (b. t. u.)	14,347	14,047
Heating value per pound of combustible (b. t. u.)	15,802	15,372

In the diagrams, figs. 43 and 44, the term "heating-surface," as employed in designating the abscissæ, includes the heat-transmitting surface of both boiler and superheater. The ordinates of the diagrams represent the percentage of heat in the fuel supplied. Distances measured on ordinates between the axis and the first line *A* represent the percentage of the total heat supplied which is absorbed by the water of the boiler. The line *A* is in fact a definition of the efficiency of the boiler under the varying rates of evaporation represented by the series of tests. While based upon a different unit, it is, as it ought to be, similar in form to curves defining the evaporative efficiency of the boiler, which show the pounds of water evaporated per pound of coal used (figs. 27 to 31). The inclination of all such lines shows the extent to which the efficiency of the boiler suffers as the rate of evaporation is increased. The nature and extent of the losses leading to such a result are to be found in the areas above the line *A*. The fact that the points representing different tests, through which this line *A* is drawn, do not result in a smooth curve is

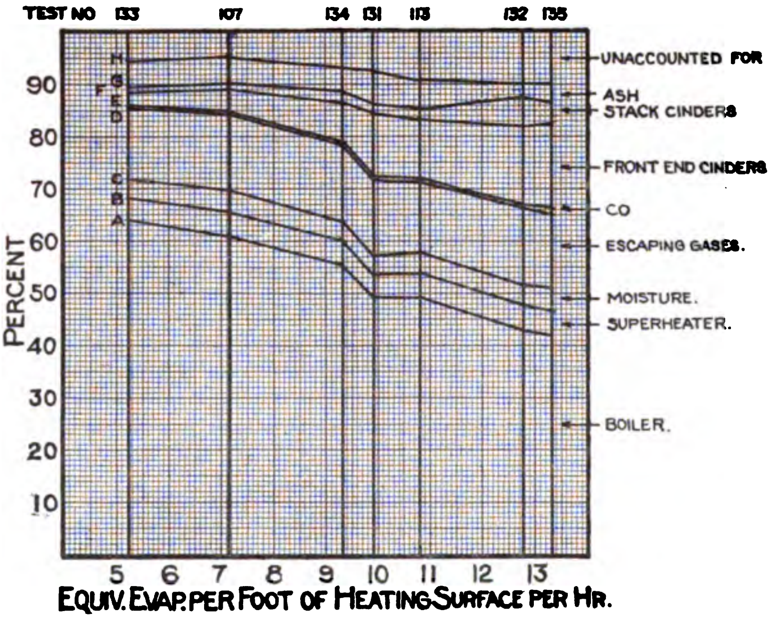


FIG. 43.—Heat-balance of combined boiler and superheater as derived from tests of Pocahontas coal.

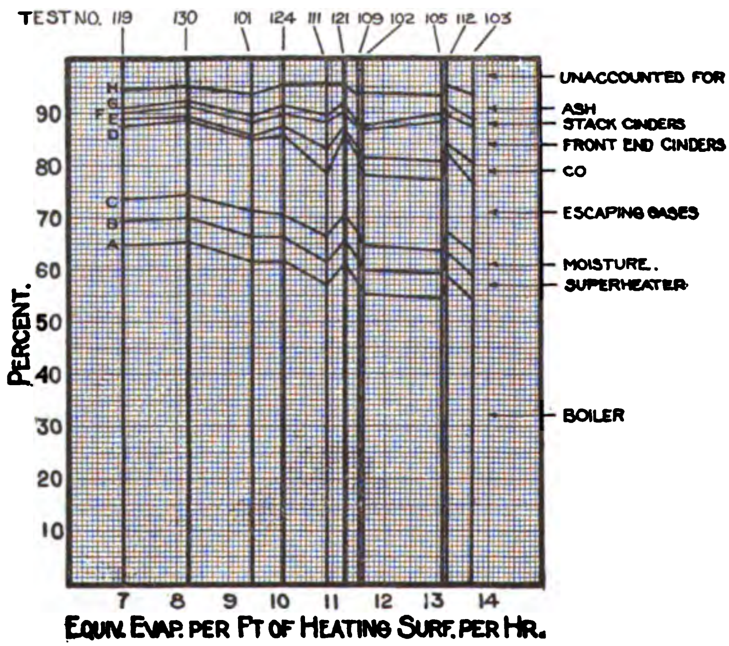


FIG. 44.—Heat-balance of combined boiler and superheater as derived from tests of Youghiogheny coal.

due to irregularities in furnace conditions which were beyond the vigilance of the operator, an explanation which applies equally to other lines, *B*, *C*, *D*, etc., of the same diagrams.

The percentage of the total heat which is absorbed by the superheater is measured by distances on ordinate between the line *A* and the line *B*. It is apparent from the record that the percentage of the total heat absorbed by the superheater is practically constant, whatever may be the power to which the boiler is driven. The normal maximum power of a locomotive may, for present purposes, be assumed to be that power which is represented by an evaporation of 12 pounds of water per foot of heating-surface per hour. Basing a statement on the record as it appears from the rate of power, the superheater, which contains 16 per cent of the total heat-transmitting surface, receives approximately 8 per cent of the total heat absorbed. Distances between the broken line *B* and the axis represent the efficiency of the combined boiler and superheater. Distances above this line *B* account for the various heat-losses incident to the operation of the furnace, boiler, and superheater.

Losses of heat arising from the presence of accidental and combined moisture in the fuel, the presence of moisture in the atmospheric air admitted to the fire-box, and of moisture resulting from the decomposition of hydrogen in the coal are represented by distances measured on ordinates between the lines *B* and *C*. It is of passing interest to note that the heat thus accounted for is practically equal to that absorbed by the superheater.

Losses of heat in gases discharged from the stack are represented by distances measured on ordinates between the lines *C* and *D*. The distances between the lines *D* and *E* represent that portion of these losses which is due to the incomplete burning of the combustible gases. The record shows that this loss is necessarily large, but does not increase with increased rates of combustion, as has commonly been supposed. In other words, the loss in evaporative efficiency with increase of power (figs. 27 to 32) does not occur in any degree through the channel of the smoke-box gases. That portion of this loss which is chargeable to incomplete combustion is small under low rates of combustion, but may increase to values of some significance under the influence of very high rates of combustion, as will be seen from the record of the Youghiogheny coal.

Losses of heat through the discharge from the fire-box of unconsumed fuel are represented by distances measured on ordinates between the lines *E* and *H*. The loss thus defined is separated into three parts, namely: the heat lost by partially consumed fuel in the form of cinders collecting in the front-end (*EF*); the heat lost by partially consumed fuel in the form of cinders or sparks thrown out of the stack (*FG*); the heat lost by partially burned fuel dropping through the grate into the ash-pan (*GH*).

The first two of these losses increase with the rate of power developed. They are in fact the chief cause of the falling off of the evaporative efficiency of a locomotive boiler with increased rates of power. This is well shown by a comparison of the two diagrams. In the case of tests with the Pocahontas coal (fig. 43) the cinder loss is comparatively heavy and the boiler efficiency diminishes in a marked degree under high rates of power, while tests under similar conditions with the Youghiogheny coal (fig. 44), involving less loss by cinders, show an efficiency of the boiler under high rates of power which is much better sustained.

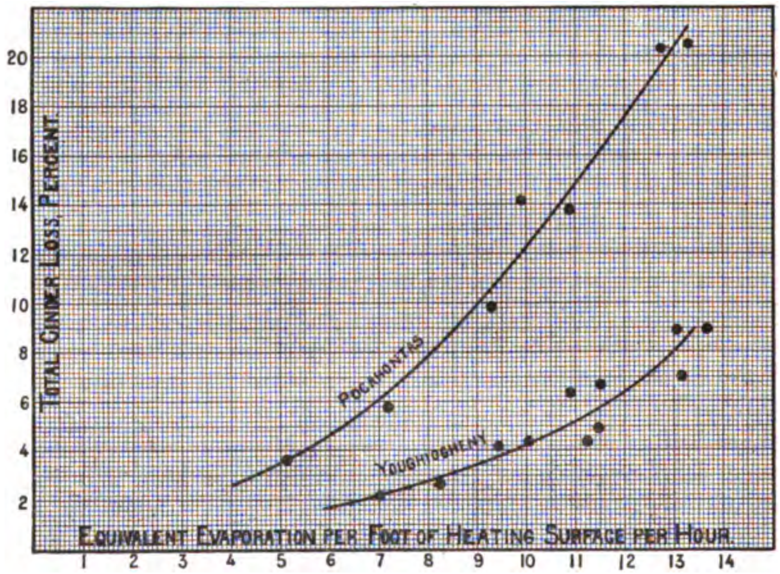


FIG. 45.—Stack and front-end cinder loss, per cent of coal fired.

The cinder loss, expressed as a percentage of the total weight of coal fired, is shown by fig. 45, and the heating value of the material thus accounted for by fig. 46. It will be seen that cinders from the Pocahontas coal have more than double the weight and that each pound has nearly double the heating value of those resulting from the Youghiogheny coal, a result doubtless due in part to the large percentage of fine coal in the Pocahontas and to the absence of such material in the Youghiogheny. The stack cinders from both coals have a higher calorific value than those caught in the smokebox. Under the practice of the laboratory, in no case was the coal wetted previous to its being fired. Concerning the general significance of the results, it will be well to remember that the fuel used in all tests is of high quality. Lighter and more friable coals are as a rule more prolific producers of stack and front-end cinders.

Radiation, leakage, and all other losses unaccounted for are represented by distances measured on ordinates between the line H and the 100 per cent line of the diagram. The radiation losses are probably from 1 to 2 per cent of the total heat available, the remainder equaling from 2 to 4 per cent, representing leakage of steam or water, or inaccuracy in the determination of quantities already discussed.

24. A Summarized Statement with Reference to the Distribution of Heat in the Locomotive Experimented upon.—It is sometimes convenient, for the purpose of fixing values in one's mind, to have an elaborate statement of fact summarized into a few representative values, the relation between which may be easily remembered. Such a summary may be framed in the present case

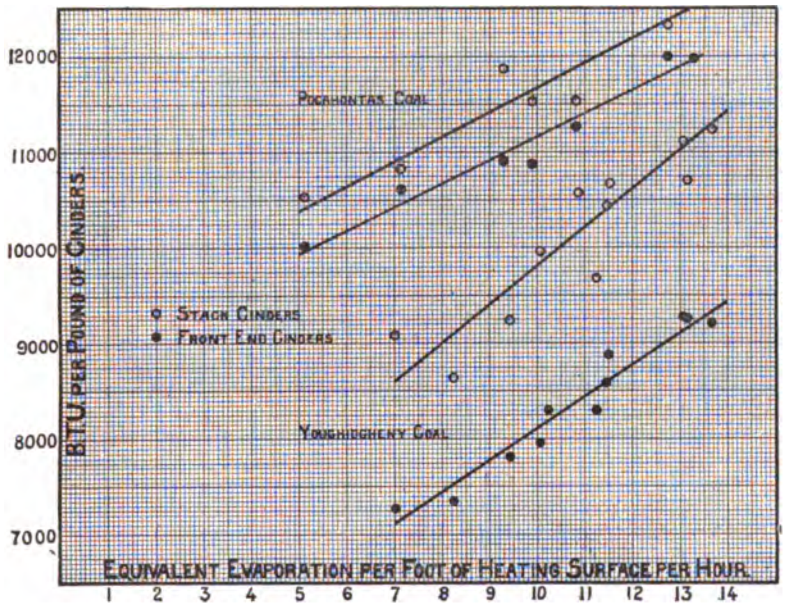


FIG. 46.—Heat value of stack and front-end cinders.

by assuming that the normal maximum power of the locomotive tested is that which involves a rate of evaporation of 12 pounds of water per square foot of heating surface per hour, and by averaging values for this rate of power, from the diagrams, figs. 43 and 44. The result may be accepted as showing in general terms the action of such a locomotive as that tested when fired with a good Pennsylvania or West Virginia coal. It is as follows:

	Per cent.
Total heat available, absorbed by water in boiler	52
Total heat available, absorbed by steam in superheater	5
Total heat available, lost in vaporizing moisture in coal	5
Total heat available, lost through discharge of CO	1
Total heat available, lost through high temperature of escaping gases, the products of combustion	14
Total heat available, lost through unconsumed fuel in the form of front-end cinders	3
Total heat available, lost through unconsumed fuel in the form of cinders or sparks passed out of stack	9
Total heat available, lost through unconsumed fuel in ash	4
Total heat available, lost through radiation, leakage of steam and water, etc.	7

V. PERFORMANCE OF THE ENGINE AND OF THE LOCOMOTIVE AS A WHOLE.

25. Indicator-Cards.—Data from indicator-cards taken from each end of each cylinder at 10-minute intervals appear as columns 113 to 162, Appendix II. An exhibit of cards, reproduced at the size taken, make up Appendix IV.

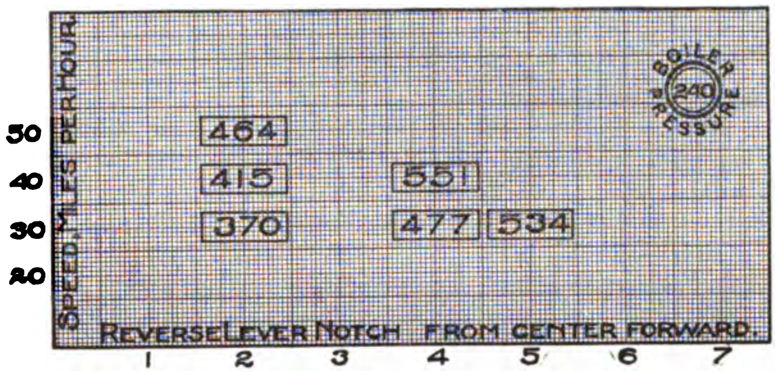


FIG. 47.—Indicated horse-power; boiler-pressure 240 pounds.

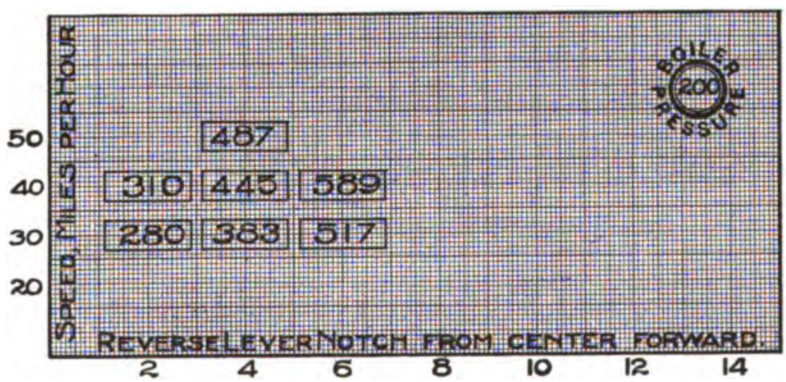


FIG. 48.—Indicated horse-power; boiler-pressure 200 pounds.

Two series represent tests at each pressure: one in which the speed is constant and the point of cut-off variable, and the other in which the point of cut-off is constant and the speed variable. While the cards thus selected do not represent all tests which were run, a sufficient number is included adequately to show the form of card given by the engine under its entire range of action.

26. Indicated Horse-Power.—The indicated horse-power is shown in detail by columns 163 to 167, Appendix II, and graphically by figs. 47 to 50. These figures show well the effect, upon the amount of power developed, of changes in speed and of changes in cut-off. In these and in succeeding diagrams the

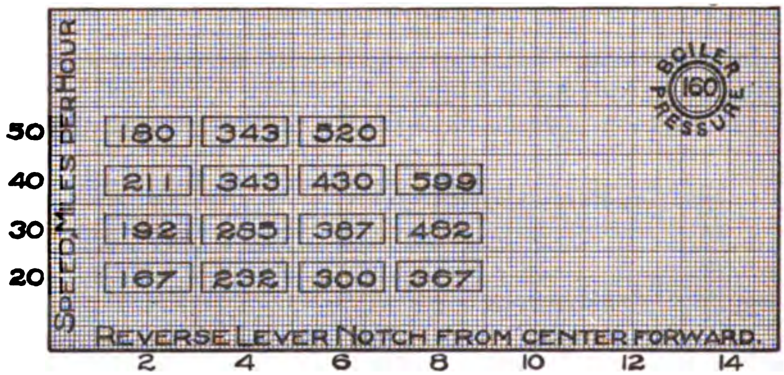


FIG. 49.—Indicated horse-power; boiler-pressure 160 pounds.

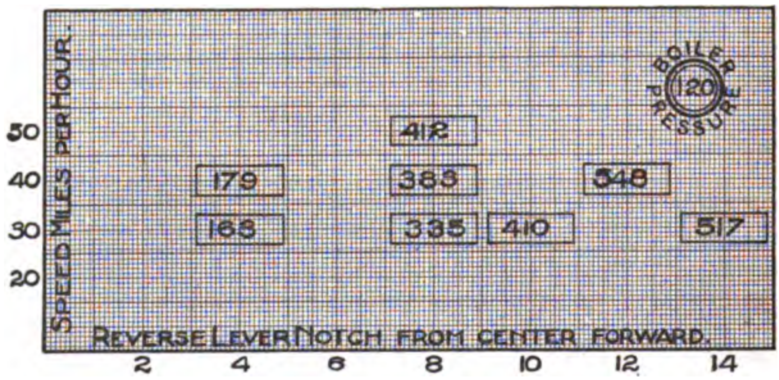


FIG. 50.—Indicated horse-power; boiler-pressure 120 pounds.

degree of expansion is expressed by the position of the reverse lever; the corresponding cut-off in per cent of piston-stroke is approximately as follows:

Reverse-lever	2d notch, cut-off approximately	16 per cent.
	4th " " "	21
	6th " " "	27
	8th " " "	35
	10th " " "	43
	12th " " "	51
	14th " " "	57

All tests, it will be remembered, were run with a wide-open throttle. The figures show that the maximum power (599) was developed under a boiler-pressure of 160 pounds and a speed of 40 miles an hour, with the reverse-lever in the eighth notch. A comparison of the diagrams one with another will show the effect of changes in boiler-pressure upon the power output of the engine for any given position of the reverse-lever. For example, the power developed at a speed of 40 miles an hour with the reverse-lever in the fourth notch under the several pressures carried is as follows:

Pressure.	Corresponding horse-power.
Pounds.	
120	179
160	343
200	445
240	551

27. Steam Consumption per Indicated Horse-power.—The steam consumption per indicated horse-power is shown by column 168, Appendix II, and is presented graphically by figs. 51 to 54. These diagrams show clearly the effect of speed and cut-off on the steam consumption of the cylinders. The most complete exhibit is that of tests run at a pressure of 160 pounds. In this series the full range of speed and cut-off possible under a wide-open throttle has been carried out and consequently the exhibit of results for this pressure discloses a record of the maximum and minimum performance under a wide-open throttle. The maximum steam consumption for any test of record is 29.06 pounds and the minimum is 20.29.

Reviewing the results with reference to cut-off, it appears that under 240 pounds pressure the highest efficiency is obtained when the reverse-lever is in the fourth notch (cut-off 21 per cent of stroke). Under 200 pounds pressure the highest efficiency is obtained when the reverse-lever is in the sixth notch (cut-off 27 per cent of stroke). Under 160 pounds pressure the highest efficiency is obtained when the reverse-lever is in the eighth notch (cut-off 35

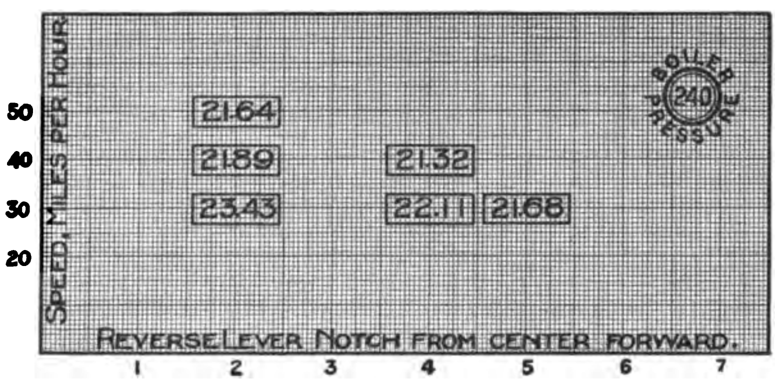


Fig. 51.—Steam per indicated horse-power hour; boiler-pressure 240 pounds.

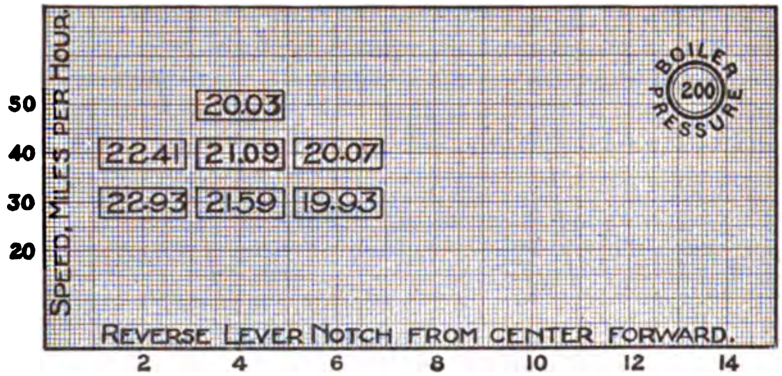


FIG. 52.—Steam per indicated horse-power hour; boiler-pressure 200 pounds.

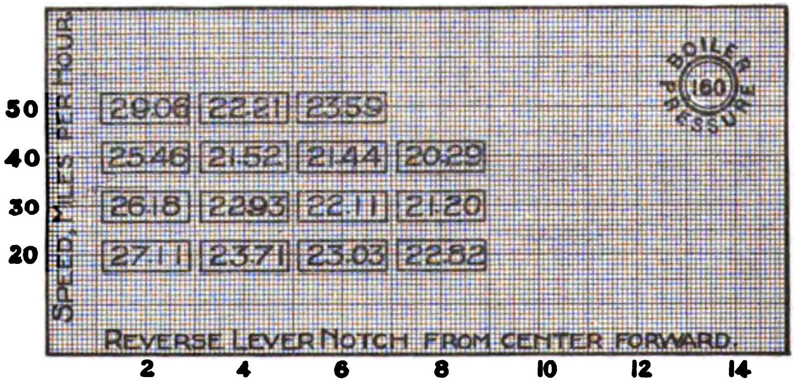


FIG. 53.—Steam per indicated horse-power hour; boiler-pressure 160 pounds.

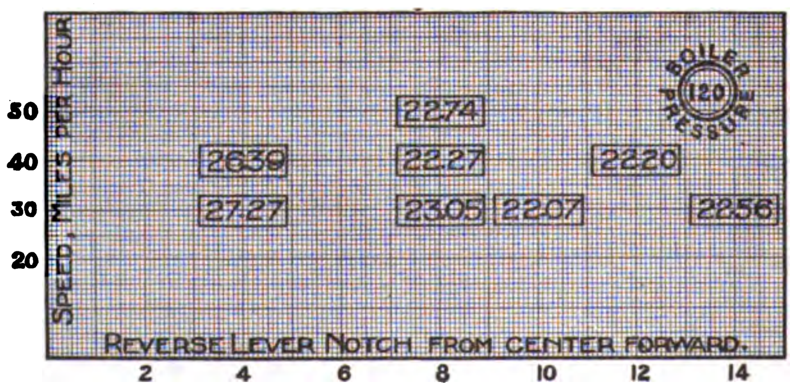


FIG. 54.—Steam per indicated horse-power hour; boiler-pressure 120 pounds.

per cent of stroke). When the pressure was 120 pounds the highest efficiency was obtained when the reverse-lever was in the twelfth notch (cut-off 51 per cent of stroke). These conditions of cut-off attending maximum efficiency are substantially the same as those which were found to be necessary when the engine was served with saturated steam; that is, supplying the engine with steam superheated 150° or more requires no change in cut-off for maximum efficiency.

Changes in steam consumption with changes of speed are of the same character as those occurring when saturated steam is used. Thus, under a constant cut-off and full-open throttle, and beginning at a low speed, the steam consumption generally diminishes with increase of speed. Tests at lower pressures, however, show that the minimum consumption is reached at a speed of approximately 40 miles an hour and that higher speeds involve increased consumption. The least steam consumption per horse-power hour for each of the several pressures at which tests were run is shown by fig. 55.

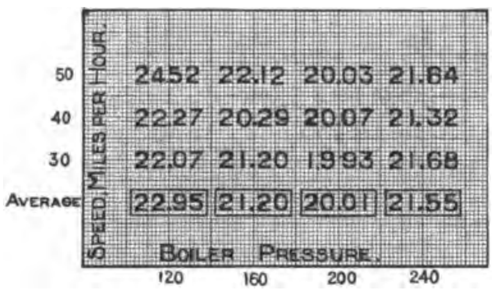


FIG. 55.—Least steam consumption for each of the several speeds at different pressures.

For the purpose of securing a statement of the steam consumption of the engine as set forth by the data presented, values for all pressures have been plotted upon a single sheet. In making up this figure, values for the second-notch tests at 160 pounds have been excluded, since these tests were at a very low power and there are no corresponding tests at other pressures. In a few cases values for other pressures not covered by the data have been derived by extrapolation. Points thus plotted fall within the shaded area of fig. 56, which area may therefore be accepted as a full representation of the facts developed with reference to steam consumption by the present series of tests. The least steam consumption for each of the several pressures as represented by the average values given in fig. 55 is indicated upon the shaded zone by points designated by crosses, while the average of all accepted values for each given pressure are represented upon the shaded area by circles. In order that the steam consumption of the engine may be defined by a single series of values, a line (AB, fig. 56) has been drawn through the average points represented by the circle. It is proposed to accept this line as representing the steam consumption of the experimental engine under the several pressures employed. It should be noted that it is not the least consumption nor the maximum, but that it is the average of a group of results all of which represent normal working conditions, and none of which represent a consumption more than 4 pounds above the minimum.

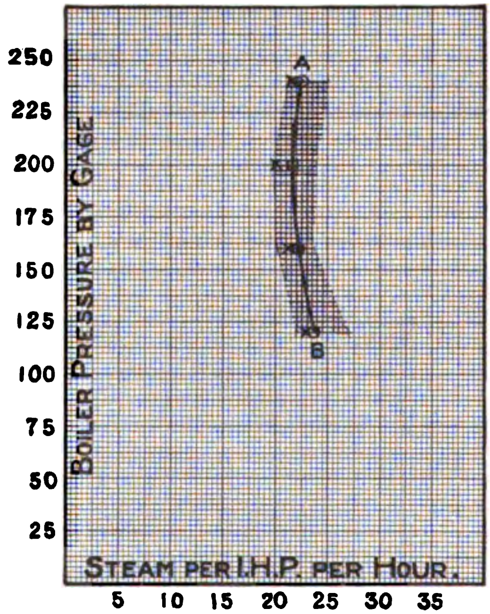


FIG. 56.—Steam consumption under different pressures.

From the curve it appears that the minimum normal consumption is obtained under a pressure of 200 pounds, and that at this pressure it amounts approximately to 21.6 pounds per indicated horse-power hour.

28. Steam Shown by Indicator (column 169, also columns 175 to 195, Appendix II).—Values in these columns disclose the condition of the mixture in the cylinder. If, for any test, it should appear that there is present in the cylinder more than 100 per cent of mixture, it is to be accepted as evidence that for that test the steam was superheated at release. The data show that such a condition is not closely approached for any of the high-pressure tests, all of which were necessarily run under comparatively short cut-off. As the pressure is reduced and the cut-off is lengthened the percentage of steam accounted for increases, and for two tests under a pressure of 120 pounds the actual presence of superheated steam is shown. This applies to tests for which the cut-off was not less than half stroke. By reference to columns 168 and 169 it will appear that for these tests, also, the percentage of steam accounted for by the indicator was greater than that accounted for by the tank, which is conclusive evidence that the exhaust was superheated.

A comparison of the percentages of the total mixture, which are shown by the indicator at release (column 193, Appendix II), with similar values taken from the performance of the saturated-steam locomotive *Schenectady No. 2*, is presented in table 1. Results obtained at a speed of 30 miles an hour only are included. For example, when the boiler-pressure is 240 pounds, the percentage of the mixture shown as steam is 83 per cent when superheated steam is used and 77 per cent when saturated steam is used. Similarly, when the boiler-pressure is 120 pounds, the percentage of total mixture accounted for varies from 90 to 106 when superheated steam is used and from 72 to 85 when saturated steam is used. In general, it appears that, under conditions herein defined, the substitution of superheated for saturated steam results in an increase of the percentage of mixture, which is shown by the indicator for all events of the stroke, and that the rate of increase becomes greater as the cut-off is prolonged and also as the boiler-pressure is diminished—results which are consistent and easy of explanation.

TABLE 1.—*Percentage of mixture shown as steam at release by indicator-cards.*
(*Speed, 30 miles per hour.*)

Cut-off, reverse-lever notch from center forward.	Percentage of mixture shown as steam at release by indicator-cards.							
	Boiler-pressure 240 pounds.		Boiler-pressure 200 pounds.		Boiler-pressure 160 pounds.		Boiler-pressure 120 pounds.	
	Super-heated.	Sat-urated.	Super-heated.	Sat-urated.	Super-heated.	Sat-urated.	Super-heated.	Sat-urated.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
2	82.8	75.0	85.2	72.9	85.7	....	....	....
4	82.2	76.7	86.2	77.5	87.4	75.7	89.8	72.0
6	....	....	89.7	75.5	86.0	77.0	....	....
8	....	....	....	....	90.9	80.0	89.7	74.6
12	....	....	....	....	....	....	93.5	....
14	....	....	....	....	....	....	106.0	84.7

29. Coal Consumption.—The coal consumption per indicated horse-power hour appears as column 203, Appendix II. The values of this column show that under favorable conditions the consumption is approximately 3 pounds, the minimum value of record being 2.8 pounds. In 2 tests only, of the 38 tests of record, does it reach a maximum of 4 pounds. The coal consumption per draw-bar horse-power hour appears as column 202, Appendix II, and graphically as figs. 57 to 60. These values are based upon direct observations. They include no accounting for differences in the quality of fuel; these and irregularities arising from other sources are dealt with in paragraph 30.

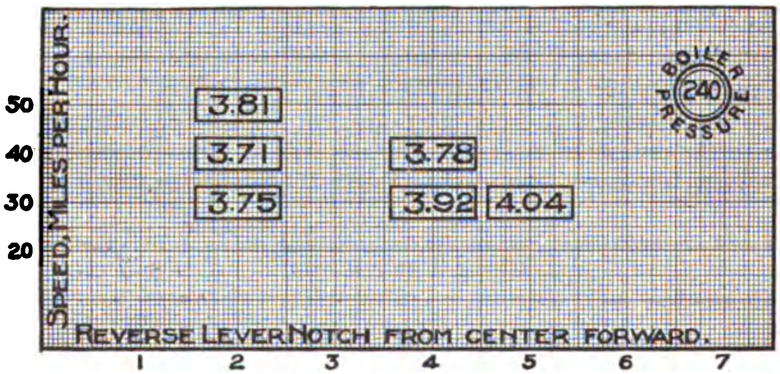


FIG. 57.—Coal per draw-bar horse-power hour; boiler-pressure 240 pounds.

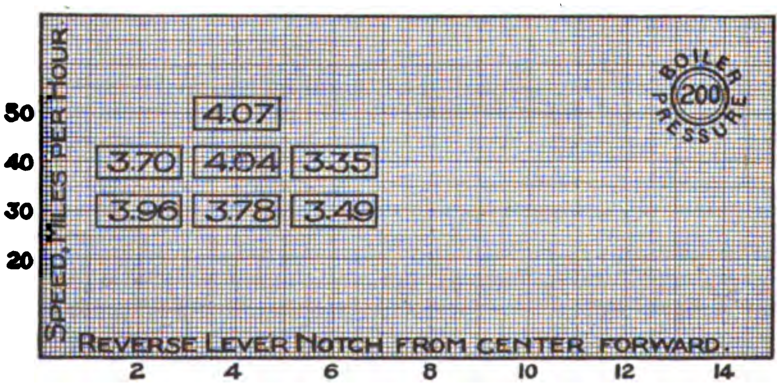


FIG. 58.—Coal per draw-bar horse-power hour; boiler-pressure 200 pounds.

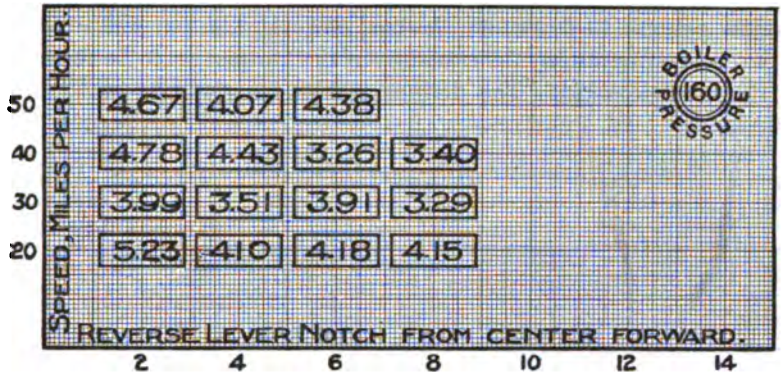


FIG. 59.—Coal per draw-bar horse-power hour; boiler-pressure 160 pounds.

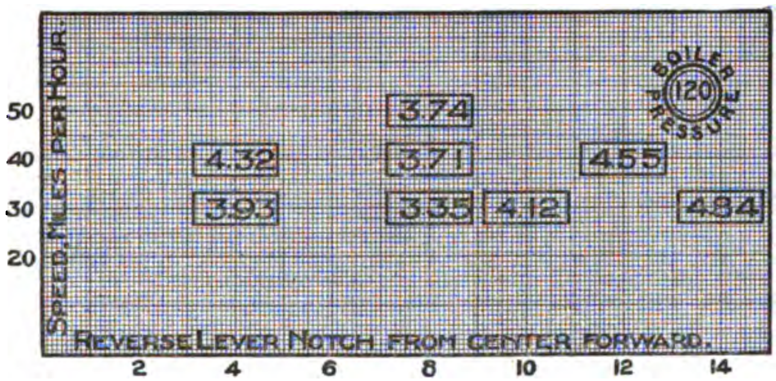


FIG. 60.—Coal per draw-bar horse-power hour; boiler-pressure 120 pounds.

30. Comparing the Performance of the Locomotive, assuming Incidental Irregularities in the Tests to have been Eliminated.—It is apparent that any series of values based directly upon experimental observations will present irregularities. In the course of the preceding discussion it was sought to eliminate the effect of certain of these irregularities and to define the performance of the boiler, of the superheater, and of the cylinders of the locotive experimented upon in terms which have resulted from a careful summarization of all the data available. Making use of the statements of performance thus secured, it is possible to compile a table of engine performance based upon the experimental data but freed from its inconsistencies. Columns 204 to 215, Appendix II, make up such a table. The basis of the correction and calculations underlying each value will be found set forth in its proper place.

Obviously, the exhibit of such a table will have the highest value for purposes of comparison. Thus, the equation defining the performance of the boiler and superheater combined is $E = 11.706 - 0.214\ H$, and that defining the performance of the superheater is $T = 123 - 0.265P + 7.28\ H$, and the performance of the engine is defined by the curve $A\ B$, fig. 56.

It is now possible to determine the coal consumption per indicated horse-power per hour by assuming the efficiency of the locomotive to be that defined in the above relationship. The derived results are given as table 2, which follows.

