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LABORATORY TESTS OF A CONSOLIDATION LOCOMOTIVE

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AND
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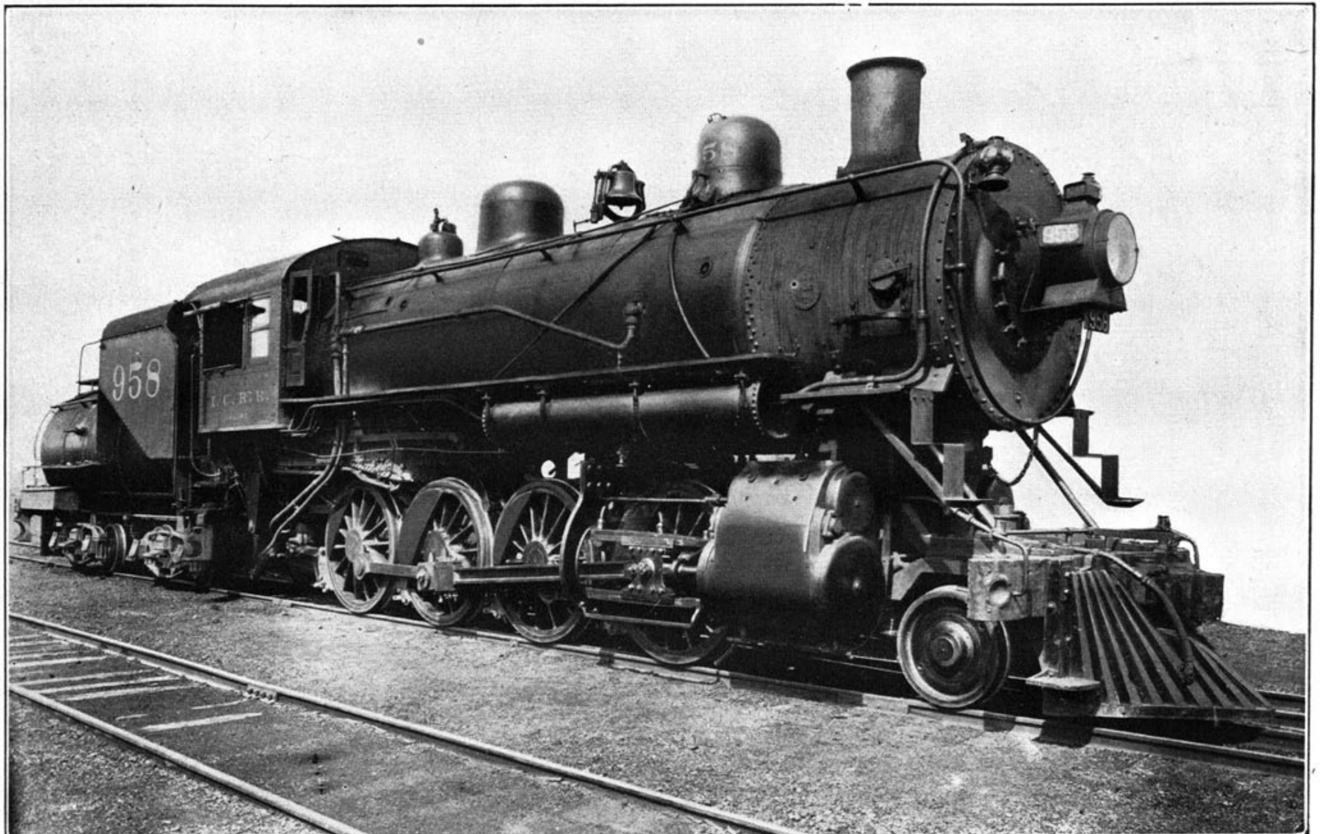

Fig 1. Illinois Central Railroad Locomotive 958.

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BY

EDWARD C. SCHMIDT,[1] JOHN M. SNODGRASS[2] AND ROBERT B. KELLER.[3]

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PART I.

I. Introduction.

1. The tests the results of which are here recorded constitute the first work of the recently established locomotive laboratory of the University of Illinois. They relate to a typical consolidation locomotive which was loaned to the University by the Illinois Central Rrailroad.

In Part I of this report the aim has been to present as brief a statement of the conditions and results as is compatible with a clear understanding of the tests. Part II, on the other hand, consists of appendixes in which supplementary detail is fully recorded. In the presentation and discussion of the results in Part I, only the more important facts concerning boiler and engine performance have been included. There remain in the complete record of results given in Appendix 4 many facts which may be of use to those interested in the details of boiler and engine tests. In this, the first publication relating to the work of the laboratory, laboratory equipment and methods are described in detail in order to complete the record and to provide a basis for reference in future publications from which such detail will be omitted.

2. *Purpose of the Tests.*—The locomotive was first tested in the condition in which it was received from service. It was then subjected to certain repairs some of which affected its performance, and was again fully tested. The main purpose of the tests was to determine the general performance of the locomotive and the performance of its boiler and engines after the repairs were made and when the locomotive was in excellent condition.

3. *Acknowledgments.*—The locomotive was loaned for the tests through the interest and courtesy of Mr. W. L. Park, Vice President, and Mr. Morgan K. Barnum, General Superintendent of Motive Power, of the Illinois Central Railroad. During the progress of the tests Mr. R. W. Bell, then General Superintendent of Motive Power, and various members of his staff frequently gave assistance and advice to those in charge of the laboratory. It is a pleasure to record here our appreciation of these services.

Mr. Franklin W. Marquis, formerly Associate in the Department of Railway Engineering, was in immediate charge of the laboratory

from its establishment until the completion of the first ten tests included in this report. He also had a large share in working out the details of the laboratory design. To him is due the successful solution of many of the problems which arose in putting the equipment in operation and in establishing the test procedure.

We would acknowledge also the assistance received from the numerous members of the laboratory staff and especially from Mr. H. H. Dunn.

II. The Locomotive.

The locomotive tested is of the consolidation (2-8-0) type, built by the Baldwin Locomotive Works in 1909. It weighs 223 000 pounds, and has 22 in. x 30 in. simple cylinders using saturated steam. Its principal dimensions are given below, and a detailed description appears in Appendix 1.

Total weight, in working order, lb.	223 000
Weight on drivers, lb.	200 900
Cylinders (simple), diameter and stroke, in.	22 x 30
Diameter of drivers, in.	63
Fire-box width, in.	66
Grate area, sq. ft.	49.55
Heating surface, tubes (fire side), sq. ft.	3094
Heating surface, total, sq. ft.	3283
Boiler pressure, lb. per sq. in.	200

When it was received at the laboratory, the locomotive had been in service three and one-third years and had run 107 800 miles. Immediately preceding the tests the locomotive had been in service only five weeks after receiving general repairs, and was in good condition when it arrived at the laboratory. It was completely tested in this condition and the results of these tests are designated as Series I. The results of this series disclosed a performance not quite so good as had been anticipated and, in the endeavor to do whatever was possible to improve the performance, valves were reset and eccentric straps shimmed; cylinders and valve chambers were re-bored; new pistons and piston rings, new valve bull-rings and packing rings were applied; rod packing renewed; the exhaust nozzle-tip changed from $5\frac{1}{4}$ in. to $5\frac{7}{8}$ in.; and a small leak in one of the steam pipe joints was stopped. Certain incidental repairs having no effect on performance were made at the same time. Following this work the locomotive was run the equivalent of about 1200 miles in wearing down the cylinders and packing before making the tests of Series 2. It should be emphasized that all of these repairs were resorted to only that nothing which would probably improve the performance be left undone, and that under ordinary service requirements they would have been regarded as quite unnecessary. After their completion the locomotive, then in excellent condition, was subjected to the tests which are designated as Series 2.

Locomotive 958 is a characteristic freight locomotive of whose type there are about twenty thousand on American railways, or one third of the total in service. Its weight and heating surface exceed the average values of these quantities for all consolidation locomotives by about twenty-five per cent. It is in most respects thoroughly representative of its type. Complete laboratory tests of simple consolidation locomotives are not common and include tests of only three different classes, all of which are somewhat smaller than the one here under consideration.*

III. Summary of the Results.

While it is not possible to summarize all the results of the tests further than is done in the curves included beyond, it is feasible briefly to state at this point the main facts defining the range through which the locomotive was worked and to indicate the minimum or maximum values of a few of the more important quantities. The statements apply to the tests of Series 1 and 2 combined.

4. *The Boiler.*—The maximum amount of dry coal fired per hour during any of the tests was 11 127 lb. or 224.5 lb. per square foot of grate per hour, an amount much in excess of what is usual or desirable on hand-fired locomotives in service. The maximum quantity of cinders ejected into the front end and from the stack amounted to 27.4 per cent of the dry coal fired. This cinder loss also is quite unusual and it occurred under conditions which rarely prevail in service, the draft during this test being equivalent to 12.8 inches of water in front of the diaphragm.

During the test in which the heating surface was forced to its greatest activity, the total equivalent evaporation per hour was 57 954 lb., or 17.65 lb. per square foot of heating surface per hour. This rate of evaporation is altogether unusual in service and has been exceeded only rarely under test conditions. The best economic performance of

*"Locomotive Tests and Exhibits" and bulletins No. 7, 8, 9, 12, 13, 15, and 16 published by the Pennsylvania Railroad Company.

the boiler was obtained in test No. 2024 during which the equivalent evaporation per pound of dry coal was 10.07 lb. There is some doubt however about the validity of this result which exceeds the next highest evaporation per pound of coal (8.96 lb.) by 12.4 per cent.

These results were all obtained when using run-of-mine coal from Mission Field Mine, Vermilion County, Illinois, which varied in heating value from 11 835 B.t.u. to 12 848 B.t.u. per pound of dry coal.

5. *The Engines and the Locomotive.*—The maximum indicated horse power developed during the tests was 1654 which occurred in test No. 2093 with a cut-off of 48.6 per cent and a speed of 30.4 miles per hour. This is the greatest power which has been developed during laboratory tests with a locomotive of this type. The maximum drawbar horse power was 1431. The maximum tractive effort developed, 29 240 lb., is only 75 per cent of the rated maximum and is not significant because of the fact that, as in all laboratory tests, it was not feasible to work the locomotive at the lowest speeds and the greatest cut-offs.

The lowest water rate attained was 27.17 lb. of dry steam per indicated horse power per hour. This steam consumption is not so low as has been previously obtained in tests of locomotives of this type under similar conditions, being almost 17 per cent in excess of the lowest figure previously recorded. The minimum heat content of the dry coal fired per indicated horse power per hour was 50 872 B.t.u. and the minimum dry coal fired per hour per indicated horse power was 4.00 lb. The minimum dry coal fired per hour per drawbar horse power was 4.62 lb.

IV. The Tests and the Test Program.

The locomotive was worked during the tests throughout a range of speed corresponding to that which would ordinarily prevail in service. At each of the various speeds the endeavor was made to vary the cut-off throughout as wide a range as the capacity of the boiler or of the grate would permit. The adhesion between the drivers and the supporting wheels in the laboratory is less however than the adhesion between the drivers and the rail on the road, and consequently it was impossible at low speeds to run at maximum cut-offs. The designations for speed and cut-off used in this section are approximate only, and represent the conditions predetermined for each test. The actual average values attained during the tests appear in Appendix 4. All tests were run with the throttle wide open.

TABLE 1.

TEST PROGRAM—SERIES 2.

SHOWING TESTS RUN AT VARIOUS SPEEDS AND CUT-OFFS.

Approximate Speed		Approximate Cut-off—Per cent of Stroke					
Rev. per Minute	Miles per Hour	16	24	32	40	48	56
55	10		2081 2086	2075 2097	2085 2096	2095 2098	
110	20	2080 2087	2077	2073	2072	2084	2094
165	30	2083	2078	2074 2092	2082	2093	
220	40	2088	2079	2076	2089		

TABLE 2.

TEST PROGRAM—SERIES 1.

SHOWING TESTS RUN AT VARIOUS SPEEDS AND CUT-OFFS.

Approximate Speed		Approximate Cut-off—Per cent of Stroke					
Rev. per Minute	Miles per Hour	16	20	24	32	40	48
55	10			2024	2028		
83	15	2017 2021		2018 2020	2019 2022	2031	
110	20	2026		2027	2029	2035	2033
138	25	2009		2012	2013	2023	
165	30			2030	2032	2037	
193	35	2016	2010	2015	2014	2034	

6. *Series 2.*—Series 2 comprises 25 tests and includes tests 2072 to 2098 (excepting only tests 2090 and 2091 which are referred to beyond). In this series the speed varied from 10 to 40 miles per hour or from 55 to 220 revolutions per minute, while the cut-off ranged from 16 per cent to 56 per cent of the stroke. The distribution of these tests at the different speeds and cut-offs is shown in Table 1.

As elsewhere explained, (see section II and Appendix 1) the locomotive during this group of tests was in excellent condition, valves having been reset, valve chambers and cylinders rebored, the packing for pistons and valves and rods renewed, a leak in one of the steam pipe joints stopped, and the exhaust nozzle tip changed from 5¼ in. to 5⅞ in.

7. *Series 1.*—Series 1 comprises 26 tests and includes tests 2009 to 2037 (excepting No. 2011, 2025, and 2036). Test 2025 is omitted from the record because of errors in water measurement, and tests 2011 and 2036 were discontinued before their completion—one on account of an injector failure, the other on account of a faulty valve in the line supplying oil to the absorption brakes.

In this group of tests the speed varied from 10 to 35 miles per hour or from 55 to 193 revolutions per minute, while the cut-off ranged from 16 per cent to 48 per cent of the stroke. The distribution of these tests at the different speeds and cut-offs is shown in Table 2. During Series 1 the locomotive was in the condition in which it was received at the laboratory, which is distinguished from the condition prevailing during Series 2 by the repairs above cited.

8. *Intermediate Tests.*—Immediately after the completion of the tests of Series 1, the valves of the locomotive were reset, the eccentric straps shimmed, rod packing replaced, and the valve rings and piston rings were renewed and refitted. After these changes eight tests—No. 2038 to 2045—were run.

These changes, intended to improve cylinder performance, did not materially affect it. Because of them, however, these tests are excluded from Series 1 and their results appear only in Appendix 4. They are not included in any of the figures presented in the report. Since during these eight tests the condition of the boiler was exactly the same as during Series 1, their results relating to boiler performance are comparable with those of that series.

During the progress of Series 2, two tests—No. 2090 and 2091—were run with the nozzle tip changed from 5⅞ in. to 5¼ in. With this exception all conditions prevailing in these two tests were the same as in Series 2. These tests are referred to beyond, and their results are separately presented in Appendix 4. They are excluded from Series 2.

In addition to the tests above mentioned, 26 runs (No. 2046-2071) were made for such purposes as to wear down the cylinder and valve chambers after re-boring, to make final choice of exhaust nozzle tip, etc. While these runs were given test numbers, they were incomplete and were not intended to be included in the report. Of the 64 tests made with the expectation that they would be embodied in the report, only the three referred to in paragraph 7 have been excluded from the record.

V. Test Methods and Test Conditions.

9. *Methods and Equipment.*—The methods employed in conducting the tests and in deriving the results are explained in detail in Appendixes 3 and 5. They conform in general to those prescribed by the American Railway Master Mechanics' Association code for conducting laboratory tests of locomotives, published in the Proceedings of the Association for 1914. Whatever deviations from this code have been found desirable are indicated in the appendixes.

The laboratory equipment is described in Appendix 2. While this equipment differs in several details from that of other laboratories, the only difference which has materially affected test methods lies in the presence of a cinder separator, through which all the exhaust gases pass and in which the entire body of cinders is collected. Except during one group of tests conducted at the Pennsylvania Railroad testing plant, when temporary provision was made to collect all the cinders issuing from the stack, the cinder discharge has been determined in other laboratory tests merely by sampling the exhaust gas stream.

The design of this cinder separator is illustrated in Appendix 2. Its operation has been entirely successful. Repeated examinations of the exhaust gases as they issued from the separator, and unsuccessful attempts to collect solid matter in the neighborhood of the laboratory stack have made it clear that the separator collects and retains even the finest cinders under all test conditions.*

10. *Conditions.*—As previously stated the coal used during all the tests came from Mission Field Mine, Vermilion County, Illinois. For all tests to and including No. 2091 run-of-mine coal was used. During tests 2092, 2093, 2094, and 2095 a mixture of run-of-mine and screened lump was used, which in appearance, analysis, and performance was not materially different from the run-of-mine alone. During the last three tests, (2096-2098) on account of a shortage in the supply of run-of-mine coal, 1½-in. screenings were used. Because of this difference in conditions, all data and all results involving coal are excluded from the record of these three tests.

The locomotive during all tests was fired by C. Welker, a skilled fireman, detailed for this purpose by the Illinois Central Railroad from their regular force. Previous to his engagement at the laboratory, he had had four and one-half years' experience as fireman on this road and upon the completion of the tests returned to their service. Dur-

*The term *cinders* is here used to mean particles of appreciable size as distinguished from impalpable dust. Samples of the stack cinders representing the entire range in rate of combustion contained from 10 to 18 per cent of material which passed a 200 mesh screen.

ing some of the tests he was assisted by one of three other firemen who were also detailed at various times from the local Illinois Central force. None of these men had had less than one year's experience. Mr. Welker in these tests, as in those in which he acted alone, remained in charge and responsible for the character of the work.

The condition of the locomotive has been briefly stated in Section II and is more fully explained in Appendix 1. The test program and the conditions of speed and cut-off have been presented in section IV.

VI. The Results of the Tests of Series 2.

All the data and the results of the tests of Series 2 are presented in detail in the tables of Appendix 4. There are included in this section only the more important data and results relating to the performance of the boiler, the engines, and the locomotive. These facts are here presented in both tabular and graphical form. In establishing the relations between results chief reliance is placed upon the figures; and the tabular matter, which is a repetition of parts of Appendix 4, is included for convenience of reference only. Except where otherwise specifically stated, the curves in the figures have been produced by averaging the coordinates of various groups of points, plotting these average values, and passing as nearly as possible through the points thus determined a smooth curve. The test designations which appear in the tables indicate first the approximate speed in revolutions per minute, next the nominal cut-off in per cent, and finally the amount of throttle opening. Thus in test 2072, designated as 110-40-F, the speed was about 110 revolutions per minute, the cut-off approximately 40 per cent, and the throttle—as in all the tests—was "full" or wide open.

A. Boiler Performance.

The more significant data and results pertaining to the performance of the boiler in Series 2 are collected from Appendix 4 and presented here in Tables 3 and 4, which include nearly all the facts used in producing the figures relating to boiler performance. In both of these tables the tests are arranged in the order of the increasing amounts of dry coal fired per hour per square foot of grate (code No. 627). If this arrangement is borne in mind, some of the relations may be more definitely and quite as conveniently studied in the tables as in the curves.

In attempting to draw from these results inferences concerning the performance of locomotives in service, it should be remembered that

TABLE 3.
BOILER PERFORMANCE—SERIES 2.

Test No.	Laboratory Designation	Average Boiler Pressure, lb. per sq. in.	Duration of Test, Minutes	Dry Coal Fired per Hour, lb.		Draft, in. of Water				Temperature, Deg. F.		Quality of the Steam in the Dome
				Total	Per sq. ft. of Grate	In the Ash-pan	In the Fire-box	Back of the Diaphragm	In Front of the Diaphragm	In the Fire-box	In the Front-end	
	Code Item☞	380		626	627	397	396	395	394	374	367	407
2081	55–24–F	198.2	150	1975	39.9	0.2	0.7	1.5	2.2	1407	507	0.9963
2086	55–24–F	199.1	170	2068	41.7	0.3	0.7	1.4	2.2		506	0.9963
2075	55–32–F	198.1	140	2327	47.0	0.3	0.9	1.8	2.8	1661	543	0.9952
2080	110–16–F	198.8	130	2422	48.9	0.2	1.0	2.0	2.9	1418	534	0.9956
2087	110–16–F	199.2	150	2474	49.9	0.2	0.9	1.9	2.9		524	0.9956
2085	55–40–F	197.9	120	3058	61.7	0.3	1.1	2.5	4.0		545	0.9962
2077	110–24–F	196.0	110	3281	66.2	0.4	1.3	2.5	4.1	1570	565	0.9947
2095	55–48–F	198.1	60	3334	67.3	0.4	1.5	3.0	5.3		567	0.9943
2083	165–16–F	198.7	100	3338	67.4	0.4	1.6	2.7	4.3	1267	563	0.9934
2088	220–16–F	197.8	100	3353	67.7	0.3	1.2	2.9	4.5		563	0.9919
2073	110–32–F	197.6	80	4359	87.9	0.5	1.6	3.5	5.7	1662	595	0.9919
2078	165–24–F	196.4	70	4707	95.0	0.5	1.9	3.9	6.0	1597	595	0.9915
2092	165–32–F	198.4	50	5640	113.8	0.6	2.2	5.1	8.2		643	0.9894
2079	220–24–F	197.4	60	5783	116.7	0.4	2.3	4.8	7.0	1688	614	0.9889
2072	110–40–F	196.7	60	5927	119.6	0.7	2.0	4.9	8.0	1643	620	0.9895
2074	165–32–F	197.1	60	6015	121.3	0.5	2.4	5.3	8.5	1662	637	0.9861
2076	220–32–F	196.0	35	7831	158.0	0.5	2.8	5.7	9.2	1785	675	0.9844
2084	110–48–F	194.0	50	7914	159.7	0.8	2.9	6.3	10.0		653	0.9896
2094	110–56–F	196.3	25	8434	170.2	0.8	3.0	7.3	12.1		679	0.9887
2082	165–40–F	195.2	50	8994	181.5	0.6	3.4	7.3	11.2	1458	673	0.9886
2093	165–48–F	191.5	30	10216	206.2	0.9	3.4	7.8	12.8		702	0.9879
2089	220–40–F	194.9	35	11127	224.5	0.7	3.5	7.1	11.9		703	0.9884

TABLE 4.

BOILER PERFORMANCE—SERIES 2.

Test No.	Dry Coal Fired, per Hour per sq. ft. of Grate, lb.	Equivalent Evaporation, lb.			Calorific Value per lb. of Dry Coal, B. t. u.	Cinders					Efficiency of the Boiler Including the Grate, per cent
		Per Hour	Per Hour per sq. ft. of Heating Surface	Per lb. of Dry Coal		Accumulated in the Front-end per Hour, lb.	Discharged from the Stack per Hour, lb.	Total per Hour, lb.	Total in Per cent of the Dry Coal Fired	Calorific Value in Per cent of the B.t.u. Contained in the Dry Coal	
	627	645	648	658	458	422 & 345	423 & 345	424 & 345	426	460 & 458	666
2081	39.9	17 277	5.26	8.75	12 700	7.2	62	69	3.5	44.93	66.89
2086	41.7	17 308	5.27	8.37	12 586	6.0	110	116	5.6	46.69	64.49
2075	47.0	19 954	6.08	8.57	12 718	5.6	165	171	7.3	55.17	65.46
2080	48.9	20 923	6.37	8.64	12 848	6.9	97	104	4.3	44.99	65.28
2087	49.9	20 846	6.35	8.43	12 272	7.2	118	126	5.1	55.34	66.63
2085	61.7	25 270	7.70	8.26	12 622	8.5	217	226	7.4	77.50	63.54
2077	66.2	26 417	8.05	8.05	12 633	7.7	245	253	7.7	66.50	61.82
2095	67.3	28 614	8.72	8.58	12 315	10.0	250	260	7.8	70.78	67.61
2083	67.4	26 448	8.06	7.92	12 660	12.6	259	271	8.2	73.70	60.72
2088	67.7	26 995	8.22	8.05	12 095	10.2	273	283	8.5	71.29	64.58
2073	87.9	33 719	10.27	7.74	12 751	9.0	553	562	12.9	75.69	58.92
2078	95.0	34 431	10.49	7.31	12 517	13.7	648	662	14.1	76.16	56.66
2092	113.8	41 770	12.72	7.41	12 620	14.5	841	855	15.1	81.42	56.95
2079	116.7	38 155	11.62	6.60	12 767	14.0	873	887	15.3	78.13	50.18
2072	119.6	40 590	12.36	6.85	12 460		1140				53.36
2074	121.3	41 701	12.70	6.93	12 575	3.0	949	952	15.8	79.55	53.50
2076	158.0	46 838	14.27	5.98	12 519	24.1	1822	1847	23.4	88.86	46.41
2084	159.7	46 913	14.29	5.93	12 305	24.1	1499	1523	19.2	88.90	46.76
2094	170.2	54 336	16.55	6.44	12 426	31.0	1931	1962	23.5	85.46	50.33
2082	181.5	49 007	14.93	5.45	12 626	22.9	1976	1999	22.1	87.08	41.87
2093	206.2	57 954	17.65	5.67	12 551	20.0	2782	2802	27.4	83.51	43.82
2089	224.5	54 989	16.75	4.94	12 356	22.4	2979	3002	26.8	91.95	38.77

during the tests the boiler was forced somewhat beyond the limits which would ordinarily be maintained in service; so that the maximum test values of such measures of boiler activity as draft, rate of combustion, and rate of evaporation are somewhat greater than the values which would be maintained on the road for any except very short periods.