TABLE 2.—*Locomotive performance under different pressures.*

Boiler-pressure.	Pounds of superheated steam per indicated horse-power per hour; values from curve.	B. t. u. per pound of steam, feed 60° and superheat from equation.	Equivalent pounds of steam per indicated horse-power hour.	Equivalent pounds of water per pound of dry coal.	Pounds of coal per indicated horse-power hour.
1	2	3	4	5	6
Pounds.					
240	22.6	1258.7	29.45	9.426	3.12
220	21.8	1261.8	28.48	9.501	3.00
200	21.6	1263.1	28.25	9.518	2.97
180	21.9	1261.7	28.61	9.491	3.01
160	22.3	1259.3	29.07	9.455	3.08
140	22.9	1256.4	29.79	9.399	3.17
120	23.8	1252.7	30.87	9.316	3.31

Column 1 in table 2 gives the boiler-pressure.

Column 2 gives the steam consumption per indicated horse-power per hour for the several pressures, as defined by the curve *A B*, fig. 56.

Column 3 gives the number of thermal units in the pounds of steam at the several pressures, assuming the feed-water temperature at 60° F. and the degrees superheat that represented by the equation $T=123-0.265P+7.28\ H$.

Column 4 gives the number of pounds of water from and at 212° F. per indicated horse-power hour. It equals column 2 times column 3÷965.8.

Column 5 gives the pounds of water evaporated from and at 212° F. per pound of coal and is calculated as follows: Assuming that a fair average load for the locomotive tested is 440 horse-power and that this unit of power is developed under all pressures, the corresponding rate of evaporation may be found by multiplying this value by those of column 4 and dividing by the area of water-heating surface plus superheating surface; that is, rate of evaporation = 440 × column 4÷1216. The equivalent pounds of water per pound of coal is found by substituting the rate of evaporation found for *H* in the equation $E=11.706-0.214\ H$.

Column 6 gives the pounds of coal per indicated horse-power hour and equals column 4 ÷ column 5.

From the values given in the table it will be seen that the coal consumption per indicated horse-power hour varies from 2.97 to 3.31. The minimum value 2.97 is found at 200 pounds boiler-pressure.

VI. LOCOMOTIVE EFFICIENCY AS AFFECTED BY ITS RUNNING SCHEDULE: AN ACCOUNT OF A SERIES OF INTERMITTENT TESTS.

31. Coal Saving as Affected by Operating Conditions.—In the work which has preceded it has been the purpose to define the efficiency of the boiler and engines of the locomotive experimented upon, under constant conditions of operation. Tests were not started until the engine had been subjected to preliminary running and until all parts of the machine had had an opportunity to assume the temperature normal to the conditions prescribed for the test. Performance thus defined may be accepted as maximum. The conditions of service introduce avenues through which losses occur which do not appear in a test run under such conditions. In the process of starting fires, in raising steam-pressure, and in moving the locomotive from its round-house to its train, fuel is required which is not made immediately available in the movement of trains; fuel is consumed while the locomotive stands at stations or upon passing tracks, and a considerable amount is in the fire-box unconsumed when the locomotive delivers up its train at its terminal. The percentage of the total fuel supplied a locomotive which is thus accounted for depends upon local conditions and upon the character of the service. It is important to note that no improvement in the thermodynamic action of the locomotive can materially effect an economy in the use of the fuel thus accounted for.

32. An Outline of Laboratory Tests Involving Intermittent Running.—As a part of a study designed to show the value of superheated steam in locomotive service, an attempt has been made to secure an estimate of those expenditures of heat which may not be reduced or otherwise affected by the general adoption of superheating locomotives. To this end tests have been made in the course of which the movement of the locomotive and the amount of work done by it have been controlled in response to a fixed schedule, the observations including the consumption of coal, water, etc., covering the entire period from the starting of fires to the end of the day's work. Altogether nine such tests have been run, the duration of each being 8 hours and 20 minutes.

In all cases the first starting of the engine occurred 120 minutes after the starting of fires and the remaining 400 minutes of the test were occupied with definite periods of running and of standing. In one series of tests the running was made to equal one-half of the total time and these tests will hereafter be referred to as "half-time tests." In the other series the running time equaled one-quarter of the total time, and these tests will hereafter be referred to as

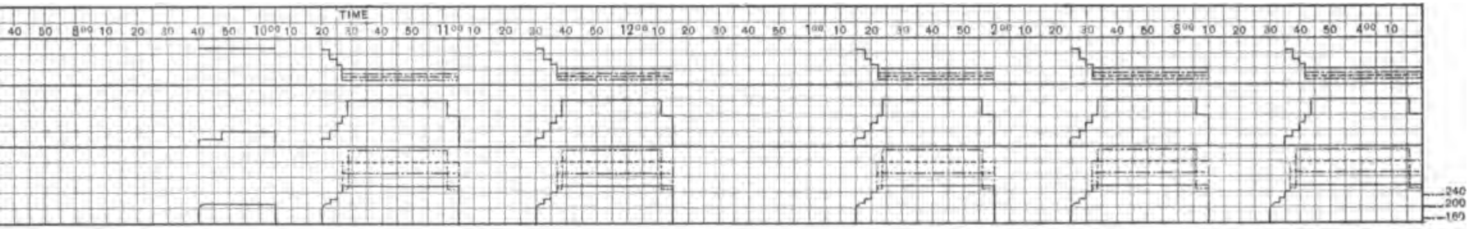


Fig. 61.—Running schedule, half-time intermittent tests.

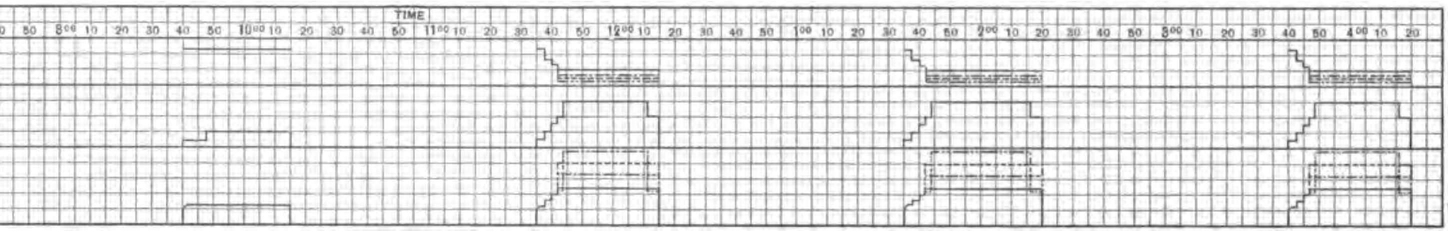


Fig. 62.—Running schedule, quarter-time intermittent tests.

the "quarter-time tests." A graphic representation of the schedule for the half-time tests is shown by fig. 61, and that of the quarter-time tests by fig. 62. A summary of the data for all tests will be found as tables 28 to 36 of Appendix III.

It was the purpose to have the draw-bar pull and the speed during the time of normal running the same for all tests. It was assumed that the value of tests run under such conditions would depend largely upon the degree of precision with which the program could be duplicated. For the purpose of demonstrating the accuracy with which this could be done, one test (No. 5) was duplicated, the results appearing in the data (Appendix III) as those of 205*a*. In the first of these duplicate tests, 34,600 pounds of water were evaporated by the use of 4,590 pounds of coal, while in the second test 33,600 pounds of water were evaporated with 4,490 pounds of coal. The difference in the total amount of steam used in these two tests is 3 per cent and the difference in the evaporative efficiency of the boiler is less than 1 per cent. The complete exhibit of data for these intermittent tests and a detailed description of the methods employed in obtaining them are presented as Appendix III.

33. Boiler Performance.—The data in detail covering the performance of the boiler are set forth by columns 22 to 40, Appendix III. The evaporative efficiency per pound of dry coal is given by column 40. In these values, however, the boiler is not charged with the coal used in firing up, which, as will be seen by column 32, is from one-sixth to one-seventh the total quantity used for a test, and the effect of including this would be to reduce the evaporative efficiency by this amount. As would be expected, even without including the coal used in firing up, the evaporative efficiency of the boiler diminishes as the schedule involves a larger percentage of idle time. For example, from column 40 it appears that the quarter-time tests are, with one exception, less efficient than the half-time tests. The results of the quarter-time tests show a tendency to improve when the boiler-pressure is reduced.

34. The Results of the Chemical Work Underlying the Heat-Balance of the Boiler appear in columns 56 to 82, and the results of the heat-balance itself are presented as columns 83 to 92, Appendix III. In reviewing the results herein set forth it should not be forgotten that all tests were run substantially at the same power; the load upon the boiler did not change materially in passing from one test to another. The pressure for the several tests, however, ranged from 240 to 120 pounds. Tests were run at each pressure both upon the quarter-time and half-time schedules. The results of the heat-balance, as obtained, are set forth graphically by figs. 63 and 64. They show the percentage of the total heat available which is absorbed by the boiler and superheater, which is discharged in the form of waste gases,

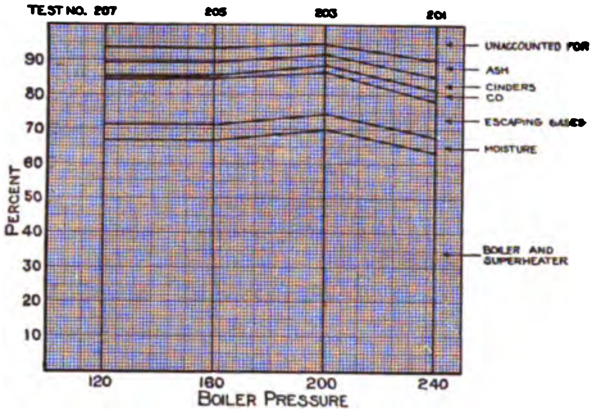


FIG. 63.—Heat-balance, half-time tests.

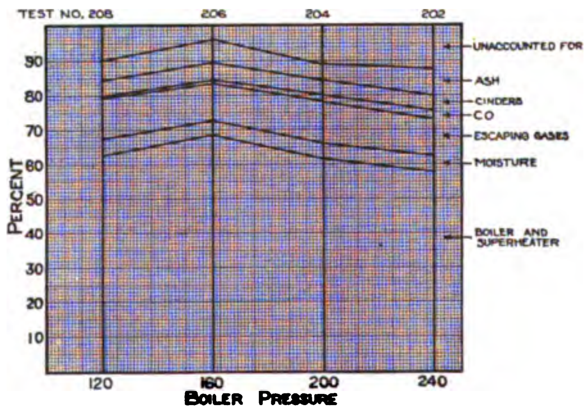


FIG. 64.—Heat-balance, quarter-time tests.

and which is due to incomplete combustion in the form of CO and in the form of unconsumed solid fuel, including cinders and fuel in the ash. The unaccounted-for loss includes the radiation and convection losses from the boiler; also, stack losses of every sort which occurred during the time the engine was not running. The period covered by the heat-balance does not include the 120 minutes occupied in getting up steam. The average values of these losses for all tests made are summarized in table 3.

Values for the full-time tests, which are quoted in this table, are those derived from the work presented in the preceding chapter. They represent results obtained when the engine was running at the same power which was employed with half-time and quarter-time tests and when fired with the same coal. It will be seen that the losses due to moisture, incomplete combustion, and cinders are but little affected by changes in the running schedule. The loss due to escaping gases is less for the quarter-time tests, principally because the heat thus accounted for includes that carried up the stack only while the engine is running. Fuel in the ash and the losses unaccounted for seem to occasion the decreased boiler efficiency which attends the intermittent action of the locomotive. It is thought that the increase in the fuel lost with the ash is caused by the more frequent stirring to which the fire was subjected in the intermittent running, an operation which assists unconsumed coal in its course through the grate. The unaccounted-for losses in the intermittent tests include, in addition to those incident to the full-time tests, the heat carried up the stack and any loss incident to incomplete combustion while the engine is at rest. The values of the table show that the effect of intermittent running upon the evaporative efficiency of the boiler is slight.

TABLE 3.—*Heat balance, average at all pressures, under various schedules of running time.*

Proportion of running time to stops.	Per cent of heat in combustible fired. Loss due to moisture.	Loss due to escaping gases.	Loss due to incomplete combustion.	Loss due to cinders and sparks.	Loss due to refuse in ash.	Loss unaccounted for.	Efficiency of boiler and superheater (per cent).
1	2	3	4	5	6	7	8
Full time...........	4.77	14.58	0.92	3.96	3.95	5.69	66.13
Half time...........	4.41	12.55	1.5	3.76	3.88	7.23	66.67
Quarter time........	4.42	11.25	1.6	4.50	6.50	10.72	61.01

35. Performance of the Engine.—A summary of results showing the performance of the engine is presented as columns 41 to 55, Appendix III. Certain of these values, compared with similar ones obtained in the full-time tests, both with superheated and saturated steam, are presented as table 4.*

TABLE 4.—*Coal and steam consumption for various schedules of running time.*

Boiler-pressure.	Speed, miles per hour.	Quarter-time tests. Cut-off, per cent.	Quarter-time tests. Pounds of steam per indicated horse-power hour.	Quarter-time tests. Pounds of coal per draw-bar horse-power hour.	Quarter-time tests. Pounds of coal per draw-bar horse-power hour, including coal used to fire up.	Half-time tests. Cut-off, per cent.	Half-time tests. Pounds of steam per indicated horse-power hour.	Half-time tests. Pounds of coal per draw-bar horse-power hour.	Half-time tests. Pounds of coal per draw-bar horse-power hour, including coal used to fire up.	Full-time tests. Superheated steam. Cut-off, per cent.	Full-time tests. Superheated steam. Pounds of steam per indicated horse-power hour.	Full-time tests. Superheated steam. Pounds of coal per draw-bar horse-power hour.	Full-time tests. Saturated steam. Cut-off, per cent.	Full-time tests. Saturated steam. Pounds of steam per indicated horse-power hour.	Full-time tests. Saturated steam. Pounds of coal per draw-bar horse-power hour.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
240	30	19	29.0	5.28	6.28	19	26.4	4.55	5.16	21	22.1	3.58	21	24.4	3.66
200	30	25	26.7	4.50	5.23	25	24.0	3.60	4.13	21	21.5	3.41	21	25.7	3.93
160	30	30	28.2	4.15	4.87	30	24.5	3.82	4.27	27	22.1	3.56	27	25.3	3.92
120	30	42	28.9	4.36	6.95	42	26.2	3.87	4.25	36	23.1	3.62	33	27.5	4.22

*Values for saturated steam are taken from "High Steam-Pressures in Locomotive Service," Publication No. 66, Carnegie Institution of Washington.

The steam consumed per indicated horse-power hour is presented as columns 49 and 50, Appendix III. Column 49 gives values based upon the time during which the engine was running under constant conditions only, while column 50 is based upon all the time elapsing between the first starting of the engine and the end of the test.

The effect of frequent stops upon the efficiency of the locomotive during the time it is in motion is best shown by fig. 65. The upper line (*B*) of this figure shows the steam consumed per indicated horse-power during the time when the engine is running under the constant conditions of the intermittent

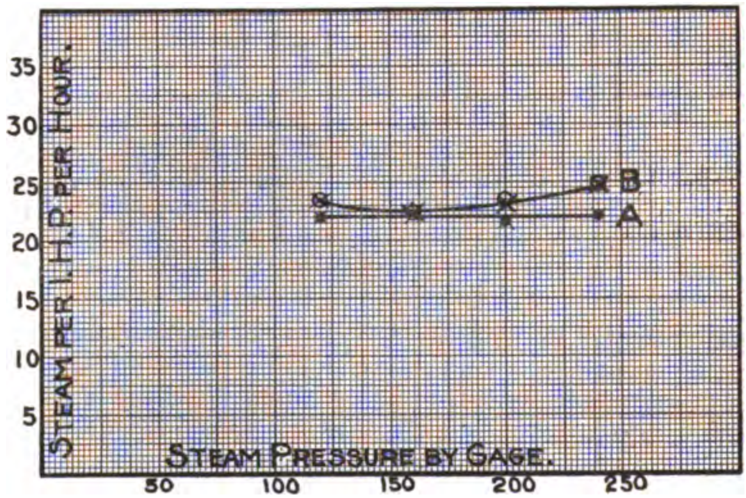


FIG. 65.—Steam consumption under identical conditions of power, speed, etc., as delivered, *A*, by constant running tests, *B*, by intermittent tests.

tests. The lower line (*A*) shows the same relation as developed by the full-time tests under constant conditions normal to the ordinary work of the locomotive. The upper curve is located from two series of points indicated by crosses in circles, one series referring to the half-time intermittent tests, the other to the quarter-time intermittent tests.

It will be seen that for all pressures the steam consumption is greater as derived from the intermittent tests, and that the difference begins to increase with increase of steam-pressure beyond 160 pounds. Thus, at 120 pounds boiler-pressure, the steam consumption is approximately 5 per cent greater for the intermittent tests, and at 240 pounds it is fully 10 per cent greater. This diagram may be accepted as showing the difference in steam consumption under identical conditions of running, except that in the case of the lower curve the running is continuous and in the case of the upper curve it is intermittent. The difference undoubtedly results from the cooling of the metallic parts of the engine during the time it is standing and the recurring necessity of reheating these parts after the engine has been started.

The amount of steam required per indicated horse-power hour, based upon the average power developed for full-time constant condition tests and for the half-time and quarter-time tests, is shown by fig. 66. The values in this figure representing the intermittent tests are based upon the total duration of the test, including periods of idleness, acceleration, and constant running. The increased steam consumption resulting from the intervals of idleness and the intervals during which the running is at half the power amounts to 19

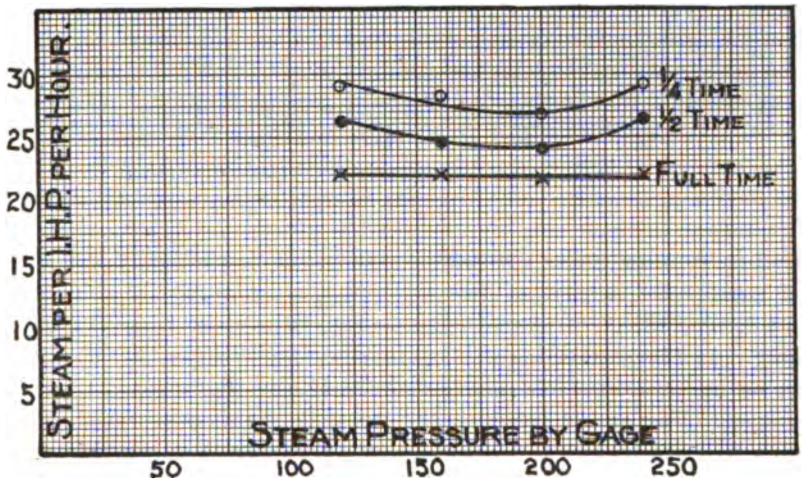


FIG. 66.—Steam consumption as affected by schedule of running.

per cent for the half-time tests and 31 per cent for the quarter-time tests, when the boiler-pressure is 120 pounds, these values being reduced to a minimum for a pressure of approximately 180 pounds. Obviously, the losses resulting from intermittent running, as set forth in this diagram, include those which are defined by fig. 65, and also those which occur through the low efficiency of the engine under starting conditions and such as result from radiation, leakage, etc., while standing. They are necessarily a function of the schedule and apply to conditions of practice only in so far as the schedules adopted may be regarded as typical of practice. They are also losses which can not be greatly affected by the substitution of superheated for saturated steam.

No steam was lost by the safety-valve during any of the intermittent tests.

36. Coal per Draw-bar Horse-power is given in columns 53 to 55, Appendix III, and is shown graphically by fig. 67. The figure shows that at the lower boiler-pressures the difference in the amount of coal required to develop a horse-power at the draw-bar for intermittent running in comparison with that

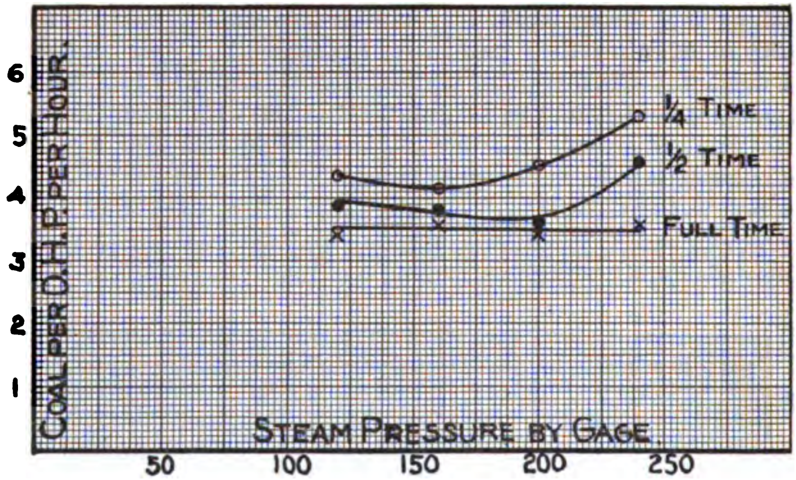


FIG. 67.—Coal consumption as affected by the schedule of running.

required in running under constant conditions is considerably less than for higher pressures. A part of this difference is undoubtedly due to small leakage losses, which of course persist even during the time the engine is standing. In this connection it is again necessary to state that the relations shown by fig. 67 do not charge against the engine the amount of coal used in firing up. The extent to which the charging of this coal would affect the values is well shown by the comparison of values which appear in table 4.

37. Conclusions to be Drawn from the Results of the Intermittent Tests.—The results show:

1. That the locomotive under test in the laboratory may be operated under any desired schedule, which schedule may be duplicated with a satisfactory degree of accuracy from day to day.

2. The boiler efficiency of a locomotive which is run intermittently is not materially lower than that of a locomotive under constant conditions of operation.

3. The steam consumption of a locomotive, the schedule of which involves standing time in excess of its running time, is increased during the time it is in motion by from 5 to 10 per cent of its normal consumption while running, due to the cooling of its cylinders and connected parts while at rest. This statement makes no allowance for losses which, in practice, may occur at the safety-valve while standing.

4. A locomotive, the schedule of which involves standing time in excess of its running time, and which in starting after its several periods of rest is required to work under conditions less efficient than those of normal running,

may consume an amount of steam 10 to 20 per cent in excess of its normal consumption under constant conditions of running.

5. The steam consumption of a locomotive, the schedule of which involves intermittent running, is from 10 to 22 per cent greater than that for constant running when the idle time equals the running time, and is from 23 to 34 per cent greater when the idle time is double the running time.

6. The coal consumption of a locomotive, the schedule of which involves intermittent running, is from 11 to 30 per cent greater than that for constant running when the idle time equals the running time, and from 24 to 52 per cent greater when the idle time is double the running time.

7. The increase in the coal consumption resulting from the intermittent movement of the locomotive is least for the locomotive experimented upon for steam-pressures between 160 and 200 pounds.

8. The coal consumption of a locomotive the schedule of which involves intermittent running, will be increased by an amount which is not less than 20 per cent of the values given in paragraphs 6, 7, and 8, if the coal used in starting the fires is charged against it.

VII. ECONOMY RESULTING FROM THE USE OF SUPERHEATED STEAM.

38. Comparisons Involving Boiler and Superheater.—The whole discussion as presented in the preceding chapters has been developed with a view to establishing in concise terms the performance of the locomotive experimented upon while operating under superheated steam. The method of expressing results and the units of measurement employed have been so chosen that a comparison may readily be made with those which have previously been derived for the same locomotive when, as *Schenectady No. 2*, it was operated with saturated steam. The changes in the extent of heat-transmitting surface resulting from the application of the superheater are described in detail by Appendix I. Data concerning the performance under saturated steam, which are made a basis for comparison, are drawn from a previous report entitled "High Steam-Pressures in Locomotive Service."* Youghiogheny coal or its reduced equivalent has been used in all cases.

39. Boiler Performance.—The boiler of *Schenectady No. 2*, designed for delivering saturated steam, gave an efficiency expressed by the equation

$$E = 11.305 - 0.221\ H$$

while the boiler as equipped with a Cole superheater, *Schenectady No. 3*, gave an efficiency expressed by the equation

$$E = 11.706 - 0.214\ H$$

Obviously, on the basis of these equations, the superheating boiler has the advantage. The comparison is, however, not a fair one, since in both cases the equations are based on the extent of heat-transmitting surface, and in *Schenectady No. 3* such surface was sacrificed in making room for the superheater. To make the comparison fair, the term in the equation representing equivalent pounds of water per square foot of heating surface must be expressed in terms of total power delivered by the boiler. Comparisons on this basis, showing the performance of the boiler in one case and of the boiler and superheater in the other case, expressed in terms of the equivalent evaporation, are shown diagrammatically by fig. 68.

It will be seen that even upon this basis the efficiency of the combined boiler and superheater is superior to that of the boiler alone, the increase averaging between 3 and 4 per cent. The reason for this is not entirely apparent. An examination of related data suggests that the lines of fig. 68

*Publication No. 66, Carnegie Institution of Washington.

should not be far apart. Draft values plotted in terms of the rate of evaporation are lower for the superheating locomotive than for the locomotive using saturated steam, but when these are reduced to equivalent values representing an equal amount of power they are identical for both locomotives—a condition which implies equality in the fuel lost in the form of cinder and spark. Similar comparisons involving smoke-box temperature lead to identical conclusions.

Upon the basis of these statements the relation defined by fig. 68 is not confirmed by collateral evidence. This statement, however, does not discredit

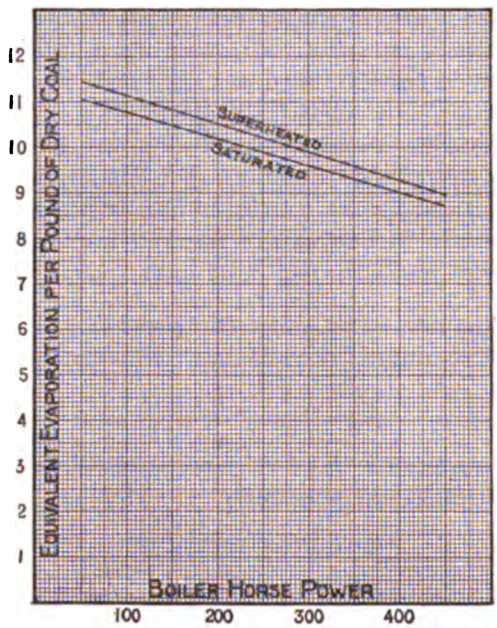


Fig. 68.—Boiler efficiency.

the record, which is in fact one of no small significance. The line of performance for the superheating locomotive (fig. 68) depends upon results of 38 tests and that for the saturated-steam locomotive upon results of 40 tests. It is therefore difficult to see how either could have been affected to the extent indicated by any incidental cause or causes. Whatever the conclusion may be with reference to this matter, it is clear that the combined boiler and superheater of *Schenectady No. 3* are not less efficient than the boiler of *Schenectady No. 2*, while being worked at the same rates of power, and the face value of the data shows its efficiency to be higher by 4 per cent.

40. Comparisons Involving the Performance of the Engine.—The steam consumption per indicated horse-power hour for the superheating locomotive as determined by the results of 38 tests has been defined as the line *A B*, fig. 56. A similar line based upon the results of 100 tests of the saturated-steam locomotive establishes the cylinder performance of that machine. Replotting the results upon a single sheet gives the diagram, fig. 69. This exhibit (or

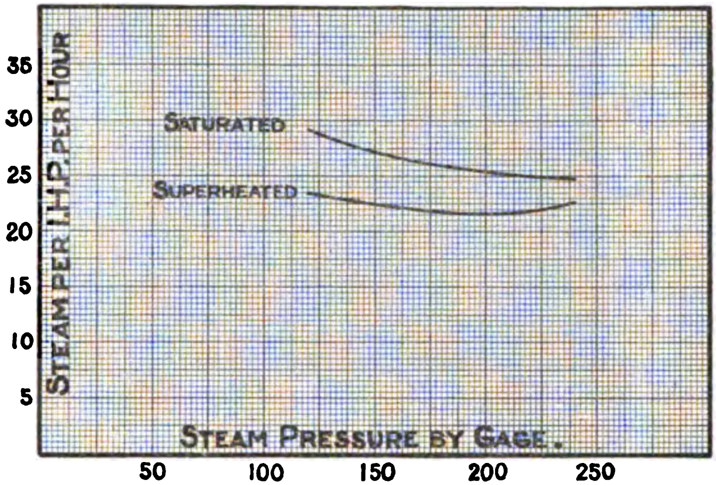


FIG. 69.—Steam per indicated horse-power hour.

better, perhaps, the numerical values given by columns 2 and 4, table 5) shows well the saving in water realized by substituting steam superheated approximately 150° F. for steam which is saturated. The saving ranges from 18 per cent when the boiler-pressure is 120 pounds to 9 per cent when the boiler-pressure is 240 pounds. It appears, also, from the diagram that with superheating the least consumption of water, 21.6 pounds per horse-power hour, is secured when the boiler-pressure is approximately 200 pounds,

TABLE 5.—*Steam per indicated horse-power hour.*

Boiler-pressure, (pounds).	Saturated steam.		Superheated steam.	
	Pounds of steam per indicated horse-power per hour.	B. t. u. per indicated horse-power per minute.	Pounds of steam per indicated horse-power per hour.	B. t. u. per indicated horse-power per minute.
1	2	3	4	5
240	24.7	483	22.6	474
220	25.1	491	21.8	459
200	25.5	498	21.6	455
180	26.0	507	21.9	461
160	26.6	517	22.3	468
140	27.7	537	22.9	481
120	29.1	563	23.8	497

and that variations in the consumption resulting from changes in pressure are slight (column 4, table 5). For example, the water consumption for all pressures between 160 pounds and 220 pounds ranges between 21.6 pounds, the minimum value obtained, and 22.3 pounds, a range of approximately 4 per cent.

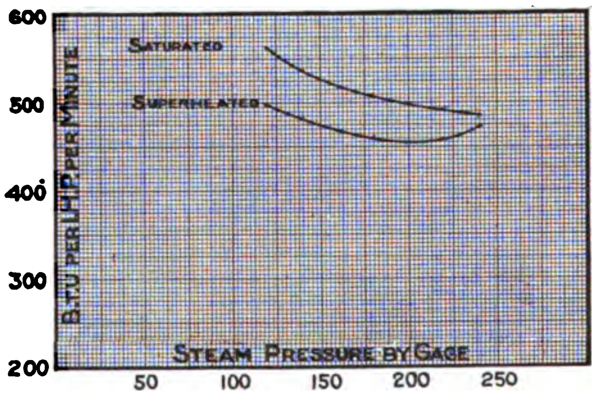


FIG. 70.—Thermal units consumed per horse-power per minute.

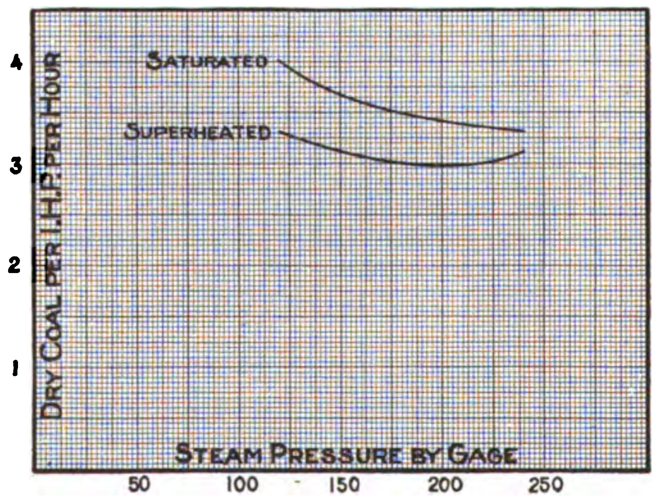


FIG. 71.—Coal per indicated horse-power hour.

The saving of water in locomotive service is always a matter of moment; it diminishes the exactions of certain conditions in operation; and in some districts, where water is bad or hard to obtain, it tends to simplify difficult problems either in locomotive maintenance or in the maintenance of the water-supply. The fact, therefore, that superheating affords a material saving in the amount of water required, is not to be overlooked in estimating the value of superheating as a practice. But the saving in heat is not proportional to the saving in water, for each pound of superheated steam must have more heat imparted to it than a pound of saturated steam at the same pressure. As an indication of the thermal advantage to be derived from the use of superheated steam in comparison with that of saturated steam, it is desirable to reduce the steam in each case to the same thermal basis. This has been shown graphically by fig. 70 and numerically by columns 3 and 5, table 5.

Upon this basis the saving effected by the use of superheated steam is 12 per cent when the pressure is 120 pounds, and 2 per cent when the pressure is 240 pounds. Under a boiler-pressure of 180 pounds the substitution of superheated steam improves the efficiency of the engine 9.1 per cent.

41. Comparisons Involving the Performance of the Locomotive as a Whole.—The performance of the locomotive as a whole, as expressed in terms of coal consumed per indicated horse-power hour, both for saturated steam and superheated steam, and the saving effected by the substitution of superheated for saturated steam, is given as table 6. These results, since they combine the performance of both engine and boiler, represent a definition of the improvement in the performance of the locomotive experimented upon as the result of the substitution of superheated for saturated steam. They show that the gain is most pronounced at the lower pressure; thus, at a pressure of 120 pounds it is 17 per cent, while at a pressure of 240 pounds it is but 6 per cent. They show also that the performance of the locomotive using superheated steam is only slightly affected by changes of pressure; for the entire range of pressure from 120 pounds to 240 pounds the difference in coal consumption from minimum to maximum is but a third of 1 pound, while for

TABLE 6.—*Saving in coal effected by the use of superheated steam.*

Boiler-pressure (pounds).	Pounds of coal per indicated horse-power per hour.		Saving effected by the use of superheated steam.			
			Over values obtained with saturated steam at same pressure.		Over values obtained with saturated steam at 180 pounds pressure.	
	Saturated steam.	Superheated steam.	Pounds per I. H. P. per hour.	Per cent.	Pounds per I. H. P. per hour.	Per cent.
1	2	3	4	5	6	7
240	3.31	3.12	0.19	5.72	0.38	10.86
220	3.37	3.00	.37	10.98	.50	14.29
200	3.43	2.97	.46	13.31	.53	15.15
180	3.50	3.01	.49	14.00	.49	14.01
160	3.59	3.08	.51	14.21	.42	12.00
140	3.77	3.17	.60	15.98	.37	10.57
120	4.00	3.31	.69	17.25	.19	5.43

pressures between 175 pounds and 225 pounds it is practically constant and always near the minimum value. The least coal consumption per indicated horse-power hour, as it appears in the summarized statement, is 2.97 pounds, and was obtained under a steam-pressure of 200 pounds.

The results sustain a claim which has been put forward by advocates of the practice of superheating, to the effect that the adoption of such practice permitted the steam-pressure to be materially reduced over that now employed in locomotives using saturated steam without material sacrifice in efficiency. A detailed numerical statement showing the saving in coal resulting from a change from saturated to superheated steam is set forth by columns 4 to 7, table 6. Columns 4 and 5 present results obtained by comparisons based on equal pressures, and columns 6 and 7 those obtained by comparing values obtained with superheating under the several different pressures employed with those obtained from saturated steam at a pressure of 180 pounds.

42. Comparisons Involving the Capacity of the Locomotive.—The maximum power presented by the data derived from the locomotive using superheated steam is not to be accepted as a measure of its capacity. Except in the case of the series of tests run at 160 pounds pressure, the number of tests was insufficient to permit the establishment at each speed of a maximum cut-off

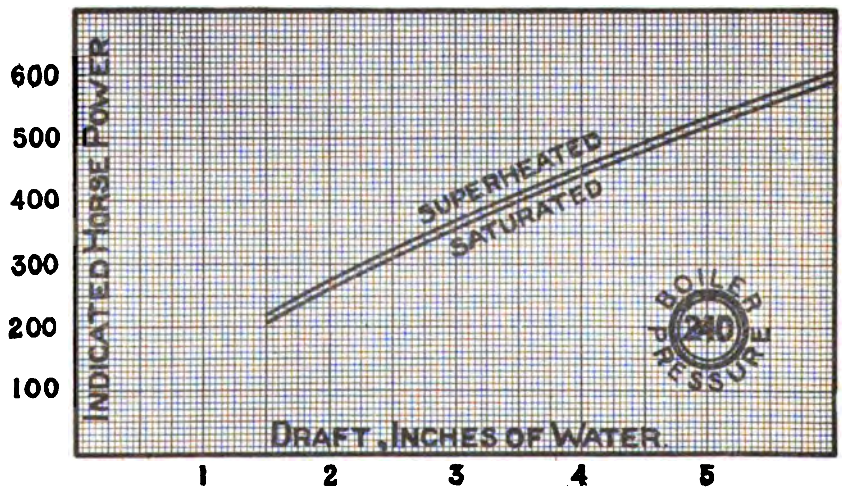


FIG. 72.—Indicated horse-power; boiler-pressure 240 pounds.

for which the boiler could be made to supply steam. But while direct evidence is lacking, the data contain much which goes to show that the superheating locomotive is a more powerful machine than the locomotive using saturated steam. For example, it has been shown that for the development of equal amounts of power the combined boiler and superheater of the superheating locomotive have an efficiency which equals or exceeds that of the saturated-steam boiler; hence the boiler-power which it may be made to deliver as a maximum equals or exceeds that which the boiler of the saturated-

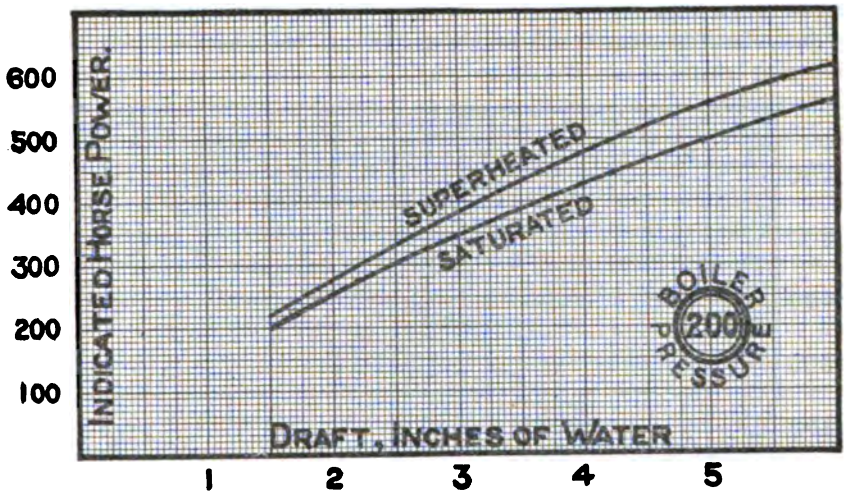


FIG. 73.—Indicated horse-power; boiler-pressure 200 pounds.

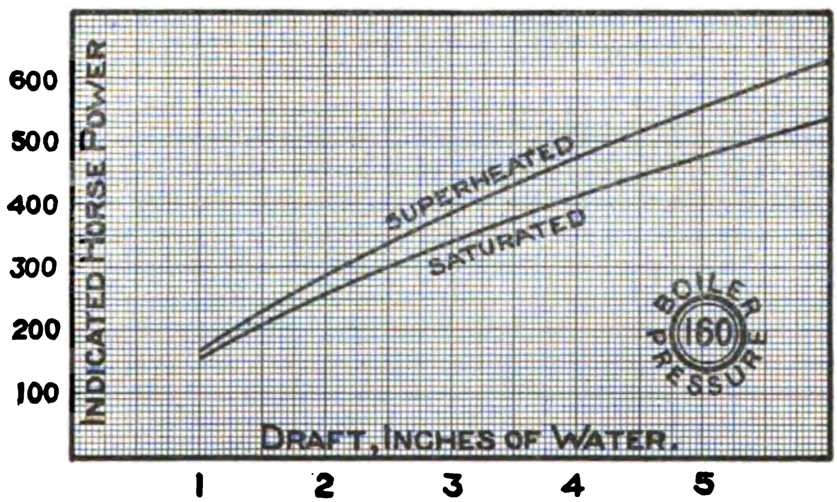


FIG. 74.—Indicated horse-power; boiler-pressure 160 pounds.

steam locomotive can be made to deliver. But each unit of power delivered from the boiler in the form of superheated steam is more effective in doing work in the cylinders than a similar unit of power delivered in the form of saturated steam; hence, at the limit, the superheating locomotive is more powerful than the one using saturated steam, and the difference is that which measures the difference in the economy with which the cylinders use steam.

The same question may be dealt with through another series of facts, as follows: It can be shown that the power of any locomotive is limited by its capacity to burn coal, and coal-burning capacity is a function of the draft. The data show that for the development of a given cylinder power the draft

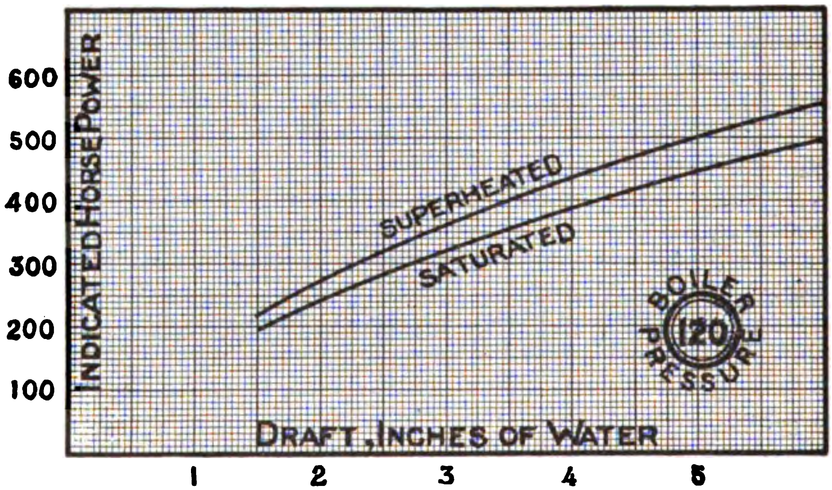


FIG. 75.—Indicated horse-power; boiler-pressure 120 pounds.

values of *Schenectady No. 3* (superheating) were in all cases less than those of *Schenectady No. 2* (saturated). The extent of these differences is well shown by figs. 72 to 75. They are of small value for tests under high pressure, but as a rule they increase as the pressure is reduced. Tests at 160 pounds (fig. 74) show that the power developed in return for a given draft is from 10 per cent to 16 per cent greater for the superheating locomotive than for the saturated-steam locomotive. Obviously there is no reason why the draft for the former should not be increased to limits practicable with the latter, and when this is done the power developed by the superheating locomotive will exceed that which is possible with the saturated-steam locomotive.

43. The Possible Economy which May Result from the Use of Superheated Steam in Locomotive Service.—In the preceding paragraphs an attempt has been made to define with accuracy the increased efficiency resulting from the substitution in locomotive service of steam superheated to approximately 150° for steam which is saturated. The facts upon which comparisons have been based have been derived by careful processes, and the results can safely be accepted as the measure which has been sought. All discussion might well end with the presentation of the facts referred to, were it not that out of them arises a group of questions of great practical significance. To some of these attention must be given.

As a general proposition, the gain which in any service will result from the introduction of a superheater is a function of the degree of superheat employed, and this in turn is limited by the ability of the materials composing the superheater and the exposed parts of the engine to withstand the temperatures which are involved. The Prussian State Railway prescribes a boiler-pressure of 180 pounds and a temperature of steam of 300° C., which temperature may rise above 300°, but must never be allowed to exceed 350°. That is, a degree of superheating of 190° F. is regarded as satisfactory, while the maximum limit never to be exceeded is fixed at 280° F. Under normal running conditions the degree of superheating is considerably above 200° F.

Comparing the superheating effects described by these statements with the degree of superheat obtained from the Purdue locomotive when working under a pressure of 180 pounds (fig. 21), it appears that those of the latter may be increased by at least 33 per cent of their present value without exceeding the limit which has been proved practicable in the every-day practice of German railroads. The means to be employed in securing such a degree of superheat are of course matters of detail which concern the design and proportions of the superheater. The savings in water and fuel resulting from the presence of the superheater, as set forth by data already presented, would have been greater had the degree of superheat been higher. In the absence of data derived from experiments it may be assumed that the possible increase in the savings will be proportional to the increase in the degree of superheat.

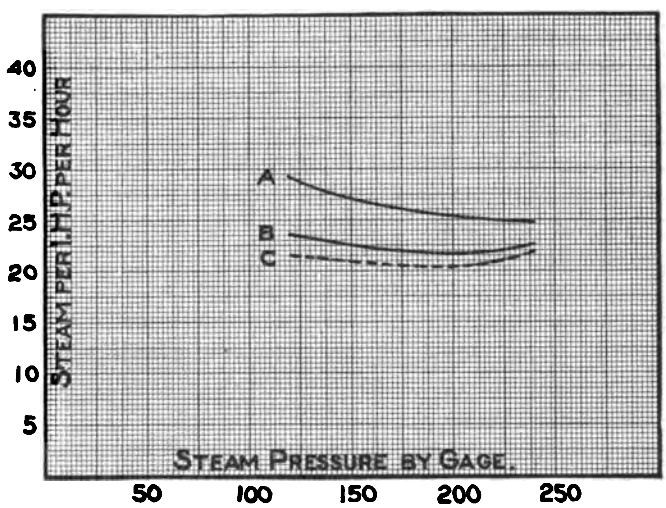


FIG. 76.—Steam per indicated horse-power hour, showing possible gain by increasing superheating 33 per cent.

On the basis, therefore, of the experimental results already presented and of these statements, the possible gain in water and fuel which may result from the adoption of the superheater is seen by figs. 76 and 77, respectively.

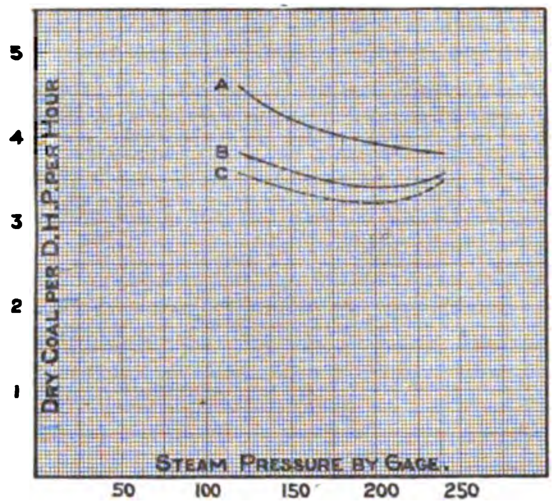


FIG. 77.—Coal per draw-bar horse-power hour, showing possible gain by increasing superheating 33 per cent.

In these figures the upper line *A* is that of saturated steam as derived from tests of locomotive *Schenectady No. 2*; the next below, *B*, is that of superheated steam as derived from tests of locomotive *Schenectady No. 3*, and the dotted line *C* is that which is assumed to represent the performance which *Schenectady No. 3* would have given had the degree of superheating been 33 per cent greater than that actually obtained. These are not maximum savings, but are such as are to be expected under normal conditions of continuous full-power operation. From this exhibit it appears that for boiler-pressure of 180 pounds the substitution of superheated steam for saturated steam may result in a reduction of water consumption from 26 pounds to 20.5 pounds, a saving of 21 per cent, and in a reduction of coal consumption per draw-bar horse-power of from 4 pounds to 3.25 pounds, a saving of 19 per cent. These values may be accepted as representing what should reasonably be expected of superheating in American locomotive service, so far as the experiments herein described define them.

It will be a mistake, however, for anyone to assume that a railway company's bills for locomotive fuel may be diminished by the percentages set forth in the preceding paragraph merely by the introduction of the superheater. It should be clear, for example, that no part of the fuel used in raising the steam of a locomotive or of its wastes which occur between the round-house and the starting of the locomotive at the head of its train can be saved by the application of a superheater to a locomotive. Assuming that the fuel thus used is 15 per cent of the total for the run, a conservative estimate, the amount which remains subject to the influence of the superheater is 85 per cent of 19 per cent, or 16 per cent.

Again, the fuel used in maintaining a normal temperature of all parts of the machine when the locomotive is at rest at stations and at passing-points is fuel over which the superheater can exert no influence. The amount of fuel thus used is a function of the schedule of the train. The results set forth in Chapter IV show that in some classes of service upon American railways it will be so small as to be negligible, but in other classes of service it will constitute a considerable percentage of the total coal used. A review of Chapter IV will suggest the difficulty which confronts one in an attempt to fix numerical values covering fuel thus to be accounted for. Again, fuel used in generating steam which is discharged through safety-valves can not in any way be affected by the presence of a superheater. In none of the experimental work the results of which are recorded in the preceding chapters has there been any loss by safety-valves. This loss in practice is necessarily indefinite. In some classes of service it is so small as to be negligible, and in others it involves a considerable percentage of the total coal used. Finally, attention should be called to the fact that the question at issue involves the whole problem of maintenance. Steam leaking past valves and pistons or coming out by leaky glands or through leaky cylinder-cocks or steam-joints wherever located causes losses which remain undiminished in the presence of the superheater.

Summarizing the preceding statements and making such deductions from the known performance of the superheater as will suffice to remove from the calculations all expenditures of heat normal to the American locomotive which are beyond the influence of the superheater, the actual net reduction in the amount of fuel needed for locomotive use by a railroad having all its locomotives equipped with satisfactory superheaters over that which would be required if all employed saturated steam will be not far from 10 per cent. This value is not to be accepted as of strictly scientific import, but merely as an estimate based upon such facts as have appeared in the course of a rather careful study of the problem.

APPENDIX I.

THE LOCOMOTIVE EXPERIMENTED UPON.

44. Locomotive Schenectady No. 3 was developed from locomotive No. 2, which has been elaborately described and illustrated in connection with an earlier research conducted under the patronage of the Carnegie Institution of Washington.* The changes made were only such as were involved by the addition of a fire-tube superheater to the machine as previously constructed. The changes were matters which concerned the construction of the boiler and the arrangement of the steam-piping; the machinery of the locomotive was not modified in any way. Figs. 78 to 86 illustrate the boiler and superheater of *Schenectady No. 3* in detail.

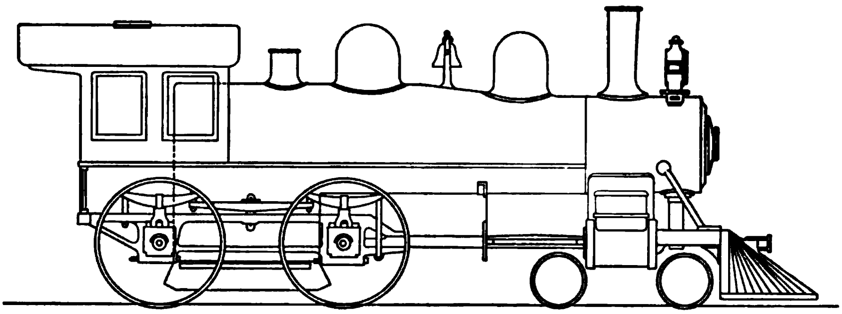


FIG. 78.—Outline elevation of locomotive.

45. The Cole Superheater as applied to the locomotive is well shown in fig. 80. It consists chiefly of a series of return-tubes extending inside of certain of the flues which make up a portion of the water-heating surface. To make room for the superheater the upper central portion of the usual flue-space is taken by sixteen 5-inch flues, which are reduced to a diameter of 4 inches for 7 inches of their length at the fire-box end and increased to a diameter of $5\frac{1}{16}$ inches at the front tube-sheet. They have a length between flue sheets of 138 inches. In each of these sixteen flues there is an upper and a lower line of superheating tubes. Each line extends from a steam-pipe header in the smoke-box back into its flue to a point near the back tube-sheet, where it meets and is screwed into a return-pipe fitting of special design. From the second of the two openings in this fitting a similar pipe extends forward through the flue and into the smoke-box to a second header, from which branch-pipes lead to the cylinders. All together, there are 32 of these

*Appendix I, "High Steam-Pressures in Locomotive Service," Publication No. 66, Carnegie Institution of Washington.

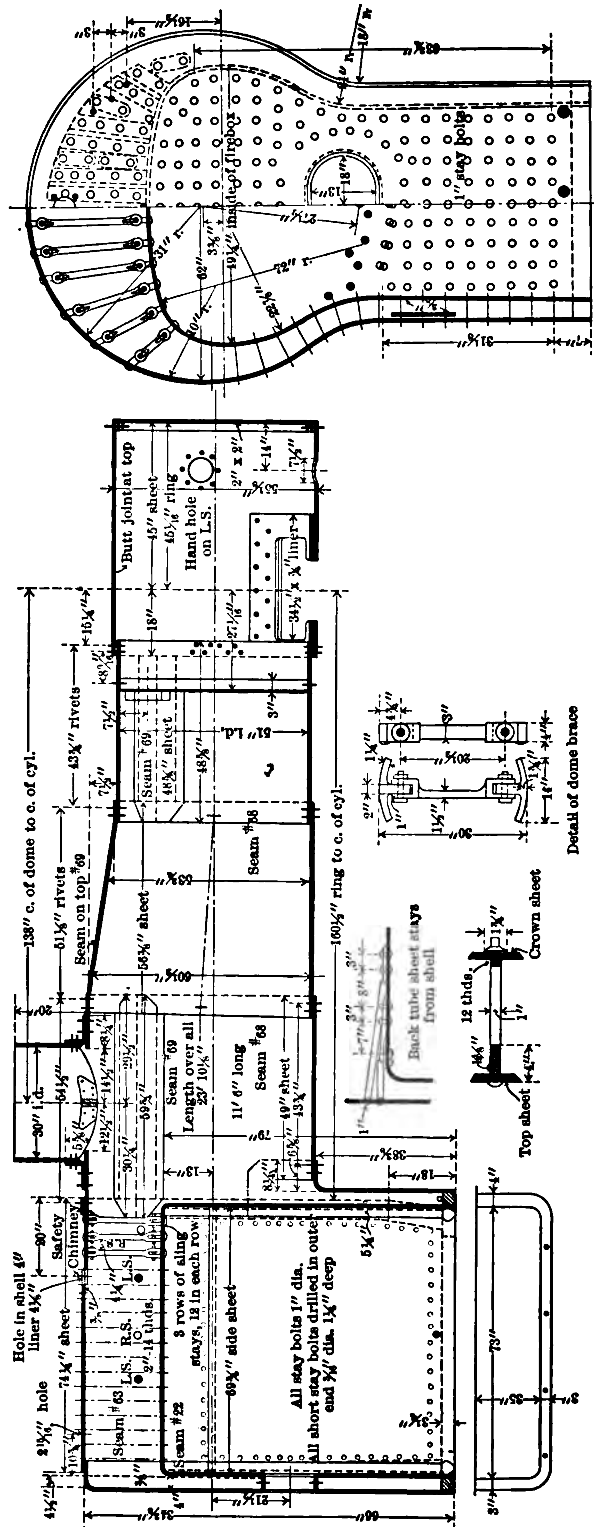


FIG. 79.—Boiler.

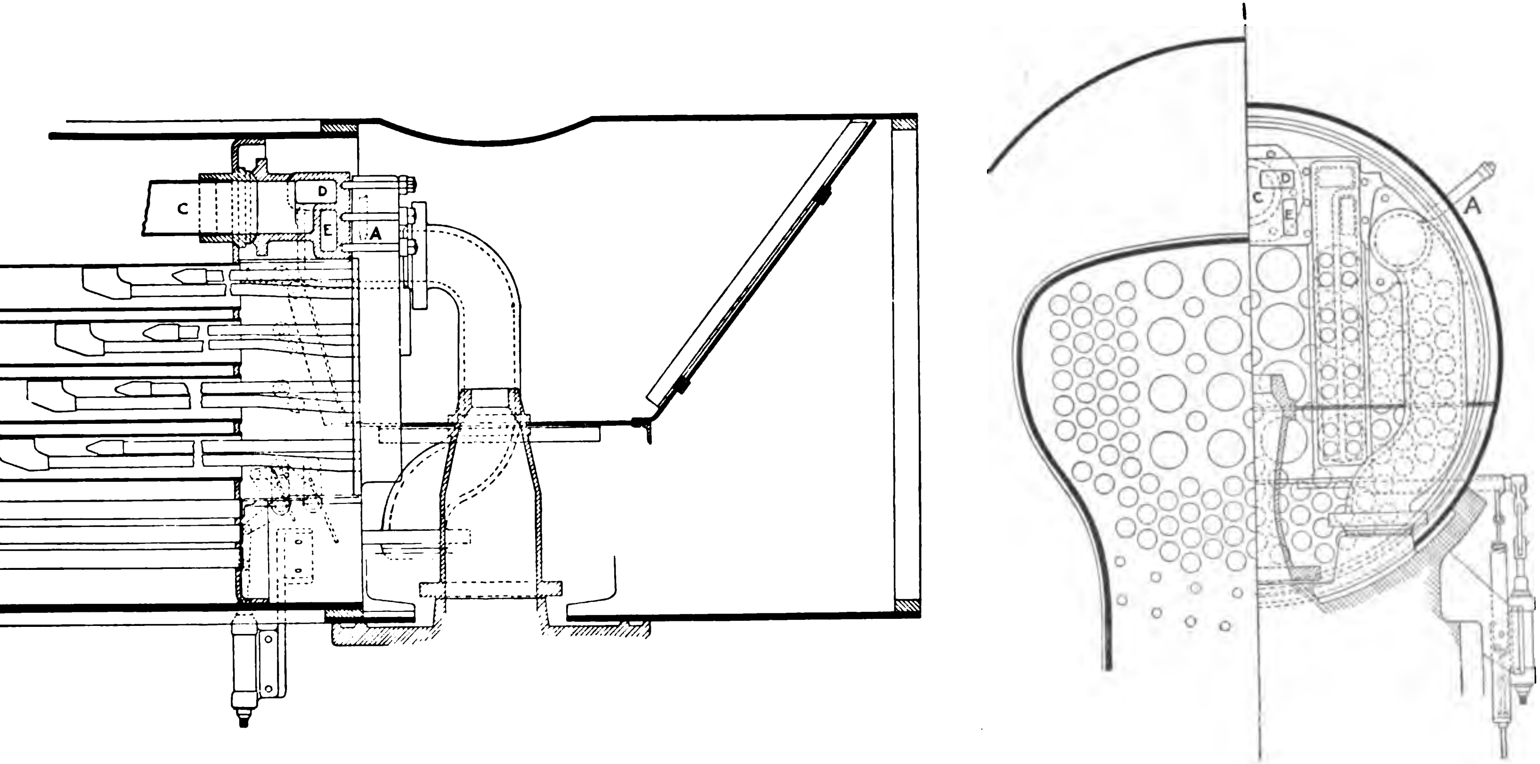


Fig. 80.—Cole superheater.

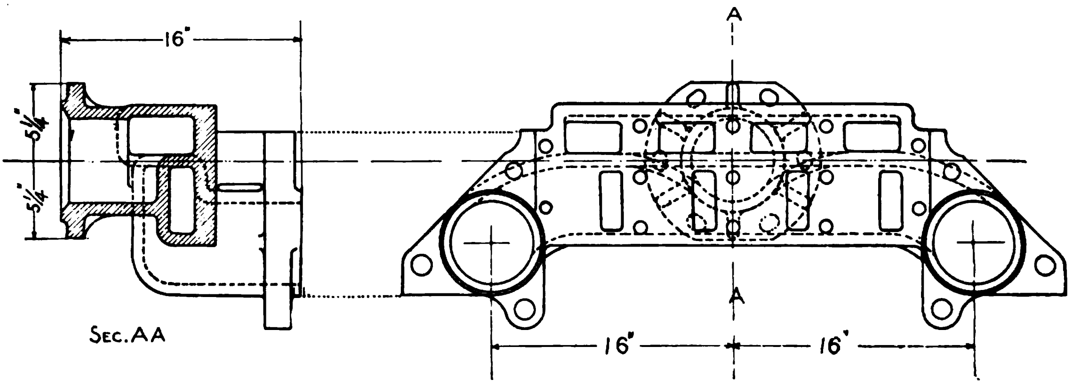


FIG. 81.—Superheater tee-head.

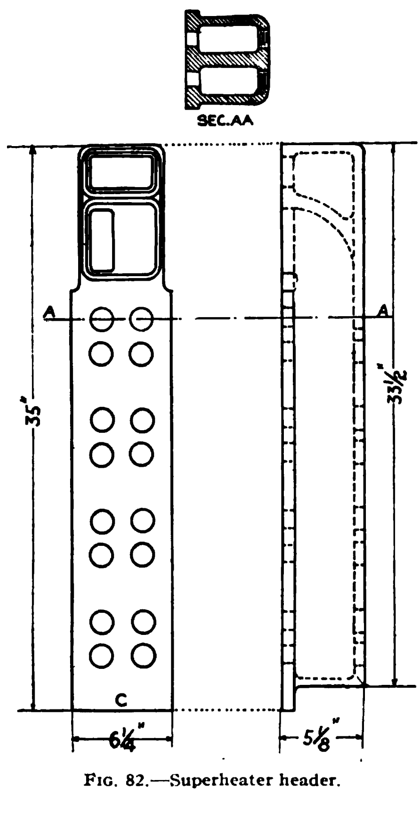


FIG. 82.—Superheater header.

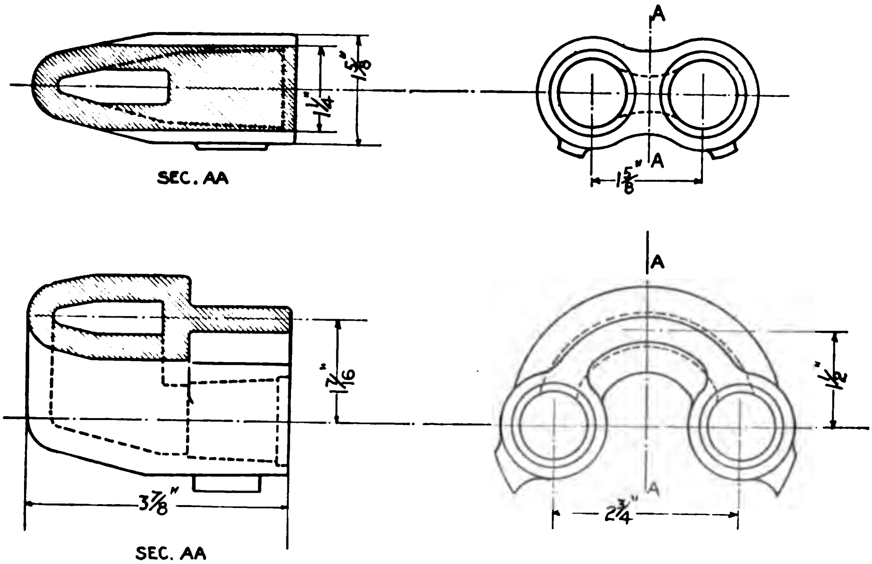


FIG. 83.—End connections for return superheater tubes.

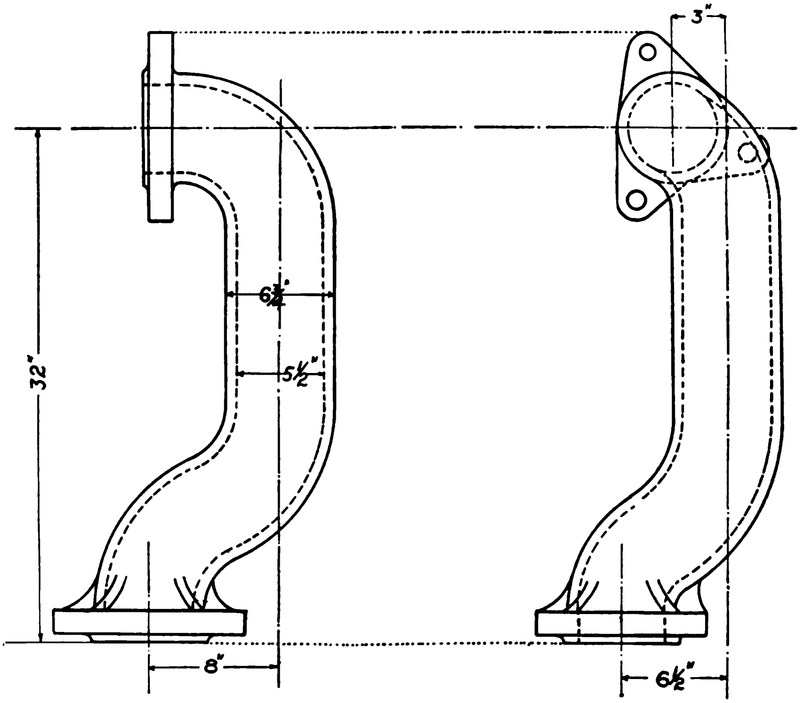


FIG. 84.—Branch-pipes.

loops. In 13 of the flues the lower loops are 116⅜ inches long, extending into the flue within 2 feet 5 inches of the back of the tube-sheet. In the other 3 flues the loops are, respectively, 3 feet, 2 feet, and 1 foot shorter than the normal. The upper loop in each flue is in all cases approximately 9 inches shorter than the lower loop. The headers to which the pipes of the superheater connect at the smoke-box end are of cast steel. They have walls three-eighths of an inch thick and are cored in such a manner that all steam passing the throttle-valve must traverse some one of the several loops. In its passage from the boiler the steam leaves the dry-pipe *C*, fig. 80, and

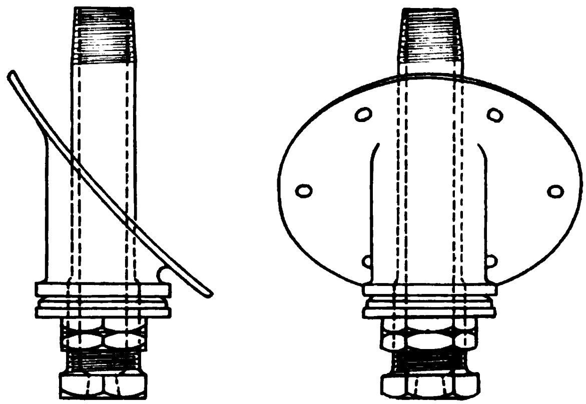


FIG. 85.—Thermometer plug.

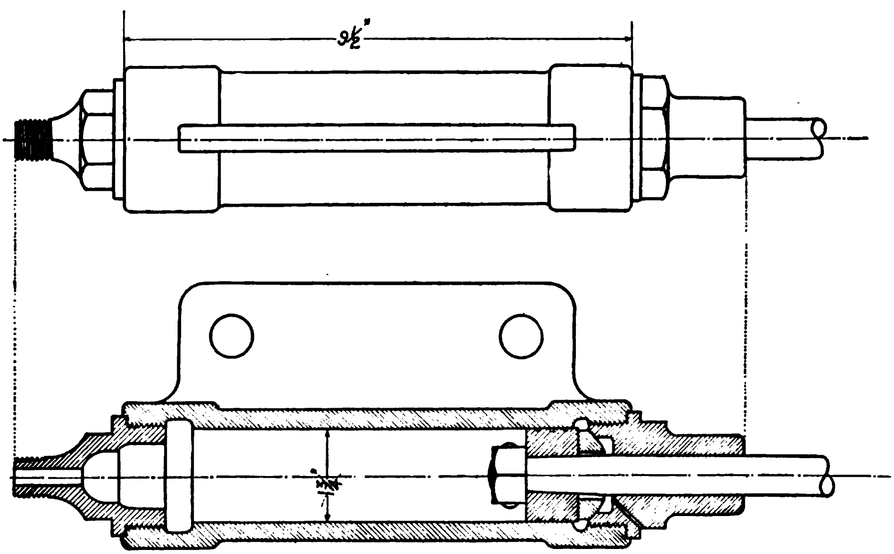


FIG. 86.—Superheater damper cylinder.

passes into the headers through the openings *D* in the top part of the tee-head. It then flows downward through the passage in one side of this header and passes back toward the fire-box through the 8 tubes which are joined to it. At the castings which form the return bends, its direction is reversed and it passes back through the return tubes to the passage in the other side of the header. It then passes upward into the lower half of the tee-head *E*, and from there into the branch steam-pipes.

46. The Principal Characteristics of Locomotive Schenectady No. 3 are as follows:

Type	4-4-0
Total weight (pounds)	109,000
Weight on four drivers (pounds)	61,000
Valves (type, Richardson balance):	
Maximum travel (inches)	6
Outside lap (inches)	$1\frac{1}{8}$
Inside lap (inches)	0
Ports:	
Length (inches)	12
Width of steam-port (inches)	$1\frac{1}{2}$
Width of exhaust-port (inches)	3
Total wheel-base (feet)	23
Rigid wheel-base (feet)	$8\frac{1}{2}$
Cylinders:	
Diameter (inches)	16
Stroke (inches)	34
Drivers, diameter outside of tire (inches)	$69\frac{1}{4}$
Boiler (type, extended wagon-top):	
Diameter of front-end (inches)	52
Length of fire-box (inches)	$72\frac{1}{16}$
Width of fire-box (inches)	$34\frac{1}{4}$
Depth of fire-box (inches)	79
Number of 2-inch tubes	111
Number of 5-inch tubes	16
Length of tubes (feet)	11.5
Heating-surface in fire-box (square feet)	126
Heating-surface in tubes, water side (square feet)	897
Heating-surface in tubes, fire side (square feet)	817
Total water-heating surface, including water side of tubes (square feet)	1,023
Total water-heating surface, including fire side of tubes (square feet)	943
Superheater; type, Cole return-tube:	
Outside diameter of superheater tubes (inches)	$1\frac{1}{4}$
Number of loops	32
Average length of tube per loop (feet)	17.27
Total superheating surface based upon outside surface of tubes, surface of headers neglected (square feet)	193
Total water and superheating surface, including water side of boiler-tubes (square feet)	1,216
Total water and superheating surface, including fire side of boiler-tubes (square feet)	1,136
Total water and superheating surface, accepted for use in all computations (square feet)	1,216
Ratio of heating-surface based on water side to that based on fire side	1.074
Thickness of crown-sheet (inch)	$\frac{7}{16}$
Thickness of tube-sheet (inch)	$\frac{9}{16}$
Thickness of side and back sheet (inch)	1
Diameter of radial stays (inches)	$1\frac{1}{8}$
Driving-axle journals:	
Diameter (inches)	$7\frac{1}{2}$
Length (inches)	$8\frac{1}{8}$

47. A Comparison of the Dimensions of the boiler as set forth above with those of *Schenectady No. 2*, follows. The exhibit shows the extent of the change brought about by the installation of the Cole superheater.

Number of 2-inch flues displaced by sixteen 5-inch flues, necessary to give place to the superheater	89
Reduction in water-heating surface (square feet)	299
Reduction in water-heating surface (per cent)	22.6
Heating-surface replaced by the installation of the superheater (square feet)	193
Heating-surface replaced by the installation of the superheater (per cent of surface removed)	64.5
Reduction in total transmitting-surface (water and superheating) (square feet)	106
Reduction in total transmitting-surface (water and superheating) (per cent)	8

APPENDIX II.