11. *General Conditions.*—The average boiler pressure varied during the tests of this series from 191.5 to 199.2 pounds, and the feed temperature ranged between 44.7 and 63.6 degrees. As is common under the uniform conditions of load which are maintained in laboratory tests, the quality of the steam was high and nearly uniform throughout the series, the lowest quality being 0.984 and the highest 0.9963.

The calorific value of the fuel varied between the limits of 10 487 and 11 660 B.t.u. per pound of coal as fired, and from 12 095 to 12 848 B.t.u. per pound of dry coal. The ash in the coal as fired varied from 9.64 to 13.96 per cent.

Of the 25 tests of Series 2, seventeen were of more than one hour's duration. In the remaining eight tests the test period was less than one hour, being in one test only 25 minutes. Even in this test, however, the coal burned amounted to 4095 pounds.

12. *Draft.*—The relation between the draft values and the rate of combustion is indicated in Fig. 2, and their relation to rate of evaporation in Fig. 3. Inspection of the curve of firebox draft in these figures reveals close agreement between the values represented by the individual points and the average value represented by the curve. This fact may be accepted as an indication of the uniformity with which the fire was managed during the tests.

In test 2093 the drafts in front of the diaphragm, back of the diaphragm, in the firebox, and in the ashpan were 12.8, 7.8, 3.4, and 0.9 inches of water respectively. The rate of combustion in this test was 118.66 pounds of coal per hour. The drafts cited are the maxima attained during this series except in the case of firebox draft which was exceeded by 0.1 of an inch in one other test.

13. *Firebox and Front-end Temperatures.*—The temperature of the gases in the firebox varied between 1267 and 1785 degrees during the first twelve tests of this series. This temperature was not recorded during the remaining tests because of a break-down in the pyrometer equipment. The relation of this temperature to both rate of combustion and rate of evaporation is exhibited by the upper curves of Fig. 4 and 5 respectively.

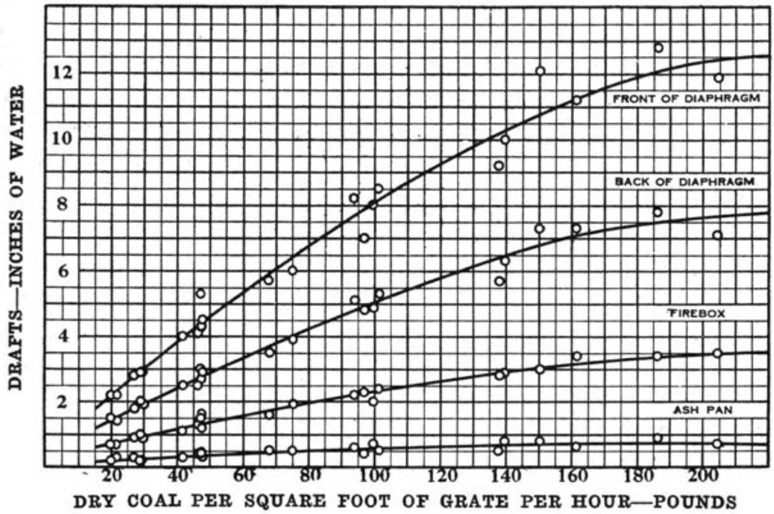

FIG. 2. THE RELATIONS BETWEEN DRAFT AND RATE OF COMBUSTION.

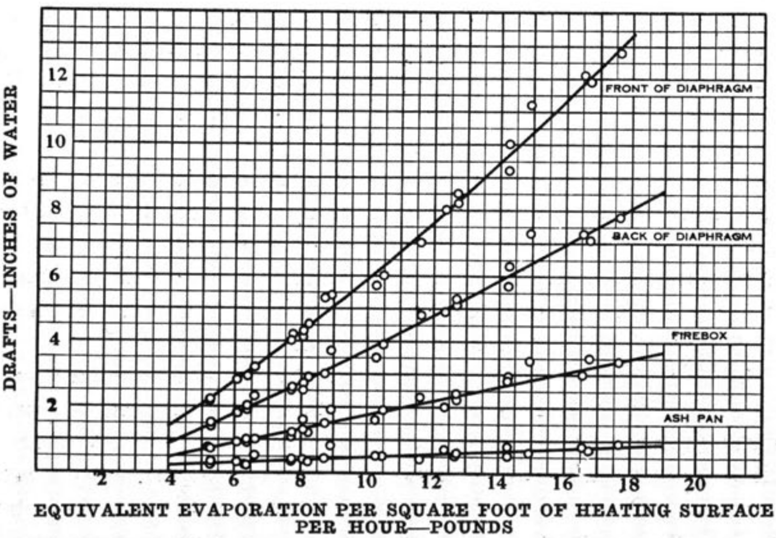

FIG. 3. THE RELATIONS BETWEEN DRAFT AND RATE OF EVAPORATION.

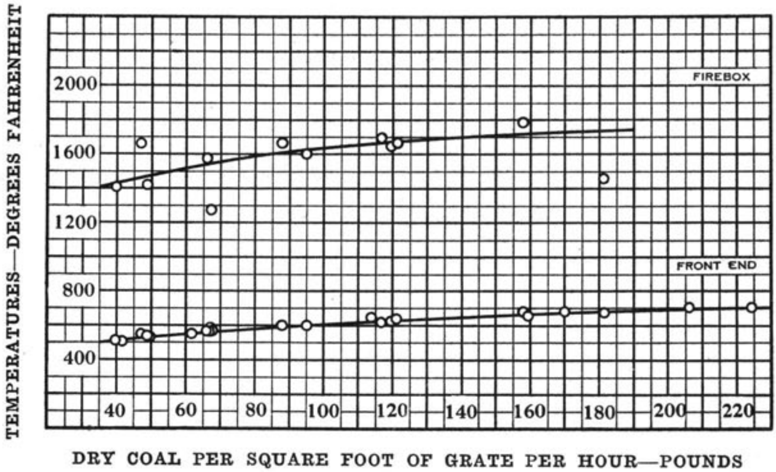

FIG. 4. THE RELATIONS BETWEEN FIREBOX AND FRONT-END TEMPERATURES AND RATE OF COMBUSTION.

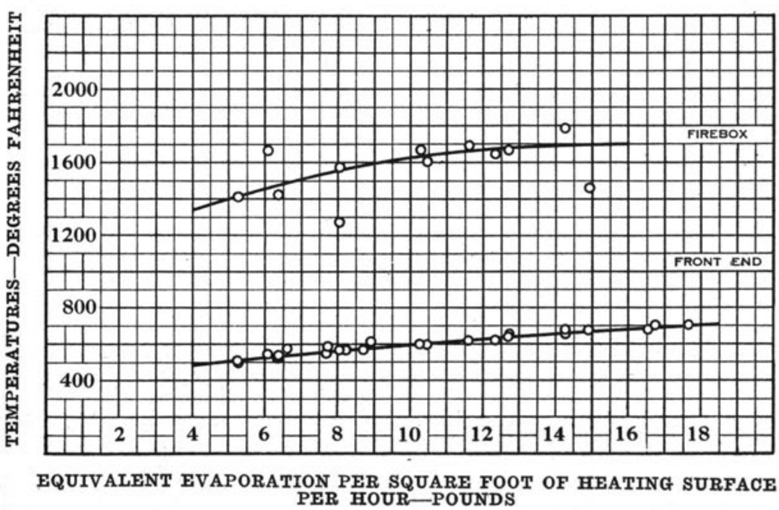

FIG. 5. THE RELATIONS BETWEEN FIREBOX AND FRONT-END TEMPERATURES AND RATE OF EVAPORATION.

The temperature of the gases in the front-end ranged between 506 and 702 degrees and increased very regularly as the activity of the grate and of the heating surface was increased. The relation of front-end temperature to rate of combustion appears in the lower curve of Fig. 4, and its relation to rate of evaporation in Fig. 5.

14. *Coal Consumption.*—The smallest amount of fuel fired during any of the tests was 3799 pounds of moist coal or 3334 pounds of dry coal. The greatest amount per test was 8506 pounds of moist coal or 7495 pounds of dry coal. The rate of firing ranged from 1975 pounds of dry coal per hour in test 2081 to 11 127 pounds of dry coal per hour in test 2089. The rate of combustion varied between 39.9 and 224.5 pounds of dry coal per square foot of grate per hour.

15. *Evaporation.*—The equivalent evaporation per hour varied between the limits of 17 277 and 57 954 pounds. The rate of increase in equivalent evaporation per hour with respect to the hourly consumption of dry coal is exhibited in Fig. 6. In this figure four of the highest values of evaporation are somewhat more divergent from the average represented by the curve than are the values for other tests. These four are all tests of short duration in which the measurement of the coal may be on this account slightly less accurate than in the other tests. Two of them, however, are tests in which the coal used was the mixture of lump and run-of-mine referred to in section V, and this fact may perhaps partially account for their divergence.

The equivalent evaporation per square foot of heating surface per hour varied in this series from 5.26 pounds to 17.65 pounds. Fig. 7 shows the relation of the rate of evaporation to the amount of dry coal fired per square foot of grate per hour.

16. *Boiler Horse Power.*—Under the usual convention of 34.5 pounds of equivalent evaporation per hour per horse power, the boiler of this locomotive developed a maximum horse power of 1680. This maximum is equivalent to one horse power for each 1.95 square feet of heating surface, or for each 0.295 of a square foot of grate area.

17. *Economic Performance.*—The equivalent evaporation per pound of dry coal ranged from a minimum of 4.94 to a maximum of 8.75 pounds. This range represents as good a performance as would be expected from the grade of coal used. The lower evaporations per pound of coal were of course obtained with the higher rates of combustion and evaporation. The rate of this decrease in evaporation per pound of dry coal is shown in Fig. 8 and 9, the former showing the decrease with respect to increase in the rate of combustion and the latter with respect to increase in the rate of evaporation. Either of these figures may serve as an index of the general performance of the boiler.

18. *Boiler Efficiency.*—By efficiency is meant, in this connection, the ratio of the heat absorbed by the boiler to the heat contained in

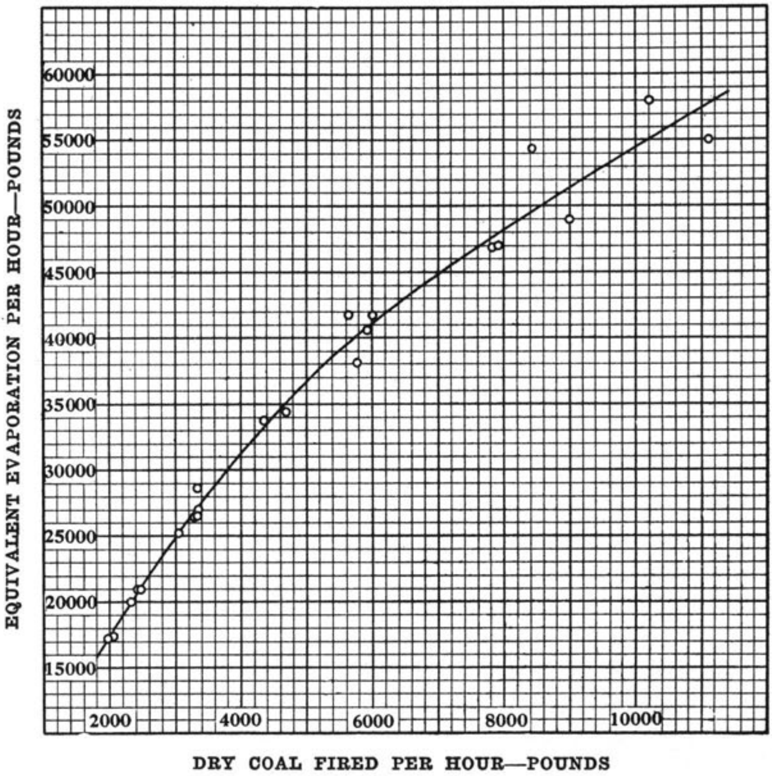

FIG. 6. THE RELATION BETWEEN HOURLY EVAPORATION AND HOURLY COAL CONSUMPTION.

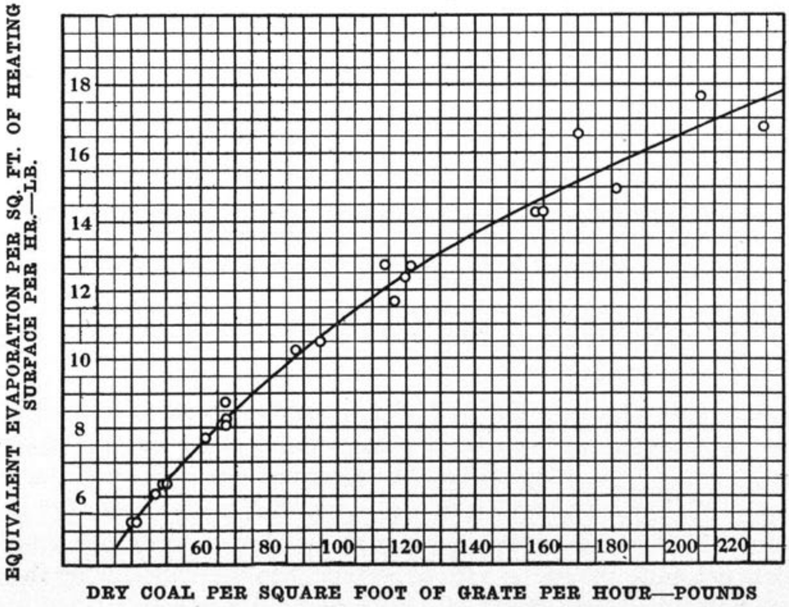

FIG. 7. THE RELATION BETWEEN RATE OF EVAPORATION AND RATE OF COMBUSTION.

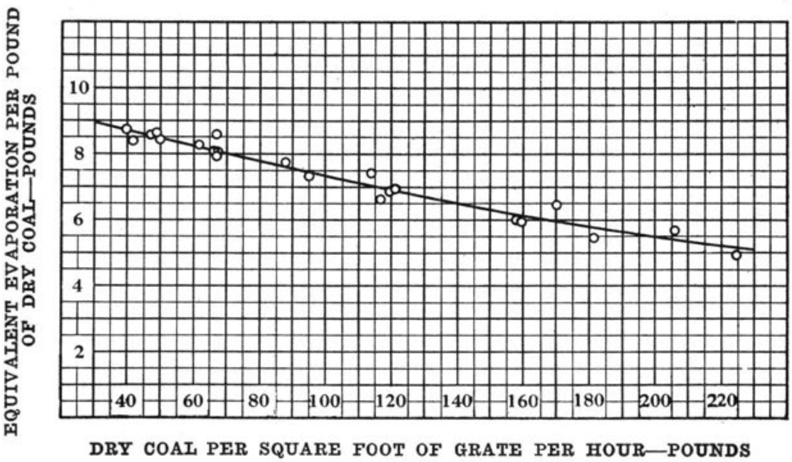

FIG. 8. THE RELATION BETWEEN EVAPORATION PER POUND OF COAL AND RATE OF COMBUSTION.

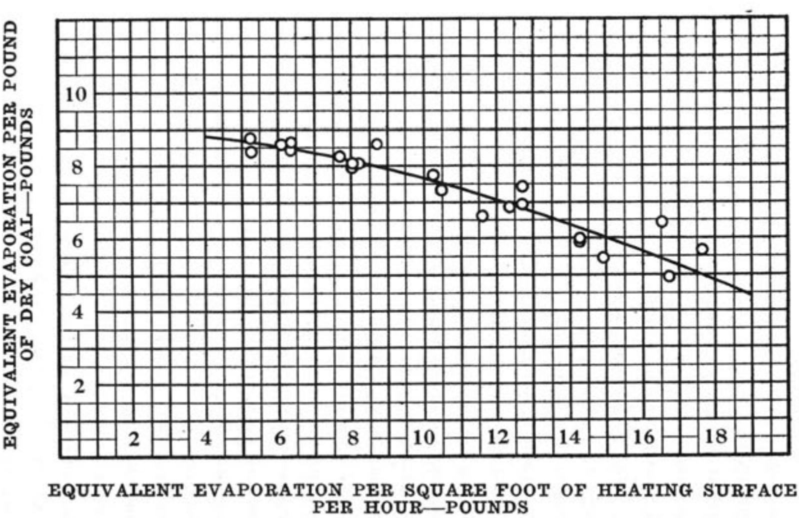

FIG. 9. THE RELATION BETWEEN EVAPORATION PER POUND OF COAL AND RATE OF EVAPORTAION.

the coal in the condition in which it was supplied to the fire, and it represents therefore the combined efficiencies of the furnace and of the boiler proper, in producing and utilizing the heat. The maximum efficiency, 67.61 per cent, was obtained in test 2095 with a rate of combustion of 67.3 pounds of dry coal per square foot of grate per hour, which is not quite the lowest rate of combustion occurring during this

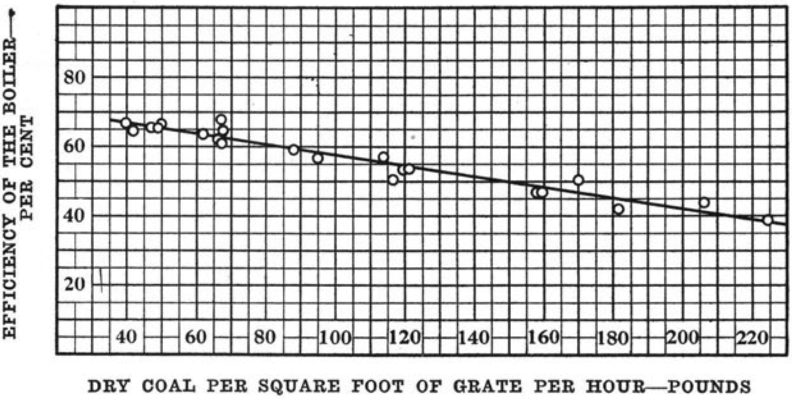

Fig. 10. The Relation Between Boiler Efficiency and Rate of Combustion.

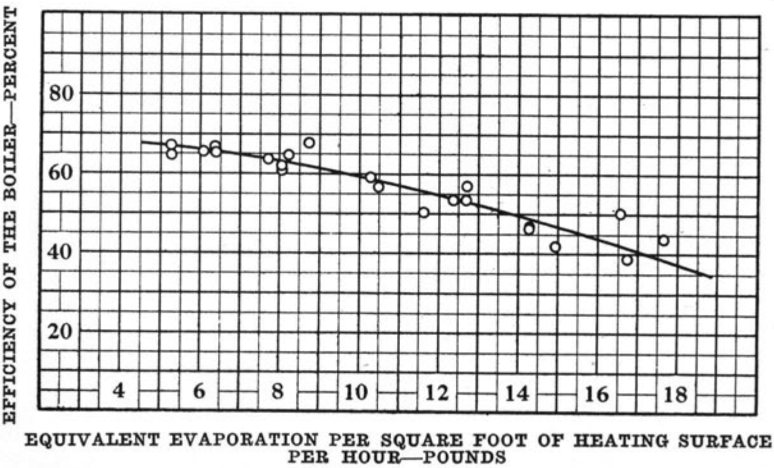

Fig. 11. The Relation Between Boiler Efficiency and Rate of Evaporation.

series. The minimum efficiency, 38.77 per cent, was obtained in test 2089 in which the highest rate of combustion prevailed, namely 224.5 pounds of dry coal per square foot of grate per hour. The relations of efficiency to rate of combustion and to rate of evaporation are shown in Fig. 10 and 11, respectively.

19. *Cinder Losses.*—The data relating to the cinder losses which occurred during these tests have an especial significance in view of the methods by which they were obtained. The locomotive was equipped with a self-cleaning front-end and the maximum amount of cinders there collected during any test was only 21 pounds. In no test did the weight of front-end cinders amount to more than 0.4 of one per cent of the dry coal fired. For this reason no attempt is made to distinguish between cinders accumulated in the front end and those discharged from the stack, in the discussion here presented, although they are so distinguished in Table 4. In the discussion only the total amounts of cinders formed are referred to. These are substantially the same as the amounts discharged from the stack.

The minimum cinder loss occurred in test 2081, during which cinders were formed at the rate of 69 pounds per hour. The draft in this test was equivalent to 2.2 inches of water in front of the diaphragm, and the rate of combustion was 39.9 pounds of dry coal per square foot of grate per hour. The greatest cinder loss amounted to 2984 pounds per hour and occurred in test 2089, in which the corresponding draft was 11.9 inches of water and the rate of combustion 224.5 pounds of dry coal per square foot of grate per hour. Fig. 12 shows the increase in cinders formed per hour as the amount of coal burned per hour increases.

These cinder losses are more conveniently expressed as percentages of the weight of dry coal fired, and they are so presented in Table 4. Inspection of this table shows the minimum loss to have amounted to 3.5 per cent of the dry coal fired. This loss occurred in test 2081 in which, as above stated, the draft in front of the diaphragm was 2.2 inches of water and 39.9 pounds or dry coal were burned per square foot of grate per hour. The maximum cinder loss amounted to 27.4 per cent of the dry coal fired and occurred in test 2093, when the draft was 12.8 inches and the rate of combustion 206.2 pounds of dry coal per square foot of grate per hour. With few exceptions the cinders increase in amount with every increase in the rate of combustion. Fig. 13 shows the relation between cinder loss in per cent of the dry coal fired and the rate of combustion. The cinder losses have been expressed as percentages of the dry coal rather than of the coal as fired, because of the accidental variations in the moisture content of the latter. For this reason the amounts of dry coal fired have seemed here as elsewhere to offer the more logical basis for computation. If the cinder losses had been based upon moist instead of dry coal they would have been de-

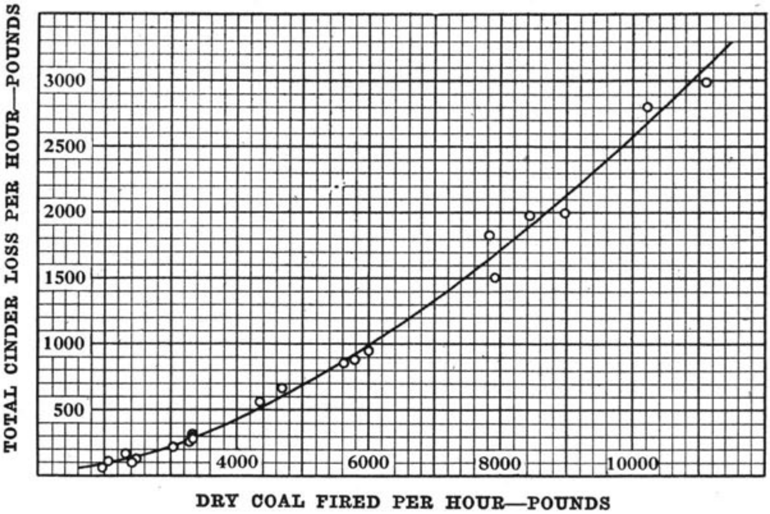

FIG. 12. THE RELATION BETWEEN HOURLY CINDER DISCHARGE AND HOURLY COAL CONSUMPTION.