TESTS UNDER CONSTANT CONDITIONS, METHODS AND DATA.

48. The Tests.—All tests the results of which appear in this Appendix were run under a fully open throttle. Four different boiler-pressures were employed, namely, 240, 200, 160, and 120 pounds. At each of these pressures tests were run at a speed of 30, 40, and 50 miles per hour, respectively, and at 160 pounds pressure tests were run also at 20 miles per hour. In general, tests were run at several cut-offs for each speed, but only at the pressure of 160 pounds was the series extended throughout the entire possible range. All tests were made on the Purdue University locomotive testing-plant. The methods of testing have been so often described that repetition here seems unnecessary.* Great care was always taken to avoid all occasion for correcting observed data. Leaks, either of water or of steam, were not permitted.

49. Observed and Calculated Data are presented in detail by tables 7 to 27. In these tables each horizontal line represents a test and the several tests are grouped with respect to steam-pressure. The duplicate tests 103*a* and 111*a* have been included in order to supply the boiler results which were omitted from tests 103 and 111 because of inaccuracies in the observed data. The engine results of these duplicates have been omitted because the record of the steam lost from the boiler is unreliable. Heat-balances have been calculated for 18 of the tests. The blank spaces in the tables are due to the omission of certain results necessary to the working out of the heat-balance only.

An explanation of the several items comprising the tables of Appendix II is as follows:

TABLE 7.—GENERAL CONDITIONS.

Column 1. *Test number.*

Column 2. *Laboratory symbol.*—The first term of this symbol represents the speed in miles per hour, the second term represents the position of the reverse-lever upon its quadrant expressed in notches from the center forward, and the third represents the steam-pressure.

Column 3. *Date* on which the test was run.

Column 4. *Duration of the test* in minutes.

Column 5. *Reverse-lever*, notch from center forward.

Column 6. *Position of throttle.*—For all tests recorded the throttle was wide open.

Column 7. *Barometer-pressure*, pounds per square inch.

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*"Locomotive Performance." John Wiley & Sons, New York City.

Column 8. *Boiler-pressure by gage.*—Values given in this column are the average of observations made at 5-minute intervals.

Column 9. *Dry-pipe pressure by gage.*—Values given in this column are the average of readings taken at 5-minute intervals. Comparison of values obtained from it with those obtained from the boiler-gage should disclose the drop in pressure between the boiler and cylinder saddle.

Column 10. *Temperature of laboratory,* degrees Fahrenheit, is the average of observations taken at 10-minute intervals.

Column 11. *Temperature by wet-bulb thermometer* is the average of readings taken at 10-minute intervals.

Column 12. *Temperature by dry-bulb thermometer* is the average of readings taken at 10-minute intervals.

TABLE 8.—WATER AND STEAM.

Column 13. *Temperature of feed-water,* in degrees Fahrenheit, is the average of readings at 10-minute intervals.

Column 14. *Water delivered to boiler* is the total amount of water weighed, less that lost by injector overflow. A large metal tank, suitably mounted upon scales and connected to the injectors through an auxiliary storage-tank, served as the means for weighing the water. The water lost by the injector overflow was received by a small calibrated barrel upon the subfloor of the laboratory.

Column 15. *Water lost from boiler* includes that discharged by the calorimeter and the loss arising from the circulation around the superheater thermometer tubes. The calorimeter loss per hour was:

When boiler-pressure was 240 pounds............	54 pounds.
200 pounds............	43
160 pounds............	32
120 pounds............	20

The superheater thermometer-plug loss was measured by passing the discharge into a surface-condenser and collecting the condensate in a calibrated tank.

Column 16. *Steam supplied the engine = column* 14 − *column* 15.

Column 17. *Water evaporation by boiler per hour* = column 14 × 60 ÷ column 4.

Column 18. *Steam supplied the engine per hour* = column 16 × 60 ÷ column 4.

Column 19. *Quality of steam in dome.*—This was determined by a throttling calorimeter attached close to the dome. It was carefully insulated to prevent loss by radiation.

Column 20. *Temperature of steam by thermometer* was measured by thermometers placed in the branch-pipes at the point where they join the superheater header. The values given are the averages of readings taken at 5-minute intervals.

Column 21. *Degrees superheat* = column 20 − the temperature corresponding to saturated steam at the pressure shown by column 8.

TABLE 9.—SPEED AND COAL.

Column 22. *Total revolutions* is the difference between the initial and final reading of the engine register. Readings were taken as the test proceeded at 5-minute intervals.

Column 23. *Revolutions per minute* = column 22 ÷ column 4.

Column 24. *Miles equivalent to total revolutions* = column 22 times the circumference of drivers in feet ÷ 5280 = column 22 ÷ 292.31.

Column 25. *Miles per hour* = column 24 × 60 ÷ column 4.

Column 26. *Kind of coal.*—Two kinds of coal were used for the tests, Pocahontas and Youghiogheny. The chemical and physical characteristics of these coals are given elsewhere (tables 14 and 15).

Column 27. *Dry coal fired.*—By dry coal is meant coal free from both surface and inherent moisture. The surface moisture was determined by placing a sample of the coal in an oven through which air heated 20° or 30° above the atmosphere was passed for 10 hours. The inherent moisture was determined in connection with approximate analysis for 21 tests, the average value for which was assumed to hold good for the remaining ones.

Column 28. *Refuse.*—The ash and the refuse caught in the ash-pan at the end of the test results not only from firing during the test, but from the firing before as well. In order, therefore, to make the proper corrections, those values in this column for all tests involving a heat-balance were calculated in the following manner: Let

a represent the weight of coal fired in raising steam-pressure and maintaining it until the locomotive was started.

b, the weight of coal fired from the time the locomotive was started until the time the test started.

c, the weight of coal fired during the test.

d, the refuse removed from the ash-pan just before the engine started.

e, the refuse removed from the ash-pan during and after the test.

f, the per cent of combustible in the refuse removed before the test started.

g, the per cent of combustible in the refuse removed during and after the test.

As no forced draft, but natural draft only, was used up to the time the locomotive started, and an examination of the smoke-box showed it to be free from cinders just before the locomotive started, the weight of refuse from coal a was calculated by the formula

$$\text{Weight of refuse} = \frac{\text{per cent chemical ash in coal } a \times \text{coal } a}{\text{per cent chemical ash in refuse } (100 - f)}$$

Let h represent the value derived from this formula; then the weight of refuse in the fire-box when the locomotive is started is $h - d$. If the per cent of combustible in refuse f and g are the same, this weight can be subtracted from e to obtain the amount of refuse rejected during the time of the test, but since f is generally considerably greater than g, the following method of correction was adopted.

$$\text{Weight of refuse} = (h - d)\,\frac{100 - f}{100 - g}$$

In addition, the weight of the refuse from coal b was subtracted from the weight of refuse e. This weight of refuse =

$$\frac{b}{b+c}\left\{ e - (h - d)\,\frac{100 - f}{100 - g} \right\}$$

Or, making one formula, the final corrected weight of refuse=

$$e-\left\{(h-d)\,\frac{100-f}{100-g}\right\}-\frac{b}{b+c}\left\{e-(h-d)\,\frac{100-f}{100-g}\right\}$$

Column 29. *Combustible fired.*—Column 27 × (column 75 + column 76) ÷ (100 − column 74).

Column 30. *Combustible consumed* = column 29 − the sum of the weights of the combustible in the cinders caught in the front-end, the combustible in the sparks ejected from the stack, and combustible in the refuse from the ash-pan.

Column 31. *Dry coal per hour* = column 27 × 60 ÷ column 4.

Column 32. *Dry coal per mile run* = column 27 ÷ column 24.

TABLE 10.—COAL.

Column 33. *Dry coal per square foot of grate-surface per hour* = column 31 ÷ 17.

Column 34. *Dry coal per square foot of water and superheating surface per hour* = column 31 ÷ 1216.

Column 35. *Combustible fired* per square foot of water and superheating surface per hour = column 29 × 60 ÷ column 4 × 1216.

Column 36. *Combustible consumed* per square foot of water and superheating surface per hour = column 30 × 60 ÷ column 4 × 1216.

Column 37. *Cinders caught in front-end per hour.*—Since the cinders caught in the smoke-box include those deposited there before and after as well as during the test, those values in this column which involve a heat-balance were calculated as follows: Let

a represent the time the engine ran before and after the test.
b, the average draft during the time a.
c, the duration of the test in hours.
d, the average draft during the test.
e, the weight of cinders removed after engine stopped.
f, the weight of cinders caught during the test.

Then,

$$f=e-\frac{\left(\frac{b}{d}\right)a}{c+\left(\frac{b}{d}\right)a}\,e$$

Tests for which heat-balances only were made were subject to the foregoing correction.

Column 38. *Sparks from the stack per hour* were measured by the aid of a cinder-trap operated throughout the entire test. The trap consists of an inverted U-shaped tube mounted as shown in fig. 87. The cage b is a closed cylinder, the sides of which are constructed of wire gauze so fine that while the gases may easily escape the sparks which pass through the tube are retained. The trap may be placed in any one of the five positions shown on the diagram. In calculating the total weight of sparks ejected it was assumed that the rate of discharge, as measured at the several positions of the tube, was true only for the annular areas represented by these positions.

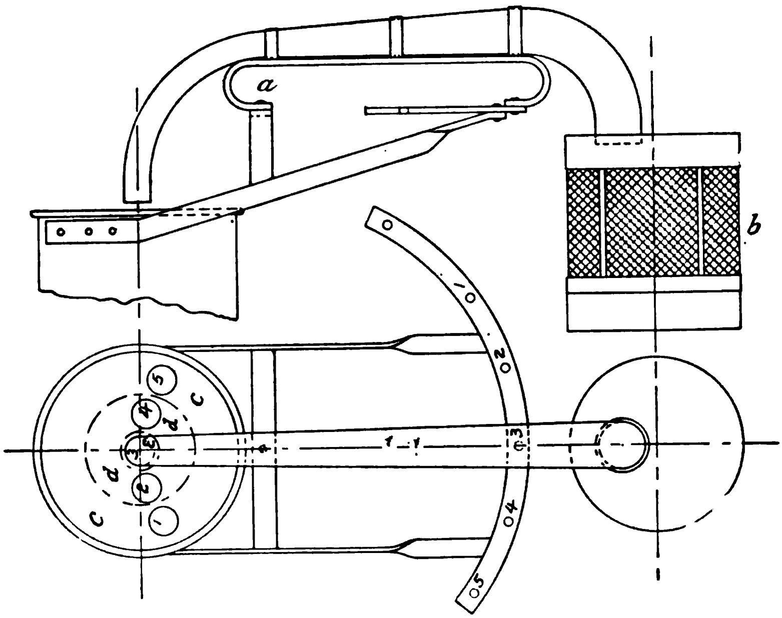


FIG. 87.—Cinder-trap.

Column 39. *Draft in the smoke-box* was measured in the front-end at a point in front of the diaphragm. It is expressed in inches of water and is the average of readings at 5-minute intervals.

Column 40. *Smoke-box temperature* was measured by a high-grade mercury thermometer. The values given are the average of readings at 10-minute intervals.

TABLE 10a—*Comparative values of Pocahontas and Youghiogheny coal.*

Test No.	Laboratory symbol.	Equivalent evaporation per pound of dry coal (Pocahontas coal).		Factor expressing ratio of efficiency of the two qualities of coal.	Equivalent evaporation per pound of dry coal (Youghiogheny coal).	
		In the boiler.	In the boiler and superheater.		In the boiler.	In the boiler and superheater.
1	2	3	4	5	6	7
107	30–2–200	9.05	9.72	1.06	9.54	10.24
108	30–4–200	8.20	8.88	1.06	8.67	9.35
113	50–4–200	7.19	7.82	1.16	8.35	9.07
117	20–8–160	7.96	8.56	1.12	8.93	9.60
118	30–2–160	9.78	10.46	1.03	10.23	10.46
122	40–2–160	9.99	10.65	1.04	10.43	10.65
126	50–2–160	9.60	10.19	1.04	10.03	10.19
127	50–4–160	8.33	8.98	1.07	8.88	9.58
131	30–10–120	7.30	7.95	1.19	8.66	9.42
132	30–14–120	6.38	6.98	1.24	8.10	8.86
133	40–4–120	9.64	10.24	1.03	9.98	10.58
134	40–8–120	8.25	8.95	1.10	9.10	9.88
135	40–12–120	6.48	7.10	1.25	8.11	8.89
136	50–8–120	8.38	9.10	1.15	9.69	10.51

While in the data of table 10*a*, on page 99, all facts are given as observed, there are elsewhere presented certain analyses in the course of which the evaporative efficiency obtained from the Pocahontas coal has been expressed in terms of an equivalent evaporation per pound of dry Youghiogheny coal. The manner of making such changes was suggested by the study of the various heat losses included in the heat-balance. It was noticed that these were practically the same for the two coals, except for the cinder-loss, which was greater for the Pocahontas coal. The diffierence in each case was added to the ratio representing the efficiency of the boiler, to give values for the efficiency such as would have resulted had Youghiogheny coal been used. The multiplier thus obtained is given in column 5 of table 10*a*.

TABLE 11.—BOILER PERFORMANCE.

Column 41. *Water evaporated per square foot of water and superheating surface per hour* = column 17 ÷ 1216.

Column 42. *Water evaporated per pound of dry coal* = column 17 ÷ column 31.

Column 43. *Equivalent evaporation per hour by boiler* = column 17 × column 54 ÷ 965.8.

Column 44. *Equivalent evaporation per hour by the superheater* = column 17 × column 55 ÷ 965.8.

Column 45. *Equivalent evaporation per hour by boiler and superheater* = column 43 + column 44.

Column 46. *Equivalent evaporation per hour per square foot of water-heating surface* = column 43 ÷ 1023.

Column 47. *Equivalent evaporation per hour per square foot of superheating surface* = column 44 ÷ 193.

Column 48. *Equivalent evaporation per hour per square foot of water and superheating surface* = column 45 ÷ 1216.

Column 49. *Ratio of heat absorbed per square foot of superheating surface to that absorbed per square foot of water-heating surface* = column 47 ÷ column 46.

Column 50. *Equivalent evaporation per square foot of grate-surface per hour* = column 45 ÷ 17.

Column 51. *Equivalent evaporation per pound of dry coal by the boiler* = column 43 ÷ column 31.

Column 52. *Equivalent evaporation per pound of dry coal by superheater* = column 44 ÷ column 31.

Column 53. *Equivalent evaporation per pound of dry coal by boiler and superheater* = column 45 ÷ column 31.

TABLE 12.—BOILER PERFORMANCE (Continued).

Column 54. *B. t. u. taken up by each pound of water in the boiler* $= q - q_0 + xr$.

Column 55. *B. t. u. taken up by each pound of steam in superheater* $= c\,(t - t_0) + r\,(1 - x)$. The values for specific heat of steam c are those recommended by Professor Carpenter.*

Column 56. *B. t. u. taken up by each pound of water in boiler and superheater* = column 54 + column 55.

*Proceedings A. S. M. E., vol. 28, No. 2, p. 278.

Column 57. *B. t. u. taken up by boiler per minute* = column 17 × column 54 ÷ 60.

Column 58. *B. t. u. taken up by superheating per minute* = column 17 × column 55 ÷ 60.

Column 59. *B. t. u. taken up by boiler and superheater per minute* = column 57 + column 58.

Column 60. *B. t. u. taken up by boiler and superheater per pound of dry coal* = column 42 × column 56.

Column 61. *B. t. u. taken up by boiler and superheater per pound of combustible fired* = column 59 × column 4 ÷ column 29.

Column 62. *B. t. u. taken up by boiler and superheater per* 100 *B. t. u. in dry coal* = 100 (column 60 ÷ column 87).

Column 63. *B. t. u. taken up by boiler and superheater per* 100 *B. t. u. in combustible consumed* = 100 × column 59 × column 4 ÷ column 30 × column 88.

Column 64. *Boiler horse-power* = column 45 ÷ 34.5.

TABLE 13.—CHEMICAL ANALYSIS OF SMOKE-BOX GASES.

The gas analyses were made with an Orsat apparatus, using the usual solutions of caustic potash, pyrogallol, and cuprous chloride for the absorption of CO_2, O_2, and CO, respectively.

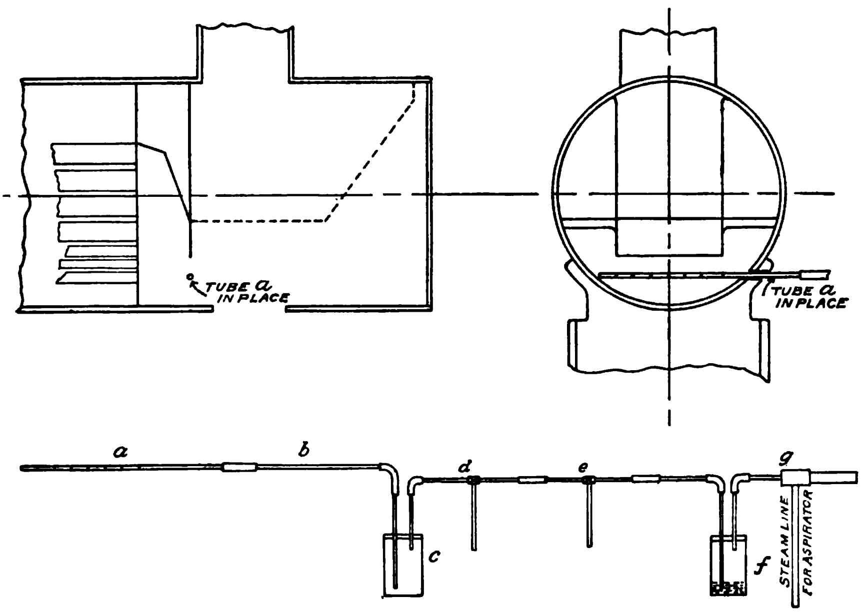


FIG. 88.—Smoke-box gas-sampling apparatus.

The sampling-tube, located as shown in fig. 88, was a $\frac{3}{8}$-inch copper tube having 7 small holes, approximately 0.05-inch in diameter, spaced 4 inches apart. The end of the tube was plugged. A small steam-aspirator *g* was used to draw the gas from the smoke-box. The gas was first passed through a bottle containing cotton to free it from cinders and moisture; it then passed through a line containing two 3-way cocks, *d* and *e*, to a mercury seal, and finally through a steam-aspirator *g* to the atmosphere. Lead tubing was used from the sampling-tube to the mercury seal, excepting where apparatus was joined by heavy rolled-rubber tubing. Two 3-way cocks were provided in order that both instantaneous and continuous samples could be collected simultaneously. This was done for the first tests, and the results were found to check very closely.

Fresh solutions were made for each test. On the longest test, of 2 hours 30 minutes duration, from 10 to 12 samples were analyzed. On the shorter tests both instantaneous and continuous samples were analyzed to insure correct results.

Although the holes in the sampling-tube were very small, they did not cause any trouble by clogging up if cleaned before each test. The rate of flow in the tube was always so well controlled by the steam-aspirator that the gas samples could be drawn very readily, even though there were 5 or 6 inches of draft in the smoke-box.

Column 65. CO_2, per cent.
Column 66. O_2, per cent.
Column 67. CO, per cent.
Column 68. N, per cent.
Column 69. *Weight of dry gas per pound of carbon consumed* =

$$\frac{11CO_2+8O_2+7(CO+N)}{3(CO_2+CO)}$$

Column 70. *Dry gas per pound of combustible fired* = per cent C in combustible (based on combustible consumed) × column 69 ÷ 100.

Column 71. *Air per pound of carbon* consumed = $N \div 0.33\ (CO_2+CO)$.

Column 72. *Air per pound of combustible* fired = per cent C in combustible (based on combustible consumed) × column 71 ÷ 100.

Column 73. *Ratio of air supplied to theoretical requirement* = column 68 ÷ (column 68 − 3.78 × column 66) = $\frac{N}{N-3.78O_2}$.

TABLE 14.—CHEMICAL ANALYSIS OF COAL.

During the test a shovelful of coal was taken from each wheelbarrow as a sample. At the end of the test these samples were crushed and quartered down to about 10 pounds. This was placed in a large sheet-iron tray in an oven in which air, heated about 30° or 40° above the surrounding atmosphere, was passed over it. About 8 or 10 hours were sufficient to drive off the surface moisture. The proximate and ultimate analyses were made at the laboratory of the fuel testing plant of the United States Geological Survey at St. Louis, Missouri.

Proximate analysis of coal as fired.

Column 74. *Moisture, per cent.*
Column 75. *Volatile matter, per cent.*
Column 76. *Fixed carbon, per cent.*
Column 77. *Ash, per cent.*

Ultimate analysis of dry coal.

Column 78. *Carbon, per cent.*
Column 79. *Hydrogen, per cent.*
Column 80. *Oxygen, per cent.*
Column 81. *Nitrogen, per cent.*
Column 82. *Sulphur, per cent.*
Column 83. *Ash, per cent.*

TABLE 15.—CALORIFIC VALUES.

A determination of the calorific value of the coal, calorific value of the front-end cinders and the percentage of ash contained in them, the calorific value of the stack cinders and the percentage of ash contained, the percentage of ash in the refuse removed before the test, and the percentage of ash in the refuse removed during the test was made from samples submitted to the fuel-testing laboratory of the United States Geological Survey at St. Louis. A Mahler bomb calorimeter was used in the work.

Column 84. *Per cent of combustible in front-end cinders.*
Column 85. *Per cent of combustible in stack cinders.*
Column 86. *Per cent of combustible in refuse from ash pan.*
Column 87. *B. t. u. per pound of dry coal.*
Column 88. *B. t. u. per pound of combustible* = column 87 × (100 − column 74) ÷ (column 75 + column 76).
Column 89. *B. t. u. per pound of front-end cinders.*
Column 90. *B. t. u. per pound of stack cinders.*
Column 91. *B. t. u. per pound of refuse from ash-pan.*

TABLE 16.—HEAT-BALANCE.

Column 92. *Calorific value in B. t. u. per pound of combustible.*
Column 93. *B. t. u. absorbed per pound of combustible fired* = column 59 × column 4 ÷ column 29.
Column 94. *B. t. u. lost per pound of combustible due to water in coal* =

$$\frac{a}{100}\left\{(212-t)+r+c\ (T-212)\right\},$$ where

t = temperature of laboratory,
a = per cent of moisture referred to combustible,
T = temperature of smoke-box gases,
r = latent heat of steam at atmospheric pressure,
c = the specific heat of steam at constant pressure.

Column 95. *B. t. u. per pound of combustible due to water in air* = per cent of moisture in the air × column 72 × 0.48 (column 40 − column 10).
Column 96. *B. t. u. lost per pound of combustible due to water formed by hydrogen in the coal* = per cent of hydrogen referred to combustible ÷ 100 × 9 × $\{(212 - \text{column } 10) + 965.8 + 0.48 \times (\text{column } 40 - 212)\}$.
Column 97. *B. t. u. lost per pound of combustible due to escaping gases* = column 70 × 0.24 × (column 40 − column 10).
Column 98. *B. t. u. per pound of combustible due to incomplete combustion* =

$$\frac{CO \times \text{per cent C in combustible} \times 10150}{100} \div (CO_2 + CO).$$

Column 99. *B. t. u. per pound of combustible due to front-end cinders* = (column 37 × column 89 × column 4) ÷ (column 29 × 60).

Column 100. *B. t. u. lost per pound of combustible due to stack cinders* = (column 38 × column 90 × column 4) ÷ (column 29 × 60).

Column 101. *B. t. u. lost per pound of combustible due to refuse in ash-pan* = column 28 × column 91 ÷ column 29.

Column 102. *B. t. u. unaccounted for* = column 92 — the sum of all calculated losses + heat absorbed by boiler and superheater. This item includes that due to radiation.

TABLE 17.—HEAT-BALANCE.

Column 103. *Per cent of heat absorbed by boiler and superheater* = 100 × column 93 ÷ column 92.

Column 104. *Per cent of heat lost due to water in coal* = 100 × column 94 ÷ column 92.

Column 105. *Per cent of heat lost due to water in air* = 100 × column 95 ÷ column 92.

Column 106. *Per cent of heat lost due to water formed by hydrogen in coal* = 100 × column 96 ÷ column 92.

Column 107. *Per cent of heat lost due to escaping gases* = 100 × column 97 ÷ column 92.

Column 108. *Per cent of heat lost due to incomplete combustion* = 100 × column 98 ÷ column 92.

Column 109. *Per cent of heat lost due to front-end cinders* = 100 × column 99 ÷ column 92.

Column 110. *Per cent of heat lost due to stack cinders* = 100 × column 100 ÷ column 92.

Column 111. *Per cent of heat lost due to refuse in ash-pan* = 100 × column 101 ÷ column 92.

Column 112. *Per cent of heat lost unaccounted for* = 100 × column 102 ÷ column 92.

TABLE 18.—EVENTS OF STROKE FROM INDICATOR-CARDS.

The indicator work received careful attention. In all cases two instruments were used on each cylinder. A short nipple and elbow constituted the only piping between the indicator and the cylinder. The drum motion was positive and provided a reciprocating-bar which moved just behind the drum of the indicators, permitting action from the shortest possible length of cord.

All events of stroke and all pressures represent average values as determined from indicator-cards taken at 10-minute intervals.

Columns 113 *to* 117. *Admission.*

Columns 118 *to* 122. *Cut-off.*

TABLE 19.—EVENTS OF STROKE (Continued).

Columns 123 *to* 127. *Release.*

Columns 128 *to* 132. *Compression.*

TABLE 20.—PRESSURES FROM INDICATOR-CARDS.

Columns 133 *to* 137. *Initial pressure.*
Columns 138 *to* 142. *Pressure at cut-off.*

TABLE 21.—PRESSURES FROM INDICATOR-CARDS (Continued).

Columns 143 *to* 147. *Pressure at release.*
Columns 148 *to* 152. *Pressure at compression.*

TABLE 22.—PRESSURES FROM INDICATOR-CARDS (Continued).

Columns 153 *to* 157. *Least back pressure.*
Columns 158 *to* 162. *Mean effective pressure.*

TABLE 23.—ENGINE PERFORMANCE.

Columns 163 *to* 167. *Indicated horse-power.*—The power was calculated by the use of a constant based upon the accurately determined dimensions of the engine and representing the horse-power, assuming the engine to make 1 revolution per minute in response to 1 pound mean effective pressure. These horse-power constants are as follows:

		Right side.	Left side.
Horse-power constants	Head end............	0.01222	0.01243
	Crank end...........	.01186	.01207

The power for each cylinder-end was determined by multiplying the horse-power constant by the average mean effective pressure for a test, columns 158 to 162, and by the revolution per minute, column 23.

Column 168. *Steam per indicated horse-power per hour by tank.* This is column 18 ÷ column 167.

Column 169. *Steam per indicated horse-power per hour by indicator* = (column 184 − column 189) × 60 × column 23 ÷ column 167.

Column 170. *Pounds of saturated steam per indicator horse-power equivalent to steam actually used* = column 168 × (column 56 + q_0) ÷ λ.

Column 171. *B. t. u. supplied engine per minute* = column 56 × column 18 ÷ 60.

Column 172. *B. t. u. supplied engine per minute, assuming temperature of feed to have been equal to temperature of exhaust* = column 18 (column 56 + t − 32 − q) ÷ 60, where t is the temperature of feed-water and q the heat in 1 pound of water at a temperature corresponding to the least back-pressure.

Column 173. *B. t. u. per indicated horse-power per minute* = column 171 ÷ column 167.

Column 174. *B. t. u. per indicated horse-power per minute on the assumption that the temperature of the feed was equal to the temperature of the exhaust* = column 172 ÷ 167.

TABLE 24.—STEAM SHOWN BY INDICATOR.

In determining the weight of steam present in the engine cylinder at any point in the stroke, three factors must be known, namely, the volume occupied by the steam in question, its pressure, and its weight per unit-volume. The constants for volumes employed in determining the weight of steam shown by indicator, as determined from accurate measurements, are as follows:

	End.	Piston displacement in cubic feet.	Cylinder clearance, per cent of piston displacement.
Right side	Head	2.8020	7.44
	Crank	2.7196	7.98
Left side	Head	2.8486	7.34
	Crank	2.7660	7.63

The volume for any point in the stroke was found by adding the percentage of that portion of whole stroke which the piston had passed over to reach the point in question (columns 118 to 132), to the percentage of clearance and multiplying by the piston displacement.

The pressure above atmosphere at the several points in the stroke to be investigated appears in columns 138 to 152. The weight per unit-volume corresponding to this pressure was found from Peabody's steam tables.

Columns 175 *to* 179. *Pounds of steam shown by indicator at cut-off.*—The values given are the average of those obtained from indicator-cards taken at 10-minute intervals.

Columns 180 *to* 184. *Pounds of steam shown by indicator at release.*—The values given are the average of those obtained from indicator-cards at 10-minute intervals.

TABLE 25.—CYLINDER PERFORMANCE.

Columns 185 *to* 189. *Pounds of steam shown by the indicator at the beginning of compression.*—The values shown are the average of those obtained from indicator-cards taken at 10-minute intervals.

Column 190. *Weight of steam per revolution by tank* = column 16 ÷ column 22.

Column 191. *Weight of mixture in cylinder per revolution* = column 190 + column 189.

Column 192. *Per cent of mixture present as steam at cut-off* = 100 × column 179 ÷ column 191.

Column 193. *Per cent of mixture present as steam at release* = (100 × column 184) ÷ column 191.

Column 194. *Reevaporation or condensation per revolution* = column 179 − column 184. Values representing the condensation are designated by the minus sign.

Column 195. *Reevaporation or condensation per indicated horse-power per hour* = column 194 × 60 × column 23 ÷ column 167.

TABLE 26.—PERFORMANCE OF THE LOCOMOTIVE AS A WHOLE.

Column 196. *Draw-bar pull.*—The values given are the average of observations made from a traction dynamometer at 5-minute intervals.

Column 197. *Dynamometer horse-power.*—To aid in calculating dynamometer horse-power, a constant was employed representing the horse-power which would be developed if the drivers were to revolve 1 revolution a minute and the locomotive were to exert 1 pound pull at the draw-bar. A factor in the determination of this constant is the circumference of the drivers, which, by accurate measurement, was found to be 18.063 feet. Upon this basis the dynamometer horse-power constant is $K = 0.000547$. The values in this column are, therefore, column 196 × column 23 × K.

Column 198. *Machine friction in terms of mean effective pressure* = column 162 − M. E. P. equivalent to the pounds pull at the draw-bar, column 196.

Column 199. *Machine friction, per cent of indicated horse-power* = (100 × column 198) ÷ column 162.

Column 200. *Machine friction horse-power* = column 199 × column 167 ÷ 100.

Column 201. *Steam per dynamometer horse-power hour* = column 18 ÷ column 197.

Column 202. *Coal per dynamometer horse-power per hour* = column 31 ÷ column 197.

Column 203. *Coal per indicated horse-power hour* = column 31 ÷ column 167.

TABLE 27.—PERFORMANCE OF THE LOCOMOTIVE AS A WHOLE, ASSUMING IRREGULARITIES IN THE RESULTS OF INDIVIDUAL TESTS TO HAVE BEEN ELIMINATED.

Column 204. *Equivalent steam to engine per hour, feed-water at a temperature of* 60° *F.* = column 18 × (column 56 + column 13 − 60) ÷ 965.8.

Column 205. *Equivalent evaporation per pound of dry coal, assuming the evaporative efficiency of the boiler to have been represented by the equation* $E = 11.706 - 0.214\ H$, where E is the equivalent evaporation per pound of coal and H is the rate of evaporation per foot of water and superheating surface per hour. For values in question, H = column 204 ÷ 1216.

Column 206. *Dry coal fired per hour, assuming the evaporative efficiency to be that shown by the equation* = column 204 ÷ column 205.

Column 207. *Dry coal per indicated horse-power hour* = column 206 ÷ column 167.

Column 208. *Equivalent steam per indicated horse-power hour* = column 204 ÷ column 167.

Column 209. *Machine friction in terms of mean effective pressure.*—The purpose of this column is to eliminate irregularities in action due to variations in lubrication, etc. The values given are those determined by the previous experimental work upon *Schenectady No. 2.**

Column 210. *Machine friction horse-power* is the power equivalent, assuming the friction M. E. P. to have been that shown by column 209.

Column 211. *Machine friction,* per cent of indicated horse-power = 100 × column 210 ÷ column 167.

Column 212. *Dynamometer horse-power* = column 167 − column 210.

Column 213. *Draw-bar pull* = 33,000 × column 212 ÷ (18.063 × column 23).

Column 214. *Coal per dynamometer horse-power hour* = column 206 ÷ column 212.

Column 215. *Equivalent steam per dynamometer horse-power per hour* = column 204 ÷ column 212.

*"High Steam-Pressures in Locomotive Service," Publication No. 66, Carnegie Institution of Washington.

TABLE 7.—*General conditions.*

Designation of tests.			Duration of test.	Reverse-lever notch from center forward.	Position of throttle.	Barometer pressure.	Boiler-pressure by gage.	Dry-pipe pressure by gage.	Temperature of laboratory.	Temperature by wet-bulb thermometer.	Temperature by dry-bulb thermometer.
No.	Laboratory symbol.	Date.									
1	2	3	4	5	6	7	8	9	10	11	12
			Min.			*Lbs.*	*Lbs.*	*Lbs.*	°*F.*	°*F.*	°*F.*
101	30–2–240	May 27, '07	120	2	Wide open	14.50	241.0	237.3	77.80	58.4	66.2
102	30–4–240	June 7, '07	120	4	...Do...	14.31	238.9	236.1	81.80	74.2	77.8
103	30–5–240	July 22, '07	95	5	...Do...	14.37	234.3	225.4	92.30	....	....
103*a*	30–5–240	June 6, '07	65	5	...Do...	14.44	236.6	234.4	88.10	73.0	83.6
104	40–2–240	May 28, '07	85	2	...Do...	14.52	236.4	231.4	79.10	70.2	80.0
105	40–4–240	May 20, '07	100	4	...Do...	14.55	239.7	235.7	81.50	53.3	61.0
106	50–2–240	June 5, '07	60	2	...Do...	14.39	235.8	231.4	85.40	72.5	81.5
107	30–2–200	Mar. 18, '07	150	2	...Do...	14.55	200.1	196.8	72.90	64.7	73.7
108	30–4–200	Apr. 5, '07	150	4	...Do...	14.41	200.5	198.3	72.50	52.2	54.2
109	30–6–200	Apr. 19, '07	150	6	...Do...	14.45	200.2	199.1	79.30	59.1	65.6
110	40–2–200	Apr. 1, '07	130	2	...Do...	14.67	200.4	198.6	73.20	48.9	55.0
111	40–4–200	July 15, '07	95	4	...Do...	14.31	200.1	193.7	86.30	....	....
111*a*	40–4–200	June 8, '07	120	4	...Do...	14.46	199.4	199.0	86.70	75.2	77.5
112	40–6–200	Apr. 22, '07	150	6	...Do...	14.42	200.0	198.4	84.50	66.7	78.1
113	50–4–200	Apr. 12, '07	50	4	...Do...	14.31	201.1	198.0	75.20	61.0	66.3
114	20–2–160	Nov. 15, '06	180	2	...Do...	14.69	160.2	....	79.30	....	....
115	20–4–160	Nov. 12, '06	150	4	...Do...	14.47	160.5	....	75.13	....	....
116	20–6–160	Nov. 26, '06	150	6	...Do...	14.41	159.9	....	76.13	....	....
117	20–8–160	Jan. 11, '07	150	8	...Do...	14.33	159.5	....	72.00	....	....
118	30–2–160	Feb. 1, '07	150	2	...Do...	14.36	160.8	160.6	73.37	....	....
119	30–4–160	June 5, '07	150	4	...Do...	14.35	160.2	159.7	82.40	66.2	71.4
120	30–6–160	Dec. 3, '06	150	6	...Do...	14.48	160.4	....	78.93	....	....
121	30–8–160	Apr. 29, '07	150	8	...Do...	14.34	160.1	158.6	73.90	53.6	55.7
122	40–2–160	Feb. 4, '07	150	2	...Do...	14.51	161.1	160.0	75.09	....	....
123	40–4–160	Nov. 23, '06	150	4	...Do...	14.69	159.9	....	73.60	....	....
124	40–6–160	May 3, '07	150	6	...Do...	14.43	160.0	....	72.90	56.4	61.0
125	40–8–160	Dec. 14, '06	150	8	...Do...	14.39	160.4	....	83.00	....	....
126	50–2–160	Feb. 8, '07	60	2	...Do...	14.49	161.2	159.6	70.20	....	....
127	50–4–160	Feb. 11, '07	60	4	...Do...	14.85	160.4	159.4	69.80	....	....
128	50–6–160	Dec. 17, '06	40	6	...Do...	14.53	161.4	....	68.50	....	....
129	30–4–120	Mar. 11, '07	150	4	...Do...	14.54	120.2	118.7	73.50	64.9	72.1
130	30–8–120	May 31, '07	150	8	...Do...	....	120.2	....	....	64.9	67.6
131	30–10–120	Feb. 15, '07	120	10	...Do...	14.40	119.9	120.9	68.40	66.0	57.0
132	30–14–120	Feb. 18, '07	120	14	...Do...	14.20	120.2	119.5	78.40	....	....
133	40–4–120	Mar. 15, '07	150	4	...Do...	14.58	120.1	119.0	76.90	61.9	70.6
134	40–8–120	Mar. 4, '07	150	8	...Do...	14.35	120.3	120.0	73.00	57.7	66.4
135	40–12–120	Feb. 22, '07	90	12	...Do...	14.72	120.6	118.3	75.50	72.0	64.8
136	50–8–120	Mar. 8, '07	60	8	...Do...	14.53	120.6	117.5	77.10	55.0	61.0

TABLE 8.—*Water and steam.*

Designation of tests.		Water and steam.								
No.	Laboratory symbol.	Temperature of feed-water.	Water delivered to boiler.	Water lost from boiler.	Steam supplied engine.	Water evaporated by boiler per hour.	Steam supplied engine per hour.	Quality of steam in dome.	Temperature of steam by thermometer.	Degrees superheat.
1	2	13	14	15	16	17	18	19	20	21
		°F.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.		°F.	
101	30–2–240	61.8	17,600	275	17,325	8,800	8,662	0.989	540.7	137.8
102	30–4–240	60.2	21,316	238	21,078	10,658	10,539	.990	554.6	152.5
103	30–5–240	71.6	18,619	285	18,334	11,759	11,580	.989	549.6	149.1
103a	30–5–240	62.0	13,752	....	....	12,698	....	.990	552.6	151.3
104	40–2–240	60.5	13,056	196	12,860	9,214	9,078	.990	528.6	127.3
105	40–4–240	59.6	20,150	560	19,590	12,090	11,758	.989	556.4	153.9
106	50–2–240	59.1	10,178	139	10,038	10,178	10,038	.989	543.8	142.7
107	30–2–200	55.1	16,754	677	16,077	6,702	6,431	.991	519.3	131.6
108	30–4–200	57.6	21,312	617	20,695	8,525	8,278	.991	539.9	152.1
109	30–6–200	57.2	26,448	682	25,766	10,579	10,306	.992	556.8	169.1
110	40–2–200	58.2	15,638	611	15,027	7,217	6,938	.992	526.3	138.4
111	40–4–200	70.1	15,837	251	15,586	10,002	9,844	.992	540.5	152.9
111a	40–4–200	59.9	20,266	....	....	10,133	....	.992	540.0	152.6
112	40–6–200	55.3	30,205	662	29,543	12,082	11,817	.993	565.2	177.5
113	50–4–200	59.1	8,372	234	8,138	10,038	9,766	.991	547.4	159.4
114	20–2–160	59.7	14,061	498	13,563	4,687	4,521	.993	495.6	125.0
115	20–4–160	60.5	13,983	222	13,761	5,594	5,504	.993	504.0	133.4
116	20–6–160	55.2	17,703	422	17,281	7,082	6,913	.992	524.2	153.8
117	20–8–160	55.0	21,297	378	20,919	8,519	8,367	.993	515.2	145.1
118	30–2–160	56.0	13,145	609	12,536	5,258	5,014	.992	495.7	125.0
119	30–4–160	62.7	16,586	229	16,357	6,634	6,543	.995	512.4	141.9
120	30–6–160	54.5	21,834	422	21,412	8,733	8,565	.993	533.5	162.9
121	30–8–160	56.9	26,123	585	25,538	10,449	10,214	.996	543.3	172.9
122	40–2–160	56.0	13,940	496	13,444	5,576	5,378	.992	494.3	123.4
123	40–4–160	54.8	18,896	423	18,473	7,558	7,389	.993	524.5	154.0
124	40–6–160	57.2	23,432	399	23,033	9,372	9,213	.995	535.3	164.9
125	40–8–160	62.0	30,836	474	30,362	12,334	12,145	.993	550.6	180.1
126	50–2–160	56.0	5,510	272	5,238	5,510	5,238	.994	489.1	118.1
127	50–4–160	54.0	7,858	237	7,621	7,858	7,621	.992	523.3	152.5
128	50–6–160	54.4	8,309	131	8,178	12,463	12,267	.993	585.2	214.1
129	30–4–120	54.6	11,604	470	11,134	4,642	4,454	.994	467.0	117.1
130	30–8–120	62.9	19,475	160	19,315	7,790	7,726	.994	505.9	156.2
131	30–10–120	54.1	18,415	330	18,085	9,208	9,043	.993	524.5	174.9
132	30–14–120	58.0	23,664	320	23,344	11,832	11,672	.995	541.1	191.4
133	40–4–120	55.5	12,231	445	11,786	4,892	4,714	.994	470.6	120.8
134	40–8–120	59.0	21,755	430	21,325	8,702	8,530	.994	520.4	170.6
135	40–12–120	58.0	18,483	250	18,233	12,322	12,156	.994	540.5	190.3
136	50–8–120	58.0	9,538	170	9,368	9,538	9,368	.993	519.2	169.1

TABLE 9.—*Speed and coal.*

Designation of tests.		Speed.				Coal.						
No.	Laboratory symbol.	Total revolutions.	Revolutions per minute.	Miles equivalent to total revolutions.	Miles per hour.	Kind of coal.	Dry coal fired.	Refuse.	Combustible fired.	Combustible consumed.	Dry coal per hour.	Dry coal per mile run.
1	2	22	23	24	25	26	27	28	29	30	31	32
							Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
101	30–2–240	17,652	147.10	60.39	30.20	Youghiogheny...	2353	206	2173	1979	1177	38.98
102	30–4–240	16,998	141.65	58.15	29.07	...Do..........	3190	360	2925	2530	1595	54.87
103	30–5–240	13,613	143.29	46.57	29.42	...Do..........	....	....	....	....	....	....
103*a*	30–5–240	9,534	146.67	32.27	29.80	...Do..........	2107	157	1929	1656	1944	64.57
104	40–2–240	16,452	193.55	56.28	39.73	...Do..........	1834	320	....	....	1294	32.57
105	40–4–240	19,299	193.00	66.02	39.86	...Do..........	3057	210	2800	2428	1834	46.02
106	50–2–240	14,785	246.41	50.58	50.58	...Do..........	1399	218	....	....	1399	27.66
107	30–2–200	22,037	146.90	75.39	30.15	Pocahontas......	2239	256	2015	1785	896	29.72
108	30–4–200	21,926	146.20	7[illegible].00	30.00	...Do..........	3139	468	....	....	1256	41.86
109	30–6–200	22,204	148.00	75.96	30.38	Youghiogheny...	3859	415	3529	3153	1544	50.82
110	40–2–200	25,286	194.50	86.50	39.92	Pocahontas......	2046	306	....	....	944	23.65
111	40–4–200	18,704	196.88	63.99	40.42	Youghiogheny...	....	....	....	....	....	....
111*a*	40–4–200	23,548	196.23	80.56	40.28	...Do..........	3099	381	2741	2385	1549	38.46
112	40–6–200	29,825	198.80	102.02	40.81	...Do..........	4294	324	3934	3470	1718	42.10
113	50–4–200	11,746	234.90	40.18	48.21	Pocahontas......	1405	169	1250	989	1685	34.96
114	20–2–160	17,488	97.15	59.82	19.94	Youghiogheny...	1974	348	....	....	658	33.00
115	20–4–160	14,560	97.06	49.81	19.92	...Do..........	1880	374	....	....	752	37.75
116	20–6–160	14,616	97.44	50.03	20.01	...Do..........	2490	313	....	....	996	49.80
117	20–8–160	14,642	97.61	50.09	20.03	Pocahontas......	3231	664	....	....	1292	64.47
118	30–2–160	21,967	146.44	75.15	30.06	...Do..........	1619	326	....	....	648	21.54
119	30–4–160	21,818	145.45	74.64	29.86	Youghiogheny...	2121	195	1950	1826	849	28.43
120	30–6–160	21,917	146.11	74.98	30.00	...Do..........	3178	381	....	....	1271	42.38
121	30–8–160	21,941	146.27	75.06	30.02	...Do..........	3515	269	3239	2962	1406	46.84
122	40–2–160	29,889	199.26	100.24	40.89	Pocahontas......	1682	289	....	....	673	16.45
123	40–4–160	29,403	196.02	100.59	40.24	Youghiogheny...	2703	420	....	....	1081	26.87
124	40–6–160	29,290	195.25	100.20	40.08	...Do..........	3208	256	2909	2652	1282	31.27
125	40–8–160	29,294	195.27	100.22	40.08	...Do..........	4160	450	....	....	1664	41.52
126	50–2–160	14,590	243.17	49.91	49.91	Pocahontas......	693	187	....	....	693	13.89
127	50–4–160	14,575	242.91	49.86	49.86	...Do..........	1139	284	....	....	1139	22.85
128	50–6–160	9,743	243.57	33.33	49.99	Youghiogheny...	1220	272	....	....	1830	36.60
129	30–4–120	21,935	146.20	75.04	30.12	Pocahontas......	1346	315	....	....	538	17.82
130	30–8–120	22,105	147.37	75.63	30.25	Youghiogheny...	2527	190	2263	2114	988	32.66
131	30–10–120	17,416	145.13	59.38	29.79	Pocahontas......	3030	327	2742	2135	1515	50.86
132	30–14–120	17,523	146.03	59.95	29.97	...Do..........	4449	294	4025	3003	2225	74.22
133	40–4–120	29,178	194.52	99.82	39.93	...Do..........	1523	205	1392	1259	609	15.26
134	40–8–120	29,182	194.55	99.83	39.93	...Do..........	3156	254	2890	2444	1262	87.17
135	40–12–120	17,515	194.61	59.92	39.94	...Do..........	3415	231	3164	2353	2277	56.99
136	50–8–120	14,632	243.87	50.05	50.05	...Do..........	1363	271	....	....	1363	27.73

TABLE 10.—*Coal.*

Designation of tests.		Coal.						Draft.	
No.	Laboratory symbol.	Dry coal per sq. ft. of grate surface per hour.	Dry coal per sq. ft. of water and superheating surface per hour.	Combustible fired per sq. ft. of water and superheating surface per hour.	Combustible consumed per sq. ft. of water and superheating surface per hour.	Cinders caught in front-end per hour.	Sparks from stack per hour.	Draft in smoke-box.	Temperature in smoke-box.
1	2	33	34	35	36	37	38	39	40
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	H_2O	°*F.*
101	30–2–240	69.23	0.968	0.894	0.814	49.7	28.6	3.09	725.9
102	30–4–240	93.80	1.312	1.203	1.040	111.0	22.5	4.28	774.5
103	30–5–240	....	....	....	....	....	....	....	....
103*a*	30–5–240	114.40	1.599	1.463	1.257	195.7	27.3	5.18	815.4
104	40–2–240	76.12	1.064	....	....	....	....	3.69	713.7
105	40–4–240	107.90	1.508	1.381	1.198	185.0	27.0	5.15	798.1
106	50–2–240	82.20	1.150	....	....	....	....	3.77	761.4
107	30–2–200	52.70	.737	.662	.587	50.9	18.1	2.04	661.8
108	30–4–200	73.90	1.033	....	....	....	....	2.98	724.0
109	30–6–200	90.82	1.270	1.161	1.037	84.6	20.3	4.37	787.0
110	40–2–200	55.53	.776	....	....	....	....	2.17	686.5
111	40–4–200	....	....	....	....	....	....	....	....
111*a*	40–4–200	91.12	1.273	1.127	.981	97.3	28.4	3.69	747.1
112	40–6–200	101.06	1.413	1.294	1.141	135.1	29.4	5.60	824.2
113	50–4–200	99.17	1.386	1.232	.975	244.5	37.8	3.85	778.1
114	20–2–160	38.70	.541	....	....	....	....	1.11	632.7
115	20–4–160	44.23	.618	....	....	....	....	1.60	626.6
116	20–6–160	58.58	.819	....	....	....	....	1.99	690.8
117	20–8–160	76.01	1.063	....	....	....	....	2.70	690.4
118	30–2–160	38.09	.533	....	....	....	....	1.38	600.9
119	30–4–160	49.90	.698	.642	.601	15.3	16.3	2.25	669.6
120	30–6–160	74.76	1.045	....	....	....	....	2.56	695.3
121	30–8–160	82.70	1.156	1.066	.975	78.2	17.5	4.56	764.4
122	40–2–160	39.57	.553	....	....	....	....	1.47	613.4
123	40–4–160	63.60	.889	....	....	....	....	2.07	682.0
124	40–6–160	75.40	1.054	.956	.872	54.1	29.9	3.50	722.1
125	40–8–160	97.89	1.370	....	....	....	....	4.77	774.8
126	50–2–160	40.76	.570	....	....	....	....	1.40	600.4
127	50–4–160	67.00	.937	....	....	....	....	2.45	676.4
128	50–6–160	107.65	1.505	....	....	....	....	4.74	797.4
129	30–4–120	31.67	.442	....	....	....	....	1.10	568.4
130	30–8–120	58.10	.812	.744	.694	33.3	16.2	3.00	676.0
131	30–10–120	89.10	1.246	1.127	.878	227.0	41.1	3.22	701.6
132	30–14–120	130.85	1.835	1.655	1.235	387.0	137.1	5.65	771.6
133	40–4–120	35.83	.501	.458	.414	21.0	9.6	1.25	579.1
134	40–8–120	74.25	1.038	.950	.804	120.0	34.0	3.10	691.5
135	40–12–120	133.92	1.872	1.735	1.290	443.0	105.0	5.74	781.9
136	50–8–120	80.15	1.121	....	....	....	....	3.54	714.9

TABLE 11.—*Boiler performance.*

Designation of tests.		Boiler performance.												
				Equivalent evaporation per hour.							Equivalent evaporation.			
No.	Laboratory symbol.	Water evaporated per sq. ft. of heating and superheating surface per hour.	Water evaporated per pound of dry coal.	By boiler.	By superheater.	By boiler and superheater.	Per sq. ft. of water-heating surface.	Per sq. ft. of superheating surface.	Per sq. ft. of water and superheating surface.	Ratio of heat absorbed per sq. ft. of superheating surface to that absorbed per sq. ft. of water-heating surface.	Per sq. ft. of grate-surface per hour.	Per pound of dry coal by boiler.	Per pound of dry coal by superheater.	Per pound of dry coal by boiler and superheater.
1	2	41	42	43	44	45	46	47	48	49	50	51	52	53
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
101	30–2–240	7.24	7.48	10,623	849	11,472	10.39	4.40	9.43	42.55	674.9	9.03	0.72	9.75
102	30–4–240	8.77	6.68	12,889	1118	14,007	12.60	5.79	11.52	45.95	824.0	8.08	.71	8.79
103	30–5–240	....	....	....	....	....	....	....	....	....	....	....	....	....
103*a*	30–5–240	10.44	6.56	15,326	1322	16,648	14.98	6.85	13.69	45.72	979.4	7.88	.68	8.56
104	40–2–240	7.58	7.12	11,141	820	11,961	10.89	4.25	9.83	39.00	703.7	8.61	.63	9.24
105	40–4–240	9.94	6.59	14,620	1289	15,909	14.29	6.67	13.08	46.68	935.8	7.97	.70	8.67
106	50–2–240	8.37	7.28	12,308	1013	13,322	12.03	5.24	10.96	43.56	783.8	8.80	.72	9.52
107	30–2–200	5.51	7.48	8,114	591	8,705	7.93	3.05	7.16	38.46	512.1	9.05	.67	9.72
108	30–4–200	7.01	6.79	10,300	859	11,159	10.07	4.45	9.17	44.19	656.4	8.20	.68	8.88
109	30–6–200	8.70	6.85	12,795	1166	13,961	12.51	6.04	11.47	48.28	821.3	8.29	.75	9.04
110	40–2–200	5.93	7.65	8,721	660	9,381	8.53	3.42	7.71	40.10	551.8	9.24	.70	9.94
111	40–4–200	....	....	....	....	....	....	....	....	....	....	....	....	....
111*a*	40–4–220	8.41	6.61	12,225	1015	13,240	11.95	5.26	10.89	44.02	778.9	7.89	.66	8.55
112	40–6–200	9.94	7.03	14,647	1384	16,031	14.32	7.18	13.18	50.14	943.1	8.53	.81	9.34
113	50–4–200	8.25	5.96	12,114	1056	13,170	11.84	5.47	10.82	46.20	774.8	7.19	.63	7.82
114	20–2–160	3.85	7.12	5,633	366	5,999	5.50	1.89	4.88	34.37	352.9	8.56	.56	9.10
115	20–4–160	4.60	7.44	6,719	469	7,188	6.57	2.43	5.91	36.98	422.8	8.94	.62	9.56
116	20–6–160	5.82	7.11	8,542	680	9,222	8.35	3.54	7.58	42.38	542.5	8.58	.68	9.26
117	20–8–160	7.00	6.59	10,281	771	11,052	10.05	3.99	9.09	39.74	650.2	7.96	.60	8.56
118	30–2–160	4.32	8.11	6,337	418	6,755	6.19	2.17	5.56	35.06	397.3	9.78	.63	10.46
119	30–4–160	5.46	7.81	7,967	575	8,542	7.79	2.98	7.02	38.25	502.5	9.38	.68	10.06
120	30–6–160	7.18	6.43	10,544	881	11,425	10.30	4.56	9.40	44.30	672.1	8.30	.69	8.99
121	30–8–160	8.59	7.43	12,620	1084	13,704	12.33	5.61	11.27	45.50	806.2	8.97	.77	9.74
122	40–2–160	4.59	8.29	6,720	462	7,162	6.57	2.29	5.89	34.85	421.3	9.99	.69	10.65
123	40–4–160	6.22	6.99	9,122	435	9,557	8.92	3.76	7.86	42.16	562.2	8.45	.40	8.85
124	40–6–160	7.71	7.31	11,309	938	12,247	11.05	4.86	10.07	44.00	720.4	8.82	.73	9.55
125	40–8–160	10.15	7.41	14,795	1372	16,166	14.46	7.11	13.29	49.16	951.1	8.89	.83	9.72
126	50–2–160	4.53	7.95	6,650	407	7,057	6.50	2.11	5.80	32.47	415.0	9.60	.59	10.19
127	50–4–160	6.46	6.90	9,486	752	10,238	9.27	3.90	8.41	42.06	602.3	8.33	.65	8.98
128	50–6–160	10.25	6.81	15,049	1630	16,679	14.72	8.44	13.71	57.30	981.2	8.22	.90	9.12
129	30–4–120	3.82	8.62	5,578	335	5,913	5.45	1.73	4.86	31.75	347.8	10.36	.62	10.98
130	30–8–120	6.41	7.88	9,295	735	10,030	9.09	3.81	8.25	41.90	590.0	9.41	.75	10.16
131	30–10–120	7.57	6.08	11,061	975	12,036	10.81	5.05	9.90	46.72	708.1	7.30	.65	7.95
132	30–14–120	9.73	5.32	14,188	1343	15,531	13.87	6.96	12.77	50.18	913.7	6.38	.60	6.98
133	40–4–120	4.02	8.03	5,875	363	6,238	5.74	1.88	5.12	32.75	366.9	9.64	.60	10.24
134	40–8–120	7.16	6.89	10,414	892	11,306	10.18	4.62	9.30	45.38	665.1	8.25	.70	8.95
135	40–12–120	10.13	5.41	14,766	1402	16,168	14.43	7.26	13.30	50.30	951.1	6.48	.62	7.10
136	50–8–120	7.84	7.00	11,421	978	12,399	11.16	5.07	10.20	45.42	729.4	8.38	.72	9.10

TABLE 12.—*Boiler performance.*

Designation of tests.		Boiler performance.										
		B. t. u. taken up by—										
No.	Laboratory symbol.	Each pound of water in boiler.	Each pound of water in superheater.	Each pound of water in boiler and superheater.	Boiler per minute.	Superheater per minute.	Boiler and superheater per minute.	Boiler and superheater per pound dry coal.	Boiler and superheater per pound combustible fired.	Boiler and superheater per 100 B. t. u. in coal.	Boiler and superheater per 100 B.t.u. in combustible consumed.	Boiler horse-power A. S. M. E. standard.
1	**2**	**54**	**55**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**
101	30-2-240	1165.8	93.17	1259.0	170,992	13,665	184,657	9,413	10,189	66.4	72.9	332.5
102	30-4-240	1168.01	101.31	1269.3	207,477	17,996	225,473	8,485	9,252	60.1	69.4	406.0
103	30-5-240	1155.0	100.0	1255.0	....	....	....	....	....	....	....	....
103*a*	30-5-240	1166.0	100.59	1266.6	246,697	21,283	267,980	8,271	9,040	58.7	68.3	482.5
104	40-2-240	1167.5	85.95	1253.4	179,332	13,202	192,534	8,924	....	....	....	346.7
105	40-4-240	1167.92	103.0	1270.9	235,336	20,752	256,088	8,373	9,136	59.3	68.4	461.2
106	50-2-240	1167.9	96.17	1264.1	198,114	16,314	214,428	9,204	....	....	....	386.2
107	30-2-200	1169.4	85.20	1254.6	130,610	9,516	140,126	9,387	10,431	65.7	74.1	252.3
108	30-4-200	1166.9	97.30	1264.2	165,796	13,823	179,619	8,576	....	....	....	323.4
109	30-6-200	1168.1	106.5	1274.6	205,963	18,775	224,738	8,731	9,552	62.3	69.7	404.7
110	40-2-200	1167.2	88.37	1255.6	140,401	10,630	151,031	9,600	....	....	69.7	271.9
111	40-4-200	1155.2	97.0	1252.1	....	....	....	....	....	....	....	....
111*a*	40-4-200	1165.25	96.75	1262.0	196,787	16,339	213,126	8,258	9,330	61.4	70.5	383.7
112	40-6-200	1170.8	110.6	1281.5	235,772	22,273	258,045	9,021	9,832	63.2	71.7	464.7
113	50-4-200	1165.5	101.6	1267.1	195,152	17,012	212,164	7,553	8,489	53.9	68.2	381.7
114	20-2-160	1160.8	75.4	1236.2	90,678	5,890	96,568	8,805	....	....	....	173.8
115	20-4-160	1160.1	80.96	1241.1	108,157	7,548	115,705	9,745	....	....	....	208.4
116	20-6-160	1165.0	92.79	1257.8	137,509	10,952	148,461	8,943	....	....	....	267.3
117	20-8-160	1165.5	87.40	1252.9	165,482	12,409	177,891	8,267	....	....	....	320.3
118	30-2-160	1164.1	76.82	1240.9	102,012	6,734	108,746	10,069	....	....	....	183.4
119	30-4-160	1159.8	83.72	1243.6	128,243	9,257	137,500	9,716	10,576	69.0	73.8	247.6
120	30-6-160	1166.12	97.38	1263.5	169,729	14,174	183,903	8,682	....	....	72.4	331.1
121	30-8-160	1166.5	100.23	1266.7	203,141	17,455	220,596	9,407	10,209	....	....	397.2
122	40-2-160	1164.1	76.51	1240.6	108,175	7,110	115,289	10,280	....	....	....	207.7
123	40-4-160	1165.6	92.65	1258.3	146,832	7,002	153,834	8,547	....	....	....	277.0
124	40-6-160	1165.3	96.61	1261.9	182,032	15,091	197,123	9,223	10,170	66.2	72.6	355.0
125	40-8-160	1158.4	107.46	1265.9	238,128	22,090	260,218	9,386	....	....	....	468.6
126	50-2-160	1165.7	71.40	1237.1	107,046	6,557	113,603	9,836	....	....	....	204.6
127	50-4-160	1165.9	92.39	1258.3	152,697	12,100	164,797	8,673	....	....	....	296.8
128	50-6-160	1166.2	126.29	1292.5	242,239	26,233	268,472	8,808	....	....	....	481.6
129	30-4-120	1160.7	69.61	1230.3	89,793	5,384	95,177	10,604	....	....	....	171.4
130	30-8-120	1152.4	91.10	1243.5	149,617	11,829	161,446	9,813	10,701	69.7	74.7	290.7
131	30-10-120	1160.3	102.27	1262.6	178,055	15,694	193,749	7,678	8,480	53.6	68.9	348.9
132	30-14-120	1158.1	109.61	1267.7	228,381	21,615	249,996	6,741	7,460	47.4	63.5	450.1
133	40-4-120	1159.8	71.60	1231.4	94,572	5,842	100,414	9,890	10,817	68.1	75.3	180.8
134	40-8-120	1155.9	99.03	1254.9	167,637	14,363	182,000	8,644	9,446	60.0	70.9	327.7
135	40-12-120	1157.4	109.90	1267.3	237,691	22,564	260,255	6,857	7,408	46.7	62.7	468.6
136	50-8-120	1156.5	99.10	1255.6	183,851	15,751	199,602	8,789	....	....	....	359.3

TABLE 13.—*Chemical analysis of smoke-box gases.*

Designation of tests.		Gas analysis.				Weight of—				Ratio of air supplied to theoretical requirement.
No.	Laboratory symbol.	CO_2.	O_2.	CO.	N.	Dry gas per pound of carbon.	Dry gas per pound of combustible.	Air per pound of carbon.	Air per pound of combustible.	
1	2	65	66	67	68	69	70	71	72	73
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	
101	30-2-240	14.27	4.05	0.12	81.55	17.63	13.41	17.17	13.06	1.23
102	30-4-240	14.11	4.32	.77	80.80	17.04	12.32	16.45	11.89	1.25
103	....	....	....	....	....	....	....	....	....	....
103a	30-5-240	14.63	2.98	1.06	81.33	16.18	11.31	15.71	10.98	1.16
104	....	....	....	....	....	....	....	....	....	....
105	40-4-240	13.95	3.81	.99	81.25	16.95	11.96	16.48	11.63	1.22
106	....	....	....	....	....	....	....	....	....	....
107	30-2-200	11.70	7.40	.01	80.90	21.47	16.95	20.94	16.53	1.53
108	....	....	....	....	....	....	....	....	....	....
109	30-6-200	13.64	4.72	.27	81.37	18.20	13.52	17.73	13.17	1.28
110	....	....	....	....	....	....	....	....	....	....
111	....	....	....	....	....	....	....	....	....	....
111a	40-4-200	14.63	3.01	1.39	80.97	15.85	11.36	15.32	10.98	1.16
112	40-6-200	13.90	3.87	.40	81.83	17.70	13.09	17.54	12.98	1.22
113	50-4-200	13.59	5.16	.10	81.15	18.49	16.64	17.96	12.28	1.32
114	....	....	....	....	....	....	....	....	....	....
115	....	....	....	....	....	....	....	....	....	....
116	....	....	....	....	....	....	....	....	....	....
117	....	....	....	....	....	....	....	....	....	....
118	....	....	....	....	....	....	....	....	....	....
119	30-4-160	12.47	6.11	.29	81.13	19.75	15.32	19.27	14.94	1.40
120	....	....	....	....	....	....	....	....	....	....
121	30-8-160	13.48	5.14	.31	81.07	18.35	14.13	17.82	13.73	1.32
122	....	....	....	....	....	....	....	....	....	....
123	....	....	....	....	....	....	....	....	....	....
124	40-6-160	12.85	5.81	.35	80.99	19.12	14.58	18.59	14.18	1.37
125	....	....	....	....	....	....	....	....	....	....
126	....	....	....	....	....	....	....	....	....	....
127	....	....	....	....	....	....	....	....	....	....
128	....	....	....	....	....	....	....	....	....	....
129	....	....	....	....	....	....	....	....	....	....
130	30-8-120	12.20	6.15	.19	81.46	20.31	15.67	19.92	15.37	1.40
131	30-10-120	11.57	7.15	.15	81.12	21.43	14.33	20.97	14.02	1.50
132	30-14-120	11.82	6.77	.16	81.25	21.01	13.66	20.58	13.37	1.46
133	40-4-120	10.81	8.82	.11	80.26	22.96	17.88	22.26	17.35	1.71
134	40-8-120	11.99	7.43	.04	80.51	20.92	15.45	20.27	14.97	1.54
135	40-12-120	12.05	6.34	.27	81.33	20.41	13.08	20.00	12.81	1.42
136	....	....	....	....	....	....	....	....	....	....

TABLE 14.—*Chemical analysis of coal.*

Designation of tests.		Proximate analysis of coal as fired. Per cent of—				Ultimate analysis of dry coal. Per cent of—					
No.	Laboratory symbol.	Moist-ure.	Volatile matter.	Fixed carbon.	Ash.	Carbon.	Hydro-gen.	Oxygen.	Nitro-gen.	Sul-phur.	Ash.
1	2	74	75	76	77	78	79	80	81	82	83
101	30–2–240	2.72	32.19	57.63	7.46	78.45	5.25	6.10	1.50	1.03	7.67
102	30–4–240	1.63	31.74	58.49	8.14	78.70	4.73	5.67	1.51	1.11	8.28
103	....	....	....	....	....	....	....	....	....	....	....
103*a*	30–5–240	1.54	31.67	58.53	8.26	77.02	4.66	7.24	1.52	1.17	8.39
104	....	....	....	....	....	....	....	....	....	....	....
105	40–4–240	1.56	31.16	59.01	8.29	76.83	4.62	7.44	1.57	1.14	8.40
106	....	....	....	....	....	....	....	....	....	....	....
107	30–2–200	3.68	15.56	71.10	9.66	81.30	4.09	2.52	1.04	1.04	10.00
108	....	....	....	....	....	....	....	....	....	....	....
109	30–6–200	1.51	32.78	57.27	8.44	77.76	4.71	6.48	1.50	1.08	8.57
110	....	....	....	....	....	....	....	....	....	....	....
111	....	....	....	....	....	....	....	....	....	....	....
111*a*	40–4–200	1.84	30.70	56.13	11.33	74.91	4.89	6.02	1.45	1.19	11.54
112	40–6–200	1.83	32.85	57.09	8.22	78.60	4.76	5.64	1.52	1.10	8.38
113	50–4–200	2.16	15.88	71.18	10.77	79.45	3.92	3.69	1.03	.91	11.00
114	....	....	....	....	....	....	....	....	....	....	....
115	....	....	....	....	....	....	....	....	....	....	....
116	....	....	....	....	....	....	....	....	....	....	....
117	....	....	....	....	....	....	....	....	....	....	....
118	....	....	....	....	....	....	....	....	....	....	....
119	30–4–160	2.01	31.39	58.67	7.93	77.14	4.52	7.43	1.55	1.27	8.09
120	....	....	....	....	....	....	....	....	....	....	....
121	30–8–160	1.65	32.94	57.70	7.71	78.90	4.88	5.68	1.54	1.16	7.84
122	....	....	....	....	....	....	....	....	....	....	....
123	....	....	....	....	....	....	....	....	....	....	....
124	40–6–160	2.24	32.33	56.28	9.15	77.09	4.82	6.12	1.52	1.09	9.36
125	....	....	....	....	....	....	....	....	....	....	....
126	....	....	....	....	....	....	....	....	....	....	....
127	....	....	....	....	....	....	....	....	....	....	....
128	....	....	....	....	....	....	....	....	....	....	....
129	....	....	....	....	....	....	....	....	....	....	....
130	30–8–120	2.30	31.53	58.03	8.14	76.65	4.61	7.58	1.57	1.26	8.33
131	30–10–120	2.85	14.70	73.26	9.19	80.54	4.10	3.90	1.05	.95	9.46
132	30–14–120	3.44	14.55	72.80	9.21	81.72	4.17	2.67	1.00	.91	9.54
133	40–4–120	3.79	15.55	72.39	8.27	79.93	3.87	5.57	1.05	.98	8.60
134	40–8–120	2.82	15.11	73.86	8.21	81.74	4.11	3.83	1.02	.84	8.44
135	40–12–120	2.93	15.27	74.66	7.14	83.14	4.16	3.52	1.08	.75	7.35
136	....	....	....	....	....	....	....	....	....	....	....

TABLE 15.—*Calorific values.*

Designation of tests.		Per cent combustible.			Calorific value in B. t. u.				
No.	Laboratory symbol.	In front-end cinders.	In stack cinders.	In refuse from ash-pan.	Per pound of dry coal.	Per pound of combustible.	Per pound of front-end cinders.	Per pound of stack cinders.	Per pound of refuse from ash-pan.
1	2	84	85	86	87	88	89	90	91
101	30–2–240	66.10	60.61	45.88	14,174	15,352	9,245	7,812	6698
102	30–4–240	81.98	61.86	51.94	14,124	15,398	11,673	8,881	7583
103	....	....	....	....	....	....	....	....	....
103a	30–5–240	79.83	66.08	53.76	14,097	15,388	11,239	9,211	7849
104	....	....	....	....	....	....	....	....	....
105	40–4–240	78.03	63.89	49.03	14,121	15,416	11,113	9,275	7160
106	....	....	....	....	....	....	....	....	....
107	30–2–200	74.14	74.79	39.85	14,283	15,875	10,615	10,832	5820
108	....	....	....	....	....	....	....	....	....
109	30–6–200	73.84	60.12	45.73	14,018	15,332	10,442	8,599	6677
110	....	....	....	....	....	....	....	....	....
111	....	....	....	....	....	....	....	....	....
111a	40–4–200	73.61	70.33	44.14	13,457	15,214	10,571	9,949	6444
112	40–6–200	76.30	65.52	48.85	14,262	15,566	10,699	9,265	7132
113	50–4–200	80.63	80.24	41.81	14,009	15,744	11,534	11,261	6103
114	....	....	....	....	....	....	....	....	....
115	....	....	....	....	....	....	....	....	....
116	....	....	....	....	....	....	....	....	....
117	....	....	....	....	....	....	....	....	....
118	....	....	....	....	....	....	....	....	....
119	30–4–160	64.87	57.47	39.25	14,062	15,300	9,090	7,272	5730
120	....	....	....	....	....	....	....	....	....
121	30–8–160	64.82	57.02	46.94	14,216	15,425	9,293	8,305	6853
122	....	....	....	....	....	....	....	....	....
123	....	....	....	....	....	....	....	....	....
124	40–6–160	69.97	56.38	47.19	13,914	15,351	9,959	7,960	6890
125	....	....	....	....	....	....	....	....	....
126	....	....	....	....	....	....	....	....	....
127	....	....	....	....	....	....	....	....	....
128	....	....	....	....	....	....	....	....	....
129	....	....	....	....	....	....	....	....	....
130	30–8–120	68.50	59.27	35.81	14,070	15,348	8,640	7,349	5228
131	30–10–120	80.55	75.38	54.73	14,305	15,799	11,534	10,875	7984
132	30–14–120	86.42	83.13	41.87	14,215	15,714	12,337	12,000	6114
133	40–4–120	74.74	70.00	37.60	14,507	15,872	10,546	10,115	5490
134	40–8–120	83.09	75.52	51.82	14,421	15,752	11,875	10,903	7565
135	40–12–120	87.95	82.51	41.73	14,690	15,857	12,627	11,980	6092
136	....	....	....	....	....	....	....	....	....