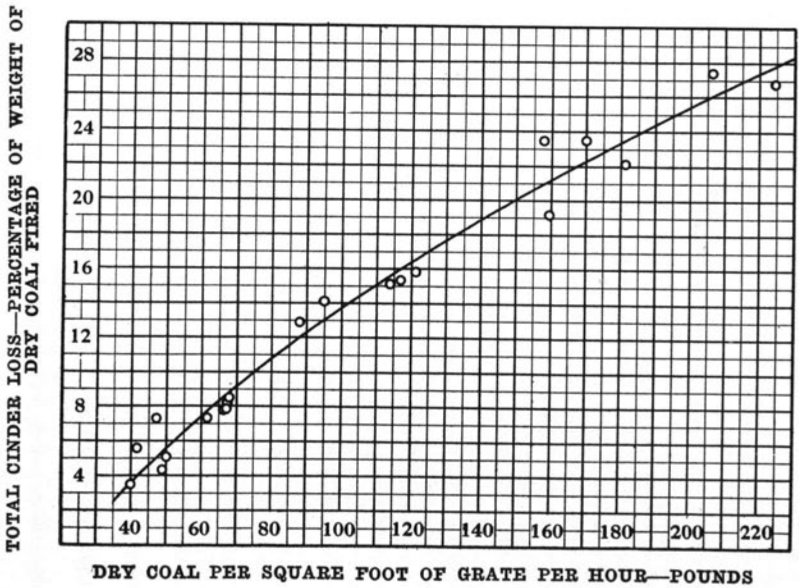

FIG. 13. THE RELATION BETWEEN CINDER DISCHARGE AND RATE OF COMBUSTION.

fined, of course, by smaller percentages. So based, the cinder losses in this series varied between 3.1 and 23.6 per cent.

In service the dry coal fired per square foot of grate per hour probably would rarely exceed 120 pounds. At this rate of combustion Fig. 13 indicates a cinder loss of about 16 per cent. On the road, therefore, except during rare and short intervals, the cinder discharge for this locomotive would probably range between 3 and 16 per cent of the weight of the dry coal fired, when using coal similar to that used during these tests.

The immediate cause of the cinder discharge is of course the intense draft which is essential in locomotive boiler operation. The relation of the cinder loss to draft is shown in Fig. 14 in which the ordinates represent cinder discharge in percentages of the dry coal, and the abscissae the draft in the front-end in front of the diaphragm. Fig. 14 shows the cinder discharge to have been almost directly proportional to draft.

The heating value of the cinders varied greatly, depending on the speed of their transit through the furnace and boiler. This speed is obviously influenced largely by the draft, which in turn determines also the rate of combustion. The increase in the heating value of the cinders as the rate of combustion increases is shown in Fig. 15, in which the ordinates represent the heating value of the cinders expressed as percentages of the B.t.u. contained in the dry coal, and the abscissae represent the rates of combustion. In test 2081 with the lowest rate of combustion and the smallest cinder loss, the calorific value of the cinders was only 44.9 per cent of the calorific value of the dry coal. In test 2089 with the highest rate of combustion and next to the greatest cinder discharge, the calorific value of the cinders was 92 per cent of that of the dry coal, the cinders in this case having passed through the boiler practically unburnt.

20. *Heat Balances.*—The heat balances for the tests of Series 2 are presented in Table 5, in which the various items of the balance are expressed in percentages of the heating value of the coal in the condition in which it was fired. The tests are arranged in the table in the order of the increasing amounts of equivalent evaporation per square foot of heating surface per hour.

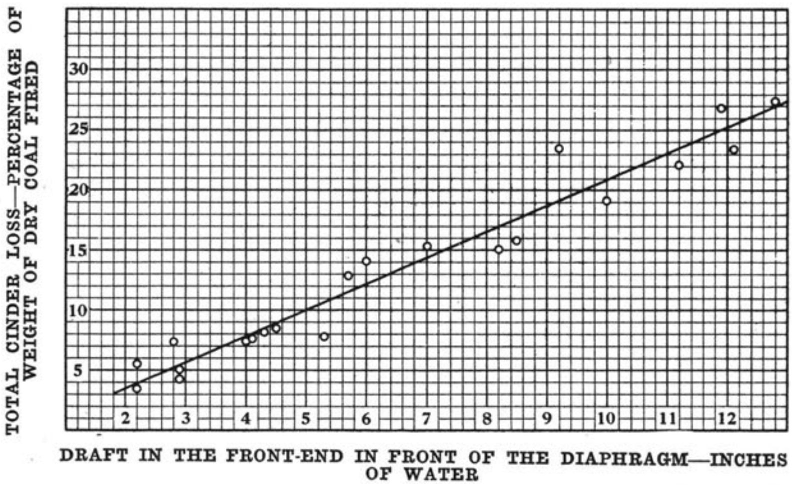

FIG. 14. THE RELATION BETWEEN CINDER DISCHARGE AND DRAFT.

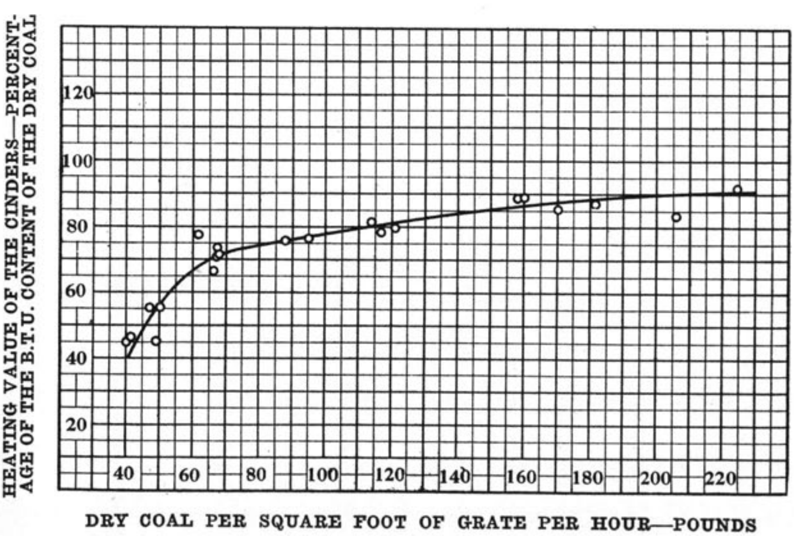

FIG. 15. THE RELATION BETWEEN THE HEATING VALUE OF THE CINDERS AND RATE OF COMBUSTION.

TABLE 5.

HEAT BALANCE FOR SERIES 2.

Test No.	Equivalent Evaporation per sq. ft. of Heating Surface per Hour, lb.	Percentages of the Heating Value of the Coal as Fired									
		Absorbed by the Boiler	To Moisture in the Coal	To Moisture in the Air	To Hydrogen in the Coal	To Escaping Gases	To Incomplete Combustion	To Combustible in the Front-end Cinders	To Combustible in the Stack Cinders	To Combustible in the Ash	To Radiation and Not-accounted for
	648	881	882	883	884	885	886	887	888	890	899
2081	5.26	60.9	1.3	0.3	4.6	18.9	0.0	0.2	1.5	3.2	3.2
2086	5.27	64.5	1.4	0.2	4.5	15.8	0.6	0.1	2.4	3.3	7.2
2075	6.08	65.5	1.5	0.3	4.6	17.9	0.7	0.1	3.9	1.4	4.3
2087	6.35	66.6	1.4	0.3	4.6	15.9	0.0	0.1	2.6	3.5	5.0
2080	6.37	65.3	1.5	0.3	4.6	17.7	1.3	0.1	1.7	2.8	4.7
2085	7.70	63.5	1.5	0.2	4.6	15.6	0.0	0.2	5.3	3.3	5.7
2077	8.05	61.8	1.5	0.2	4.6	16.0	0.3	0.1	4.9	2.0	8.5
2083	8.06	60.7	1.6	0.2	4.6	15.3	0.0	0.2	5.6	4.1	7.6
2088	8.22	64.6	1.6	0.2	4.5	14.5	0.0	0.1	5.7	3.2	5.6
2095	8.72	67.6	1.5	0.2	4.7	15.3	0.0	0.2	5.2	2.9	2.4
2073	10.27	58.9	1.6	0.2	4.7	14.8	0.5	0.1	9.4	2.4	7.4
2078	10.49	56.7	1.6	0.2	4.7	16.0	0.0	0.1	10.4	1.7	8.6
2079	11.62	50.2	1.0	0.2	4.7	15.0	0.0	0.1	11.7	4.3	13.5
2072	12.36										
2074	12.70	53.5	1.3	0.2	4.7	14.0	2.1	0.0	12.3	2.4	9.5
2092	12.72	57.0	1.8	0.2	4.8	13.7	0.2	0.1	12.0	3.0	7.3
2076	14.27	46.4	1.9	0.2	4.9	12.8	0.7	0.1	20.4	2.7	10.0
2084	14.29	46.8	1.6	0.3	4.8	14.6	0.0	0.1	16.3	2.8	12.7
2082	14.93	41.9	1.4	0.2	4.9	13.2	0.0	0.1	18.3	2.9	17.1
2094	16.55	50.3	1.8	0.2	4.9	12.0	0.3	0.2	19.4	3.0	7.9
2089	16.75	38.8	1.5	0.1	4.9	11.1	1.2	0.1	23.5	2.0	16.8
2093	17.65	43.8	1.7	0.1	4.9	11.0	0.6	0.1	22.3	5.0	10.4

TABLE 6.

ENGINE AND GENERAL PERFORMANCE—SERIES 2.

Test No.	Laboratory Designation	Duration of Test, Minutes	Revolutions, Average per Minute	Speed in Miles per Hour	Piston Speed in Feet per Minute	Position of Throttle	Average Boiler Pressure, lb. per sq. in.	Drawbar Pull, lb.	Average Cut-off, Per cent of Stroke	Average Least Back Pressure, lb. per sq. in.	Average Mean Effective Pressure, lb. per sq. in.
	Code Item☞		352	353	354	363	380	487	499	615	678
2081	55–24–F	150	50.6	9.2	252.5	Full	198.2		24.1	0.7	77.1
2086	55–24–F	170	51.3	9.3	256.1	Full	199.1	15 532	23.4	0.6	77.1
2075	55–32–F	140	50.6	9.2	252.3	Full	198.1	20 483	32.1	1.7	98.9
2097	55–32–F	110	52.1	9.5	260.0	Full	198.8	20 820	32.3	2.1	101.5
2085	55–40–F	120	51.1	9.3	255.1	Full	197.9	24 833	41.3	1.8	117.8
2096	55–40–F	90	51.5	9.4	257.0	Full	196.1	24 980	40.4	1.7	120.2
2095	55–48–F	60	51.3	9.3	255.9	Full	198.1	28 922	49.2	1.8	135.4
2098	55–48–F	50	51.7	9.4	258.2	Full	198.2	29 240	49.1	2.0	137.5
2080	110–16–F	130	110.4	20.0	550.7	Full	198.8		16.9	2.0	43.9
2087	110–16–F	150	111.1	20.2	554.4	Full	199.2	8 135	16.6	2.3	43.7
2077	110–24–F	110	110.7	20.1	552.2	Full	196.0	12 512	24.0	3.2	62.4
2073	110–32–F	80	109.4	19.9	545.9	Full	197.6	16 961	29.6	6.5	80.8
2072	110–40–F	60	109.6	19.9	546.8	Full	196.7	20 877	41.5	9.3	97.6
2084	110–48–F	50	110.4	20.0	550.8	Full	194.0	22 403	48.4	12.2	105.7
2094	110–56–F	25	110.9	20.1	553.3	Full	196.3	25 225	57.0	16.3	119.1
2083	165–16–F	100	170.3	30.9	849.8	Full	198.7	7 078	18.4	3.9	37.2
2078	165–24–F	70	169.0	30.7	843.3	Full	196.4	10 188	24.0	7.4	52.0
2074	165–32–F	60	169.6	30.8	846.3	Full	197.1	13 486	28.8	12.5	64.7
2092	165–32–F	50	168.5	30.6	840.8	Full	198.4	13 701	30.4	11.6	65.3
2082	165–40–F	50	169.7	30.8	846.7	Full	195.2	14 783	41.4	18.3	74.5
2093	165–48–F	30	167.4	30.4	835.5	Full	191.5	17 660	48.6	22.1	84.2
2088	220–16–F	100	234.2	42.5	1168.6	Full	197.8	5 568	15.9	5.1	28.1
2079	220–24–F	60	231.9	42.1	1157.2	Full	197.4	8 270	23.4	9.8	41.5
2076	220–32–F	35	229.9	41.7	1147.2	Full	196.0	10 396	32.2	15.8	51.5
2089	220–40–F	35	230.7	41.9	1151.2	Full	194.9	11 831	43.5	22.0	58.7

TABLE 7.
ENGINE AND GENERAL PERFORMANCE—SERIES 2.

Test No.	Laboratory Designation	Indicated Horse Power, Total	Dry Coal Consumed per Indicated Horse Power per Hour, lb.	Dry Steam Consumed per Indicated Horse Power per Hour, lb.	Drawbar Horse Power	Dry Coal Consumed per Drawbar Horse Power per Hour, lb.	Dry Steam Consumed per Drawbar Horse Power per Hour, lb.	Machine Friction of Locomotive in Terms of Horse Power	Machine Efficiency of Locomotive, per cent.	Efficiency of Locomotive, per cent.
	Code Item☞	711	734	736	743	744	745	770	778	779
2081	55–24–F	450.5	4.36	31.53						
2086	55–24–F	456.0	4.51	31.18	386.0	5.33	36.83	70.0	84.7	3.80
2075	55–32–F	578.6	4.00	28.40	501.4	4.62	32.76	77.2	86.7	4.33
2097	55–32–F	610.6			525.2		33.91	85.4	86.0	
2085	55–40–F	694.3	4.39	29.69	614.5	4.96	33.55	79.8	88.5	4.07
2096	55–40–F	713.6			622.8		33.46	90.8	87.3	
2095	55–48–F	804.9	4.15	29.37	718.0	4.66	32.92	86.9	89.2	4.44
2098	55–48–F	822.2			732.2		32.56	90.0	89.1	
2080	110–16–F	558.5	4.31	30.87						
2087	110–16–F	560.3	4.39	30.65	437.6	5.63	39.24	122.7	78.1	3.69
2077	110–24–F	795.7	4.10	27.36	670.2	4.87	32.48	125.5	84.2	4.14
2073	110–32–F	1019.3	4.26	27.20	898.3	4.83	30.87	121.0	88.1	4.13
2072	110–40–F	1233.8	4.79	27.19	1107.8	5.33	30.28	126.0	89.8	3.83
2084	110–48–F	1347.5	5.88	28.69	1197.2	6.62	32.30	150.3	88.9	3.13
2094	110–56–F	1521.4	5.58	29.39	1354.1	6.27	33.02	167.3	89.0	3.27
2083	165–16–F	730.4	4.52	29.65	583.6	5.65	37.10	146.8	79.9	3.56
2078	165–24–F	1011.2	4.63	28.09	833.8	5.62	34.06	177.4	82.5	3.62
2074	165–32–F	1264.3	4.73	27.17	1107.3	5.40	31.03	157.0	87.6	3.75
2092	165–32–F	1267.3	4.46	27.34	1117.6	5.06	31.01	149.7	88.2	3.99
2082	165–40–F	1457.3	6.15	27.88	1214.6	7.38	33.45	242.7	83.4	2.73
2093	165–48–F	1633.5	6.31	29.62	1431.6	7.19	33.80	201.9	87.6	2.82
2088	220–16–F	756.1	4.42	29.40	631.3	5.29	35.21	124.8	83.5	3.98
2079	220–24–F	1109.9	5.17	28.25	928.5	6.18	33.84	181.4	83.7	3.23
2076	220–32–F	1364.3	5.71	28.30	1157.1	6.73	33.36	207.2	84.8	3.02
2089	220–40–F	1559.9	7.10	29.18	1321.6	8.38	34.42	238.3	84.7	2.46

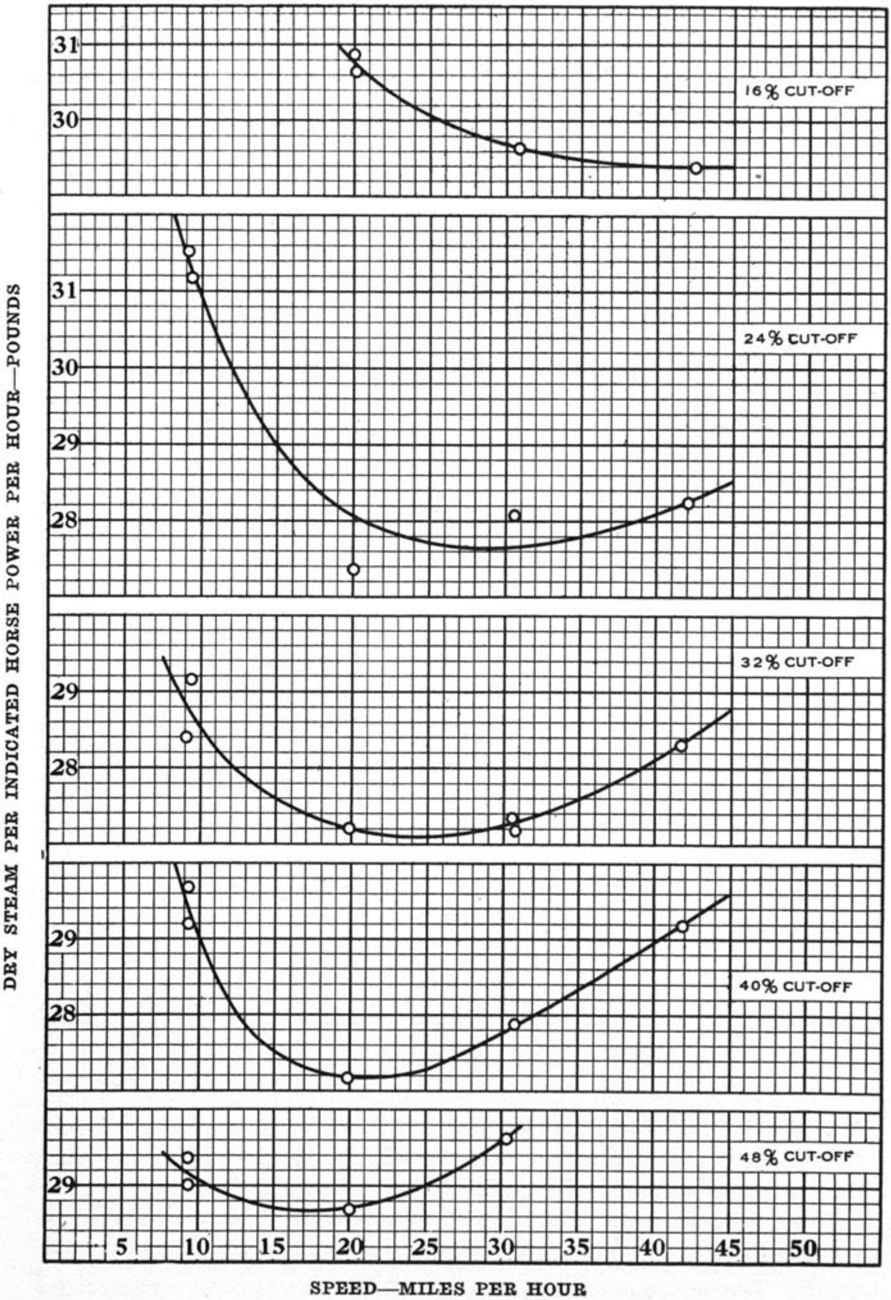

FIG. 16. THE RELATION BETWEEN STEAM CONSUMPTION AND SPEED, AT VARIOUS CUT-OFFS.

B. Engine Performance.

Tables 6 and 7 present information relating to the general conditions and the more important results concerning engine and general performance for all tests of Series 2. These data are arranged in groups with reference to the speed of the locomotive and, within each group, are arranged with reference to the indicated horse power developed, the first test in each group giving the lowest horse power developed at the group speed. Appendix 4 contains data and results for all tests including information concerning cylinder performance as shown by average values taken from indicator diagrams. Fig. 56 and 57, there included, show representative indicator diagrams.

The nominal speeds at which the locomotive was operated were 10, 20, 30, and 40 miles per hour, and the data indicate that the actual speeds obtained closely approximated these figures. The nominal cut-offs at which the locomotive was operated were 16, 24, 32, 40, 48, and 56 per cent of the stroke. The actual cut-offs, as determined from the indicator cards, do not vary greatly from the nominal cut-offs. All tests at a given nominal cut-off were made with the reverse lever in the same notch of the reverse-lever quadrant. In the discussion which follows relative to engine and general performance, speed and cut-off are referred to in terms of the nominal values. All points plotted upon the figures are, however, located with regard to the actual speed and cut-off as determined from test data.

The data in general indicate uniform conditions in those particulars in which uniformity was sought. Test conditions as to nominal speed and nominal cut-off were duplicated in six cases. Such duplicated tests show, in general, satisfactory agreement as regards both test conditions and derived results.

21. *Dry Steam per Indicated Horse Power Hour and per Drawbar Horse Power Hour.*—Fig. 16 and 17 present the relation between dry steam per indicated horse power hour and speed. In Fig. 16 this relation has been shown with a separate water-rate scale for each group of tests at a given cut-off. In Fig. 17 the same curves have been referred to a single water-rate scale in order that the curves may be compared more readily. No curve is drawn for 56 per cent cut-off, since only one test was made at that cut-off.

The minimum water-rate was 27.17 pounds of dry steam, and occurred in test 2074 at a speed of 30 miles per hour and 32 per cent cut-off. The maximum water rate was 31.53 pounds of dry steam, and occurred in test 2081 at a speed of 10 miles per hour and 24 per cent cut-off. The difference between the minimum and maximum water-

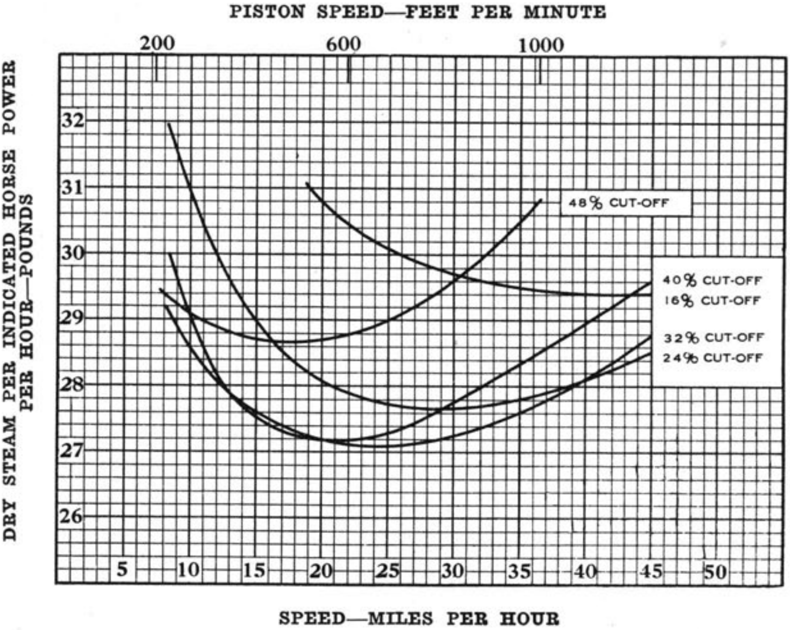

FIG. 17. THE RELATION BETWEEN STEAM CONSUMPTION AND SPEED, AT VARIOUS CUT-OFFS.