TABLE 16.—*Heat-balances.*

Designation of tests.		Calorific value in B. t. u. per pound of combustible.	B. t. u. absorbed per pound of combustible fired.	B. t. u. loss per pound of combustible fired.								
No.	Laboratory symbol.			Due to H_2O in coal.	Due to H_2O in air.	Due to H_2O formed by H in coal.	Due to escaping gases.	Due to incomplete combustion.	Due to front-end cinders.	Due to stack cinders.	Due to refuse in ash-pan.	Unaccounted for.
1	**2**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**	**101**	**102**
101	30–2–240	15,352	10,189	41	39	688	2087	72	433	205	634	965
102	30–4–240	15,398	9,252	25	82	633	2049	451	886	137	933	950
103	....	....	....	....	....	....	....	....	....	....	....	....
103*a*	30–5–240	15,388	9,040	24	70	632	1975	576	1235	141	639	1056
104	....	....	....	....	....	....	....	....	....	....	....	....
105	40–4–240	15,416	9,136	24	33	625	2057	565	1224	147	537	1068
106	....	....	....	....	....	....	....	....	....	....	....	....
107	30–2–200	15,875	10,430	56	58	541	2392	8	670	243	738	739
108	....	....	....	....	....	....	....	....	....	....	....	....
109	30–6–200	15,332	9,552	23	47	637	2297	167	625	124	785	1075
110	....	....	....	....	....	....	....	....	....	....	....	....
111	....	....	....	....	....	....	....	....	....	....	....	....
111*a*	40–4–200	15,214	9,330	29	75	671	1801	746	750	206	895	711
112	40–6–200	15,566	9,832	28	62	649	2325	243	918	173	588	748
113	50–4–200	15,744	8,489	34	55	544	2133	66	1882	284	823	1434
114	....	....	....	....	....	....	....	....	....	....	....	....
115	....	....	....	....	....	....	....	....	....	....	....	....
116	....	....	....	....	....	....	....	....	....	....	....	....
117	....	....	....	....	....	....	....	....	....	....	....	....
118	....	....	....	....	....	....	....	....	....	....	....	....
119	30–4–160	15,300	10,575	28	57	581	2160	194	178	152	573	802
120	....	....	....	....	....	....	....	....	....	....	....	....
121	30–8–160	15,425	10,209	25	42	653	2342	195	561	112	570	716
122	....	....	....	....	....	....	....	....	....	....	....	....
123	....	....	....	....	....	....	....	....	....	....	....	....
124	40–6–160	15,351	10,170	34	42	646	2272	229	463	205	604	686
125	....	....	....	....	....	....	....	....	....	....	....	....
126	....	....	....	....	....	....	....	....	....	....	....	....
127	....	....	....	....	....	....	....	....	....	....	....	....
128	....	....	....	....	....	....	....	....	....	....	....	....
129	....	....	....	....	....	....	....	....	....	....	....	....
130	30–8–120	15,348	10,701	34	59	597	2239	130	270	132	439	747
131	30–10–120	15,799	8,480	43	43	547	2178	116	1910	326	948	1208
132	30–14 120	15,714	7,456	54	44	568	2272	122	2373	817	446	1562
133	40–4–120	15,872	10,817	55	46	486	2145	89	400	174	807	853
134	40–8–120	15,752	9,446	42	44	538	2294	30	1233	320	665	1140
135	40–12–120	15,857	7,408	45	55	556	2217	199	2654	596	445	1680
136	....	....	....	....	....	....	....	....	....	....	....	....

TABLE 17.—*Heat-balances*—Continued.

Designation of tests.		Per cent of heat—									
No.	Laboratory symbol.	Absorbed by boiler and superheater.	Loss due to H_2O in coal.	Loss due to H_2O in air.	Loss due to H_2O formed by H in coal.	Loss due to escaping gases.	Loss due to incomplete combustion.	Loss due to front-end cinders.	Loss due to stack cinders.	Loss due to refuse in ash-pan.	Unaccounted for.
1	2	103	104	105	106	107	108	109	110	111	112
101	30–2–240	66.37	0.27	0.25	4.48	13.58	0.47	2.81	1.34	4.13	6.30
102	30–4–240	60.08	.16	.53	4.11	13.31	2.93	5.75	.89	6.06	6.17
103	....	....	....	....	....	....	....	....	....	....	....
103*a*	30–5–240	58.75	.16	.46	4.11	12.83	3.74	8.02	.92	4.15	6.86
104	....	....	....	....	....	....	....	....	....	....	....
105	40–4–240	59.28	.15	.20	4.05	13.35	3.67	7.94	.95	3.48	6.93
106	....	....	....	....	....	....	....	....	....	....	....
107	30–2–200	65.70	.35	.37	3.41	15.07	.05	4.22	1.53	4.65	4.65
108	....	....	....	....	....	....	....	....	....	....	....
109	30–6–200	62.34	.15	.31	4.16	14.98	1.09	4.08	.81	5.12	6.96
110	....	....	....	....	....	....	....	....	....	....	....
111	....	....	....	....	....	....	....	....	....	....	....
111*a*	40–4–200	61.34	.19	.49	4.41	11.86	4.90	4.95	1.35	5.88	4.63
112	40–6–200	63.16	.18	.40	4.17	14.93	1.56	5.90	1.11	3.78	4.81
113	50–4–200	53.90	.22	.35	3.45	13.32	.42	11.96	1.80	5.23	9.37
114	....	....	....	....		....	....	....	....	....	....
115	....	....	....	....		....	....	....	....	....	....
116	....	....	....	....		....	....	....	....	....	....
117	....	....	....	....		....	....	....	....	....	....
118	....	....	....	....	....	....	....	....	....	....	....
119	30–4–160	69.12	.18	.37	3.80	14.11	1.27	1.16	.99	3.74	5.26
120	....	....	....	....	....	....	....	....	....	....	....
121	30–8–160	66.16	.16	.27	4.24	15.18	1.27	3.64	.73	3.70	4.65
122	....	....	....	....	....	....	....	....	....	....	....
123	....	....	....	....	....	....	....	....	....	....	....
124	40–6–160	66.25	.22	.27	4.21	14.79	1.49	3.02	1.33	3.93	4.49
125	....	....	....	....	....	....	....	....	....	....	....
126	....	....	....	....	....	....	....	....	....	....	....
127	....	....	....	....	....	....	....	....	....	....	....
128	....	....	....	....	....	....	....	....	....	....	....
129	....	....	....	....	....	....	....	....	....	....	....
130	30–8–120	69.73	.22	.38	3.89	14.58	.85	1.76	.86	2.86	4.87
131	30–10–120	53.67	.27	.27	3.46	13.78	.73	12.09	2.06	6.00	7.67
132	30–14–120	47.45	.34	.28	3.61	14.46	.78	15.10	5.20	2.84	9.94
133	40–4–120	68.14	.35	.29	3.06	13.58	.56	2.52	1.10	5.09	5.31
134	40–8–120	59.97	.26	.27	3.42	14.56	.19	7.82	2.03	4.22	7.26
135	40–12–120	46.72	.28	.35	3.51	13.98	1.26	16.74	3.76	2.81	10.59
136	....	....	....	....	....	....	....	....	....	....	....

TABLE 18.—*Events of the stroke from indicator-cards.*

Designation of tests.		Indicator results—Events of stroke—Per cent.									
		Admission.					Cut-off.				
No.	Laboratory symbol.	Right side.		Left side.		Average.	Right side.		Left side.		Average.
		H. E.	C. E.	H. E.	C. E.		H. E.	C. E.	H. E.	C. E.	
1	2	113	114	115	116	117	118	119	120	121	122
101	30–2–240	4.00	3.12	2.37	2.49	2.99	15.70	13.41	16.79	16.20	15.52
102	30–4–240	2.54	2.25	1.20	1.91	1.97	20.87	20.08	22.45	22.20	21.40
103	30–5–240	1.97	1.42	1.21	1.55	1.54	25.30	23.17	25.63	27.55	25.41
103a	30–5–240	....	....	....	....	....	....	....	....	....	....
104	40–2–240	....	....	....	....	....	15.61	15.55	17.00	17.22	16.34
105	40–4–240	3.21	2.94	2.09	2.71	2.74	22.36	20.81	24.09	26.35	23.40
106	50–2–240	....	....	....	....	....	18.08	16.83	17.41	17.00	17.32
107	30–2–200	5.33	4.37	2.96	3.13	3.95	15.53	12.93	15.46	14.80	14.68
108	30–4–200	3.50	2.60	1.87	2.43	2.60	21.00	18.60	20.46	23.40	20.86
109	30–6–200	2.39	1.27	1.10	1.50	1.57	26.21	25.23	26.87	30.20	27.13
110	40–2–200	5.04	3.55	3.65	3.08	3.83	16.77	15.08	17.15	16.31	16.33
111	40–4–200	2.67	2.47	2.20	2.77	2.53	21.12	21.30	21.87	25.37	22.41
111a	40–4–200	....	....	....	....	....	....	....	....	....	....
112	40–6–200	4.00	2.97	3.14	3.32	3.36	28.60	27.73	30.07	31.64	29.51
113	50–4–200	3.40	2.10	2.10	2.10	2.43	22.20	22.40	22.40	24.00	22.75
114	20–2–160	4.47	5.72	3.69	3.11	4.24	16.27	12.99	14.96	13.72	14.48
115	20–4–160	2.10	3.26	1.86	1.60	2.20	22.07	19.56	22.96	21.26	21.46
116	20–6–160	.60	2.60	.30	1.30	1.20	28.06	24.20	25.80	30.33	27.09
117	20–8–160	1.06	2.03	.83	1.16	1.27	36.86	30.87	34.60	39.93	35.56
118	30–2–160	5.00	4.32	3.93	3.46	4.18	15.16	12.80	14.77	14.46	14.29
119	30–4–160	....	....	....	....	....	20.06	18.63	21.61	21.57	20.47
120	30–6–160	1.93	2.23	.93	1.53	1.65	26.67	24.60	26.00	31.23	27.12
121	30–8–160	2.06	1.96	1.32	.86	1.55	35.13	31.93	33.78	36.06	34.22
122	40–2–160	5.40	4.06	4.06	3.00	4.13	15.26	13.33	16.26	14.93	14.94
123	40–4–160	3.30	3.93	3.57	2.93	3.43	20.80	21.00	20.80	22.57	21.29
124	40–6–160	....	....	....	....	....	27.20	25.71	27.80	30.66	27.83
125	40–8–160	1.33	3.00	.98	1.33	1.66	36.13	34.14	35.87	41.47	36.90
126	50–2–160	5.41	4.58	5.83	4.50	5.08	16.33	14.16	17.50	14.66	15.66
127	50–4–160	4.91	4.33	6.08	5.25	5.14	22.83	20.50	23.66	22.33	22.33
128	50–6–160	1.77	1.75	1.37	1.25	1.53	26.50	26.50	28.25	30.75	28.00
129	30–4–120	....	....	....	....	....	20.40	17.70	20.40	19.00	19.38
130	30–8–120	....	....	....	....	....	35.63	32.25	35.00	38.36	35.31
131	30–10–120	1.63	1.92	1.29	1.54	1.60	43.83	39.50	41.25	46.33	42.73
132	30–14–120	.33	.63	.21	.25	.35	58.42	52.42	55.42	61.92	57.04
133	40–4–120	....	....	....	....	....	21.40	18.40	21.93	20.13	20.47
134	40–8–120	3.40	3.43	3.43	4.00	3.56	36.13	31.67	35.33	38.28	35.60
135	40–12–120	2.22	2.56	1.72	1.89	2.10	52.55	47.67	49.22	55.33	51.19
136	50–8–120	....	....	....	....	....	36.50	32.33	35.50	37.83	35.54

TABLE 19.—*Events of the stroke*—Continued.

Designation of tests.		Indicator results—Events of stroke—Per cent.									
		Release.					Compression.				
No.	Laboratory symbol.	Right side.		Left side.		Average.	Right side.		Left side.		Average.
		H. E.	C. E.	H. E.	C. E.		H. E.	C. E.	H. E.	C. E.	
1	2	123	124	125	126	127	128	129	130	131	132
101	30–2–240	62.99	62.03	64.15	64.94	63.53	37.28	33.24	36.12	34.37	35.25
102	30–4–240	68.03	66.07	70.08	71.66	68.96	31.58	31.33	31.75	29.37	31.01
103	30–5–240	71.30	70.97	72.80	75.57	72.66	29.90	29.27	27.45	28.50	28.78
103*a*	30–5–240	....	....	....	....	....	....	....	....	....	....
104	40–2–240	64.66	60.88	63.96	64.27	63.44	36.77	35.27	37.22	36.61	36.46
105	40–4–240	65.57	66.42	70.00	69.45	67.86	31.55	32.00	31.09	33.40	32.01
106	50–2–240	64.75	60.25	65.41	60.83	62.81	29.08	36.00	39.08	35.00	34.79
107	30–2–200	65.13	62.27	65.40	66.13	64.73	40.00	36.40	37.93	31.80	36.53
108	30–4–200	69.00	66.53	68.46	70.86	68.71	35.93	31.46	30.93	33.00	32.83
109	30–6–200	69.21	67.33	68.87	71.80	69.30	30.29	27.77	26.57	30.17	28.70
110	40–2–200	65.23	63.69	63.07	63.76	63.94	40.31	34.85	40.85	36.92	38.23
111	40–4–200	70.12	69.80	70.87	71.87	70.65	33.30	34.42	26.60	30.47	31.20
111*a*	40–4–200	....	....	....	....	....	....	....	....	....	....
112	40–6–200	71.47	70.13	72.21	73.36	71.79	32.13	29.27	28.00	29.36	29.69
113	50–4–200	62.80	64.40	64.00	67.40	64.65	35.40	33.40	31.80	34.80	34.10
114	20–2–160	59.38	58.82	59.22	61.00	59.60	36.83	37.55	35.83	35.50	36.43
115	20–4–160	69.40	67.70	70.00	69.80	69.22	33.21	32.13	31.53	30.06	31.73
116	20–6–160	71.46	68.60	72.40	72.40	71.21	26.80	29.40	24.93	23.06	26.05
117	20–8–160	75.14	73.66	75.47	77.47	75.43	25.20	26.20	21.80	23.66	24.21
118	30–2–160	63.20	62.22	62.83	62.83	62.77	42.10	36.64	43.26	37.56	39.89
119	30–4–160	68.56	66.03	69.10	68.79	68.12	37.56	35.80	36.18	35.18	36.18
120	30–6–160	66.46	66.90	66.07	68.10	66.88	30.60	32.17	29.00	29.86	30.41
121	30–8–160	76.27	73.47	75.64	75.54	75.23	26.20	23.66	25.00	25.13	24.99
122	40–2–160	64.93	66.13	63.26	63.13	64.36	46.20	39.93	43.40	41.06	42.65
123	40–4–160	66.53	65.34	64.74	68.28	66.22	35.80	36.00	37.47	35.07	36.08
124	40–6–160	72.33	69.64	71.60	71.93	71.35	31.80	31.50	31.93	31.00	31.51
125	40–8–160	75.74	74.79	75.74	77.87	76.03	26.67	29.22	25.53	23.40	26.20
126	50–2–160	64.66	60.16	63.33	62.33	62.37	44.16	40.16	47.66	42.00	43.49
127	50–4–160	68.58	66.80	70.16	70.16	68.92	37.16	34.66	39.50	36.66	36.99
128	50–6–160	65.50	69.00	68.00	69.75	68.06	32.75	33.50	29.75	31.50	33.45
129	30–4–120	67.10	69.70	66.80	68.40	68.00	40.00	36.90	37.80	35.10	37.45
130	30–8–120	76.35	74.07	75.58	75.94	75.48	29.23	25.90	25.79	25.54	26.61
131	30–10–120	82.08	77.25	79.92	81.33	80.14	26.33	24.00	22.67	22.92	23.75
132	30–14–120	86.58	84.08	86.33	87.67	86.17	17.75	15.50	16.00	15.67	16.23
133	40–4–120	68.47	67.53	68.66	67.20	67.97	42.07	37.73	41.07	36.93	39.45
134	40–8–120	79.86	76.26	78.20	79.67	78.50	29.80	28.27	28.07	28.40	28.64
135	40–12–120	84.33	80.67	83.33	84.78	83.28	20.89	20.44	20.22	21.11	20.67
136	50–8–120	70.33	66.50	67.33	68.50	68.16	30.33	29.33	27.33	27.67	28.66

TABLE 20.—*Pressures from indicator-cards.*

Designation of tests.		Indicator results—Pressure above atmosphere.									
		Initial.					At cut-off.				
No.	Laboratory symbol.	Right side.		Left side.		Average.	Right side.		Left side.		Average.
		H. E.	C. E.	H. E.	C. E.		H. E.	C. E.	H. E.	C. E.	
1	2	133	134	135	136	137	138	139	140	141	142
101	30–2–240	239.20	232.70	221.30	224.60	229.45	159.16	166.98	150.48	147.90	156.13
102	30–4–240	231.40	232.50	211.10	222.10	224.27	152.17	158.49	141.65	149.82	150.53
103	30–5–240	221.25	223.35	202.15	212.30	214.76	144.20	151.60	138.31	145.85	144.99
103*a*	30–5–240	....	....	....	....	....	....	....	....	....	....
104	40–2–240	233.90	232.40	222.80	224.00	228.27	135.00	140.00	130.60	129.22	133.70
105	40–4–240	233.00	229.50	205.90	225.10	223.37	138.10	143.40	124.40	127.60	133.37
106	50–2–240	236.00	231.31	224.80	218.80	227.72	118.83	126.50	120.70	117.30	120.83
107	30–2–200	200.40	194.80	186.26	183.20	191.16	129.10	133.00	119.10	121.40	125.65
108	30–4–200	198.40	191.60	182.00	185.80	189.45	128.70	131.53	120.40	124.13	126.19
109	30–6–200	196.28	187.93	178.73	185.93	187.22	139.14	138.80	128.66	130.00	134.15
110	40–2–200	212.70	201.07	201.85	194.92	202.63	119.07	116.38	109.08	112.08	114.15
111	40–4–200	195.00	194.00	185.90	183.60	189.62	108.40	119.75	105.70	107.65	110.37
111*a*	40–4–200	....	....	....	....	....	....	....	....	....	....
112	40–6–200	195.13	195.80	184.50	191.07	191.63	115.27	118.13	109.50	113.21	114.03
113	50–4–200	200.80	197.60	187.40	189.40	193.80	112.00	110.00	104.20	105.40	107.90
114	20–2–160	160.60	156.70	151.33	157.32	156.48	109.11	115.55	107.95	116.16	112.19
115	20–4–160	157.57	155.33	153.39	146.92	153.30	103.86	106.47	102.20	108.39	105.23
116	20–6–160	156.33	154.60	146.66	155.12	153.18	108.00	118.06	106.13	115.46	111.91
117	20–8–160	154.13	154.13	150.00	150.80	152.26	108.20	115.00	111.87	110.53	111.40
118	30–2–160	162.20	158.85	155.80	157.67	158.63	98.87	104.67	97.94	103.53	101.25
119	30–4–160	157.33	155.46	150.27	155.85	154.73	98.87	102.93	91.07	104.43	99.32
120	30–6–160	155.20	152.86	141.80	155.00	151.21	99.53	108.20	96.60	103.93	102.06
121	30–8–160	153.10	153.50	148.10	150.00	151.17	104.90	106.40	103.00	113.60	106.97
122	40–2–160	167.86	164.65	159.27	168.20	164.99	89.06	98.40	86.80	93.71	91.99
123	40–4–160	162.67	155.47	156.66	159.28	158.52	93.54	93.74	85.68	95.80	92.19
124	40–6–160	157.20	155.20	149.80	156.66	154.73	90.93	93.57	88.40	93.60	91.60
125	40–8–160	147.92	151.13	138.73	151.07	147.21	88.94	97.22	90.21	98.93	93.82
126	50–2–160	169.50	164.00	171.50	158.50	165.87	76.66	84.00	76.50	81.33	79.62
127	50–4–160	165.66	166.00	156.83	163.33	162.95	76.00	83.33	74.83	84.33	79.62
128	50–6–160	159.25	155.00	150.50	158.25	155.75	84.75	89.50	78.75	91.00	86.00
129	30–4–120	118.80	116.40	115.20	117.00	116.85	70.20	71.90	68.20	70.00	70.08
130	30–8–120	109.93	113.40	109.21	110.36	110.72	70.94	77.34	69.50	75.36	73.28
131	30–10–120	112.40	115.10	108.20	111.60	111.82	77.00	77.42	75.75	79.50	77.41
132	30–14–120	109.42	114.50	110.42	110.30	111.16	82.42	86.83	84.33	89.87	85.86
133	40–4–120	121.86	119.60	122.73	114.33	119.63	62.87	68.00	64.73	60.02	63.91
134	40–8–120	116.20	115.07	109.13	114.93	113.83	64.20	71.87	64.60	71.60	68.07
135	40–12–120	112.90	112.89	107.55	112.22	111.39	68.33	75.33	71.44	79.44	73.64
136	50–8–120	124.83	114.67	115.17	123.83	119.62	61.17	65.16	61.17	64.67	63.04

TABLE 21.—*Pressures from indicator-cards*—Continued.

Designation of tests.		Indicator results—Pressure above atmosphere.									
		At release.					At compression.				
No.	Laboratory symbol.	Right side.		Left side.		Average.	Right side.		Left side.		Average.
		H. E.	C. E.	H. E.	C. E.		H. E.	C. E.	H. E.	C. E.	
1	2	143	144	145	146	147	148	149	150	151	152
101	30–2–240	48.41	43.91	45.58	41.07	44.74	16.58	14.99	15.33	14.83	15.43
102	30–4–240	49.74	53.00	46.92	46.83	49.12	13.00	15.08	11.75	15.91	13.93
103	30–5–240	51.00	51.30	49.16	51.10	50.64	14.45	14.40	13.05	15.30	14.30
103*a*	30–5–240	....	....	....	....	....	....	....	....	....	....
104	40–2–240	34.77	39.98	35.22	36.77	36.68	13.77	14.89	12.88	12.66	13.55
105	40–4–240	45.50	47.40	42.10	44.60	44.90	20.20	21.30	14.50	17.10	18.27
106	50–2–240	33.33	36.16	32.66	32.00	33.53	14.66	15.16	14.33	10.00	13.53
107	30–2–200	32.73	31.80	29.73	27.13	30.35	9.93	10.40	7.80	6.93	8.76
108	30–4–200	40.27	36.47	36.27	37.60	37.65	10.60	10.20	10.07	9.00	9.97
109	30–6–200	50.50	50.40	46.46	50.07	49.36	12.85	11.93	11.26	12.00	12.01
110	40–2–200	33.38	28.08	30.23	27.69	29.85	16.15	13.62	10.85	11.85	13.12
111	40–4–200	30.95	35.45	31.35	33.40	32.79	12.25	11.55	12.30	9.10	11.30
111*a*	40–4–200	....	....	....	....	....	....	....	....	....	....
112	40–6–200	41.53	43.87	42.50	43.43	42.83	16.00	17.87	15.14	17.07	16.52
113	50–4–200	40.40	36.80	36.00	34.20	36.85	23.60	16.46	16.40	14.00	17.60
114	20–2–160	31.94	30.44	30.44	31.55	31.09	6.55	6.05	6.77	7.33	6.67
115	20–4–160	31.64	31.66	35.13	32.06	32.62	4.50	6.93	5.13	5.26	5.45
116	20–6–160	40.20	42.80	43.66	46.19	43.21	6.53	6.73	5.06	6.26	6.14
117	20–8–160	48.13	46.86	48.07	50.26	48.33	5.20	6.06	4.66	5.86	5.44
118	30–2–160	24.93	23.86	24.53	25.33	24.66	6.66	9.50	6.33	8.40	7.72
119	30–4–160	26.93	29.40	26.93	33.29	29.14	5.33	7.20	6.21	7.64	6.59
120	30–6–160	36.60	38.13	34.73	44.00	38.36	6.80	8.06	6.20	8.20	7.31
121	30–8–160	43.26	42.06	42.35	47.86	43.88	10.66	12.40	10.64	10.26	10.99
122	40–2–160	19.00	21.73	19.47	21.00	20.30	7.20	9.13	5.86	8.80	7.75
123	40–4–160	30.00	26.13	25.80	29.64	27.89	12.00	9.26	8.20	8.71	9.54
124	40–6–160	30.33	29.85	30.53	35.33	31.47	11.93	10.42	9.66	11.73	10.93
125	40–8–160	35.80	39.21	35.67	45.40	39.02	9.40	11.00	7.46	9.47	9.33
126	50–2–160	16.83	19.66	18.66	15.66	17.70	8.00	9.66	8.33	8.00	8.49
127	50–4–160	21.83	21.33	19.50	24.00	21.66	9.66	10.73	8.16	10.30	9.71
128	50–6–160	28.50	29.50	26.75	33.00	29.44	10.00	10.50	10.00	11.00	10.37
129	30–4–120	19.80	18.30	19.10	17.70	18.72	5.60	4.80	6.00	5.20	5.40
130	30–8–120	28.13	28.66	26.71	32.57	29.02	5.93	9.73	5.36	4.71	6.43
131	30–10–120	34.08	34.00	32.25	39.58	34.98	7.00	7.58	6.58	6.50	6.91
132	30–14–120	48.75	49.17	47.75	57.08	50.69	8.92	13.75	9.67	9.42	10.44
133	40–4–120	15.60	14.73	18.33	13.60	15.57	6.53	7.60	7.60	7.20	7.23
134	40–8–120	22.60	23.87	22.93	28.27	24.42	8.93	9.47	7.33	8.80	8.68
135	40–12–120	35.78	38.67	35.78	45.00	38.81	12.11	14.33	10.44	12.11	12.25
136	50–8–120	25.00	25.17	26.67	31.83	27.17	11.83	11.00	12.33	12.67	11.93

TABLE 22.—*Pressures from indicator-cards*—Continued.

Designation of tests.		Indicator results—Pressure above atmosphere.									
		Least back.					Mean effective.				
No.	Laboratory symbol.	Right side.		Left side.		Average.	Right side.		Left side.		Average.
		H. E.	C. E.	H. E.	C. E.		H. E.	C. E.	H. E.	C. E.	
1	2	153	154	155	156	157	158	159	160	161	162
101	30–2–240	6.58	2.16	3.75	2.16	3.66	52.26	51.94	51.39	51.62	51.80
102	30–4–240	2.66	3.08	1.75	4.16	2.91	68.72	69.66	68.21	70.63	69.30
103	30–5–240	3.70	4.35	4.21	4.65	4.23	75.47	75.90	75.03	80.60	76.75
103*a*	30–5–240	....	....	....	....	....	....	....	....	....	....
104	40–2–240	2.66	2.11	2.00	3.11	2.47	41.62	45.11	44.99	44.96	44.17
105	40–4–240	5.15	5.10	4.00	5.00	4.81	58.13	57.09	60.00	60.02	58.81
106	50–2–240	3.16	2.00	2.50	1.66	2.33	36.61	41.36	37.39	39.76	38.78
107	30–2–200	2.20	1.06	1.53	1.40	1.55	39.33	38.20	39.66	39.96	39.29
108	30–4–200	1.53	1.26	1.73	2.13	1.66	54.46	52.62	52.24	56.64	53.99
109	30–6–200	3.93	3.00	1.06	5.00	3.25	70.84	72.88	68.63	75.40	71.94
110	40–2–200	7.54	1.00	1.85	1.69	3.02	32.50	31.91	32.58	34.07	32.76
111	40–4–200	3.05	3.50	3.70	3.45	3.42	45.40	51.23	45.27	53.44	48.83
111*a*	40–4–200	....	....	....	....	....	....	....	....	....	....
112	40–6–200	4.80	6.27	6.07	7.14	6.07	58.73	59.82	61.17	64.09	60.95
113	50–4–200	9.00	6.00	5.20	4.80	6.25	39.48	44.59	42.29	44.60	42.74
114	20–2–160	1.00	1.00	1.11	1.83	1.23	35.90	33.70	34.57	37.23	35.35
115	20–4–160	1.00	1.06	1.00	1.00	1.01	48.89	44.67	52.13	51.10	49.19
116	20–6–160	1.00	1.46	1.20	2.26	1.48	63.77	59.15	60.15	70.57	63.41
117	20–8–160	1.33	1.00	1.40	1.40	1.28	77.84	71.06	77.84	82.46	77.30
118	30–2–160	1.00	1.86	1.33	1.86	1.51	27.45	25.03	26.43	28.75	26.91
119	30–4–160	1.46	1.20	1.28	2.07	1.50	39.21	38.54	39.20	44.63	40.39
120	30–6–160	1.00	1.60	1.06	2.80	1.61	53.45	51.60	51.19	62.11	54.59
121	30–8–160	1.86	2.00	3.35	2.66	2.46	67.16	64.32	64.30	75.44	67.80
122	40–2–160	1.06	2.20	1.00	1.80	1.51	19.42	23.07	22.32	22.62	21.85
123	40–4–160	4.53	1.40	1.80	3.21	2.73	35.35	34.91	33.04	40.98	36.07
124	40–6–160	3.33	2.57	2.66	3.53	3.02	42.76	43.52	43.82	51.30	45.35
125	40–8–160	1.80	2.71	1.73	4.20	2.61	60.38	58.82	60.53	72.78	63.13
126	50–2–160	1.00	2.00	1.83	1.16	1.05	12.89	17.18	15.11	15.92	15.27
127	50–4–160	1.66	2.16	1.66	4.00	2.37	28.53	29.29	26.91	31.63	29.09
128	50–6–160	1.75	2.00	2.00	3.25	2.25	41.67	42.18	42.83	49.16	43.96
129	30–4–120	1.00	1.10	1.20	1.40	1.18	22.44	22.97	23.02	23.56	23.00
130	30–8–120	2.27	2.40	1.21	1.36	1.81	45.21	44.35	45.29	52.50	46.84
131	30–10–120	1.75	1.41	1.67	2.50	1.83	58.68	55.32	55.46	63.04	58.12
132	30–14–120	3.75	4.67	5.17	6.50	5.02	72.20	69.82	70.80	79.00	72.95
133	40–4–120	1.00	1.07	2.23	1.27	1.39	18.58	18.91	19.96	18.12	18.89
134	40–8–120	2.93	2.73	2.47	4.20	3.08	38.54	37.97	39.76	45.79	40.52
135	40–12–120	5.89	6.00	5.11	7.22	6.06	55.63	55.55	55.74	64.82	57.93
136	50–8–120	3.33	3.33	3.50	5.33	3.87	32.56	32.94	33.58	39.98	34.76

TABLE 23.—*Engine performance.*

Designation of tests.		Engine performance.											
		Indicated horse-power.					Steam per I. H. P. per hour.		Pounds saturated steam per I. H. P. per hour equivalent to heat in steam used.	B. t. u. supplied.			
		Right side.		Left side.						Engine per min.		Per I. H. P. per min.	
No.	Laboratory symbol.	H. E.	C. E.	H. E.	C. E.	Total.	By tank.	By indicator.		Actual calculated from observed temperature of feedwater.	Comparative, assuming temperature of feed equal to that of exhaust.	Actual.	Comparative.
1	2	163	164	165	166	167	168	169	170	171	172	173	174
							Lbs.	*Lbs.*					
101	30–2–240	93.88	90.56	93.90	91.42	369.76	23.43	17.94	25.08	181,768	159,116	491.6	430.4
102	30–4–240	118.91	117.00	120.06	120.72	476.69	22.11	17.21	23.82	222,953	194,585	467.7	408.2
103	30–5–240	132.12	128.95	133.61	139.39	534.07	21.68	17.25	23.32	242,215	212,956	453.5	398.7
103*a*	30–5–240	136.20	132.35	135.49	142.58	546.62	....	....	....	....	....	....	....
104	40–2–240	98.38	103.50	108.21	105.00	415.09	21.89	17.37	23.29	189,639	165,477	456.9	398.7
105	40–4–240	137.00	130.60	143.94	139.82	551.36	21.32	17.23	22.98	248,973	215,684	451.6	391.2
106	50–2–240	110.23	120.86	114.52	118.26	463.87	21.64	18.18	23.20	211,484	184,532	455.9	397.8
107	30–2–200	70.60	66.55	72.43	70.86	280.44	22.93	18.20	24.40	134,468	117,126	479.5	417.7
108	30–4–200	97.30	91.24	94.95	99.95	383.44	21.59	17.76	23.20	175,471	153,055	457.7	399.2
109	30–6–200	128.11	127.91	126.26	134.69	516.97	19.93	17.41	20.98	218,937	191,060	423.5	369.6
110	40–2–200	77.24	73.60	78.76	79.98	309.58	22.41	18.84	23.93	145,185	126,696	469.0	409.3
111	40–4–200	109.12	119.60	110.81	126.98	466.51	21.09	17.83	22.65	204,116	182,294	440.3	391.0
111*a*	40–4–200	105.14	111.10	109.08	119.85	445.17	....	....	....	....	....	....	....
112	40–6–200	142.66	141.03	151.16	153.78	588.63	20.07	17.80	21.82	252,391	218,594	428.8	371.3
113	50–4–200	113.32	124.21	123.48	126.45	487.46	20.03	17.49	21.44	206,245	179,682	423.2	368.6
114	20–2–160	42.59	38.81	41.73	43.64	166.77	27.11	19.47	29.40	93,170	8,180	558.7	490.5
115	20–4–160	57.98	51.42	62.89	59.86	232.15	23.71	18.62	25.07	113,842	99,738	490.4	429.6
116	20–6–160	75.93	68.37	72.86	83.00	300.16	23.03	19.37	24.57	144,914	126,616	482.8	421.9
117	20–8–160	92.84	82.26	94.45	97.16	366.71	22.82	18.87	24.38	174,718	152,196	476.5	415.1
118	30–2–160	49.12	43.47	48.12	50.82	191.53	26.18	20.54	27.71	105,716	90,494	552.0	472.0
119	30–4–160	69.68	66.47	70.88	78.36	285.39	22.93	19.07	24.44	135,602	118,875	475.2	416.6
120	30–6–160	95.44	89.41	92.98	109.53	387.36	22.11	18.28	23.68	180,364	157,210	465.7	405.9
121	30–8–160	120.06	111.61	116.93	133.22	481.82	21.20	18.88	22.92	215,630	187,236	447.6	388.6
122	40–2–160	47.28	54.52	55.26	54.40	211.46	25.46	20.79	25.46	112,753	96,947	533.3	459.1
123	40–4–160	84.67	81.15	80.50	96.96	343.28	21.52	18.76	23.17	154,960	135,083	451.5	393.5
124	40–6–160	101.90	100.75	106.32	120.83	429.80	21.44	18.86	23.10	193,765	168,582	450.9	392.3
125	40–8–160	144.06	136.20	146.91	171.53	598.70	20.29	18.68	21.89	256,231	224,007	428.0	374.2
126	50–2–160	38.30	49.54	45.67	46.73	180.24	29.06	23.39	30.66	107,999	94,205	599.2	521.9
127	50–4–160	84.68	84.38	81.25	92.74	343.05	22.21	19.20	23.70	159,829	138,974	465.9	405.1
128	50–6–160	124.01	121.84	129.66	144.52	520.03	23.59	17.33	25.83	264,252	230,783	508.2	443.8
129	30–4–120	40.05	39.83	41.84	41.58	163.30	27.27	23.12	28.75	91,327	79,441	559.2	486.5
130	30–8–120	81.42	77.51	82.96	93.38	335.27	23.05	20.12	24.72	160,115	140,117	477.6	418.0
131	30–10–120	104.06	95.21	100.05	110.40	409.72	22.07	20.36	23.85	190,277	165,600	464.4	404.2
132	30–14–120	128.83	120.91	128.51	139.24	517.49	22.56	24.07	24.55	246,611	213,458	476.6	412.5
133	40–4–120	44.16	43.62	48.26	42.54	178.58	26.39	22.18	27.36	96,751	84,203	541.8	471.5
134	40–8–120	91.62	87.60	96.15	107.52	382.89	22.27	20.32	24.02	178,410	155,520	466.1	406.2
135	40–12–120	132.28	128.20	134.83	152.26	547.57	22.20	22.85	24.14	256,755	221,827	468.9	405.2
136	50–8–120	97.03	95.28	101.80	117.69	411.80	22.74	20.72	24.52	196,036	170,213	476.1	413.4