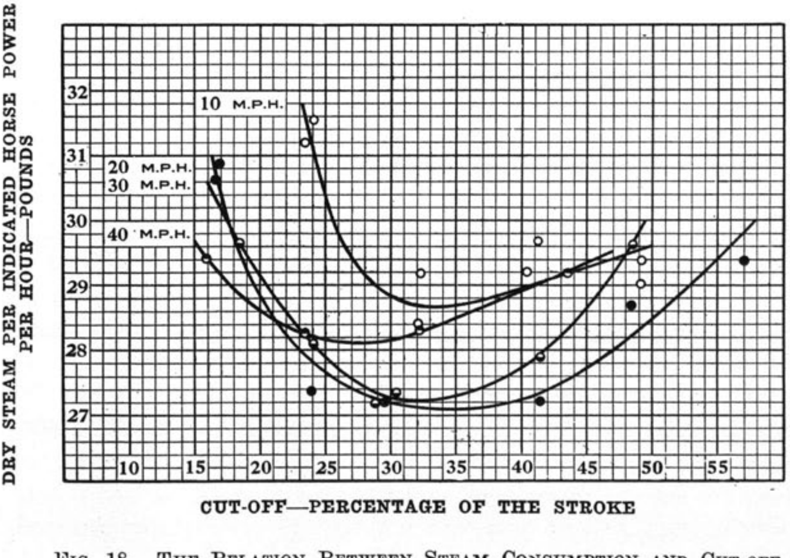

FIG. 18. THE RELATION BETWEEN STEAM CONSUMPTION AND CUT-OFF, AT VARIOUS SPEEDS.

rates for all tests was only 4.36 pounds of dry steam. The corresponding differences between minimum and maximum rates at a given cut-off are in general much smaller.

A decrease in steam consumption per indicated horse power per hour as speed increases is shown until the speed has become from 20 to 30 miles per hour. Further increase of speed is then accompanied by increased steam consumption, as shown by all curves with the exception of that for tests at 16 per cent cut-off. The tests at both short and long cut-off show comparatively high water-rates. The best performance is shown by the curve for tests at 32 per cent cut-off. The tests at 40 per cent cut-off show rather better performance for freight service conditions than those made at 24 per cent cut-off.

Fig. 18 presents curves showing the dry steam consumed per indicated horse power per hour in its relation to cut-off. A curve is shown for each of the four nominal speeds at which tests were made—10, 20, 30, and 40 miles per hour. The tests made at 10 and at 40 miles per hour show much higher water-rates than do the tests made at 20 and 30 miles per hour. This is particularly true for cut-offs between 20 and 50 per cent. At short cut-off the 40 miles per hour curve shows a lower water-rate than the 20 and 30 miles per hour curves. At long cut-off the 10 miles per hour curve appears likewise to show a lower water-rate than the 20 and 30 miles per hour curves.

Except during short periods at starting and on heavy grades, the speed of this locomotive in service would probably vary between about 15 and 35 miles per hour, and the cut-off would range from say 50 to 20 per cent. Under these conditions of speed and cut-off the steam consumption varies between approximately 27 and 29 pounds of steam per indicated horse power per hour. It is probable that this range fairly represents the general average water rate for a very considerable number of freight locomotives in service.

22. *Indicated Horse Power and Drawbar Horse Power.*—Fig. 19 presents indicated horse power in its relation to speed, each curve of the figure representing all of the tests made at a particular nominal cut-off. In addition to the relationship just mentioned this figure shows clearly the range of the tests as to speed, cut-off, and load. It further shows the range covered within each group of tests when the tests are grouped either according to constant speed or to constant cut-off. The six different conditions of speed and cut-off at which duplicate tests were made are evident, and the proximity of the two points representing each pair of such tests indicates the uniformity obtained as to speed and indicated horse power developed.

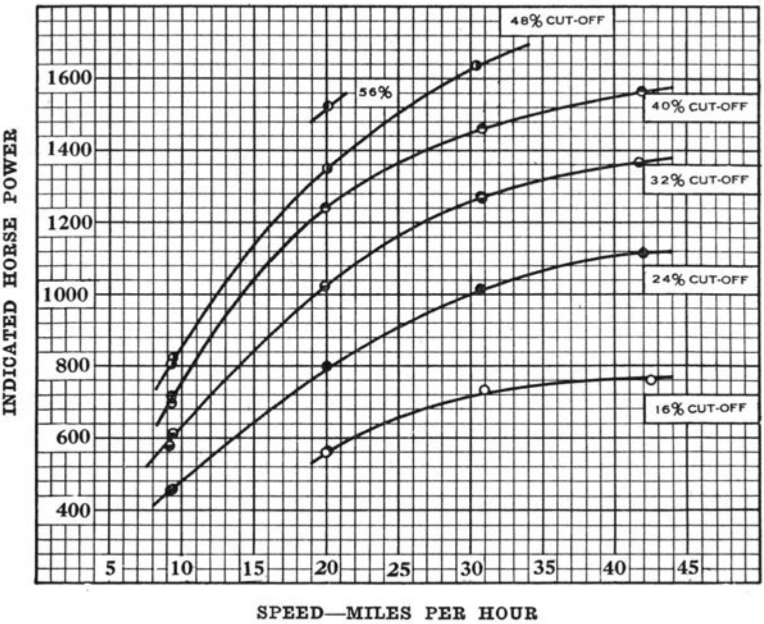

FIG. 19. THE RELATION BETWEEN INDICATED HORSE POWER AND SPEED, AT VARIOUS CUT-OFFS.

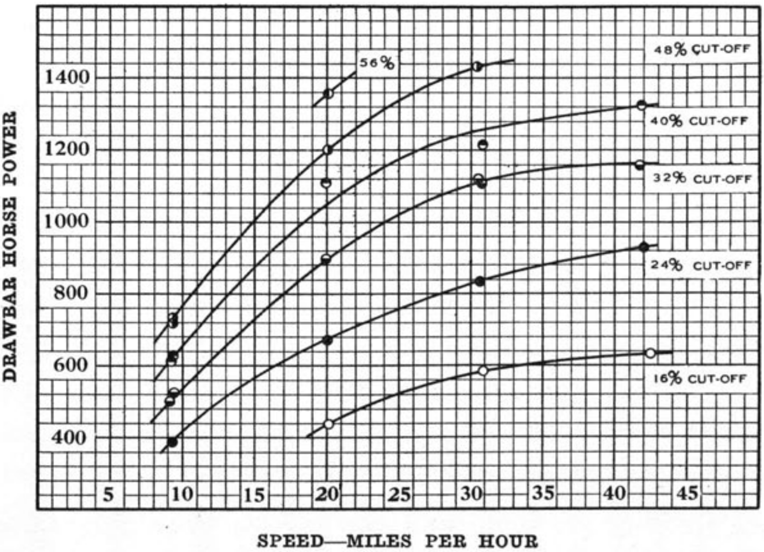

FIG. 20. THE RELATION BETWEEN DRAWBAR HORSE POWER AND SPEED, AT VARIOUS CUT-OFFS.

The maximum indicated horse power was developed in test 2093 at a speed of 30 miles per hour and at 48 per cent cut-off. The average rate of working for this test was 1633.5 indicated horse power. The lowest rate of working was for test 2081, being 450.5 indicated horse power while running at 10 miles per hour with 24 per cent cut-off. The dry steam supplied to the engines per hour when developing 1633.5 indicated horse power was 48 387 pounds. The moist steam delivered to the engines for the same test was 48 812 pounds per hour.

The relations between the horse power developed at the locomotive drawbar and the speed are shown in Fig. 20, in which each of the curves presents this relation for a particular cut-off. The maximum rate of 1431.6 drawbar horse power and the minimum rate of 386.0 drawbar horse power were developed during tests 2093 and 2086 respectively, the former test being at 30 miles per hour and 48 per cent cut-off, and the latter at 10 miles per hour and 24 per cent cut-off. Owing to incomplete dynamometer records for tests 2081 no record is available for the drawbar horse power developed for this test. Tests 2081 and 2086 were made under similar conditions of speed and cut-off.

The plotted points and curves of Fig. 19 and 20 show the engines to have been tested throughout a range of speed, cut-off, and load which would cover all ordinary service conditions above a speed of 10 miles per hour.

23. *Machine Friction.*—The diagrams in Fig. 21 present information concerning machine friction and its relation to indicated horse power for speeds of 10, 20, 30, and 40 miles per hour. Upon each diagram is shown the relation between the indicated horse power developed and machine friction expressed in horse power and also the relation between the indicated horse power developed and machine friction expressed in per cent of indicated horse power. Obviously the ordinates of each pair of curves in this figure bear to each other a definite numerical relation, and the curves have been so drawn that they satisfy this relation and also fairly represent the plotted values for the individual tests.

The range in machine friction is, for the entire series, from 70 to 242.7 horse power. These values were obtained in tests 2086 and 2082 during which 456.0 and 1457.3 indicated horse power respectively were developed. Test 2086 was at 10 miles per hour and 24 per cent cut-off, and test 2082 was at 30 miles per hour and 40 per cent cut-off. Expressed as percent of the indicated horse power developed, the minimum machine friction was 10.2 per cent and occurred in test 2072;

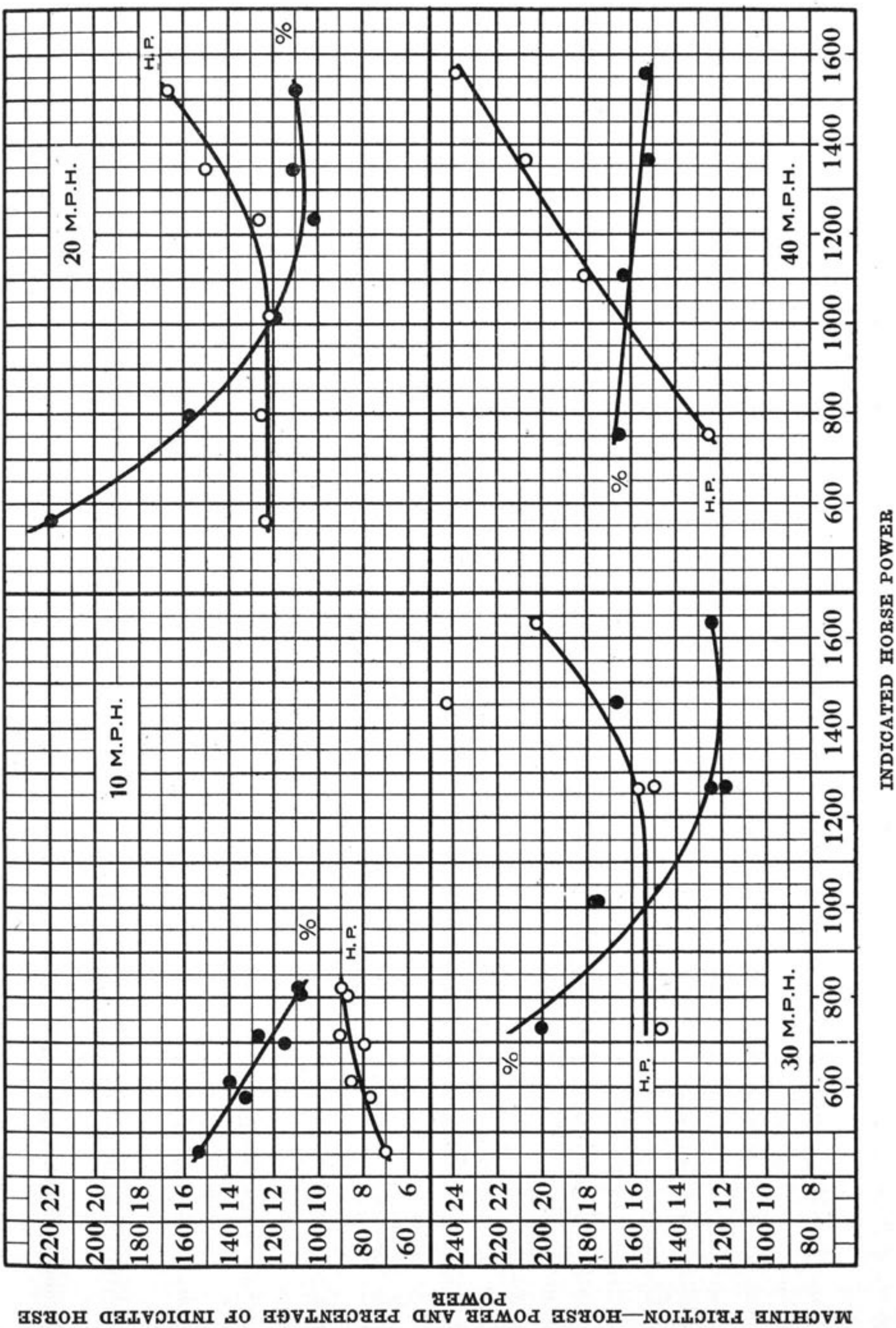

FIG. 21. THE RELATION BETWEEN MACHINE FRICTION AND INDICATED HORSE POWER, AT VARIOUS SPEEDS.

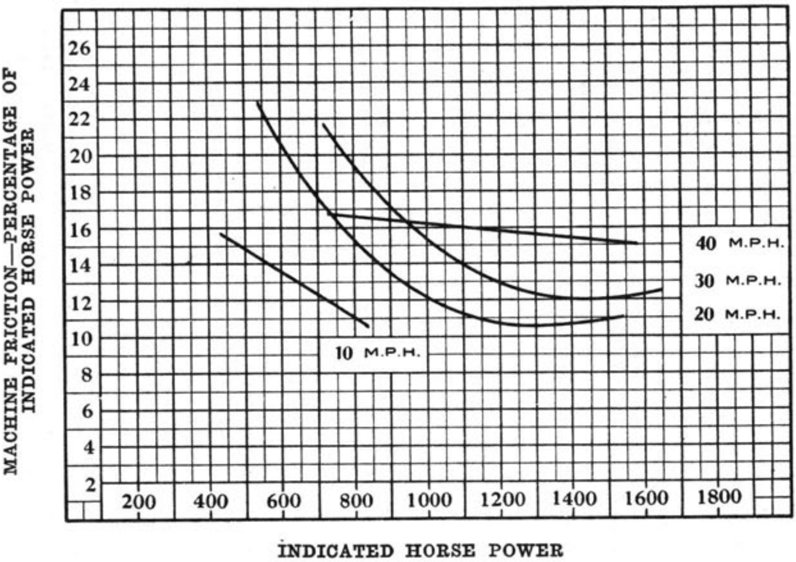

FIG. 22. THE RELATION BETWEEN MACHINE FRICTION AND INDICATED HORSE POWER, AT VARIOUS SPEEDS.

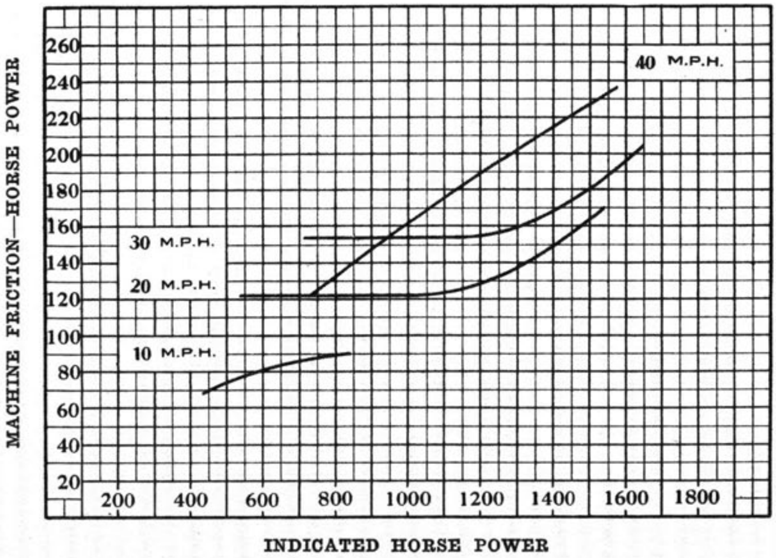

FIG. 23. THE RELATION BETWEEN MACHINE FRICTION POWER AND INDICATED HORSE POWER, AT VARIOUS SPEEDS.

the maximum was 21.9 per cent and occurred in test 2087. The former test was at 20 miles per hour and 40 per cent cut-off, developing 1233.8 indicated horse power, and the latter test at 20 miles per hour and 16 per cent cut-off, developing 560.3 indicated horse power.

While the curves differ more or less for different speeds, they all show the machine friction horse power to increase with increasing indicated horse power. In general, the ratio of machine friction horse power to indicated horse power decreases with increasing load. The rate of decrease of this ratio appears to be quite rapid for loads under 1000 horse power, but at greater loads the ratio becomes fairly constant for a given speed and ranges from 10 per cent to 15 per cent for the different speeds.

Fig. 22 presents upon a single diagram the four curves showing the relation between the machine friction in percentage of indicated horse power and the indicated horse power, which are included in Fig. 21. The curves so grouped indicate that as the speed increased, the percentage of power which was absorbed by machine friction also increased.

Fig. 23 likewise presents upon a single diagram the four curves showing the relation between machine friction and indicated horse power, the machine friction being expressed in terms of horse power. A general increase in machine friction both with increase of speed and with increase of indicated horse power is shown. The curves of Fig. 23, taken as a whole, show a tendency for the machine friction horse power to be fairly constant at a given speed or to increase rather slowly as the load increases up to about 1000 horse power. With loads greater than 1000 to 1200 horse power, the increase in machine friction is more rapid.

Fig. 24, 25, and 26 again present machine friction in its relation to indicated horse power. In these figures however each curve represents the data for all tests at a given nominal cut-off, instead of at a given speed as in the three preceding diagrams. The curves have been located and are presented in a manner similar to that used in connection with Fig. 21, 22, and 23.

These curves indicate that for a given cut-off machine friction horse power increased with the load, and at a rate approximately proportional to the increase of the load. The curves further indicate that, within the range of the tests, machine friction horse power increased with decreasing cut-off when the load remained constant. The per cent of indicated horse power absorbed in machine friction increased rap-

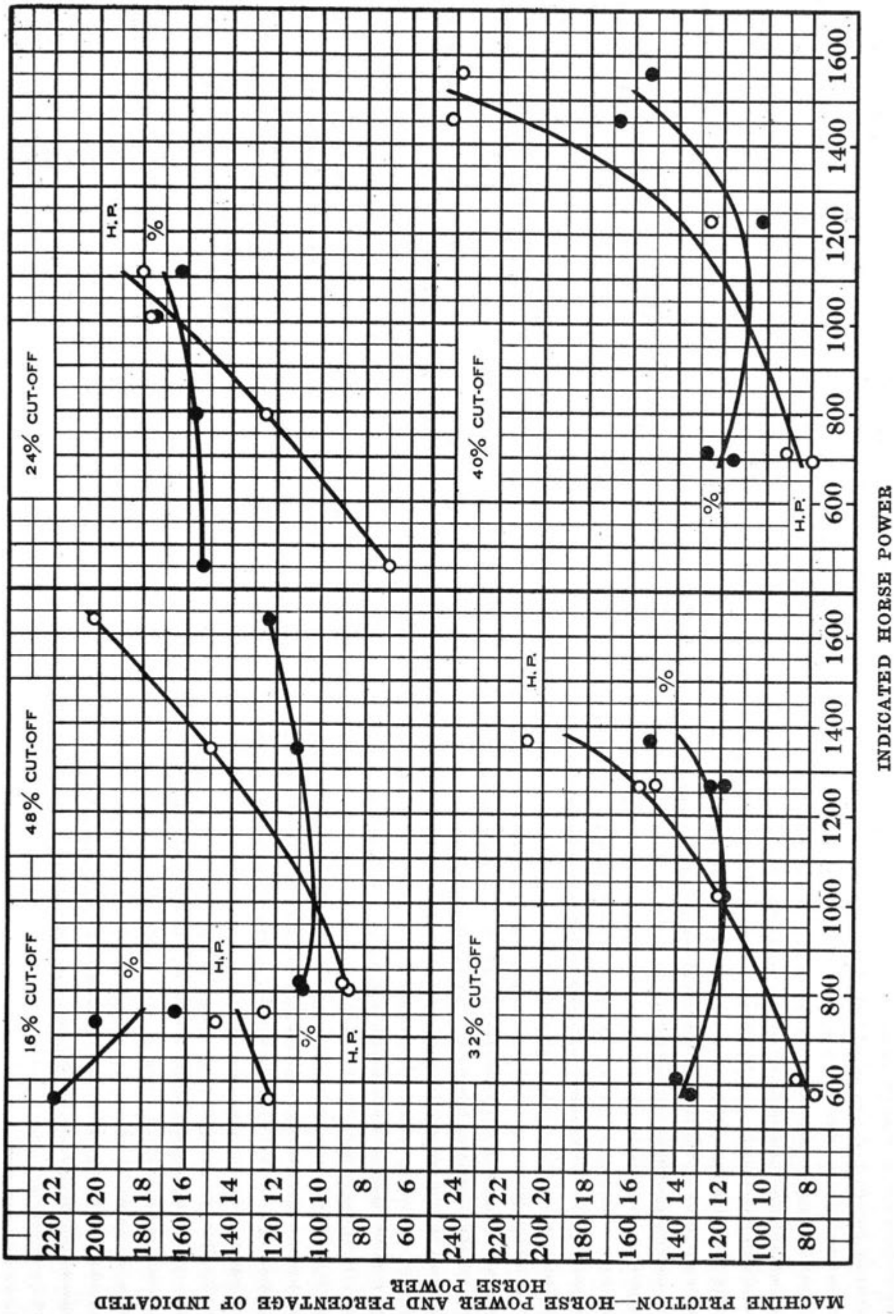

FIG. 24. THE RELATION BETWEEN MACHINE FRICTION AND INDICATED HORSE POWER, AT VARIOUS CUT-OFFS.

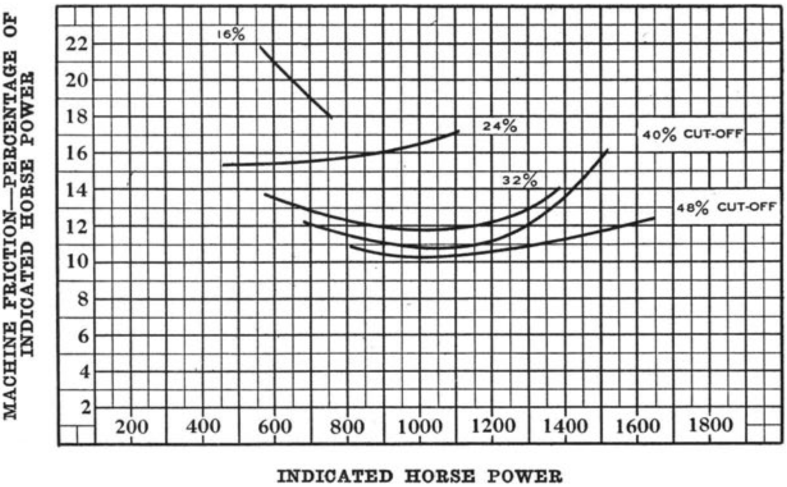

Fig. 25. The Relation Between Machine Friction and Indicated Horse Power, at Various Cut-offs.

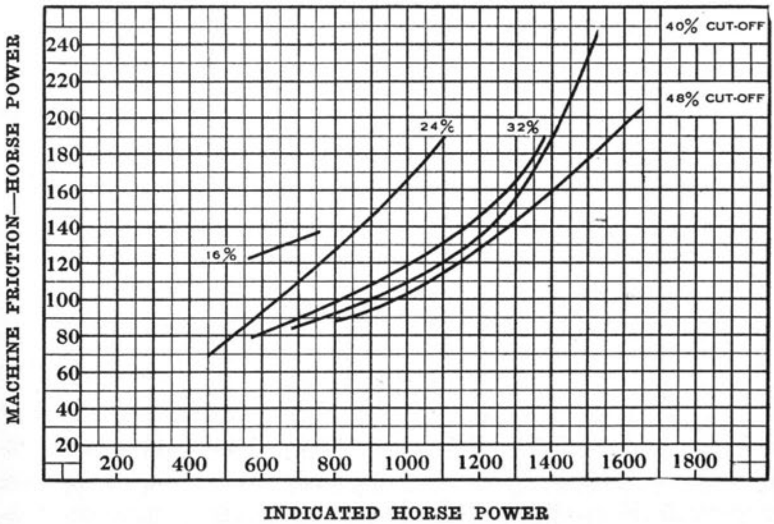

Fig. 26. The Relation Between Machine Friction Power and Indicated Horse Power, at Various Cut-offs.

idly with decreasing cut-off at constant load, and increased but slightly with increasing load at constant cut-off.

The locomotive tested carried 100.45 tons upon the drivers. The following table presents machine friction in terms of tractive force in pounds per ton upon drivers. The values given in the table were calculated from the curves of Fig. 23, making use of the minimum, maximum, and average values for machine friction horse power as shown by the various curves. In making these calculations nominal speed was employed.

TABLE 8.

MACHINE FRICTION.—SERIES 2.

Speed in Miles per Hour	Machine Friction Expressed as Tractive Force in Pounds per Ton of Weight upon Drivers.		
	Minimum	Average	Maximum
10	25	31	34
20	23	25	31
30	19	20	26
40	12	17	22
Averages	20	23	28

For the locomotive tested the values given in Table 8 show 20 to 23 pounds tractive force per ton of weight on drivers to be values fairly representative of machine friction for practically all speeds when the load does not exceed 1000 to 1200 indicated horse power. For conditions of low speed, however, and for all speeds where the indicated horse power is comparatively high and the maximum tractive effort is approached, the machine friction is materially greater, as shown by the values given in the table for the speed of 10 miles per hour, and by the maximum values, which vary from 22 to 34 lb. per ton of weight upon the drivers.

Fig. 27 and 28 present machine friction in its relation to speed in miles per hour. A curve is drawn for each nominal cut-off. The values presented are the same as have been shown in preceding curves concerning machine friction, and some of the relations already considered in connection with Fig. 21 to 26 may be seen in Fig. 27 and 28. While the curves of Fig. 27 and 28 exhibit considerable lack of uniformity, the former figure shows machine friction horse power to increase more or less uniformly with increasing speed for all cut-offs; and Fig. 28 indicates that at constant speed the ratio of machine friction horse power to indicated horse power decreases as the cut-off increases, and that for any given cut-off this ratio is fairly constant throughout the range of speed shown.

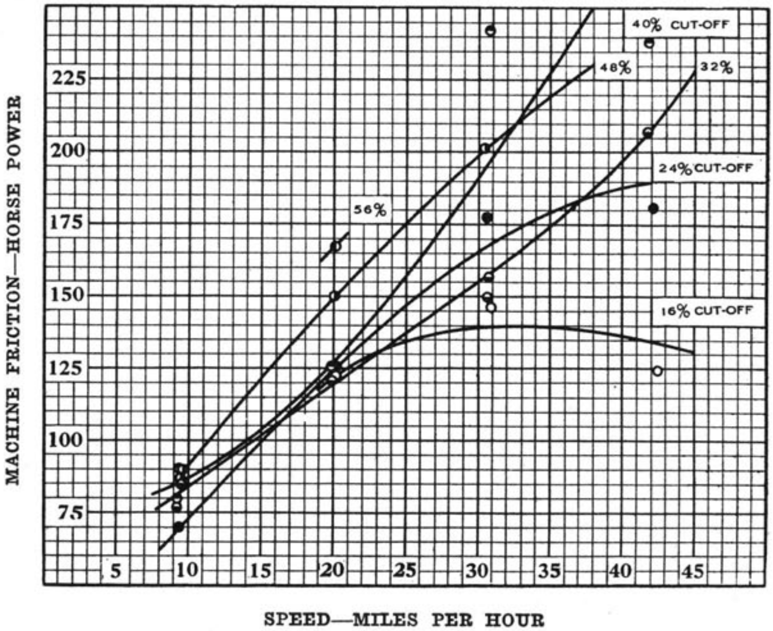

Fig. 27. The Relation Between Machine Friction Power and Speed, at Various Cut-offs.

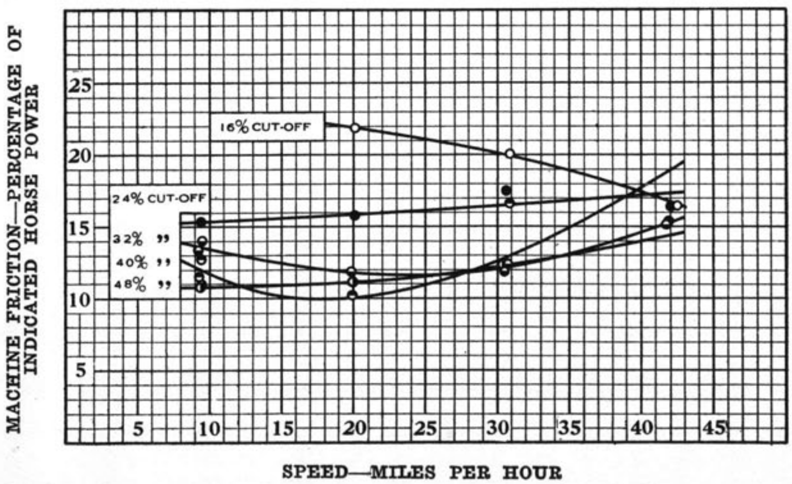

Fig. 28. The Relation Between Machine Friction and Speed, at Various Cut-offs.

The facts here presented seem to warrant the conclusions that, for this locomotive, the percentage of indicated horse power absorbed by the friction of the machinery varies rather definitely with respect to speed, to cut-off, and to load; and that this machine friction entails a loss in tractive force between the cylinders and the locomotive draw-bar which varies from about 15 to about 30 pounds for each ton of weight carried on the driving wheels.

C. General Performance.

24. *Coal Consumption per Indicated Horse Power Hour and per Drawbar Horse Power Hour.*—The curves of Fig. 29 show the relation between speed and the amount of dry coal consumed per indicated horse power per hour. Each of the curves there drawn applies to a particular cut-off. In a similar manner the relation between speed and the dry coal consumed per drawbar horse power per hour is presented in Fig. 30.

The most economical performance was obtained in test 2075, made at a speed of 10 miles per hour and at 32 per cent cut-off. During this test 4.00 pounds and 4.62 pounds of dry coal per indicated horse power hour and per drawbar horse power hour respectively were used. The highest coal rate occurred in test 2089, made at a speed of 40 miles per hour and at 40 per cent cut-off, during which 7.10 pounds and 8.38 pounds of dry coal per indicated horse power hour and per drawbar horse power hour respectively were used. Both figures show a more rapid increase in coal consumption with increase of speed at long cut-off than with increase of speed at short cut-off. This is in conformity with the results presented in Fig. 19 where the relation between indicated horse power and speed is shown. The curves of Fig. 29 and 30 show that the economy was fairly constant, or increased slowly as speed was increased from 10 to 20 miles per hour. Tests at 24 per cent cut-off show an economy apparently better at 15 to 20 miles per hour than at 10 miles per hour. As speed increased above 20 miles per hour the coal consumption increased more rapidly than at lower speeds, with the exception of the tests made at 16 per cent cut-off.

25. *General Efficiency.*—By general efficiency is meant, in this connection, the ratio of the heat equivalent of the work done at the locomotive drawbar to the heat content of the coal. This ratio is a measure of the economic performance of the locomotive as a whole. General efficiency and its relation to speed are shown in Fig. 31, in which a separate curve is presented for each nominal cut-off.

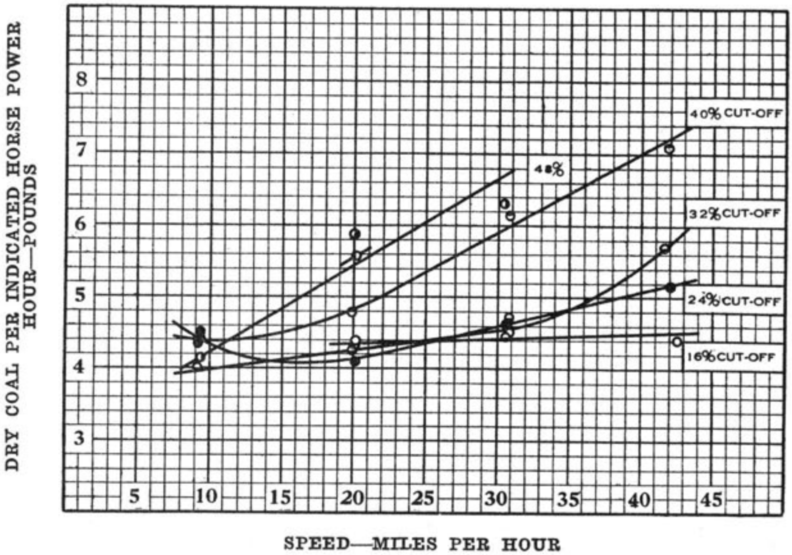

FIG. 29. THE RELATION BETWEEN COAL CONSUMED PER INDICATED HORSE POWER HOUR AND SPEED, AT VARIOUS CUT-OFFS.

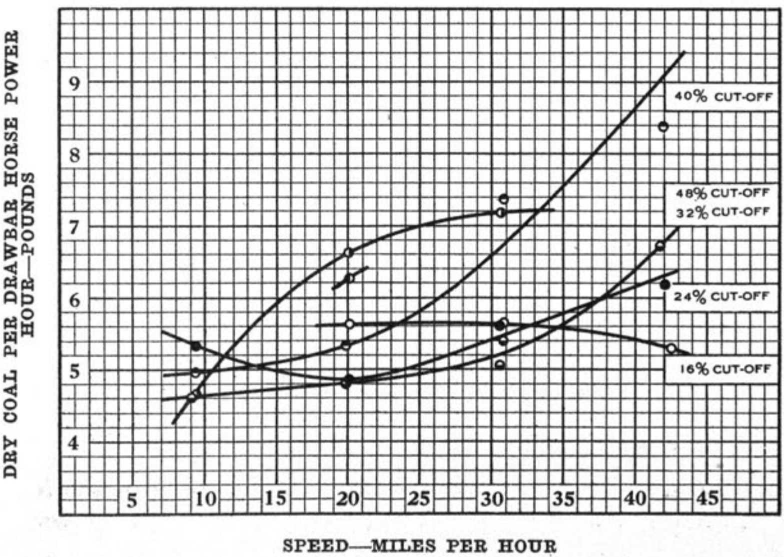

FIG. 30. THE RELATION BETWEEN COAL CONSUMED PER DRAWBAR HORSE POWER HOUR AND SPEED, AT VARIOUS CUT-OFFS.

The maximum efficiency obtained was 4.44 per cent, and occurred in test 2095 which was made at a speed of 10 miles per hour with 48 per cent cut-off, while developing 804.9 indicated horse power. The minimum efficiency obtained was 2.46 per cent, and occurred in test 2089 made at a speed of 40 miles per hour with 40 per cent cut-off, while developing 1559.9 indicated horse power. This group of curves shows substantially the same relations as were shown by Fig. 29 and 30 which presented coal consumption per indicated horse power hour and drawbar horse power hour. Collectively the curves indicate a fairly constant efficiency of about 4 per cent, for speeds from 10 to 20 miles per hour. As the speed increases above 20 miles per hour the efficiency decreases from about 4 per cent to about 3 per cent.

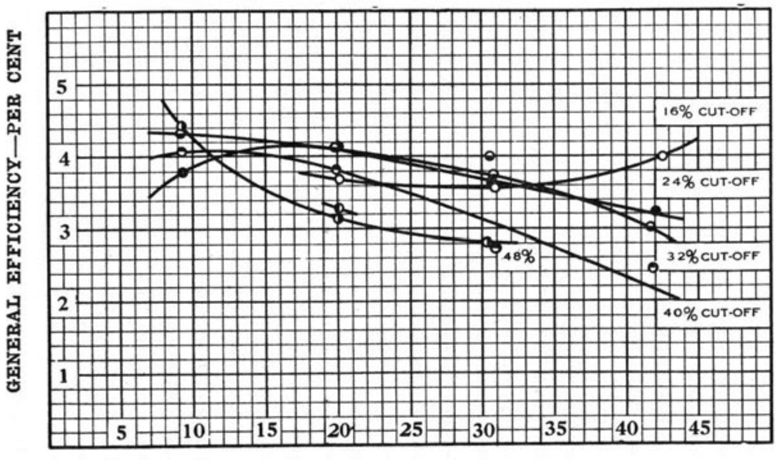

FIG. 31. THE RELATION BETWEEN GENERAL EFFICIENCY AND SPEED, AT VARIOUS CUT-OFFS.

VII. THE RESULTS OF THE TESTS OF SERIES I.

Series 1 comprises tests 2009 to 2037 inclusive. The conditions which prevailed during the tests of this series have been set forth in sections IV and V, and the differences in the condition of the locomotive during Series 1 as compared with Series 2 are stated in section II and in Appendix 1. It is sufficient here to recall the fact that during Series 1 the locomotive was in the condition in which it was delivered to the laboratory. The repairs made between Series 1 and 2 did not prove to have affected radically the performance of the locomotive, and most of the relations presented in the preceding section relating to Series 2 remain substantially the same for Series 1. For these reasons it has seemed unnecessary to present the results for Series 1 in very great detail. All the results are given in Appendix 4; but only the more important measures of performance are here included and discussed.

D. Boiler Performance.

26. *The Range of Performance.*—The more significant data and results pertaining to the performance of the boiler during Series 1 are given in Table 9, in which the tests are arranged in the order of the increasing amounts of dry coal fired per hour. In order to exhibit the range of the boiler performance, the minimum and maximum values of the main data and results are assembled in the table immediately following. As in all the tables, the quantities cited are the average values prevailing during the tests.

	Minimum	*Maximum*
Duration of test, minutes	40	180
Boiler pressure, lb. per sq. in.	189.9	198.1
Feed water temperature, deg. F	57.7	72.2
Quality of the steam in the dome	0.9833	0.9956
Calorific value of coal as fired, B.t.u.	9929	11 376
Calorific value of dry coal, B.t.u.	11 835	12 757
Ash content of coal as fired—per cent	10.68	14.27
Draft in front of diaphragm, inches of water	2.2	10.7
Firebox temperature, deg. F.	1552	2081
Front-end temperature, deg. F.	494	761
Dry coal fired per test, lb	3568	10031
Dry coal fired per hour, lb	1814	7767
Dry coal fired per hour per square foot of grate, lb	36.6	156.8
Equivalent evaporation per hour, lb.	16 934	46 380
Equivalent evaporation per hour per square foot of heating surface, lb.	5.16	14.13
Total cinder loss, per hour, lb	66	1509
Total cinder loss, per cent of dry coal	3.4	20.8

27. *Economic Performance.*—In Series 1 the equivalent evaporation per pound of dry coal ranged from a minimum of 5.97 pounds to a maximum of 10.07 pounds. This latter value, applying to test 2024,

TABLE 9.
BOILER PERFORMANCE—SERIES 1.

Test No.	Laboratory Designation	Average Boiler Pressure, lb. per sq. in.	Dry Coal Fired per Hour, lb.		Duration of Test, Minutes	Quality of the Steam in the Dome	Cinders, lb.		Calorific Value per lb. of Dry Coal, B. t. u.	Equivalent Evaporation, lb.		Efficiency of the Boiler Including the Grate, per cent
			Total	Per sq. ft. of Grate			Total per Hour	Total in Per cent of the Dry Coal Fired		Per Hour per sq. ft. of Heating Surface	Per lb. of Dry Coal	
	Code Item ☞	380	626	627		407	424 & 345	426	458	648	658	666
2024	55–24–F	196.3	1814	36.6	120	.9950	68	3.7	12 712	5.56	10.07	76.87
2017	83–16–F	193.4	1957	39.5	180	.9910	66	3.4	12 422	5.33	8.96	69.88
2021	83–16–F	193.7	2211	44.6	120	.9945	133	6.0	12 274	5.16	7.66	60.56
2026	110–16–F	196.9	2293	46.3	130	.9895	140	6.1	12 309	6.00	8.59	67.75
2028	55–32–F	198.1	2406	48.6	140	.9912	166	6.9	12 653	6.14	8.37	64.21
2020	83–24–F	190.7	2472	49.9	120	.9929	151	6.1	12 302	6.42	8.53	67.33
2018	83–24–F	194.2	2537	51.2	160	.9930	153	6.1	12 265	6.50	8.41	66.49
2009	138–16–F	190.5	2647	53.4	150	.9900	176	6.6	12 553	6.60	8.19	63.30
2019	83–32–F	193.8	3215	64.9	130	.9910	277	8.6	12 523	8.17	8.35	64.68
2016	193–16–F	193.9	3255	65.7	140	.9890	297	9.1	11 992	7.56	7.62	61.68
2027	110–24–F	196.8	3256	65.7	150	.9914	306	9.4	12 688	7.68	7.74	59.22
2022	83–32–F	189.9	3673	74.1	120	.9956	453	12.3	11 875	8.02	7.17	58.54
2012	138–24–F	191.8	3707	74.8	110	.9890	359	9.7	12 280	8.69	7.69	60.80
2010	193–20–F	192.0	3834	77.4	70	.9870	438	11.4	12 433	8.71	7.45	57.63
2030	165–24–F	196.5	4013	81.0	100	.9894	519	13.0	12 757	9.60	7.85	59.71
2029	110–32–F	197.1	4242	85.6	90	.9902	589	13.9	12 486	9.78	7.57	58.85
2031	83–40–F	196.4	4244	85.6	90	.9896	638	15.0	11 989	10.14	7.84	63.43
2013	138–32–F	190.1	4749	95.8	90	.9850	623	13.1	12 242	10.54	7.29	57.78
2015	193–24–F	192.1	4927	99.5	90	.9870	736	14.9	12 307	10.04	6.69	52.84
2033	110–48–F	196.0	5126	103.5	80	.9867	924	18.0	12 243	11.77	7.54	59.76
2032	165–32–F	196.8	5352	108.0	40	.9862	1003	18.8	12 242	11.26	6.91	54.79
2035	110–40–F	194.3	5565	112.3	70	.9833	803	14.5	12 329	12.06	7.11	55.94
2014	193–32–F	191.5	6199	125.1	70	.9840	901	14.6	12 184	11.83	6.27	49.92
2037	165–40–F	196.1	6554	132.3	60	.9860	1217	18.6	12 441	13.97	7.00	54.54
2023	138–40–F	190.8	6687	135.0	90	.9930	1388	20.8	12 311	12.89	6.33	49.86
2034	193–40–F	192.1	7767	156.8	60	.9857	1509	19.4	11 835	14.13	5.97	48.95

is however so divergent from the other values for similar rates of combustion as to raise doubt of its validity, although errors can not be found in the data. The next highest evaporation per pound of dry coal is 8.96 pounds. The rate of decrease in the evaporation per pound of coal with respect to increase in rate of combustion is shown in Fig. 32. The rate of this decrease with respect to increase in rate of evaporation is shown in Fig. 33. These two figures are comparable with Fig. 8 and 9 of Series 2.

28. *Boiler Efficiency.*—As previously explained, efficiency in this connection means the ratio of the heat absorbed by the steam generated, to the heat contained in the coal as it was fired. If, for the reason above suggested, we exclude test 2024, the highest efficiency obtained during Series 1 was 69.88 per cent, which occurred during test 2017 with a rate of combustion of 39.5 pounds of dry coal per square foot of grate per hour. The lowest efficiency, 48.95 per cent, prevailed during test 2034 in which the rate of combustion was 156.8 pounds of dry coal per square foot of grate per hour. The relation between efficiency and rate of combustion is shown in Fig. 34.

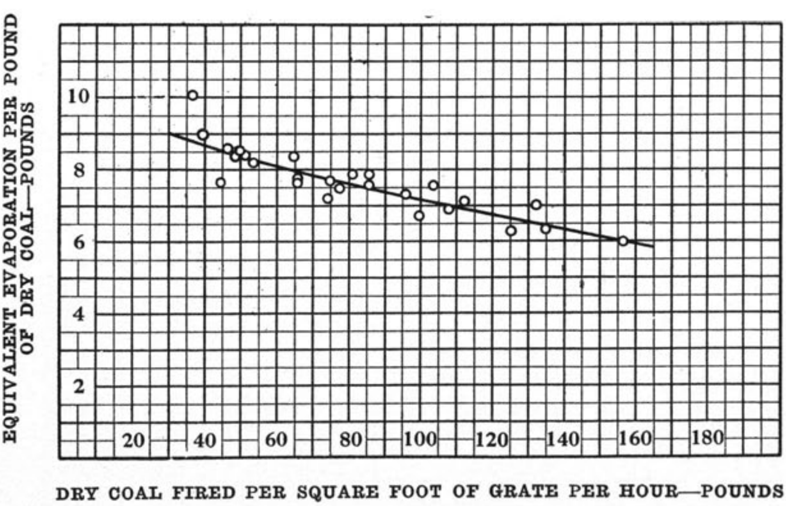

FIG. 32. THE RELATION BETWEEN EVAPORATION PER POUND OF COAL AND RATE OF COMBUSTION.

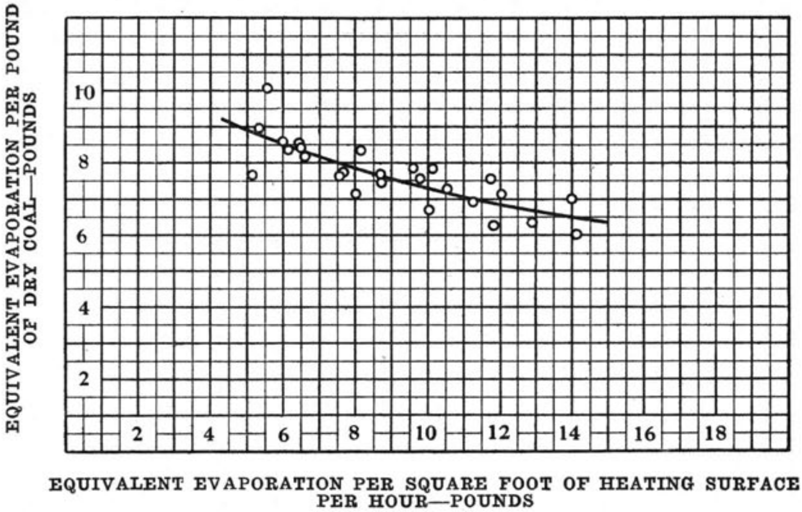

FIG. 33. THE RELATION BETWEEN EVAPORATION PER POUND OF COAL AND RATE OF EVAPORTION.