TABLE 24.—*Steam shown by indicator.*

Designation of tests.		Engine performance.									
		Pounds steam at cut-off by indicator.					Pounds steam at release by indicator.				
No.	Laboratory symbol.	Right side.		Left side.		Total.	Right side.		Left side.		Total.
		H. E.	C. E.	H. E.	C. E.		H. E.	C. E.	H. E.	C. E.	
1	2	175	176	177	178	179	180	181	182	183	184
101	30–2–240	0.2472	0.2312	0.2498	0.2359	0.9641	0.2905	0.2616	0.2872	0.2631	1.1024
102	30–4–240	.2906	.2895	.2923	.2984	1.1708	.3167	.3159	.3166	.3144	1.2636
103	30–5–240	.3211	.3095	.3172	.3439	1.2917	.3368	.3291	.3392	.3518	1.3569
103*a*	30–5–240	....	....	....	....	....	....	....	....	....	....
104	40–2–240	.2139	.2186	.2232	.2193	.8750	.2368	.2412	.2401	.2420	.9601
105	40–4–240	.2820	.2731	.2768	.2969	1.1288	.2895	.2940	.2942	.2968	1.1745
106	50–2–240	.2124	.2112	.2122	.2009	.8367	.2301	.2226	.2327	.2098	.8952
107	30–2–200	.2053	.1859	.1936	.1879	.7727	.2294	.2115	.2196	.2044	.8649
108	30–4–200	.2532	.2340	.2380	.2645	.9897	.2767	.2449	.2597	.2679	1.0492
109	30–6–200	.3202	.3061	.3097	.3354	1.2714	.3260	.3105	.3102	.3313	1.2780
110	40–2–200	.2023	.1835	.2038	.1972	.7868	.2331	.2000	.2156	.2008	.8495
111	40–4–200	.2201	.2380	.2242	.2496	.9319	.2352	.2500	.2428	.2500	.9780
111*a*	40–4–200	....	....	....	....	....	....	....	....	....	....
112	40–6–200	.2925	.2873	.2959	.3100	1.1857	.2919	.2915	.3041	.3053	1.1928
113	50–4–200	.2348	.2302	.2257	.2361	.9268	.2545	.2388	.2428	.2397	.9758
114	20–2–160	.1843	.1659	.1746	.1725	.6973	.2083	.1962	.2048	.2098	.8191
115	20–4–160	.2199	.2033	.2264	.2199	.8695	.2372	.2268	.2597	.2377	.9614
116	20–6–160	.2731	.2587	.2555	.3046	1.0919	.2854	.2809	.3105	.3147	1.1915
117	20–8–160	.3410	.3053	.3374	.3679	1.3516	.3385	.3186	.3449	.3559	1.3579
118	30–2–160	.1616	.1512	.1595	.1619	.6342	.1877	.1764	.1876	.1866	.7383
119	30–4–160	.1965	.1908	.1968	.2155	.7996	.2115	.2109	.2163	.2399	.8786
120	30–6–160	.2454	.2436	.2381	.2860	1.0131	.2511	.2538	.2449	.2882	1.0380
121	30–8–160	.3196	.2940	.3088	.3456	1.2680	.3182	.2946	.3159	.3351	1.2638
122	40–2–160	.1493	.1474	.1546	.1526	.6039	.1656	.1771	.1664	.1688	.6779
123	40–4–160	.1935	.1931	.1827	.2083	.7776	.2218	.1959	.2002	.2227	.8406
124	40–6–160	.2317	.2236	.2331	.2586	.9473	.2393	.2238	.2419	.2602	.9652
125	40–8–160	.2859	.2884	.2916	.3466	1.2125	.2778	.2854	.2814	.3320	1.1766
126	50–2–160	.1387	.1348	.1472	.1345	.5552	.1548	.1541	.1628	.1431	.6148
127	50–4–160	.1761	.1729	.1811	.1868	.7169	.1894	.1785	.1845	.2019	.7543
128	50–6–160	.2145	.2210	.2157	.2536	.9048	.2111	.2209	.2131	.2427	.8878
129	30–4–120	.1517	.1384	.1505	.1430	.5836	.1745	.1691	.1726	.1654	.6816
130	30–8–120	.2362	.2291	.2323	.2609	.9585	.2392	.2300	.2332	.2587	.9611
131	30–10–120	.2999	.2708	.2852	.3195	1.1754	.2894	.2673	.2749	.3142	1.1458
132	30–14–120	.4058	.3776	.4005	.4534	1.6373	.3883	.3713	.3874	.4363	1.5833
133	40–4–120	.1446	.1362	.1524	.1326	.5658	.1574	.1472	.1738	.1436	.6220
134	40–8–120	.2213	.2132	.2213	.2504	.9063	.2190	.2117	.2200	.2470	.8977
135	40–12–120	.3209	.3116	.3183	.3739	1.3247	.3083	.3047	.3096	.3586	1.2812
136	50–8–120	.2156	.2013	.2137	.2296	.8602	.2078	.1960	.2098	.2331	.8467

TABLE 25.—*Steam shown by indicator*—Continued.

Designation of tests.		Engine performance.										
No.	Laboratory symbol.	Pounds of steam at compression by indicator.					Weight of steam per revolution, by tank.	Weight of mixture in cylinder per revolution.	Per cent of mixture present as steam at cut-off.	Per cent of mixture present as steam at release.	Reevaporation + or condensation − per revolution.	Reevaporation + or condensation − per I. H. P. per hour.
		Right side.		Left side.		Total.						
		H. E.	C. E.	H. E.	C. E.							
1	2	185	186	187	188	189	190	191	192	193	194	195
							Lbs.	*Lbs.*				
101	30-2-240	0.0953	0.0812	0.0906	0.0836	0.3507	0.9814	1.3321	72.37	82.76	+0.1383	+3.3011
102	30-4-240	.0736	.0772	.0717	.0758	.2983	1.2400	1.5383	76.12	82.15	+ .0928	+1.6545
103	30.5-240	.0741	.0717	.0670	.0728	.2856	1.3468	1.6324	79.14	83.13	+ .0652	+1.0490
103*a*	30-5-240	....	....	....	....	....	....	....	....	....	....	....
104	40-2-240	.0863	.0849	.0858	.0821	.3391	.7817	1.1208	78.06	85.69	+ .0851	+2.3800
105	40-4-240	.0925	.0948	.0783	.0880	.3556	1.0150	1.3686	82.48	85.83	+ .0457	+ .9590
106	50-2-240	.0731	.0868	.0934	.0714	.3247	.6789	1.0036	83.37	89.20	+ .0585	+1.8645
107	30-2-200	.0808	.0746	.0719	.0586	.2859	.7296	1.0155	76.10	85.20	+ .0922	+2.8976
108	30-4-200	.0753	.0655	.0663	.0655	.2726	.9439	1.2165	81.36	86.24	+ .0595	+1.3611
109	30-6-200	.0712	.0634	.0615	.0683	.2644	1.1605	1.4249	89.20	89.70	+ .0066	+ .1133
110	40-2-200	.1010	.0811	.0867	.0808	.3496	.5945	.9442	83.30	90.00	+ .0627	+2.3635
111	40-4-200	.0749	.0738	.0635	.0614	.2736	.8333	1.1069	84.18	88.35	+ .0461	+1.1673
111*a*	40-4-200	....	....	....	....	....	....	....	....	....	....	....
112	40-6-200	.0825	.0799	.0731	.0788	.3143	.9906	1.3049	90.92	91.40	+ .0071	+ .1439
113	50-4-200	.1101	.0847	.0941	.0818	.3707	.6929	1.0636	87.14	91.74	+ .0490	+1.4160
114	20-2-160	.0660	.0643	.0660	.0656	.2619	.7755	1.0374	67.22	78.95	+ .1218	+4.256
115	20-4-160	.0545	.0584	.0545	.0516	.2190	.9451	1.1641	74.69	82.58	+ .0919	+2.3054
116	20-6-160	.0503	.0538	.0459	.0440	.1940	1.1823	1.3763	79.32	86.60	+ .0998	+1.9440
117	20-8-160	.0449	.0475	.0397	.0439	.1760	1.4285	1.6045	84.26	84.65	+ .0063	+ .1006
118	30-2-160	.0731	.0720	.0748	.0709	.2908	.5707	.8615	73.62	85.70	+ .1041	+4.7760
119	30-4-160	.0624	.0642	.0640	.0650	.2556	.7497	1.0050	79.56	87.42	+ .0790	+2.4160
120	30-6-160	.0568	.0614	.0536	.0586	.2304	.9769	1.2073	83.91	85.98	+ .0249	+ .5636
121	30-8-160	.0584	.0568	.0570	.0553	.2275	1.1635	1.3910	91.15	90.86	− .0042	− .7650
122	40-2-160	.0815	.0766	.0739	.0782	.3102	.4498	.7600	79.46	89.20	+ .0740	+4.1840
123	40-4-160	.0799	.0712	.0728	.0689	.2928	.6282	.9210	84.43	91.27	+ .0630	+2.1584
124	40-6-160	.0716	.0660	.0667	.0690	.2733	.7864	1.0597	89.39	91.09	+ .0179	+ .4880
125	40-8-160	.0565	.0636	.0511	.0509	.2221	1.0364	1.2585	96.35	93.50	− .0359	− .7027
126	50-2-160	.0811	.0786	.0891	.0770	.3258	.3589	.6847	81.10	89.80	+ .0596	+4.822
127	50-4-160	.0760	.0735	.0765	.0764	.3024	.5228	.8252	86.88	91.43	+ .0374	+ .1589
128	50-6-160	.0686	.0699	.0643	.0684	.2712	.8393	1.1105	81.48	79.94	− .0170	− .4752
129	30-4-120	.0671	.0593	.0661	.0585	.2510	.5075	.7585	76.94	89.85	+ .0989	+5.2610
130	30-8-120	.0522	.0550	.0467	.0440	.1980	.8737	1.0717	89.41	89.68	+ .0026	+ .0686
131	30-10-120	.0507	.0478	.0449	.0442	.1876	1.0384	1.2260	95.88	93.45	− .0296	− .6291
132	30-14-120	.0407	.0440	.0394	.0379	.1620	1.3322	1.4941	109.56	105.97	− .0540	− .9151
133	40-4-120	.0732	.0688	.0764	.0642	.2826	.4039	.6865	82.42	90.60	+ .0562	+3.6740
134	40-8-120	.0604	.0584	.0548	.0575	.2311	.7305	.9616	94.24	93.34	− .0086	− .2622
135	40-12-120	.0526	.0552	.0489	.0527	.2094	1.0219	1.2313	107.53	104.04	− .0435	− .9276
136	50-8-120	.0689	.0636	.0655	.0655	.2635	.6406	.9041	95.14	93.66	− .0135	− .4797

TABLE 26.—*Performance of the locomotive as a whole.*

Designation of tests.		Locomotive performance.							
No.	Laboratory symbol.	Draw-bar pull.	Dynamometer horse-power.	Machine friction.			Steam per D. H. P. per hour.	Coal per D. H. P. per hour.	Coal per I. H. P. per hour.
				M. E. P.	Per cent I. H. P.	Horse-power.			
1	2	196	197	198	199	200	201	202	203
		Lbs.		*Lbs.*			*Lbs.*	*Lbs.*	*Lbs.*
101	30–2–240	3905	314.20	7.80	15.06	55.56	27.56	3.75	3.195
102	30–4–240	5258	407.30	10.09	14.56	69.40	25.88	3.92	3.346
103	30–5–240	5910	463.15	10.19	13.28	70.92	26.13	....	....
103*a*	30–5–240	....	....	....	....	....	......	4.04	3.556
104	40–2–240	3295	348.80	7.05	15.97	66.30	26.03	3.71	3.130
105	40–4–240	4596	485.29	7.04	11.98	66.05	24.23	3.78	3.327
106	50–2–240	2723	367.04	8.09	20.87	96.83	27.35	3.81	3.018
107	30–2–200	2816	226.28	7.59	19.31	54.16	28.42	3.96	3.195
108	30–4–200	4154	332.20	7.22	13.37	51.24	24.92	3.78	3.276
109	30–6–200	5471	442.91	10.30	14.32	74.06	23.27	3.49	2.987
110	40–2–200	2396	255.38	5.74	17.52	54.20	27.16	3.70	3.052
111	40–4–200	3549	382.18	8.82	18.07	84.33	25.77	....	....
111*a*	40–4–200	....	....	....	....	....	....	4.04	3.482
112	40–6–200	4714	512.62	7.87	12.91	76.01	23.06	3.35	2.919
113	50–4–200	3219	413.68	6.47	15.13	73.78	23.61	4.07	3.457
114	20–2–160	2367	125.77	8.69	24.58	41.00	35.90	5.23	3.945
115	20–4–160	3457	183.53	10.30	20.94	48.62	29.99	4.10	3.239
116	20–6–160	4466	238.00	13.13	20.70	62.16	29.04	4.18	3.318
117	20–8–160	5836	311.57	11.63	15.04	55.14	26.85	4.15	3.523
118	30–2–160	2028	162.45	4.08	15.18	29.08	30.85	3.99	3.382
119	30–4–160	3043	242.13	6.12	15.16	43.26	27.02	3.51	2.975
120	30–6–160	4065	324.90	8.81	16.13	62.46	26.36	3.91	3.280
121	30–8–160	5342	427.50	8.64	11.27	54.32	23.90	3.29	2.918
122	40–2–160	1291	140.71	7.31	33.46	70.75	38.18	4.78	3.183
123	40–4–160	2279	244.16	10.41	28.87	99.12	30.26	4.43	3.150
124	40–6–160	3688	393.80	3.80	8.37	36.00	23.39	3.26	2.983
125	40–8–160	4577	488.85	11.58	18.35	109.85	24.85	3.40	2.780
126	50–2–160	1115	148.31	2.70	17.71	31.93	35.30	4.67	3.845
127	50–4–160	2107	279.98	5.35	18.38	63.07	27.22	4.07	3.321
128	50–6–160	3140	418.33	8.60	19.56	101.70	29.33	4.38	3.520
129	30–4–120	1715	137.15	3.68	16.01	26.15	32.48	3.93	3.297
130	30–8–120	3654	294.55	5.69	12.15	40.72	26.23	3.35	2.947
131	30–10–120	4638	368.20	5.86	10.08	41.32	24.56	4.12	3.698
132	30–14–120	5758	459.90	8.12	11.13	57.59	25.38	4.84	4.298
133	40–4–120	1325	140.98	3.98	21.07	37.60	33.44	4.32	3.412
134	40–8–120	3195	339.95	4.54	11.21	42.94	25.09	3.71	3.296
135	40–12–120	4697	500.00	5.03	8.69	47.57	24.31	4.55	4.157
136	50–8–120	2731	364.30	4.01	11.53	47.50	25.71	3.74	3.316

TABLE 27.—*Comparative performance of the locomotive, assuming irregularities in the results of individual tests to have been eliminated.*

Designation of tests.		Corrected locomotive performance.											
No.	Laboratory symbol.	Equivalent steam to engine per hour. Feed water at 60°F.	Equiv. evap. per pound of dry coal by equation $E=11.706-0.214H$	Dry coal fired per hour corrected by equation.	Dry coal per I. H. P. per hour.	Equiv. steam per I. H. P. per hour.	Machine friction. M. E. P.	Machine friction. H. P.	Machine friction. Per cent I. H. P.	Dynamometer horse-power.	Draw-bar pull.	Coal per D. H. P. per hour.	Equivalent steam per D. H. P. per hour.
1	2	204	205	206	207	208	209	210	211	212	213	214	215
		Lbs.		*Lbs.*	*Lbs.*	*Lbs.*					*Lbs.*	*Lbs.*	*Lbs.*
101	30–2–240	11,308	9.716	1164	3.14	30.59	6.5	46.45	12.58	323.31	4020	3.60	34.97
102	30–4–240	13,853	9.268	1495	3.13	29.07	8.5	58.49	12.27	418.19	5396	3.58	33.13
103	30–5–240	15,187	9.034	1681	3.07	27.79	8.9	61.95	11.33	472.12	6022	3.56	32.17
103*a*	30–5–240	....	....	....	....	....	....	....	....	....	....	....	....
104	40–2–240	11,786	9.632	1224	2.95	28.40	6.5	61.12	14.72	353.97	3343	3.46	33.30
105	40–4–240	15,467	8.984	1722	3.12	28.06	8.5	79.69	14.45	471.67	4465	3.87	34.77
106	50–2–240	13,129	9.396	1397	3.01	28.31	6.5	77.24	16.65	386.63	2865	3.61	33.96
107	30–2–200	8,312	10.242	812	2.90	29.64	6.5	46.38	16.54	234.06	2910	3.47	35.51
108	30–4–200	10,815	9.802	1103	2.88	28.21	8.5	60.37	15.74	323.07	4037	3.41	33.48
109	30–6–200	13,571	9.318	1457	2.82	26.26	9.3	66.86	12.94	450.11	5559	3.24	30.15
110	40–2–200	9,007	10.121	890	2.87	29.10	6.5	61.42	19.84	248.16	2331	3.59	36.30
111	40–4–200	12,865	9.442	1363	2.92	27.58	8.5	81.29	17.43	385.22	3579	3.54	33.40
111*a*	40–4–200	....	....	....	....	....	....	....	....	....	....	....	....
112	40–6–200	15,622	8.957	1744	2.96	26.54	9.3	89.82	15.26	498.81	4584	3.50	31.33
113	50–4–200	12,803	9.453	1355	2.78	26.27	8.5	96.99	19.90	390.47	3039	3.47	32.80
114	20–2–160	5,929	10.911	414	2.48	35.55	6.5	30.67	18.39	136.10	2559	3.04	43.56
115	20–4–160	7,070	10.462	676	2.91	30.45	8.5	40.08	17.26	192.07	3611	3.52	36.81
116	20–6–160	8,969	10.128	885	2.95	29.88	9.3	44.02	14.66	256.14	4802	3.45	35.01
117	20–8–160	10,811	9.803	1103	3.01	29.49	8.4	39.83	10.86	326.88	6115	3.37	33.08
118	30–2–160	6,421	10.824	463	2.42	33.53	6.5	46.24	24.14	145.29	1811	3.19	44.91
119	30–4–160	8,443	10.220	826	2.89	29.58	8.5	60.06	21.04	225.33	2830	3.67	37.47
120	30–6–160	11,156	9.743	1145	2.96	28.81	9.3	66.01	17.04	321.35	4019	3.56	34.72
121	30–8–160	13,363	9.354	1429	2.97	27.74	8.4	59.69	12.39	422.13	5272	3.39	31.66
122	40–2–160	6,886	10.760	500	2.36	32.56	6.5	62.72	29.66	148.74	1362	3.36	46.30
123	40–4–160	9,587	10.019	957	2.79	27.93	8.5	80.94	23.58	262.34	2447	3.65	36.54
124	40–6–160	12,011	9.592	1252	2.91	27.95	9.3	88.21	20.52	341.59	3199	3.67	35.17
125	40–8–160	15,944	8.900	1792	2.99	26.63	8.4	79.68	13.31	519.02	4857	3.45	30.72
126	50–2–160	6,688	10.784	486	2.70	37.10	6.5	76.78	42.60	103.46	778	4.70	64.62
127	50–4–160	9,882	9.967	992	2.89	28.81	8.5	100.30	29.24	242.75	1827	4.09	40.71
128	50–6–160	16,344	8.830	1851	3.56	31.43	9.3	110.04	21.16	409.99	3076	4.52	39.87
129	30–4–120	5,649	10.712	527	3.23	34.60	8.5	60.37	36.97	102.93	1287	5.12	54.89
130	30–8–120	9,924	9.960	996	2.97	29.60	8.4	60.13	17.93	275.14	3412	3.62	36.07
131	30–10–120	11,766	9.637	1221	2.98	28.72	6.9	48.65	11.87	361.07	4546	3.38	32.59
132	30–14–120	15,296	9.014	1697	3.28	29.56	3.0	21.28	4.11	496.21	6208	3.42	30.83
133	40–4–120	5,989	10.652	562	3.15	33.54	8.5	80.32	44.97	98.26	922	5.72	60.96
134	40–8–120	11,074	9.757	1135	2.96	28.93	8.4	79.39	20.74	303.50	2851	3.74	36.49
135	40–12–120	15,925	8.904	1789	3.27	29.09	5.0	47.27	8.63	500.30	4698	3.58	31.83
136	50–8–120	12,159	9.566	1271	3.09	29.53	8.4	99.51	24.17	312.29	2339	4.07	38.94

APPENDIX III.

TESTS UNDER INTERMITTENT CONDITIONS OF RUNNING, METHODS, AND DATA.

50. The Conditions under which Tests Were Run.—Nine intermittent tests were made, two each under a boiler-pressure of 240, 200, 160, and 120 pounds, respectively, and one duplicate. The plan of the tests involved the operation of the locomotive under each pressure, according to two definite schedules governing periods of running and periods of standing. Grouped by schedules, therefore, the tests may be arranged in two series. The schedule of the first of these series provides six periods of running and five periods of standing, the duration of the running time being one-half the duration of the test. Tests of this series will, therefore, be hereafter referred to as half-time tests. The schedule of the second series provides four periods of running and three of standing, the total duration of the running time being equal to one-fourth the total duration of the test. Tests of this series will hereafter be referred to as one-quarter time tests. A period of 120 minutes at the beginning of the test was used to start the fire and to bring the pressure of the boiler to the required standard. Graphical schedules showing the exact program of running are presented as figs. 61 and 62. These give the time of occurrence and the duration of the running and standing periods. They also show the speed, the position of the reverse-lever, and the dry-pipe pressure.

51. A Summary of the Observed and Calculated Data is presented by tables 28 to 36. An explanation of the several items comprising these tables is as follows:

TABLE 28.—GENERAL CONDITIONS.

Column 1. *Test number.*

Column 2. *Laboratory symbol.*—The first term of this symbol defines the proportion of the running time to the total time of the test, and the last three represent the speed, the position of cut-off, and the boiler-pressure, respectively. Thus, $\frac{1}{2}(30-3-240)$ designates a half-time test at a boiler-pressure of 240 pounds, speed 30 miles per hour, and cut-off third notch from center forward.

Column 3. *Date of test.*

Column 4. *Duration of period when engine is starting and stopping.*—This item includes the time during which the locomotive is in the process of starting and stopping and the preliminary running at slow speed at the beginning of the test.

Column 5. *Duration of periods when engine is running at speed.*

Column 6. *Duration of periods when engine is standing.*

Column 7. *Duration of period before starting,* during which fire was burning and steam-pressure was being raised.

Column 8. *Total duration of period after starting engine.*—This item includes the total time from the starting of the engine to the conclusion of the test.

Column 8*a*. *Total duration of test.*—This item includes the total time from the time the fire was started to the conclusion of the test.

Column 9. *Temperature of the laboratory, °F.*—The values given are the average of observations taken at 20-minute intervals.

Column 10. *Barometer-pressure, pounds per square inch.*

Column 11. *Boiler-pressure when the engine is starting and stopping.*—The values given are the average of observations taken at 2-minute intervals.

Column 12. *Boiler-pressure when the engine is running at speed.*—The values given are the average of observations taken at 5-minute intervals.

Column 13. *Dry-pipe pressure when engine is starting and stopping.*—The values given are the average of observations taken at 2-minute intervals.

TABLE 29.—SPEED AND WATER.

Column 14. *Temperature of steam when engine is starting and stopping.*—The values of this column represent the average of observations taken at 2-minute intervals. The thermometer used was placed in the left branch-pipe at a point immediately adjoining the connection to steam-header.

Column 15. *Temperature of steam when engine is running at speed.*—The values in this column are averages of observations at 5-minute intervals.

Column 16. *Degrees superheat when engine is running at speed.*—The values in this column are obtained by subtracting the temperature corresponding to the pressure shown in column 12, from the average observed temperature when the engine is running at speed (column 15).

Column 17. *Speed, revolutions per minute when engine is starting and stopping.*—The values in this column are averages of the engine register made at 2-minute intervals.

Column 18. *Speed, miles per hour, when engine is starting and stopping,* equals $\frac{\text{column } 17 \times 60}{292.31}$.

Column 19. *Revolutions per minute when engine is running under constant conditions.*—The values in this column are averages of readings at 5-minute intervals.

Column 20. *Speed, miles per hour, when engine is running* at speed, equals $\frac{\text{column } 19 \times 60}{292.31}$.

Column 21. *Miles equivalent to total revolutions* equals

$$\frac{\text{column } 17 \times \text{column } 4 + \text{column } 19 \times \text{column } 5}{292.31}$$

Column 22. *Temperature of feed-water.*—The values of this column are averages of observations made at 10-minute intervals.

Column 23. *Water delivered to the boiler when engine is starting and stopping* equals the total amount of water weighed to the injectors during conditions of starting, stopping, and standing, less the loss due to injector overflow, during this time.

Column 24. *Water delivered to the boiler when engine is running at speed* equals the total amount of water weighed to the injectors during the time the engine is running at speed less the injector overflow during this period.

Column 25. *Total water delivered to the boiler* equals column 23 + column 24.

TABLE 30.—WATER, COAL, AND DRAFT.

Column 26. *Water used by the engine when the engine is starting and stopping* equals column 23 minus the steam lost by the calorimeter, the aspirator, and at the thermometer-plugs during the total time of starting, stopping, and standing.

Column 27. *Water used by the engine when engine is running at speed* equals column 24 minus the steam lost by the calorimeter, the aspirator, and at the thermometer-plugs during the total time during which the engine is running at speed.

Column 28. *Total water used by the engine* equals column 26 + column 27.

Column 29. *Dry coal fired when engine is starting and stopping.*

Column 30. *Dry coal fired when engine is running at speed.*

Column 31. *Total dry coal used from time of starting the engine* equals column 29 + column 30.

Column 32. *Dry coal used to raise steam-pressure.*—Both coal and wood were used in "firing up." The values in this column include both coal and wood, the latter being expressed in terms of coal under the assumption that its heating value equals one-fourth that of coal.

Column 33. *Front-end cinders, pounds.*

Column 34. *Stack cinders, pounds.*

Column 35. *Dry ash, pounds.*

Column 36. *Draft in front-end, inches of water.*—The values in this column are averages of readings taken at 2 and 5 minute intervals. The average is based on the relative time of the two periods of running, starting, and stopping, and running at speed.

Column 37. *Temperature of escaping gases.*—The values in this column are averages of observations at 5-minute intervals.

TABLE 31.—BOILER AND ENGINE PERFORMANCE.

Column 38. *Equivalent evaporation per hour from and at 212° F.*

Column 39. *Equivalent evaporation from and at 212° F. per square foot of water and superheating surface per hour* equals column 38 divided by 1216.

Column 40. *Equivalent evaporation from and at 212° F. per pound of dry coal* equals column 38 × column 8 ÷ column 31 × 60.

Column 41. *Average indicated horse-power when engine is starting and stopping.*

Column 42. *Average indicated horse-power when engine is running at speed.*

Column 43. *Total average indicated horse-power* equals

$$\frac{\text{column } 41 \times \text{column } 4 + \text{column } 42 \times \text{column } 5}{\text{column } 4 + \text{column } 5}$$

Column 44. *Draw-bar pull when engine is starting and stopping.*—The values in this column are averages of observations made at 2-minute intervals.

Column 45. *Draw-bar pull when engine is running at speed.*—The values in this column are averages of observations made at 5-minute intervals.

Column 46. *Draw-bar horse-power when engine is starting and stopping* equals 0.000547 × column 17 × column 44.

Column 47. *Draw-bar horse-power when engine is running at speed* equals 0.000547 × column 45 × column 19.

Column 48. *Average draw-bar horse-power* equals

$$\frac{\text{column } 46 \times \text{column } 4 + \text{column } 47 \times \text{column } 5}{\text{column } 4 + \text{column } 5.}$$

TABLE 32.—ENGINE AND LOCOMOTIVE PERFORMANCE.

Column 49. *Steam per indicated horse-power per hour when engine is running at speed* equals column 27 × 60 divided by column 42 × column 5.

Column 50. *Steam per indicated horse-power per hour for total time* equals column 28 × 60 divided by (column 4 + column 5) × column 43.

Column 51. *Equivalent steam from and at 212° F. per draw-bar horse-power per hour when engine is running at speed.*

Column 52. *Equivalent steam from and at 212° F. per draw-bar horse-power per hour for total time.*

Column 53. *Dry coal per draw-bar horse-power per hour when engine is running at speed* equals column 30 × 60 divided by column 5 × column 47.

Column 54. *Dry coal per draw-bar horse-power for* total time equals column 31 × 60 divided by column 48 × (column 4 + column 5).

Column 55. *Dry coal per draw-bar horse-power per hour for total time,* including coal used to start fire in boiler, equals (column 31 + column 32) × 60 divided by column 48 × (column 4 + column 5).

TABLE 33.—CHEMICAL ANALYSIS OF SMOKE-BOX GASES.

Columns 56, 57, 58, and 59. *Gas analysis* was made with the Orsat apparatus. The method of drawing the sample was the same as described in Appendix II. The values given are the average of observations taken during the time when the engine was running only.

Column 60. *Dry gas per pound of carbon consumed* =

$$\frac{11CO_2 + 8O_2 + 7(CO + N)}{3(CO_2 + CO)}$$

Column 61. *Dry gas per pound of combustible fired* = column 60 × per cent of carbon in combustible (based on combustible consumed) ÷ 100.

Column 62. *Air per pound of carbon consumed* = $\frac{N}{0.33\ (CO_2 + CO)}$

Column 63. *Air per pound of combustible fired* = column 62 × per cent of carbon in combustible (based on combustible consumed) ÷ 100.

Column 64. *Ratio of air supplied to theoretical requirements* = $\frac{N}{N - 3.78 \times O_2}$

TABLE 34.—CHEMICAL ANALYSIS OF COAL.

PROXIMATE ANALYSIS.

Column 65. *Moisture, per cent.*
Column 66. *Volatile matter, per cent.*
Column 67. *Fixed carbon, per cent.*
Column 68. *Ash, per cent.*

ULTIMATE ANALYSIS.

Column 69. *Carbon, per cent.*
Column 70. *Hydrogen, per cent.*
Column 71. *Nitrogen, per cent.*
Column 72. *Oxygen, per cent.*
Column 73. *Sulphur, per cent.*
Column 74. *Ash, per cent.*

TABLE 35.—CALORIFIC VALUES.

The values of this table are those reported by the Fuel Testing Laboratory of the Technologic Branch of the United States Geological Survey, to which laboratory sealed samples were delivered.

Column 75. *Per cent of combustible in front-end cinders.*
Column 76. *Per cent of combustible in stack cinders.*
Column 77. *Per cent of combustible in refuse from ash-pan.*
Column 78. *Calorific value per pound of dry coal, B. t. u.*
Column 79. *Calorific value per pound of combustible, B. t. u.*
Column 80. *Calorific value per pound of front-end cinders, B. t. u.*
Column 81. *Calorific value per pound of stack cinders, B. t. u.*
Column 82. *Calorific value per pound of refuse from ash-pan, B. t. u.*

TABLE 36.—HEAT-BALANCE.

Column 83. *Calorific value per pound of combustible, B. t. u.*
Column 84. *B. t. u. absorbed by boiler per pound of combustible.*
Column 85. *B. t. u. lost per pound of combustible due to water in coal* =

$$\frac{a}{100}\left\{(212 - t) + r + c\,(T - 212)\right\}$$

where t = temperature of laboratory.
a = per cent of moisture referred to combustible.
r = 965.8.
c = specific heat of steam at constant pressure.
T = temperature of the smoke-box gases.

Column 86. *B. t. u. lost per pound of combustible* by water formed from hydrogen in coal = per cent of hydrogen referred to combustible ÷ 100 × 9 [(212 − column 9) + 965.8 + 0.48 × (column 37 − 212)].

Column 87. *B. t. u. lost per pound of combustible due to escaping gases* = column 61 × 0.24 (column 37 − column 9).

Column 88. *B. t. u. lost per pound of combustible due to incomplete combustion*=

$$CO\,\frac{\text{per cent of carbon in combustible}}{100} \times \frac{10150}{(CO_2 + CO)}$$

Column 89. *B. t. u. lost per pound of combustible due to front-end cinders* = 100 × column 33 × column 80 ÷ column 31 × (100 − column 74).

Column 90. *B. t. u. lost per pound of combustible due to stack cinders* = 100 × column 34 × column 81 ÷ column 31 ÷ (100 − column 74).

Column 91. *B. t. u. lost per pound of combustible due to refuse in ash* = 100 × column 35 × column 82 ÷ column 31 × (100 − column 74).

Column 92. *B. t. u. lost per pound of combustible unaccounted for* = column 83 − column 84 − column 85 − column 86 − column 87 − column 88 − column 89 − column 90 − column 91.

TABLE 28.—*General conditions* (*intermittent tests*).

Designation of test.			Duration of periods.						Temperature of laboratory.	Barometer pressure per sq. in.	Boiler-pressure by gage.		Dry-pipe pressure when engine is starting and stopping.
No.	Laboratory symbol.	Date.	When engine is starting and stopping.	When engine is running at speed.	When engine is standing.	Before starting engine.	Total after starting engine.	Total of test.			When engine is starting and stopping.	When engine is running at speed.	
1	2	3	4	5	6	7	8	8a	9	10	11	12	13
			Min.	*Min.*	*Min.*	*Min.*	*Min.*	*Min.*	°F	*Lbs.*			
201	½(30–3–240)	July 19	100	150	150	120	400	520	86.2	14.39	194.6	232.5	91.6
202	¼(30–3–240)	July 23	80	80	240	120	400	520	88.1	14.42	195.0	236.7	86.7
203	½(30–5–200)	July 18	100	150	150	120	400	520	85.4	14.47	183.5	200.3	85.7
204	¼(30–5–200)	July 16	80	80	240	120	400	520	84.0	14.40	158.4	199.7	73.5
205	½(30–7–160)	July 9	100	150	150	120	400	520	87.7	14.37	171.3	160.6	64.9
205*a*	½(30–7–160)	July 10	100	150	150	120	400	520	85.6	14.35	161.4	160.1	70.1
206	¼(30–7–160)	July 13	80	80	240	120	400	520	82.4	14.41	141.8	159.7	65.4
207	½(30–10–120)	July 11	100	150	150	120	400	520	79.6	14.31	126.5	119.7	65.6
208	¼(30–10–120)	July 12	80	80	240	120	400	520	81.1	14.43	117.9	121.1	64.8

TABLE 29.—*Speed and water* (*intermittent tests*).