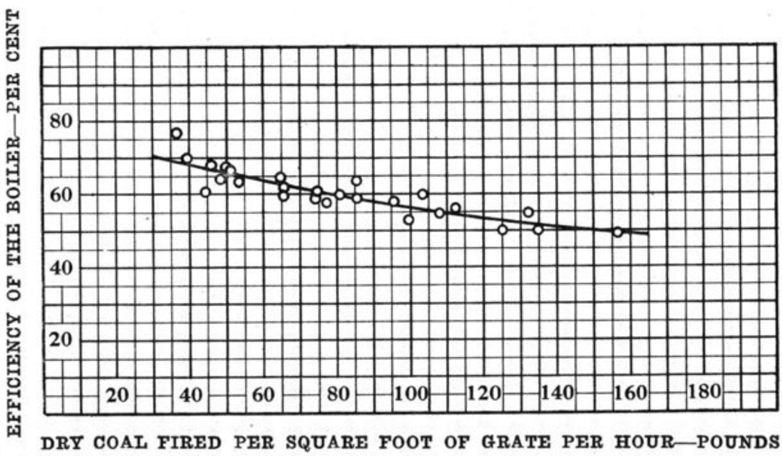

FIG. 34. THE RELATION BETWEEN BOILER EFFICIENCY AND RATE OF COMBUSTION.

E. ENGINE PERFORMANCE AND GENERAL PERFORMANCE.

The more important data and results pertaining to the performance of the engines and to the general performance of the locomotive during Series 1 are assembled in Table 10. The remaining data and results appear in Appendix 4. In the table all tests run at like speed are grouped and, within these groups, the tests are arranged in the order of the values of cut-off. The tests of Series 1 were made at speeds varying from 10 to 35 miles per hour, and at cut-offs of 16, 20, 24, 32, 40, and 48 per cent. Only one test however was made at 20 per cent cut-off and one at 48 per cent cut-off, and these are omitted from the figures here included.

29. *Dry Steam per Indicated Horse Power Hour.*—In Fig. 35 is shown the relation between steam consumption and speed for each of the four cut-offs. The curves here drawn show the minimum steam consumption to have occurred in each case at a speed of from 20 to 25

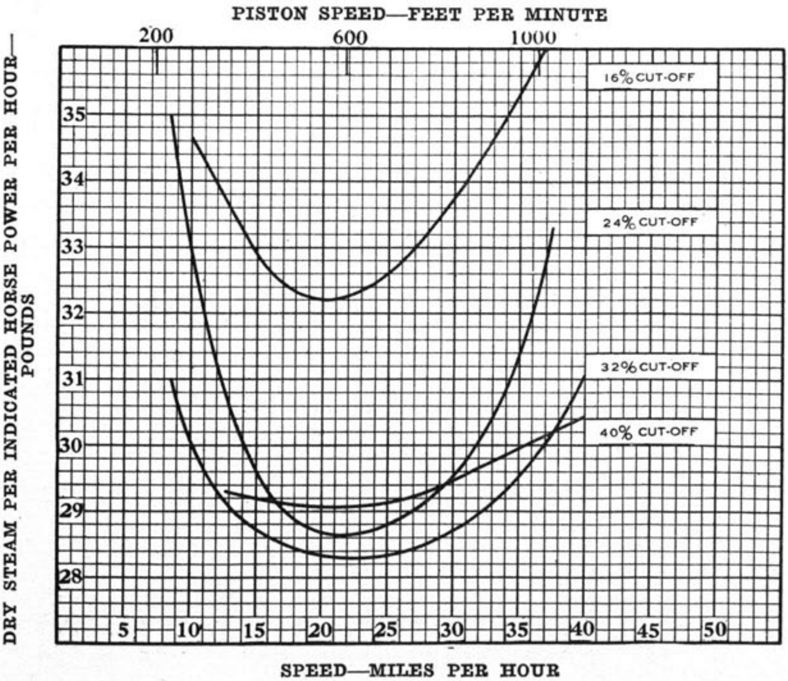

FIG. 35. THE RELATION BETWEEN STEAM CONSUMPTION AND SPEED, AT VARIOUS CUT-OFFS.

TABLE 10.

ENGINE AND GENERAL PERFORMANCE—SERIES 1.

Test No.	Laboratory Designation	Duration of Test, Minutes	Speed in Miles per Hour	Piston Speed in Feet per Minute	Average Cut-off, Per cent of Stroke	Average Least Back Pressure, lb. per sq. in.	Indicated Horse Power, Total	Dry Steam Consumed per I.H.P. per Hour, lb.	Drawbar Horse Power	Machine Efficiency of Locomotive, per cent	Efficiency of Locomotive, per cent
	Code Item☞		353	354	499	615	711	736	743	778	779
2025	55–16–F	120	9.4	257.0			301.6	47.16	231.7	76.8	3.11
2024	55–24–F	120	9.2	253.0			431.0	34.74	355.6	82.5	3.97
2028	55–32–F	140	9.1	251.0	31.7		548.7	30.57	488.1	89.0	4.10
2017	83–16–F	180	14.5	399.2	16.9	2.6	428.1	34.08	357.1	83.4	3.76
2021	83–16–F	120	14.5	399.7	14.9	4.4	428.6	32.10	346.3	80.8	3.31
2020	83–24–F	120	14.6	401.7	22.4	5.1	584.4	29.99	508.9	87.1	4.27
2018	83–24–F	160	14.5	399.2	22.6	4.0	593.8	29.71	511.7	86.2	4.21
2019	83–32–F	130	14.6	402.0	30.6	5.2	765.7	28.96	683.1	89.2	4.35
2022	83–32–F	120	14.6	402.2	30.3	7.2	773.9	28.14	674.6	87.2	3.94
2031	83–40–F	90	15.6	428.1	39.5	10.3	953.9	28.75	869.7	91.2	4.38
2026	110–16–F	130	19.9	545.9	19.1	3.1	515.0	31.67	415.1	80.6	3.75
2027	110–24–F	150	20.0	548.9	24.3	6.1	749.1	27.84	633.6	84.6	3.91
2029	110–32–F	90	19.9	547.9	30.7	10.5	968.6	27.51	820.8	84.7	3.94
2035	110–40–F	70	20.3	557.9	39.9	14.7	1119.1	29.43	942.9	84.3	3.49
2033	110–48–F	80	20.0	548.4	40.7	15.2	1142.3	27.83	1007.9	88.2	4.12
2009	138–16–F	150	25.2	694.6	17.1	5.3	545.5	33.06			
2012	138–24–F	110	25.3	696.3	23.3	7.7	802.8	29.44	684.9	85.3	3.84
2013	138–32–F	90	25.4	697.2	30.8	11.6	986.3	29.14	863.7	87.6	3.78
2023	138–40–F	90	25.2	693.6	39.4	19.5	1188.7	29.10	1070.5	90.1	3.36
2030	165–24–F	100	30.8	845.3	23.4	11.5	899.6	28.99	725.8	80.7	3.62
2032	165–32–F	40	30.5	838.8	30.2		1094.6	27.84	922.8	84.3	3.61
2037	165–40–F	60	30.7	844.8	40.1	18.1	1277.7	29.56	1045.3	81.8	3.29
2016	193–16–F	140	36.3	998.0	16.4	6.4	583.8	35.18	418.2	71.6	2.74
2010	193–20–F	71	35.7	981.8	19.2	8.2	737.0	32.07			
2015	193–24–F	90	36.3	998.0	22.7	12.1	845.6	32.32	626.2	74.1	2.63
2014	193–32–F	70	36.3	996.4	31.4	17.1	1079.0	29.82	853.1	79.1	2.88
2034	193–40–F	60	36.0	990.5	41.4	24.1	1276.7	30.02	961.7	75.3	2.67

miles per hour. The best performance was obtained during the tests made at 32 per cent cut-off. The minimum steam consumption was 27.51 pounds of dry steam per indicated horse power per hour, and the maximum 35.18 pounds. The difference between these quantities, 7.67 pounds, represents a comparatively small variation in water rate, considering the variety and range of the test conditions. Fig. 35 is comparable with Fig. 17, and a comparison of these figures shows the steam consumption during Series 1 to have been considerably greater than in Series 2, at all cut-offs.

30. *Indicated Horse Power.*—The relation of indicated horse power to speed is shown in Fig. 36, in which each of the curves represents all the tests made at a particular cut-off. This figure shows also the range of the test conditions for Series 1. The maximum load, 1278 indicated horse power, was developed during test 2037 when the speed was 30 miles per hour and the cut-off 40 per cent. The minimum average load, 428 indicated horse power, occurred in test 2017 at a speed of 15 miles per hour and 16 per cent cut-off. The work performed at the locomotive drawbar varied from 346 to 1071 horse power.

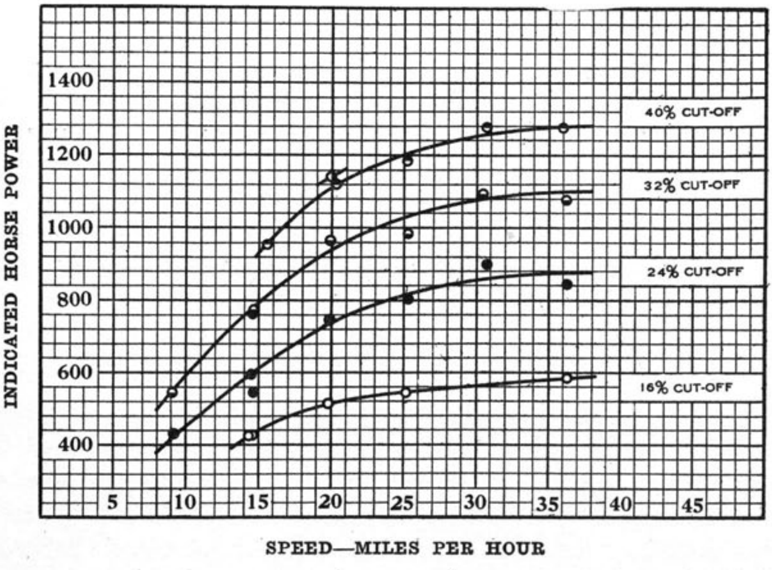

FIG. 36. THE RELATION BETWEEN INDICATED HORSE POWER AND SPEED, AT VARIOUS CUT-OFFS.

31. *Machine Friction.*—Machine friction horse power during Series 1 and its relation to speed are shown in Fig. 37. This figure indicates also the influence of cut-off on machine friction, and is comparable with Fig. 27 which presents the same relations for Series 2.

An analysis of machine friction similar to that developed in section VI for Series 2 has been made for Series 1, although the figures are not here included. This analysis shows that during Series 1 the machine friction was somewhat greater than during Series 2—a result which was expected, in view of the work done upon the machinery between these two groups of tests. This analysis indicates also that for constant cut-off the machine friction increased more rapidly with increasing load during Series 1 than during Series 2. With these two exceptions, the relations shown in the discussion of machine friction for Series 2, and the conclusions there drawn, remain substantially the same for Series 1.

32. *Coal Consumption per Indicated Horse Power.*—The dry coal consumed per indicated horse power per hour, and the relation of this coal consumption to speed are shown in the curves of Fig. 38. The curves show this coal rate to vary in general between 4 and 6 pounds per hour for the range of conditions which prevailed in Series 1. Again excluding test 2024, the lowest coal rate, 4.18 pounds per hour, was obtained during test 2019 at 15 miles per hour and 32 per cent cut-off. The highest coal rate, 6.07 pounds per hour, was obtained during test 2034, at 35 miles per hour and 40 per cent cut-off. Test 2034 is the one during which the lowest boiler efficiency prevailed.

33. *General Efficiency.*—The general efficiency of the locomotive and the relation of this efficiency to speed are shown in Fig. 39, which is comparable with Fig. 31 of Series 2. The greatest efficiency was 4.38 per cent, and the lowest 2.63 per cent. This is practically the same range in efficiency as is represented in Fig. 31.

VIII. Comparison of the Results of Series 1 and 2.

A few of the differences in the performance of the locomotive during the tests of Series 1 and Series 2 have already been referred to incidentally in the preceding discussion. It is the purpose to discuss in this section the effects on the general performance of the boiler and engines caused by the repairs and changes which were made between these two groups of tests. While these changes are elsewhere enumer-

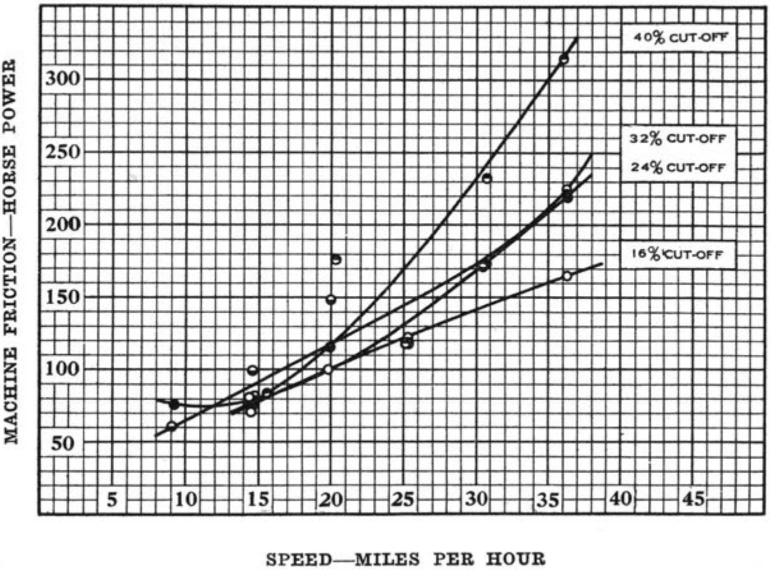

FIG. 37. THE RELATION BETWEEN MACHINE FRICTION POWER AND SPEED, AT VARIOUS CUT-OFFS.

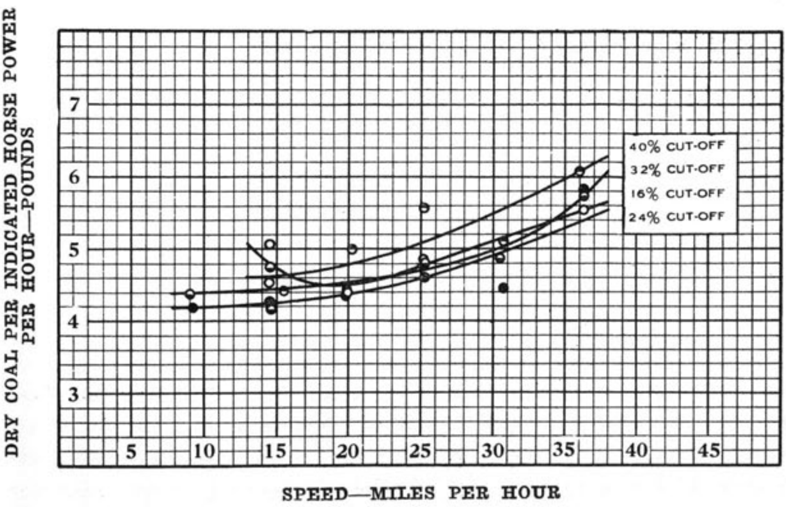

FIG. 38. THE RELATION BETWEEN COAL CONSUMED PER INDICATED HORSE POWER PER HOUR AND SPEED, AT VARIOUS CUT-OFFS.

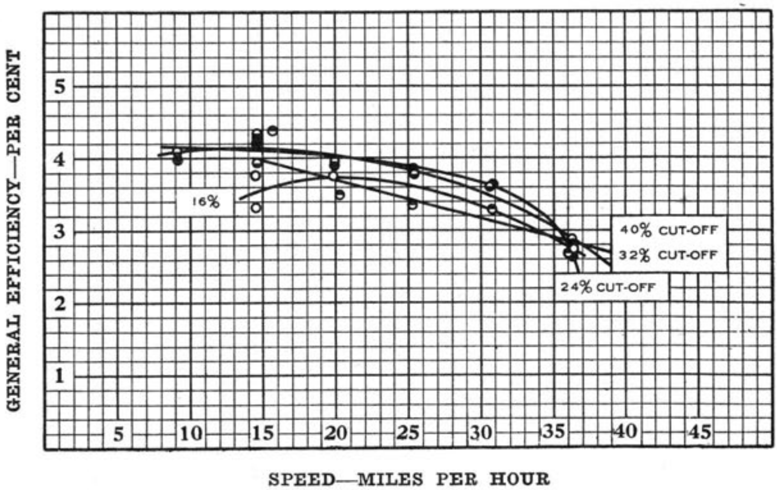

FIG. 39. THE RELATION BETWEEN GENERAL EFFICIENCY AND SPEED, AT VARIOUS CUT-OFFS.

ated, it will be convenient to have restated at this point those which might have affected the general performance. They were:

1. The nozzle tip, 5¼ in. in diameter, used during Series 1 was replaced by a 5⅞-in. tip.
2. A small leak in one of the branch-pipe joints was stopped.
3. The cylinders and valve chambers were re-bored.
4. New pistons and new piston rings were applied.
5. New valve bull-rings and valve packing rings were applied.
6. Lost motion in the eccentric straps was taken up.
7. The valves were reset.
8. The piston rods were trued and the rod packing renewed on both sides.
9. The side-rod bushings were renewed.
10. Three new driving-wheel tires were applied.

34. *Comparison of the Boiler Performance.*—Perhaps the best basis for a comparison of the boiler performance during the two series is to be found in the curves of Fig. 8 and 32, which present the average values of the equivalent evaporation per pound of dry coal per hour for Series 2 and Series 1 respectively. These two curves, when plotted on the same diagram, almost coincide. The curve for Series 1 lies below that for Series 2 by an amount which at no rate of combus-

tion exceeds one-fifth of a pound of equivalent evaporation per pound of coal. At no point throughout the range of the rate of combustion is the performance of the boiler in Series 2 better than in Series 1 by more than 3 per cent. A comparison of boiler efficiency based on Fig. 10 and 34 shows an even closer agreement in the boiler performance of the two series. Of the various changes cited above only item 1, the change in nozzle tip, could have affected boiler performance, and the facts just stated seem to warrant the conclusion that this had no substantial effect upon the general performance of the boiler and furnace.

35. *Comparison of the Cylinder Performance.*—Any of the first seven items in the list of changes given might conceivably have affected the cylinder performance. The steam leak referred to in item 2, however, was proved at the time to have been inconsiderable in amount. The combined effect of these seven items should be disclosed by a comparison of the steam consumption per indicated horse power hour for all tests of both series which are comparable as regards speed and cut-off. The values of steam consumption for such tests are brought together in the following table. In four instances in this table a pair of tests from Series 2 is compared with a single test from Series 1, and in these cases the water rate presented for Series 2 is the average rate for the pair.

TABLE 11.
STEAM CONSUMPTION FOR COMPARABLE TESTS OF SERIES 1 AND 2.

Speed, m. p. h.	Cut-off, per cent	Test Numbers		Steam Consumption, lb. per i. h. p. hour		Difference in Steam Consumption, Percentage of Consumption for Series 2.
		Series 1	Series 2	Series 1	Series 2	
10	24	2024	2081 2086	34.74	31.35	10.8
,,	32	2028	2075 2097	30.57	28.40	7.6
20	16	2026	2080 2087	31.67	30.76	2.9
,,	24	2027	2077	27.84	27.36	1.8
,,	32	2029	2073	27.51	27.20	1.1
,,	40	2035	2072	29.43	27.19	8.2
,,	48	2033	2084	27.83	28.69	−3.0
30	24	2030	2078	28.99	28.09	3.2
,,	32	2032	2074 2092	27.84	27.25	2.2
,,	40	2037	2082	29.56	27.88	6.0
					Average	4.1

Except for the two tests run at 20 miles per hour and 48 per cent cut-off, all the tests of Series 2 show a lower steam consumption than the corresponding tests of Series 1. The differences in steam consumption are shown in the last column of the table, where they are expressed in percentages of the water rate for Series 2. With the one exception cited, the improvement in water rate ranged from 1.1 to 10.8 per cent and the average improvement for all tests amounted to 4.1 per cent. Neither this average nor the range is very great, and these facts emphasize the statement previously made that all the repairs and changes were such as would have been regarded as unnecessary under ordinary conditions, and that they were resorted to only that nothing which would probably improve performance should be left undone.

In the data for tests 2090 and 2091 means are at hand for roughly differentiating the effect of the changes in nozzle tip from the effect of the other changes. It will be recalled that during these two tests the conditions were identical with those prevailing during the tests of Series 2, except that the 5⅞-in. nozzle tip used in Series 2 was replaced by the 5¼-in. tip which had been used in Series 1. A comparison of the water rates for these two tests with the water rates for the comparable tests of Series 2 is exhibited below.

TABLE 12.

COMPARISON OF WATER RATE WITH 5⅞-IN. NOZZLE TIP AND 5¼-IN. NOZZLE TIP.

Speed, m. p. h.	Cut-off, per cent	Test Numbers		Steam Consumption, lb. per i. h. p. hour		Difference in Steam Consumption, Percentage of Consumption for Series 2
		Tests with 5¼-in. Tip	Tests with 5⅞-in. Tip, Series 2	Tests with 5¼-in. Tip	Tests with 5⅞-in. Tip, Series 2	
20	24	2090	2077 2074	28.99	27.36	6.0
30	32	2091	2092	29.10	27.25	6.8

It is apparent that in both tests 2090 and 2091, with the smaller nozzle tip, the water rate was higher than in the corresponding tests of Series 2 in which the larger tip was used. The average difference based on the tests of Series 2 is 6.4 per cent. In view of the range in the differences in water rate for all tests of the two series, which is exhibited in the first table in this section, it is doubtless unsafe to draw too sweeping a conclusion from a showing which rests on a comparison of two pairs of tests only. Since, however, the average difference in steam consumption for all tests of both series was only 4.1 per cent, and since such information as is available concerning the effect of the change in nozzle tip shows that it made an average change in steam consumption of 6.4 per cent; the inference is perhaps warranted, that practically all the improvement effected by the changes and repairs was accomplished by the increase in the size of the exhaust nozzle tip, through its influence on back pressure.

PART II.

APPENDIX I.

THE LOCOMOTIVE.

Illinois Central Railroad locomotive 958 is of the consolidation type. It was built by the Baldwin Locomotive Works in December, 1909, and in the classification of the Associated Lines is designated as C — 63 — $\frac{22}{30}$ — 39.2. The locomotive uses saturated steam in simple cylinders twenty-two inches in diameter by thirty inches stroke, weighs 223 000 pounds, and has a rated tractive effort of 39 180 pounds. This tractive effort assumes a driving wheel diameter of 63 inches. The drivers however had been turned to 61 inches for which the rated tractive effort would be 40 470 pounds. The general design of the locomotive is shown in Fig. 40 and 42, and its appearance in service is shown in Fig. 1. The period of its service and its mileage have been stated in section II.

Repairs and Changes.—The repairs and changes which have been referred to in Part I were as follows.

After test No. 2037. The valves were reset; the valve and cylinder packing-rings were renewed; lost motion in the eccentric straps was taken up; the piston-rod packing was renewed; cylinder cocks were repaired or renewed; side-rod bushings were renewed; a new injector was applied; the boiler seams were caulked; three new tires were applied; and certain minor adjustments were made in order to take up lost motion.

After test No. 2045. The cylinders and the valve chambers were rebored; the pistons and piston packing-rings were renewed; the valve bull-rings and packing-rings were renewed; the piston rods were trued; a small leak in one of the branch pipe joints was stopped; and the $5\frac{1}{4}$-in. nozzle tip previously in use was replaced by a $5\frac{7}{8}$-in. tip. The $5\frac{1}{4}$-in. tip was again used during tests 2090 and 2091.

The Boiler.—The boiler, which carried a working pressure of 200 pounds, was of the crown-bar type, with straight top and wide firebox. Its general design appears in Fig. 41, 43, and 44. The principal dimensions of the boiler are given in the following list.

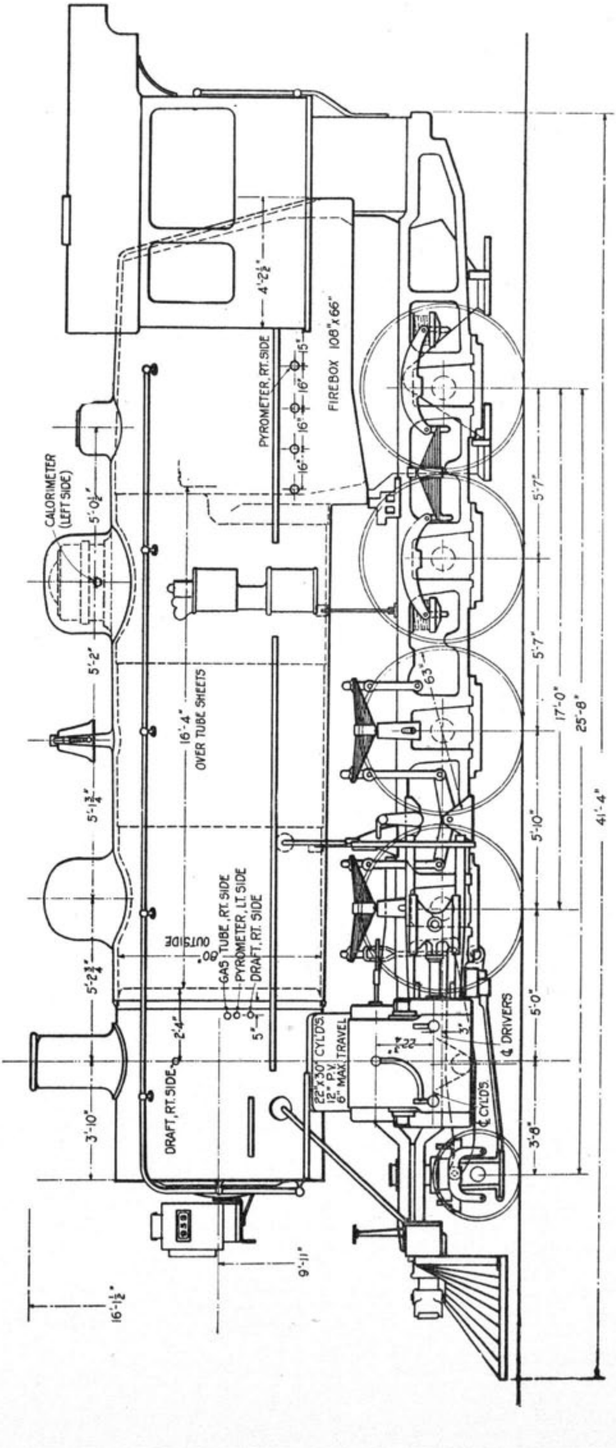

FIG. 40. SIDE ELEVATION OF ILLINOIS CENTRAL RAILROAD LOCOMOTIVE 958.

Outside diameter of first ring *(205)**	80 inches
Thickness of sheets:	
Cylindrical courses	¾ ”
Wrapper sheet	⅝ ”
Flue sheets	½ ”
Firebox sheets	⅜ ”
Number of tubes *(211)*	413
Outside diameter of tubes *(212)*	2 inches
Thickness of tubes *(213)*	0.133 ”
Length between tube sheets *(214)*	195.2 ”
Length of firebox, inside *(234)*	108.25 ”
Width of firebox, inside *(235)*	66.13 ”
Volume of firebox *(238)*	244 cu. ft.
Heating surface of the tubes, fire side *(272)*	3094 sq. ft.
Heating surface of front tube sheet *(277)*	21 ” ”
Heating surface of the firebox, fire side *(273)*	168 ” ”
Total heating surface, fire side *(275)*	3283 ” ”
Water space in the boiler *(282)*	429 cu. ft.
Steam space in the boiler *(283)*	107 ” ”
Grates, of the interlocking finger type, area *(252)*	49.55 sq. ft.

The Cylinders and Valves.—The cylinders and valve chambers were of cast-iron with cast iron bushings. The pistons were of the box type, cast in one piece. The steam distribution was controlled by piston valves with inside admission. The nominal piston travel was 6 inches, and the actual travel 5-55/64 inches on the right side, and 5-27/32 on the left side. The valves were set with 1/32 inch lead in full gear and were actuated by an indirect shifting link motion.

The principal cylinder and valve dimensions during the various tests included in this report were as follows:

	During Tests 2009-2045	During Tests 2072-2098
Cylinder Diameter		
Right side *(68)*	22.071 inches	22.107 inches
Left side *(69)*	22.282 ”	22.314 ”
Valve Chamber Diameter		
Right side	12.031 ”	12.102 ”
Left side	12.020 ”	12.078 ”

*Code item number.

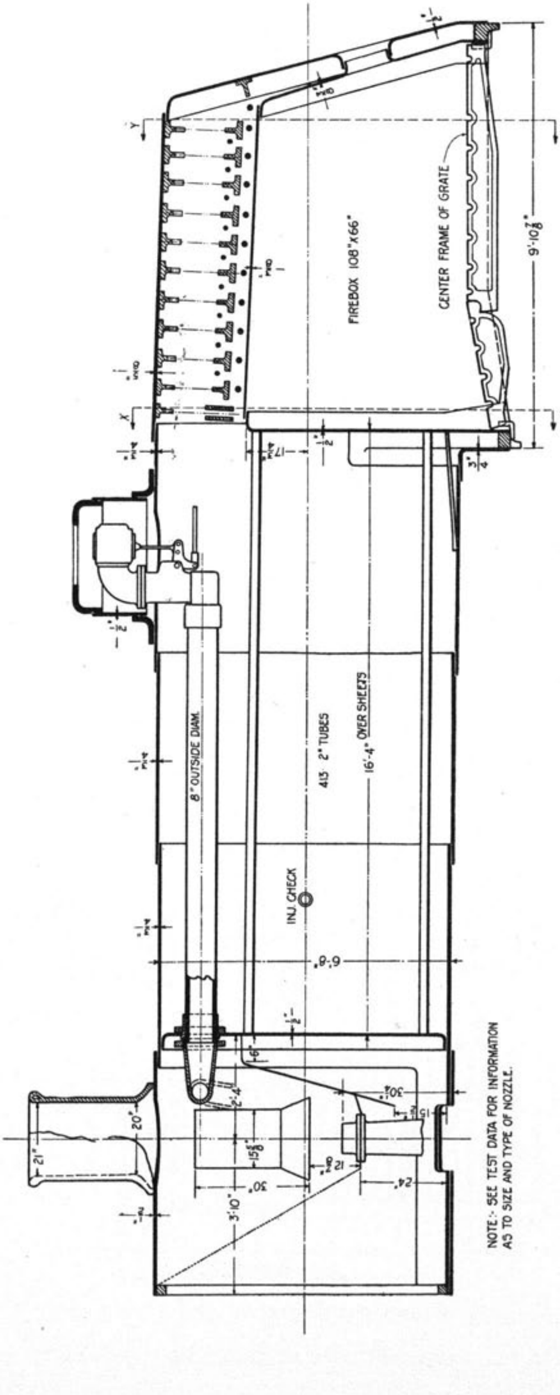

FIG. 41. LONGITUDINAL SECTION THROUGH THE BOILER.

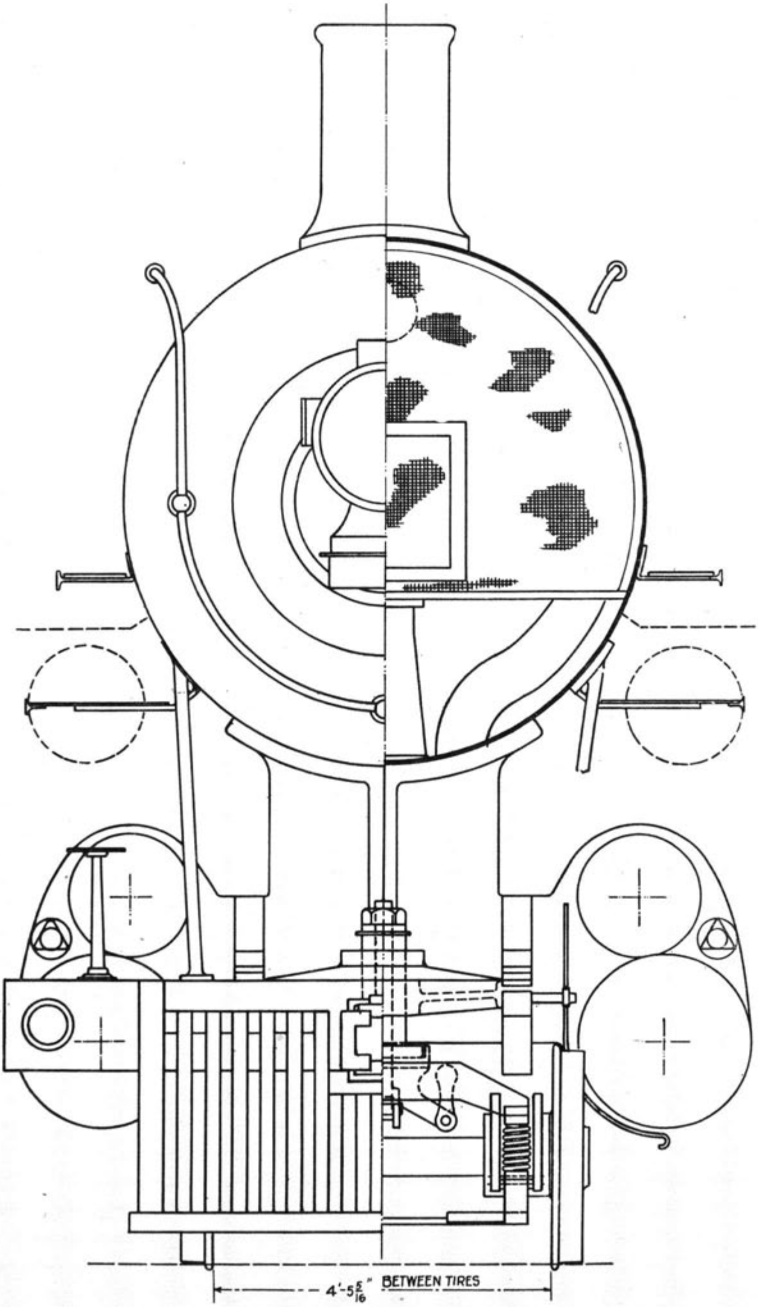

FIG. 42. FRONT ELEVATION OF THE LOCOMOTIVE.

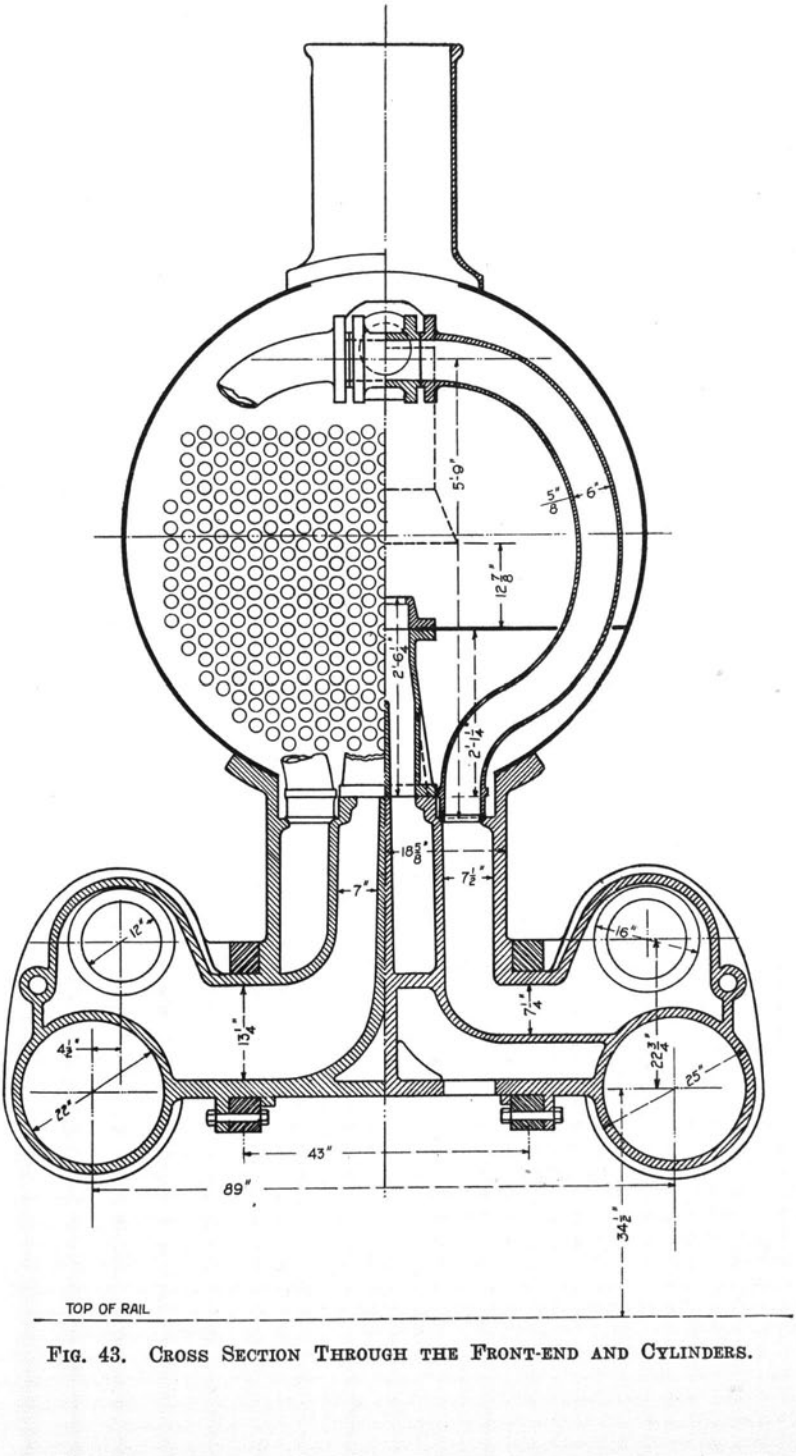

FIG. 43. CROSS SECTION THROUGH THE FRONT-END AND CYLINDERS.

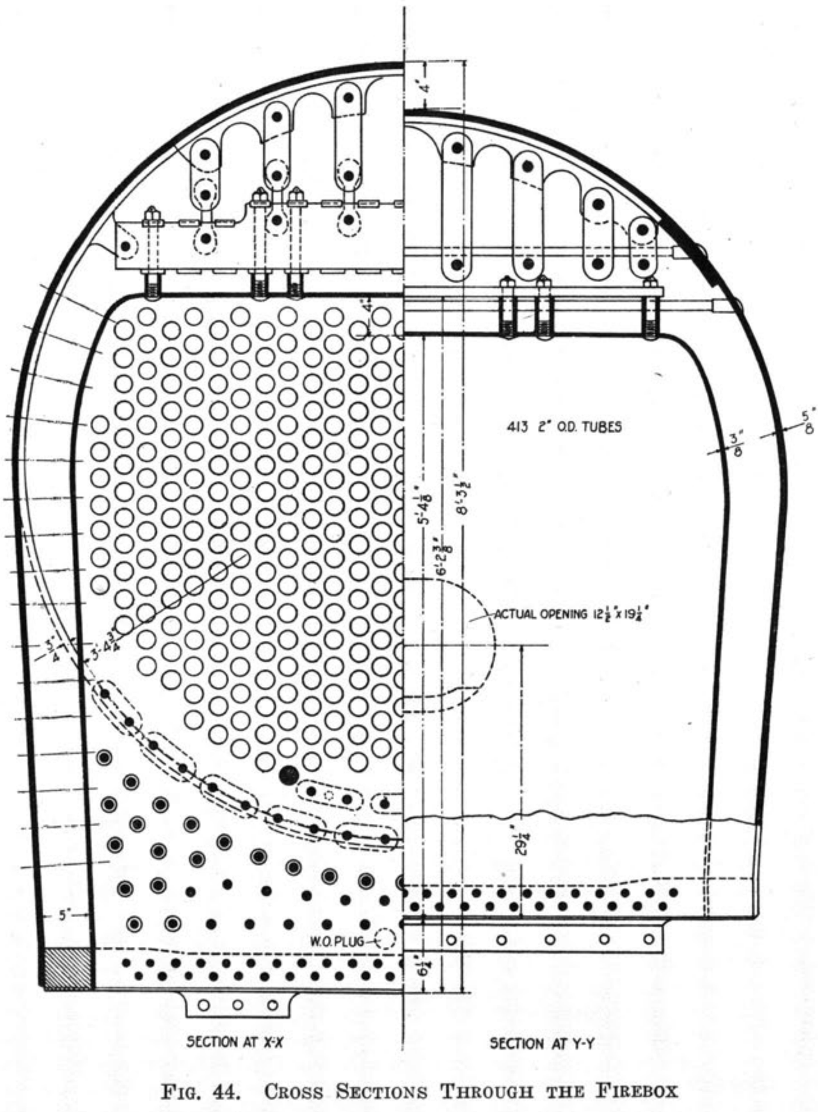

FIG. 44. CROSS SECTIONS THROUGH THE FIREBOX

	During Tests 2009-2045		During Tests 2072-2098	
Piston Stroke				
Right side *(77)**	29.92	inches	29.94	inches
Left side *(78)*	29.94	”	29.94	”
Piston Rod Diameter				
Right side *(135)*	3.917	”	3.907	”
Left side *(136)*	3.928	”	3.907	”
Cylinder Volume (both sides)	13.199	cu. ft.	13.199	cu. ft.

	During Tests 2009-2037		During Tests 2038-2098	
Clearance Volume				
Ride side, head end *(86)*	9.89	per cent	11.42	per cent
Right side, crank end *(87)*	9.74	”	11.01	”
Left side, head end *(88)*	9.73	”	10.60	”
Left side, crank end *(89)*	10.06	”	11.01	”

General Dimensions.—The principal general dimensions not already cited are shown in the following list.

Total weight in working order *(63)*	223 000 lb.
Weight on drivers *(64)*	200 900 ”
Weight on leading truck *(48)*	22 100 ”
Weight of tender, loaded	135 000 ”
Weight of locomotive and tender, in working order	358 000 ”
Driving wheel base *(39)*	17 ft. – 0 in.
Total wheel base *(41)*	25 ft. – 8 in.
Driving wheel diameter, over tires (nominal) *(2)*	63 in.
Truck wheel diameter *(27)*	33½ in.
Driving journal, main	10 in. x 12 in.
Driving journals, other	9 in. x 12 in.
Truck journals	6 in. x 10 in.

The actual average driving wheel diameter was 61.01 inches during tests 2009–2037, and 61.03 inches during tests 2038–2098. The corresponding actual average circumferences *(code No. 19)* were 15.972 and 15.978 feet respectively. The principal ratios are given below. Where two values of the ratio appear, the first is based on nominal dimensions, the second on actual dimensions.

*Code item number.

$$\frac{\text{Weight on drivers}}{\text{Tractive effort}} = \frac{200\,900}{39\,180} = 5.12$$

$$\frac{\text{Weight on drivers}}{\text{Tractive effort}} = \frac{200\,900}{40\,470} = 4.96$$

$$\frac{\text{Total weight}}{\text{Tractive effort}} = \frac{223\,000}{39\,180} = 5.69$$

$$\frac{\text{Total weight}}{\text{Tractive effort}} = \frac{223\,000}{40\,470} = 5.51$$

$$\frac{\text{Tractive effort} \times \text{diameter of drivers}}{\text{Total heating surface}} = \frac{39\,180 \times 63}{3283} = 751.8$$

$$\frac{\text{Tractive effort} \times \text{diameter of drivers}}{\text{Total heating surface}} = \frac{40\,470 \times 61}{3283} = 751.8$$

$$\frac{\text{Firebox heating surface}}{\text{Total heating surface}} = \frac{168}{3283} = .0513$$

$$\frac{\text{Weight on drivers}}{\text{Total heating surface}} = \frac{200\,900}{3283} = 61.19$$

$$\frac{\text{Total weight}}{\text{Total heating surface}} = \frac{223\,000}{3283} = 67.92$$

$$\frac{\text{Heating surface}}{\text{Grate area}} = \frac{3283}{49.55} = 66.26$$

$$\frac{\text{Tube surface}}{\text{Firebox heating surface}} = \frac{3094}{168} = 18.41$$

$$\frac{\text{Total heating surface}}{\text{Cylinder volume}} = \frac{3283}{13.199} = 248.8$$

Horse Power Constants.—The constants used in computing the test results are as follows:

For dynamometer horse power (power developed when the speed is one revolution per minute and the pull is one pound) the constants are

For tests 2009 to 2037 *(318)** .... .0004840
For tests 2038 to 2098 *(318)* .... .0004842

*Code item number.

For indicated horse power (power developed at one revolution per minute and one pound mean effective pressure) the constants are

	Tests 2009-2045	2072-2098
For right cylinder, head end *(319)**	.02893	.02902
For right cylinder, crank end *(320)*	.02802	.02811
For left cylinder, head end *(321)*	.02948	.02957
For left cylinder, crank end *(322)*	.02857	.02866

*Code item number.

APPENDIX 2.

THE LABORATORY.

The general purpose underlying the design of this and of all other locomotive laboratories is to provide means whereby the locomotive machinery may be run and the locomotive worked throughout its range of capacity, while the locomotive as a whole remains stationary; thus permitting all test measurements to be made with the degree of accuracy possible in a stationary power plant test.

The laboratory equipment consists of, first, a means for so supporting the locomotive that its driving wheels may be rotated and that the power developed may be absorbed and dissipated; second, a means for anchoring the locomotive when so mounted and for measuring the tractive effort developed; third, means for supplying and measuring coal and water; and finally, means for disposing of the waste gases and exhaust steam.

The Building.—The building in which the plant is housed is shown in Fig. 45. It is 40 feet wide and 115 feet long, with a height of 22 feet under the roof trusses. At the rear end of the building is a coal room, above which are a platform for the exhaust fan and a wash-room. A basement extends under all of the main floor, except under the space occupied by the coal room. The walls are laid up both inside and out with faced brick, the floors are of reinforced concrete, and the roof is of the same material covered with slate. With the exception of the coal room all portions of the building are served by a ten-ton traveling crane.

Supporting Wheels and Axles.—The supporting mechanism consists primarily of pairs of wheels, whose location may be adjusted to suit the wheel base of any locomotive. Fig. 51 shows the general design of wheels, axles, bearings, and bed-plates. The supporting element for each pair of locomotive drivers consists of an axle, two wheels, and two bearings. The supporting wheels are 52 inches in diameter, have plain 5-inch tires, and are pressed on 11½-inch axles.