Designation of test.		Temperature of steam when engine is starting and stopping.	Temperature of steam when engine is running at speed.	Degrees superheat when engine is running at speed.	Speed when engine is starting and stopping.		Speed when engine is running at speed.		Miles equivalent to total number of revolutions.	Temperature of feed-water.	Water delivered to boiler and presumably evaporated.		
No.	Laboratory symbol.				Revolutions per minute.	Miles per hour.	Revolutions per minute.	Miles per hour.			When engine is starting and stopping.	When engine is running at speed.	Total.
1	2	14	15	16	17	18	19	20	21	22	23	24	25
										°F.	*Lbs.*	*Lbs.*	*Lbs.*
201	½(30–3–240)	477.3	535.3	135.4	67.5	13.9	146.1	30.0	98.1	69.1	11,377	24,422	35,799
202	¼(30–3–240)	446.9	537.9	136.5	64.9	13.3	146.6	30.1	57.9	69.5	9,890	13,137	23,027
203	½(30–5–200)	476.4	533.1	145.3	66.4	13.6	145.8	30.0	97.5	70.0	9,501	24,962	34,463
204	¼(30–5–200)	462.0	527.4	139.8	69.5	14.3	153.6	31.6	61.1	69.9	9,376	13,648	23,024
205	½(30–7–160)	467.9	519.4	148.8	77.8	16.0	144.6	29.7	101.0	70.6	9,302	25,312	34,614
205*a*	½(30–7–160)	459.6	519.8	149.5	67.2	13.8	148.7	30.5	99.3	69.0	9,174	24,397	33,571
206	¼(30–7–160)	466.2	525.5	155.3	68.2	14.0	147.5	30.3	59.1	68.1	9,088	13,548	22,636
207	½(30–10–120)	456.6	509.1	159.7	72.4	14.9	146.6	30.1	100.3	68.0	10,196	24,146	34,342
208	¼(30–10–120)	452.4	506.3	156.0	68.0	14.0	152.9	31.4	60.5	69.9	8,878	13,450	22,328

TABLE 30.—*Water, coal, and draft (intermittent tests).*

Designation of test.		Water used by engine.			Dry coal fired.								
No.	Laboratory symbol.	When engine is starting and stopping.	When engine is running at speed.	Total.	When engine is starting and stopping.	When engine is running at speed.	Total from time of starting engine.	Dry coal used to raise steam-pressure.	Front-end cinders.	Sparks ejected from stack.	Dry ash and refuse.	Draft in front of diaphragm, inches of water.	Temperature of smoke-box gases.
1	**2**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		*°F.*
201	½(30–3–240)	10,980	24,120	35,100	1695	3271	4966	659	183	62	447	2.61	666.4
202	¼(30–3–240)	9,362	12,942	22,304	1461	2019	3480	661	160	35	461	2.59	725.3
203	½(30–5–200)	9,100	24,611	33,711	1340	3015	4355	645	159	58	331	2.70	664.5
204	¼(30–5–200)	8,909	13,471	22,380	1519	1771	3290	526	146	37	294	2.84	667.7
205	½(30–7–160)	8,891	25,022	33,913	1162	3427	4589	533	205	53	371	3.30	662.8
205*a*	½(30–7–160)	8,798	24,113	32,911	1054	3441	4495	553	175	59	415	2.76	661.2
206	¼(30–7–160)	8,712	13,375	22,087	1275	1638	2913	499	115	29	339	2.43	648.5
207	½(30–10–120)	9,793	23,951	33,744	1242	3263	4505	441	208	55	410	2.73	637.2
208	¼(30–10–120)	8,450	13,345	21,795	1268	1810	3078	421	179	32	350	2.81	632.7

TABLE 31.—*Boiler and engine performance (intermittent tests).*

Designation of test.		Equivalent evaporation.			Average indicated horse-power.					Average draw-bar horse-power.		
No.	Laboratory symbol.	Per hour.	Per sq. ft. of heating-surface per hour.	Per pound of dry coal.	When engine is starting and stopping.	When engine is running at speed.	Total.	Draw-bar pull starting and stopping.	Draw-bar pull running at speed.	When engine is starting and stopping.	When engine is running at speed.	Total.
1	**2**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
201	½(30–3–240)	6899	5.67	9.262	181.98	410.48	319.08	4243	4148	156.70	331.59	261.63
202	¼(30–3–240)	4405	3.62	8.438	156.50	421.00	288.81	4066	4363	144.36	349.89	247.12
203	½(30–5–200)	6641	5.46	10.165	173.67	446.63	337.44	4414	4736	160.30	377.70	290.72
204	¼(30–5–200)	4410	3.62	8.936	169.52	455.93	312.72	4243	4601	161.23	386.59	273.91
205	½(30–7–160)	6637	5.46	9.642	173.53	437.21	331.74	3923	4670	166.88	369.28	288.32
205*a*	½(30–7–160)	6438	5.29	9.548	165.08	426.39	321.86	4136	4541	151.83	369.28	282.30
206	¼(30–7–160)	4346	3.57	9.947	162.20	425.83	294.01	4245	4557	158.40	367.58	262.99
207	½(30–10–120)	6577	5.41	9.637	185.26	391.69	309.10	4470	4333	177.05	347.54	279.34
208	¼(30–10–120)	4256	3.50	9.219	160.30	406.80	283.60	4333	4406	161.26	368.50	264.88

TABLE 32.—*Engine and locomotive performance (intermittent tests).*

Designation of test.		Steam per I. H. P. per hour.		Equivalent steam per D. H. P. per hour		Dry coal per D. H. P. per hour.		
No.	Laboratory symbol.	When engine is running at speed.	For total time.	When engine is running at speed.	For total time.	When engine is running at speed.	For total time.	Including coal used to raise steam-pressure.
1	**2**	**49**	**50**	**51**	**52**	**53**	**54**	**55**
201	½(30–3–240)	23.50	26.40	37.62	40.96	3.95	4.55	5.16
202	¼(30–3–240)	23.05	28.97	35.85	42.55	4.33	5.28	6.28
203	½(30–5–200)	22.04	23.98	33.67	35.40	3.19	3.60	4.13
204	¼(30–5–200)	22.16	26.85	33.66	39.00	3.44	4.50	5.23
205	½(30–7–160)	22.89	24.54	34.78	35.68	3.71	3.83	4.26
205*a*	½(30–7–160)	22.63	24.55	33.59	35.39	3.73	3.82	4.29
206	¼(30–7–160)	23.56	28.24	35.21	39.90	3.34	4.15	4.87
207	½(30–10–160)	24.47	26.21	35.40	36.68	3.76	3.87	4.25
208	¼(30–10–160)	24.60	28.89	34.80	38.89	3.68	4.36	4.95

TABLE 33.—*Chemical analysis of smoke-box gases (intermittent tests).*

Designation of test.		Gas analysis.				Weight of—				Ratio of air supplied to theoretical requirement.
No.	Laboratory symbol.	CO_2.	O_2.	CO.	N_2.	Dry gas per pound of carbon.	Dry gas per pound of combustible	Air per pound of carbon.	Air per pound of combustible.	
1	**2**	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**
		P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	
201	½(30–3–240)	14.91	2.81	0.86	81.42	16.12	11.72	15.65	11.38	1.15
202	¼(30–3–240)	14.94	2.56	.70	81.80	16.25	10.57	15.85	10.30	1.15
203	½(30–5–200)	13.19	5.48	.45	80.88	18.53	13.34	17.97	12.93	1.32
204	¼(30–5–200)	12.48	6.00	.46	81.06	19.47	13.09	18.98	12.76	1.39
205	½(30–7–160)	12.08	6.95	.23	80.74	20.45	15.06	19.87	14.65	1.51
205*a*	½(30–7–160)	12.50	6.70	.15	80.65	19.94	14.50	19.32	14.06	1.46
206	¼(30–7–160)	13.43	5.01	.33	81.23	18.14	11.77	17.89	11.61	1.30
207	½(30–10–120)	11.86	7.18	.19	80.77	20.87	15.09	20.31	14.70	1.50
208	¼(30–10–120)	11.64	6.95	.14	81.27	21.32	13.82	20.91	13.57	1.48

TABLE 34.—*Chemical analysis of coal (intermittent tests).*

Designation of test.		Proximate analysis (coal as fired).				Ultimate analysis (dry coal).					
No.	Laboratory symbol.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Carbon	Hydrogen.	Nitrogen.	Oxygen.	Sulphur.	Ash.
1	2	65	66	67	68	69	70	71	72	73	74
201	½(30–3–240)	1.84	32.16	58.47	7.53	78.61	5.03	1.28	6.49	0.92	7.67
202	¼(30–3–240)	1.84	32.55	58.03	7.58	78.51	5.03	1.61	6.14	.98	7.73
203	½(30–5–200)	2.90	30.71	58.75	7.64	76.06	5.11	1.29	8.69	.98	7.87
204	¼(30–5–200)	2.19	31.96	58.73	7.12	78.41	5.13	1.70	6.53	.94	7.28
205	½(30–7–160)	1.59	32.52	56.23	9.66	77.31	4.90	1.49	5.42	1.06	9.82
205*a*	½(30–7–160)	1.59	32.58	57.20	8.63	78.20	5.00	1.58	5.29	1.16	8.77
206	¼(30–7–160)	2.56	31.55	58.50	7.39	78.05	5.00	1.60	6.60	1.16	7.59
207	½(30–10–120)	1.65	31.53	58.21	8.61	77.18	5.06	1.54	6.34	1.13	8.75
208	¼(30–10–120)	2.20	31.86	58.43	7.51	78.45	5.06	1.67	5.96	1.18	7.68

TABLE 35.—*Calorific values (intermittent tests).*

Designation of test.		Per cent combustible in—			Calorific value in B. t. u. per pound of—				
No.	Laboratory symbol.	Front-end cinders.	Stack cinders.	Refuse from ash-pan.	Dry coal.	Combustible.	Front-end cinders.	Stack cinders.	Refuse from ash-pan.
1	2	75	76	77	78	79	80	81	82
201	½(30–3–240)	81.94	61.77	51.22	14,119	15,291	11,578	8676	7502
202	¼(30–3–240)	73.80	65.60	57.17	14,063	15,240	10,294	9164	8374
203	½(30–5–200)	69.16	58.19	38.46	14,062	15,262	9,576	8127	5633
204	¼(30–5–200)	77.22	65.47	52.56	14,057	15,161	11,021	9126	6687
205	½(30–7–160)	72.35	55.36	45.65	13,791	15,323	10,223	7803	5862
205*a*	½(30–7–160)	75.77	58.25	39.99	13,910	15,247	10,664	8280	8318
206	¼(30–7–160)	71.19	57.75	56.79	14,192	15,357	10,051	8113	5818
207	½(30–10–120)	69.89	61.05	39.85	13,948	15,280	9,918	8555	5837
208	¼(30–10–120)	70.36	61.84	54.70	14,196	15,377	9,961	8660	8012

TABLE 36.—*Heat balance (intermittent tests).*

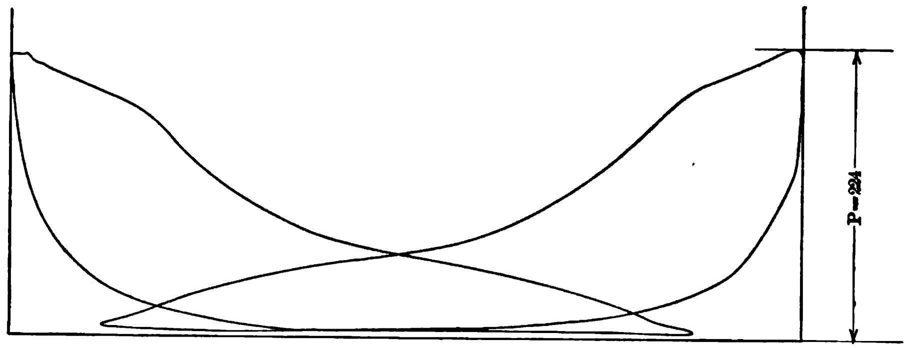
Designation of test. No.	Designation of test. Laboratory symbol.	B. t. u. per pound of combustible.	B. t. u. absorbed per pound of combustible by the boiler and superheater.	B. t. u. lost per pound of combustible due to water in coal.	B. t. u. lost per pound of combustible due to water formed by hydrogen in coal.	B. t. u. lost per pound of combustible due to escaping gases.	B. t. u. lost per pound of combustible due to incomplete combustion.	B. t. u. lost per pound of combustible due to front-end cinders.	B. t. u. lost per pound of combustible due to stack cinders.	B. t. u. lost per pound of combustible due to refuse in ash.	B. t. u. lost per pound of combustible unaccounted for.
1	**2**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**
201	½(30–3–240)	15,291	9,688	26	652	1632	471	463	117	730	1512
202	¼(30–3–240)	15,240	8,831	27	655	1617	386	557	100	1202	1865
203	½(30–5–200)	15,262	10,656	41	654	1853	276	379	117	465	821
204	¼(30–5–200)	15,161	9,308	31	654	1834	305	526	111	742	1650
205	½(30–7–160)	15,323	10,327	23	639	2080	162	524	100	599	869
205*a*	½(30–7–160)	15,247	10,046	23	644	2004	103	434	119	586	1278
206	¼(30–7–160)	15,357	10,509	36	633	1600	205	650	87	1047	590
207	½(30–10–120)	15,280	10,200	22	650	2019	135	502	114	582	1056
208	¼(30–10–120)	15,377	9,644	31	641	1829	102	627	98	987	1318
PER CENT IN TERMS OF B. T. U. PER POUND OF COMBUSTIBLE.											
201	½(30–3–240)	100	63.36	0.17	4.26	10.67	3.08	3.03	0.76	4.78	9.89
202	¼(30–3–240)	100	57.95	.18	4.30	10.61	2.53	3.65	.65	7.89	12.24
203	½(30–5–200)	100	69.82	.27	4.28	12.14	1.81	2.48	.77	3.05	5.38
204	¼(30–4–200)	100	61.40	.20	4.31	12.10	2.01	3.47	.73	4.90	10.88
205	½(30–7–160)	100	67.39	.15	4.17	13.57	1.06	3.42	.65	3.91	5.68
205*a*	½(30–7–160)	100	65.95	.15	4.22	13.15	.68	2.85	.78	3.84	8.38
206	¼(30–7–160)	100	68.43	.23	4.12	10.40	1.34	4.23	.57	6.82	3.86
207	½(30–10–120)	100	66.75	.14	4.25	13.21	.88	3.29	.75	3.81	6.92
208	¼(30–10–120)	100	62.75	.20	4.17	11.90	.66	4.08	.64	6.38	9.22

APPENDIX IV.

AN EXHIBIT OF TYPICAL INDICATOR-CARDS.

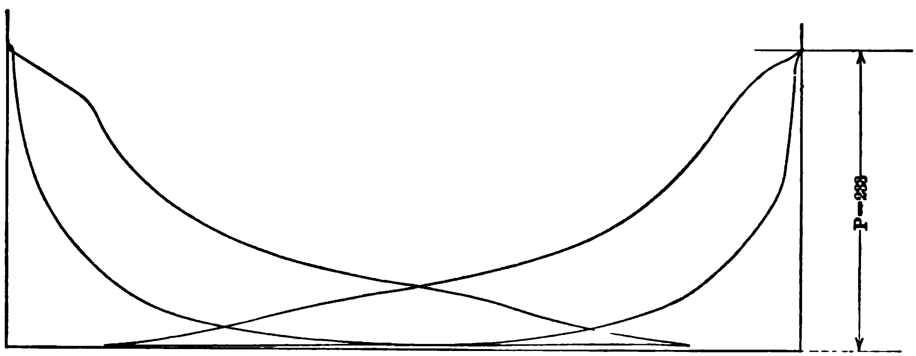
All cards in this exhibit are reproduced at the size taken.

I



Reverse Lever Fifth Notch from Center Forward.

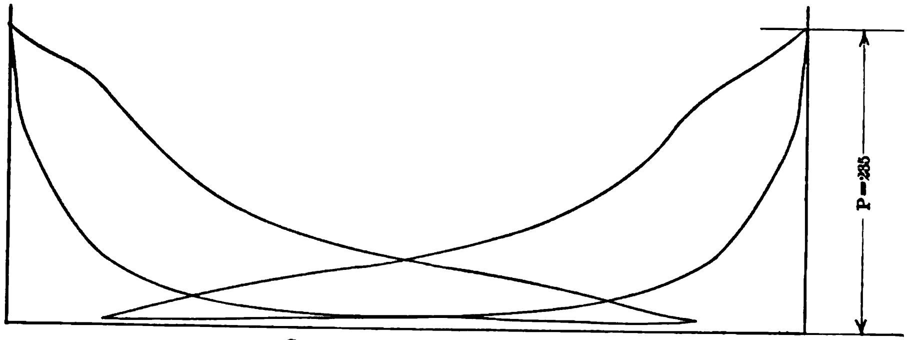
II



Reverse Lever Second Notch from Center Forward.

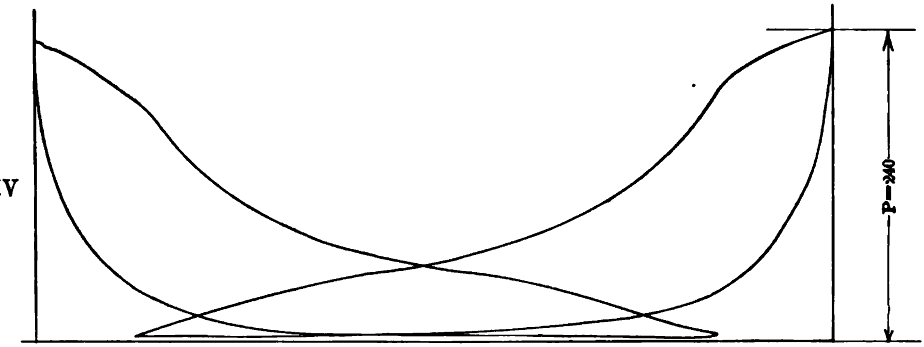
Boiler pressure 240 pounds, speed 30 miles per hour.

III



SPEED 40 MILES PER HOUR.

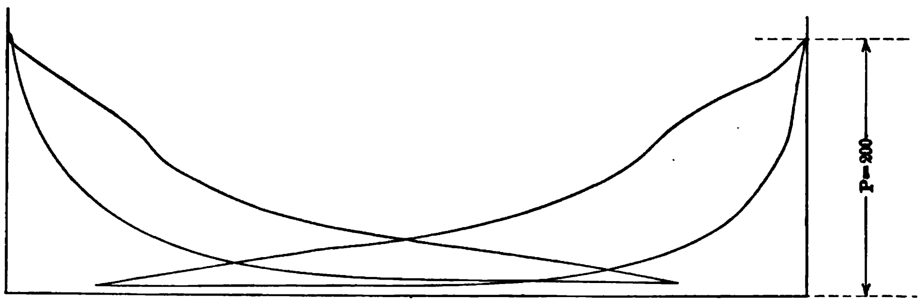
IV



SPEED 30 MILES PER HOUR.

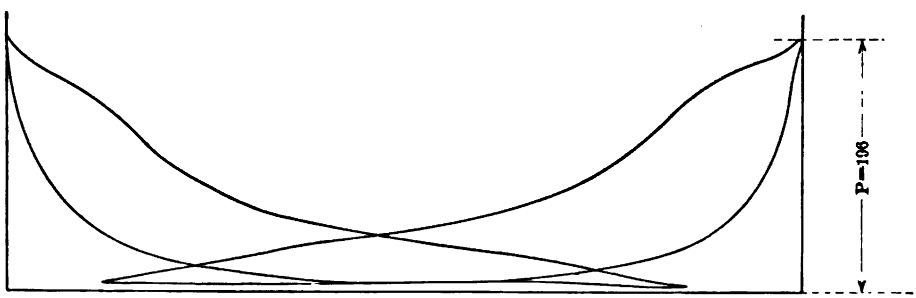
BOILER PRESSURE 240 POUNDS, REVERSE LEVER FOURTH NOTCH FROM CENTER FORWARD.

V



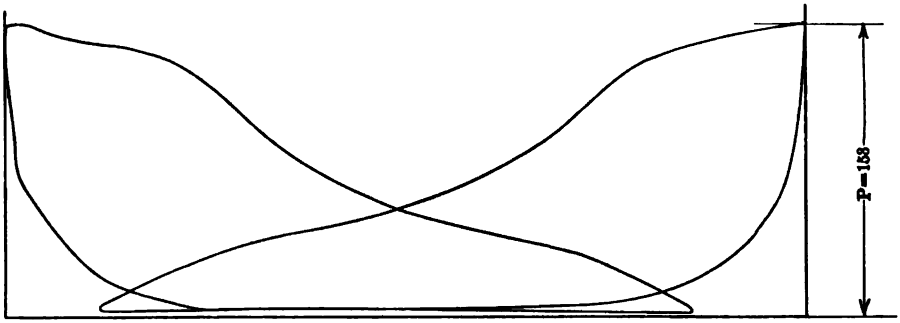
SPEED 50 MILES PER HOUR.

VI



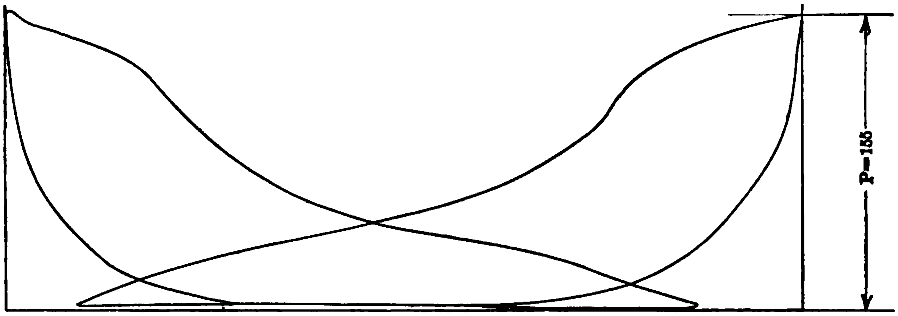
SPEED 40 MILES PER HOUR.

VII



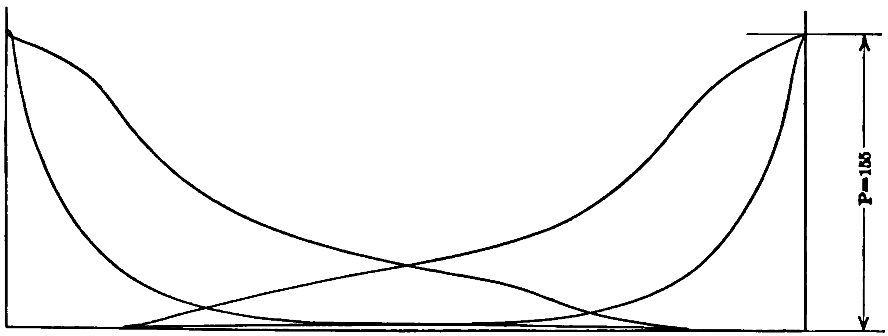
Reverse Lever Eighth Notch from Center Forward.

VIII



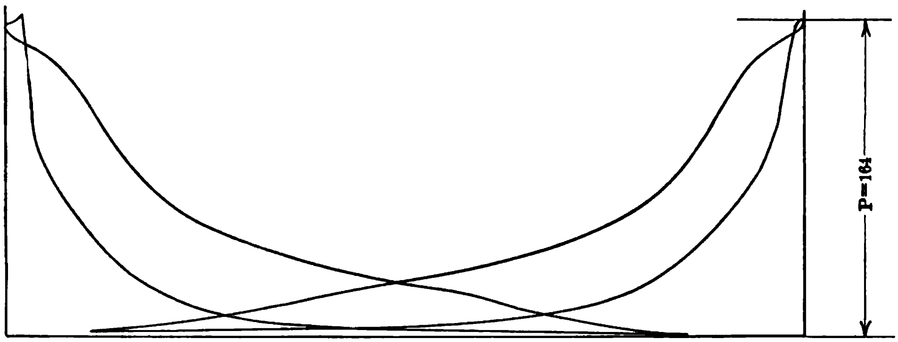
Reverse Lever Sixth Notch from Center Forward.

IX



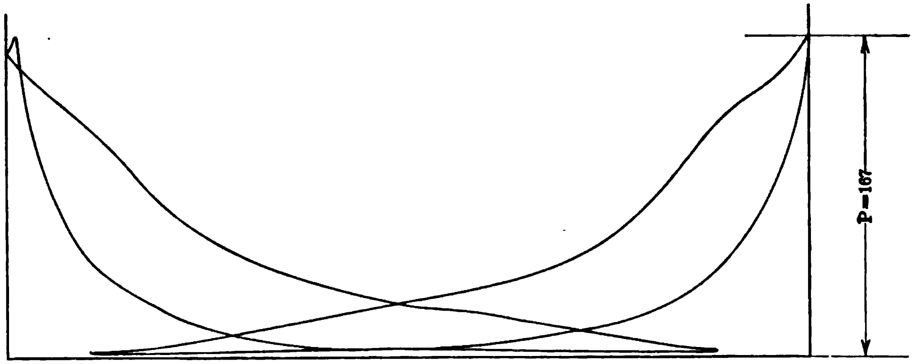
Reverse Lever Fourth Notch from Center Forward.

X



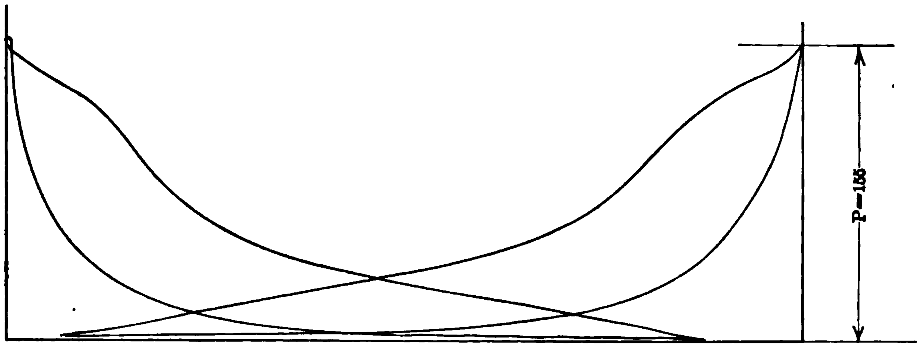
Reverse Lever Second Notch from Center Forward.

XI



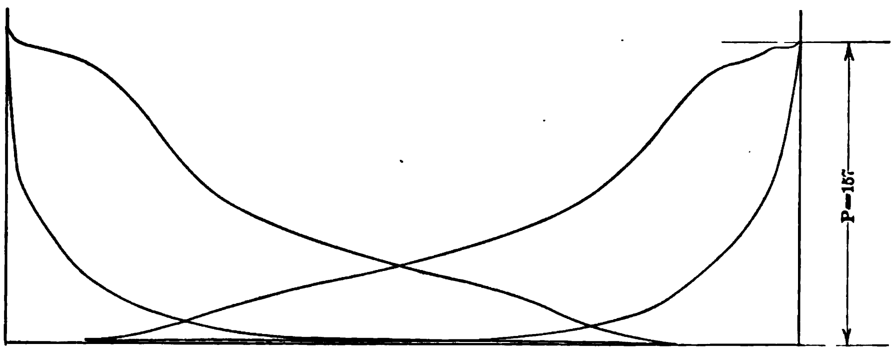
SPEED 50 MILES PER HOUR.

XII



SPEED 40 MILES PER HOUR.

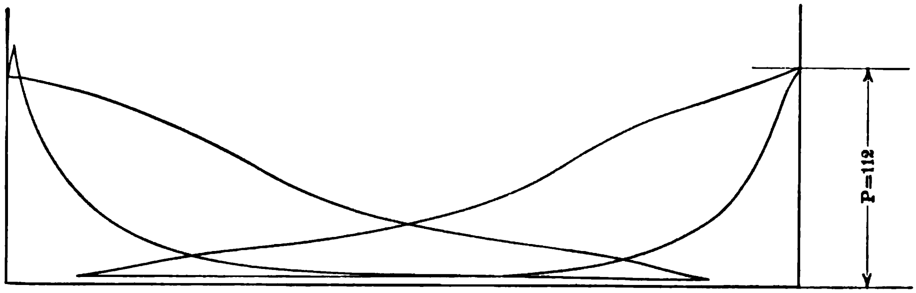
XIII



SPEED 20 MILES PER HOUR.

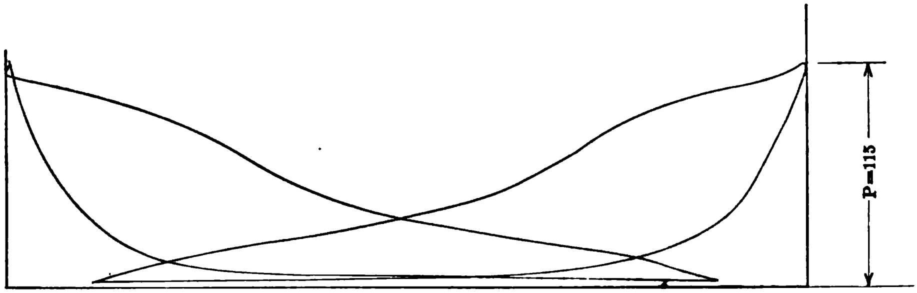
BOILER PRESSURE 160 POUNDS, REVERSE LEVER FOURTH NOTCH FROM CENTER FORWARD.

XIV



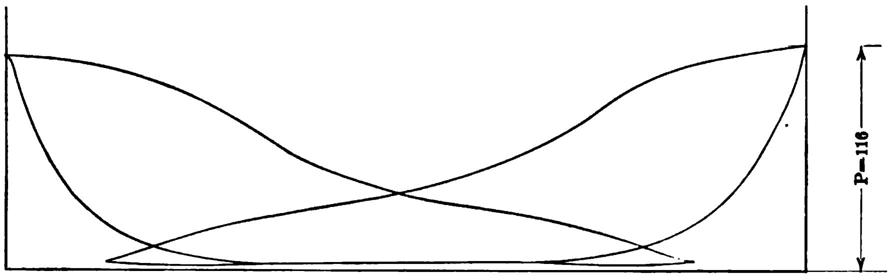
SPEED 50 MILES PER HOUR.

XV



SPEED 40 MILES PER HOUR.

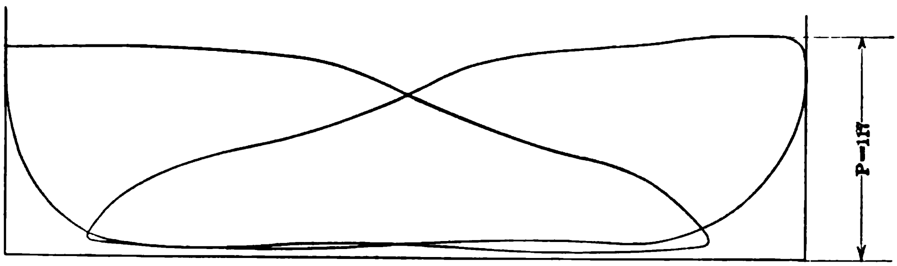
XVI



SPEED 20 MILES PER HOUR.

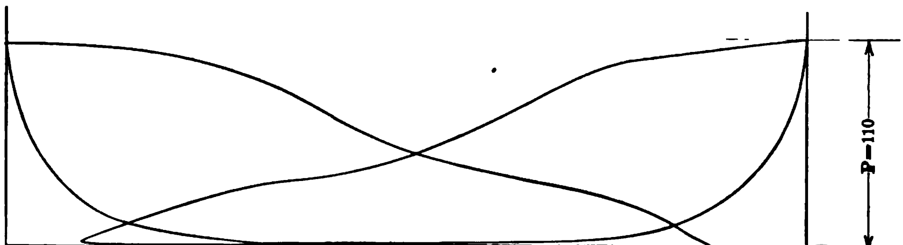
BOILER PRESSURE 120 POUNDS, REVERSE LEVER EIGHTH NOTCH FROM CENTER FORWARD.

XVII

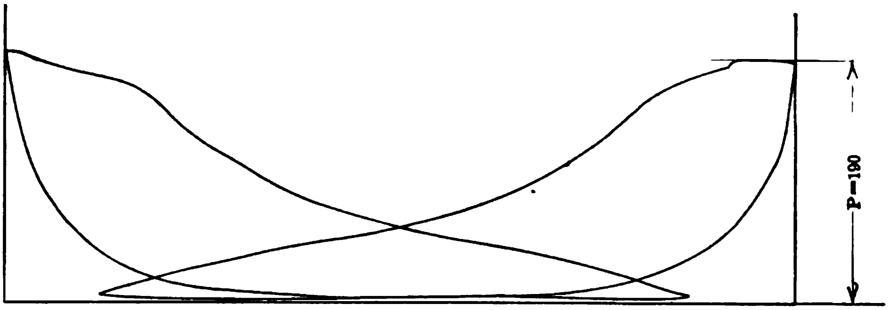


REVERSE LEVER FOURTEENTH NOTCH FROM CENTER FORWARD.

XVIII

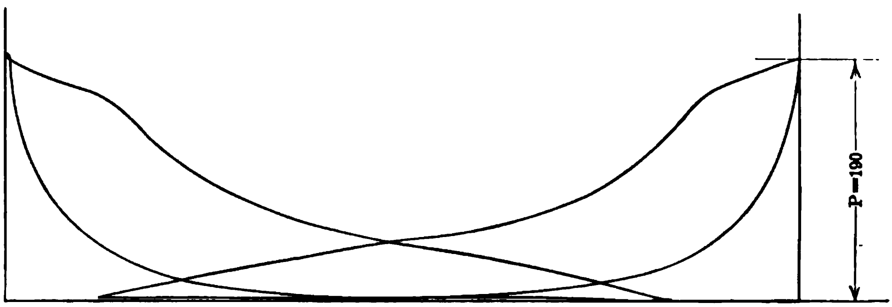


XIX



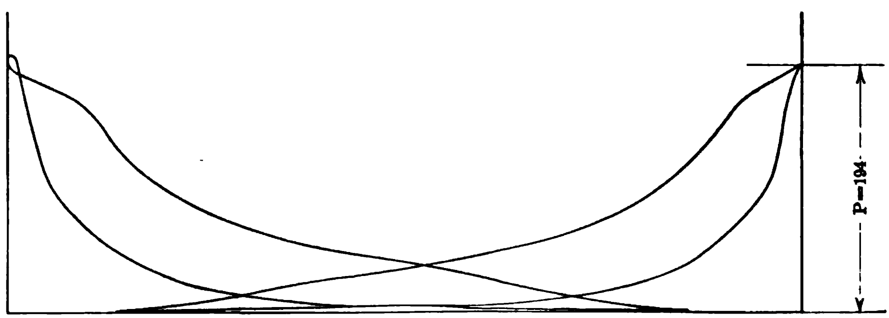
Reverse Lever Sixth Notch from Center Forward.

XX



Reverse Lever Fourth Notch from Center Forward.

XXI



Reverse Lever Second Notch from Center Forward.

Boiler pressure 200 pounds, speed 30 miles per hour.