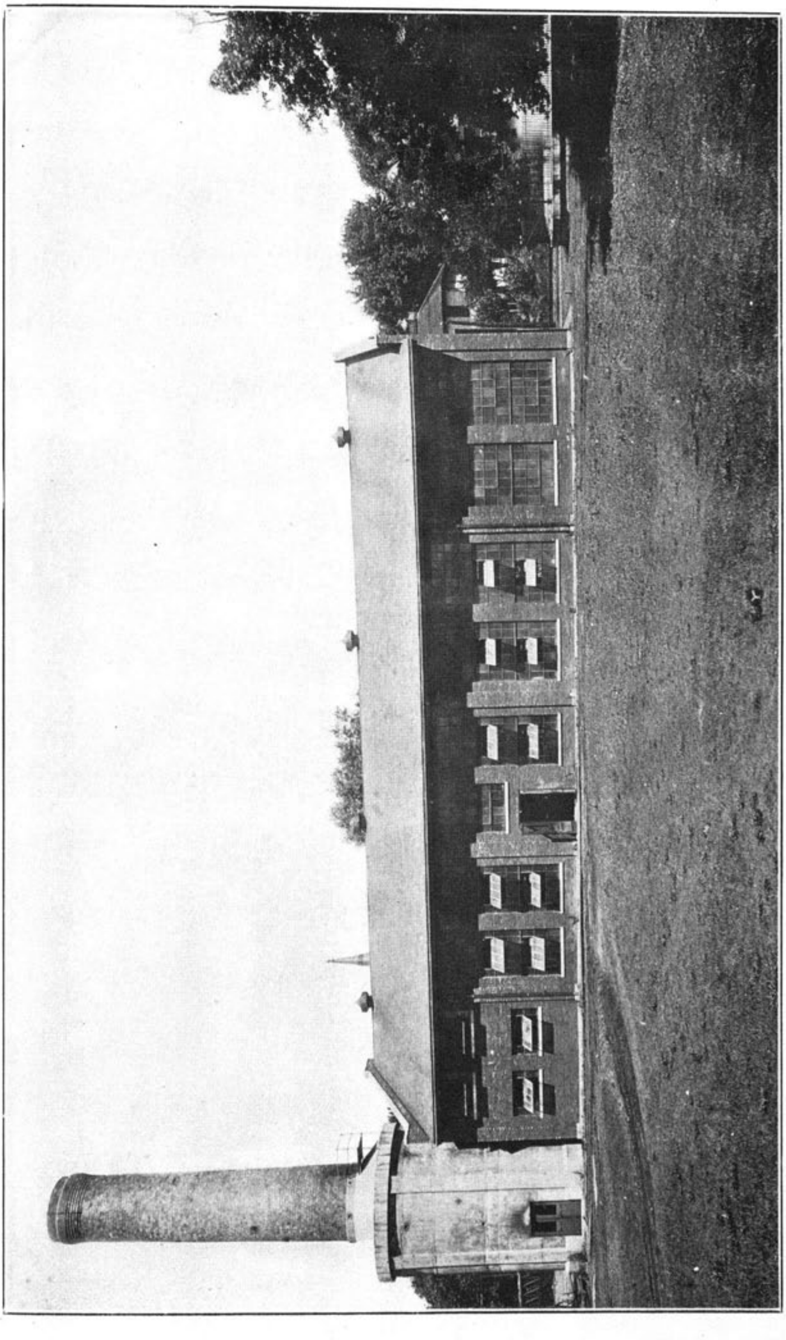

Fig. 45. The Locomotive Laboratory.

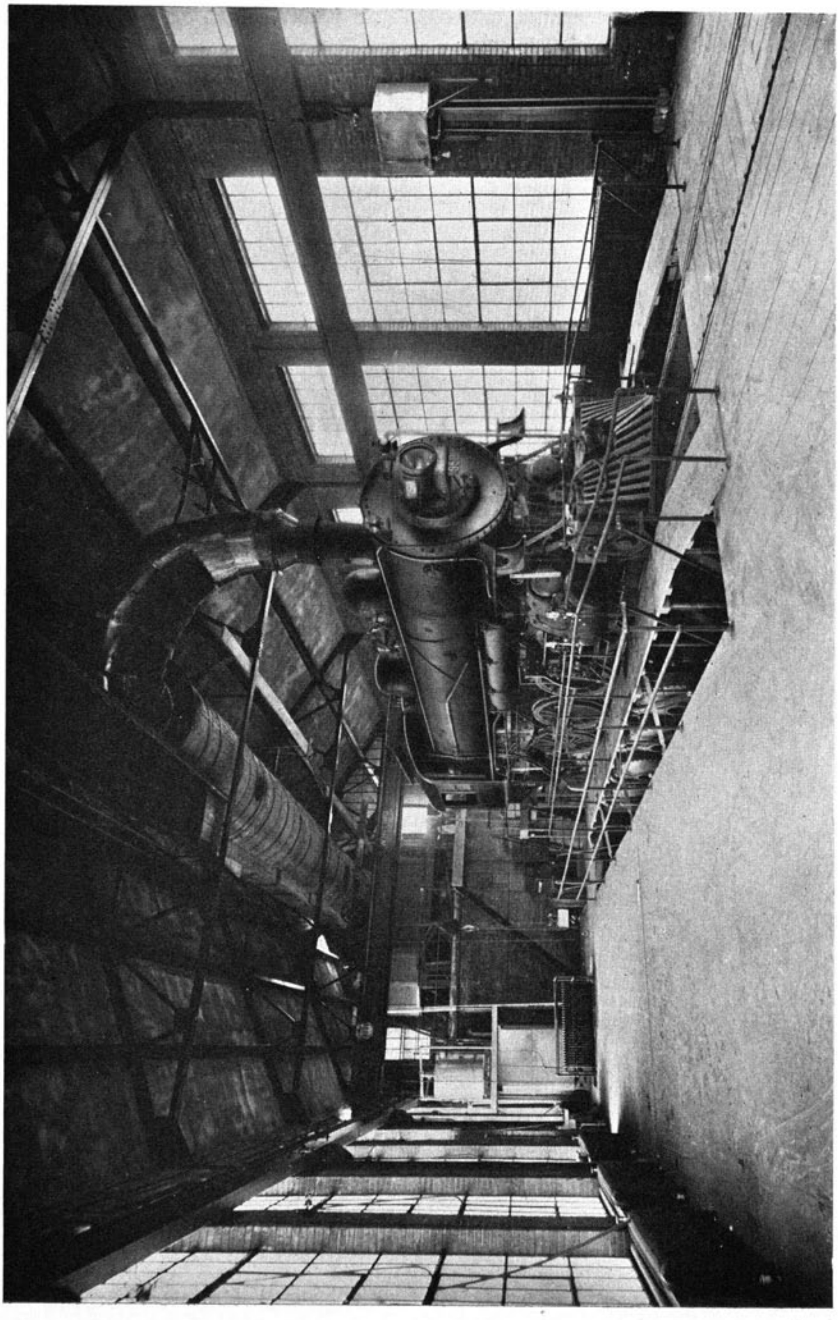

FIG. 46. AN INTERIOR VIEW OF THE LABORATORY WITH LOCOMOTIVE 958 IN POSITION.

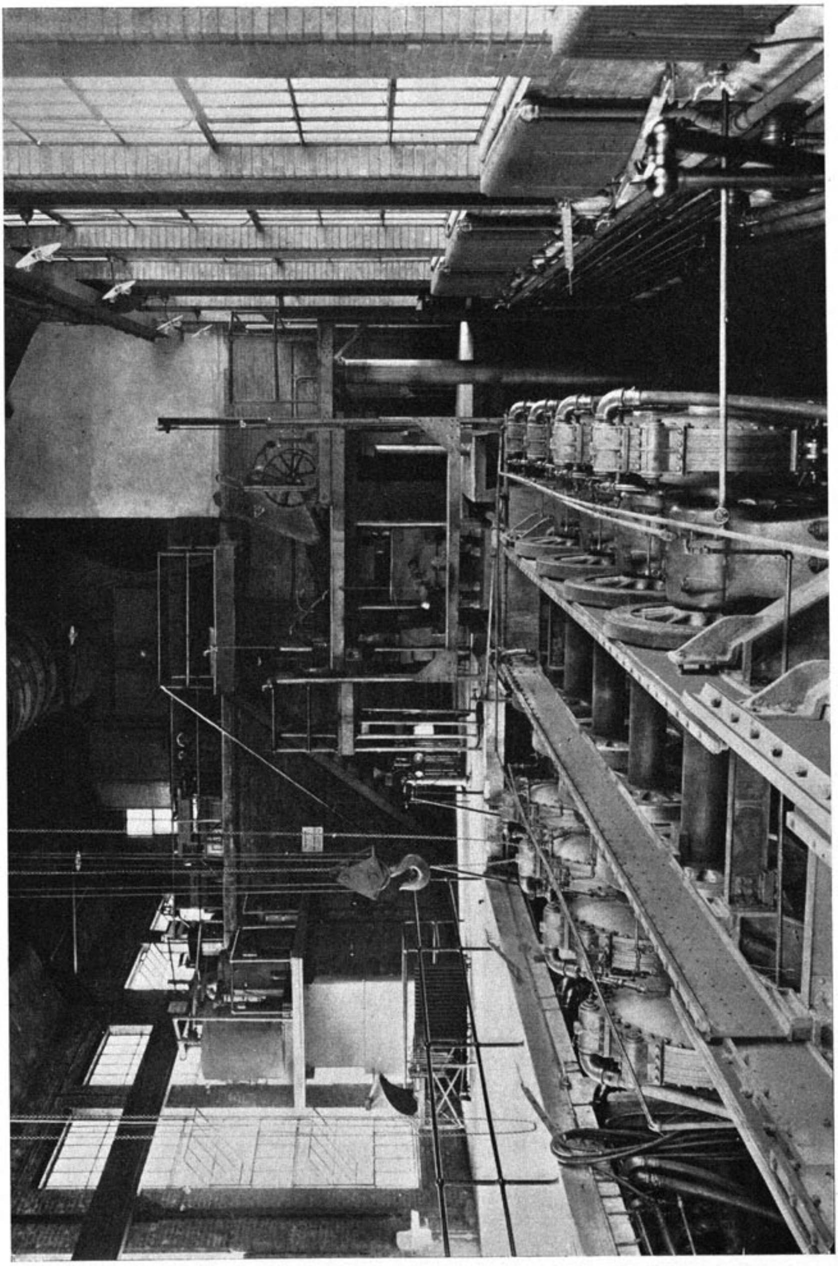

FIG. 47. THE REAR END OF THE TESTING PIT, SHOWING THE REMOVABLE TRACK, THE SUPPORTING WHEELS AND THEIR BEARINGS, AND THE BRAKES.

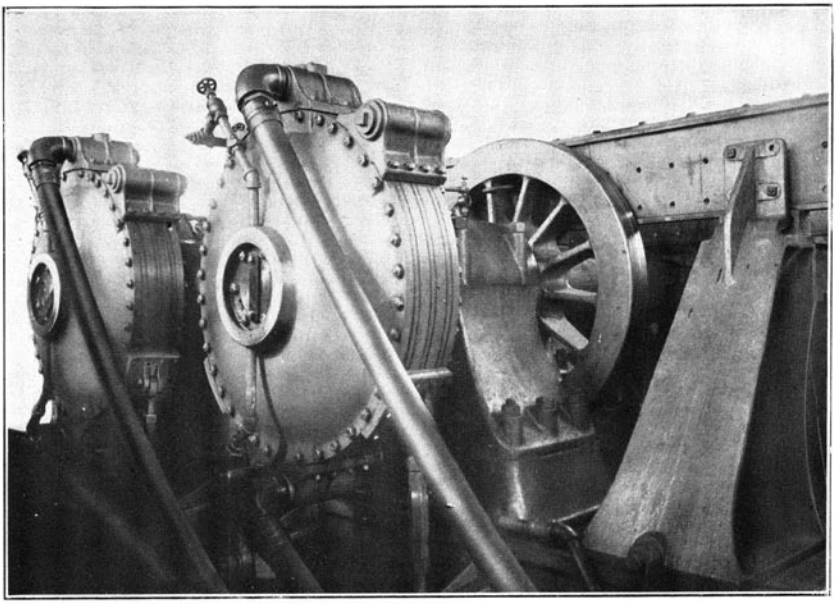

FIG. 48. AN EXTERIOR VIEW OF THE BRAKES.

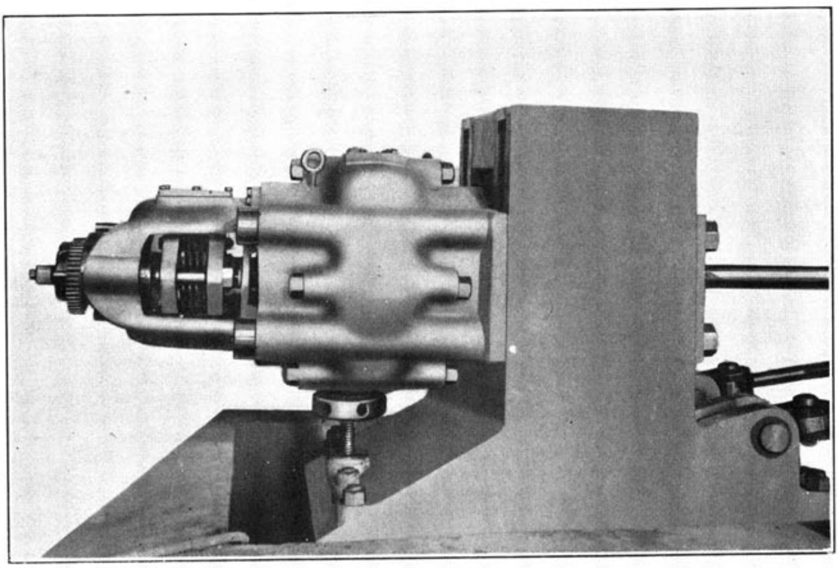

FIG. 49. THE WEIGHING HEAD AND PEDESTAL OF THE DYNAMOMETER.

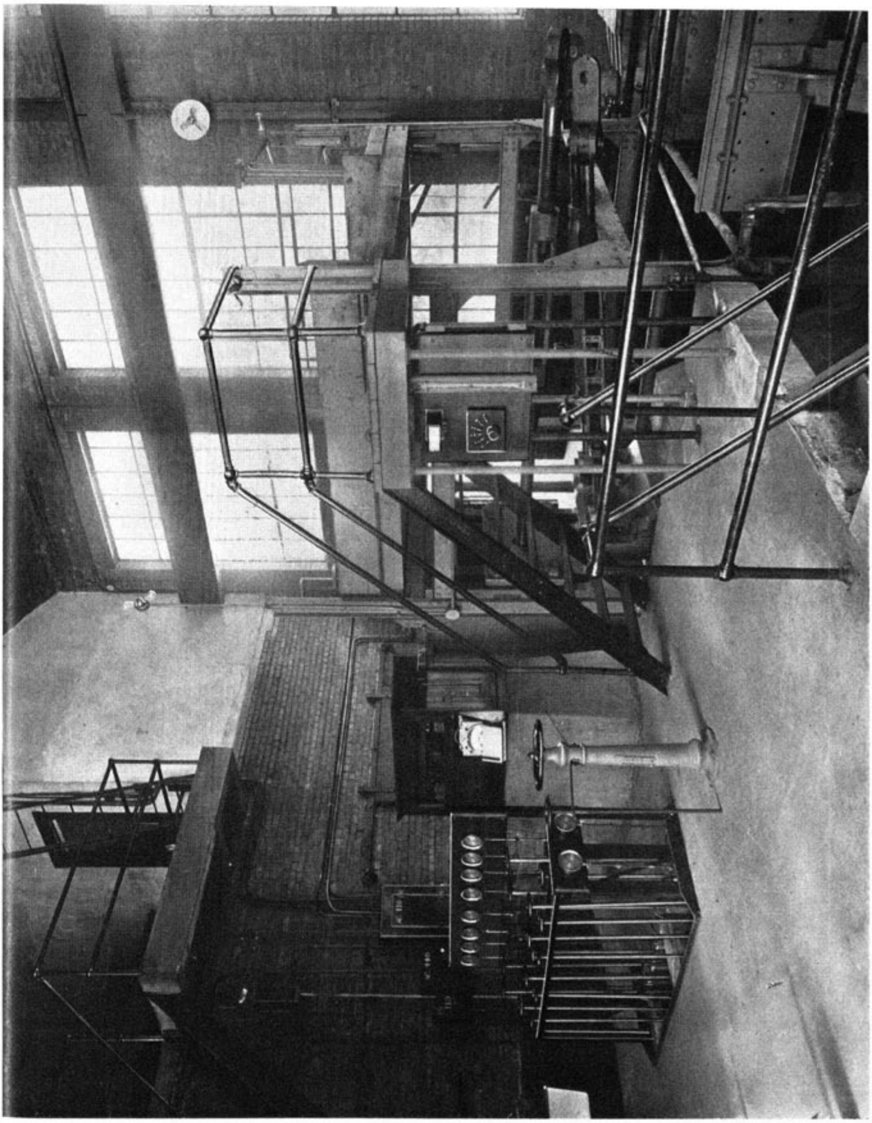

FIG. 50. THE BRAKE CONTROL VALVES, THE DYNAMOMETER SCALE, THE DRAWBAR AND SAFETY LINKS, AND THE FIRING PLATFORM.

The axles and tires are of the highest grade of heat-treated carbon steel and were donated by the Midvale Steel Company. Provision has been made for replacing the 52-inch wheels by 72-inch wheels for testing high speed locomotives, where the use of the smaller wheels would involve rotating speeds as high as 530 revolutions per minute.

Bearings.—The bearings for the supporting-wheel axles are self-aligning, their shells being carried in spherical sockets which form the upper part of the pedestal. The journals are 9½ inches by 20 inches, and the axles bear on the underside only. Oil for lubrication enters the bearing cap at two points and is supplied under head from an elevated tank. The pedestal is made in two parts, so that by removing the lower section, its height may be adjusted to provide for the 72-inch supporting wheels. This arrangement will continue to bring the top edge of the larger supporting wheels level with the outside track. The base of the pedestal is secured to a massive cast-iron bed-plate by T-bolts held in slots running the entire length of the bed. Each bed-plate consists of three sections placed end to end, 18 inches in height and 36 inches wide over all. The length of the present bed-plate is 42 feet, which provides for a maximum driving-wheel base of 36 feet, and the foundation is built to receive two more 14-foot sections of bed-plate. The supporting machinery rests on a concrete foundation 12 feet wide and 93 feet long, which varies in thickness from 3½ feet at the front to 5 feet at the rear end. The rear end is surmounted by a pyramidal base of reinforced concrete, to which the dynamometer is bolted.

Hydraulic Brakes.—Supported in this way the driving wheels are free to turn and the power produced at the driving wheel rim is absorbed by means of the brakes shown in Fig. 47, 48, and 52. One of these brakes is mounted on each end of each supporting-wheel axle. Each brake consists essentially of three cast iron discs (C, Fig. 52) which, bolted to the cast iron hub (F), are keyed to the supporting axle and form with it an integral revolving element. These three discs rotate between 1/16-inch copper diaphragms (D), bolted to the rim of a stationary housing (H), and flanged over the edges of the floating rings (E) and of the housing, to which they are secured by means of the expanding rings (G). The housing is prevented from turning by means of the links (L) attached to the bed-plate. The rubbing surfaces of the discs and diaphragms are lubricated with a medium grade of cylinder oil which enters the brake under pressure through the oil-

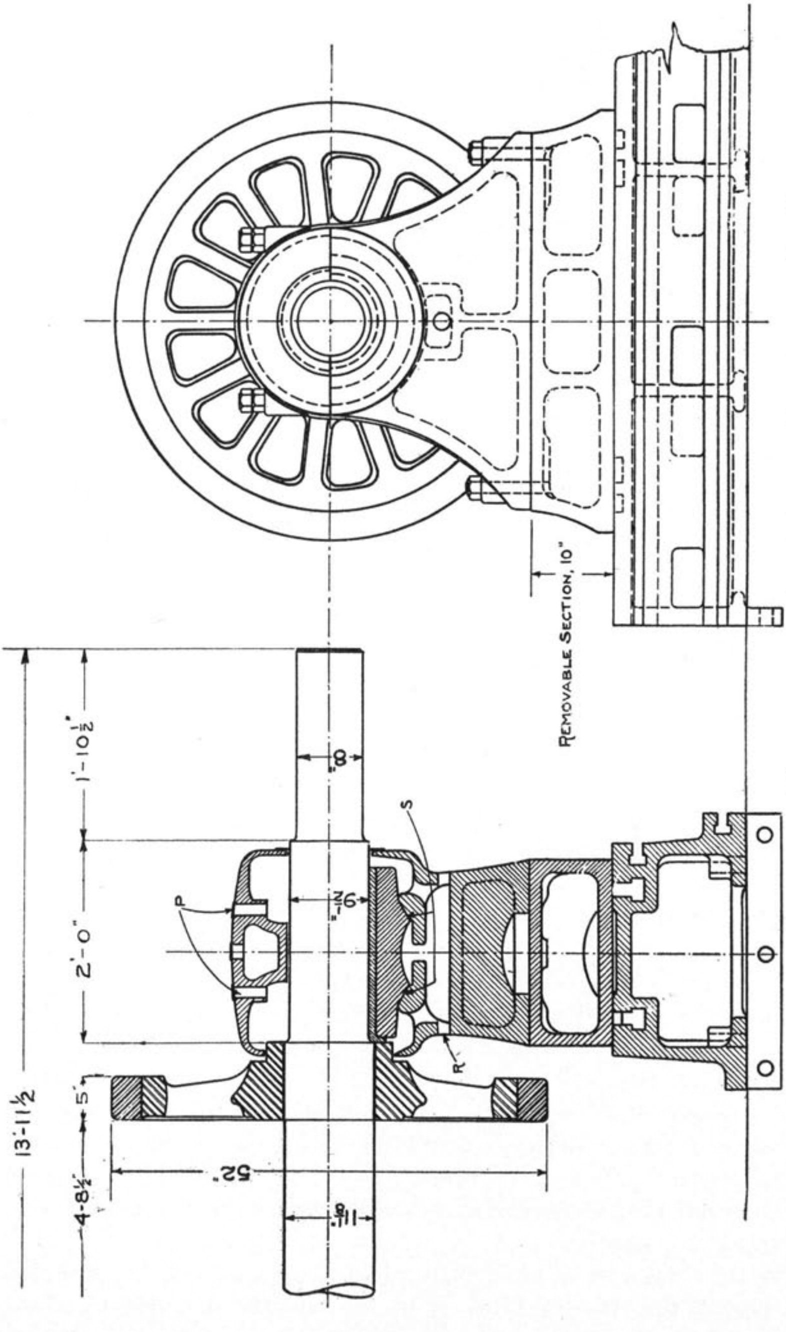

FIG. 51. ONE OF THE SUPPORTING WHEELS, WITH ITS AXLE, BEARING, PEDESTAL, AND BED PLATE.

header (N) at the periphery of the discs, and through the oil-duct (K). The oil is taken off at M as it oozes out around the disc hub. The diaphragms form also within the casing four water compartments which have no communication whatever with the compartments in which the discs rotate. Water at about 60 deg. F. is forced through 3-inch hose connections into the brake at the lower header (B) and leaves through the upper header (A). The amount of water passing through any individual brake and the water pressure within the brake may be regulated at will by means of suitable valves in the piping. The brake load is controlled by thus modifying the water pressure. This is accomplished simultaneously for all of the brakes by means of the large control-valve in the brake supply main, shown in Fig. 50. The auxiliary brake-valves and gages shown at the left in this same figure permit the separate adjustment of load on each brake. Each of these brakes has the capacity of absorbing 450 horse power, having been designed to develop a resisting torque of 18 000 pounds-feet at speeds up to 130 revolutions per minute. This capacity allows for a considerable increase in wheel loads above that which could be imposed by the most heavily loaded driver of the present day.

Placing the Locomotive.—Fig. 47 shows the mounting machinery arranged to receive an eight-driver locomotive. The top of the supporting-wheels is level with the main floor of the building and one-fourth inch higher than the outside track. Before the locomotive to be tested is placed upon the plant, its wheel-spacing is determined and the supporting-wheel centers spaced accordingly. The tender having been removed, the locomotive is backed into the laboratory and onto the temporary track shown in place between the supporting-wheels. The drivers run on their flanges over the temporary track, which leaves their treads free to engage the supporting-wheels, so that when the locomotive is properly placed the supporting-wheels carry all of the weight except, of course, that borne by leading or trailing trucks. The temporary track being relieved, may be removed. Mounted in this way, the locomotive is held in place and prevented from moving forward or backward by means of the dynamometer draw-bar, which is supplemented by two safety-bars that come into play in case of failure of the draw-bar. These three bars are shown in Fig. 50. Forward and trailing-truck wheels are carried on track sections which are level with the supporting wheels.

The Dynamometer.—The dynamometer, the chief function of which is to permit the tractive force of the locomotive to be measured, is

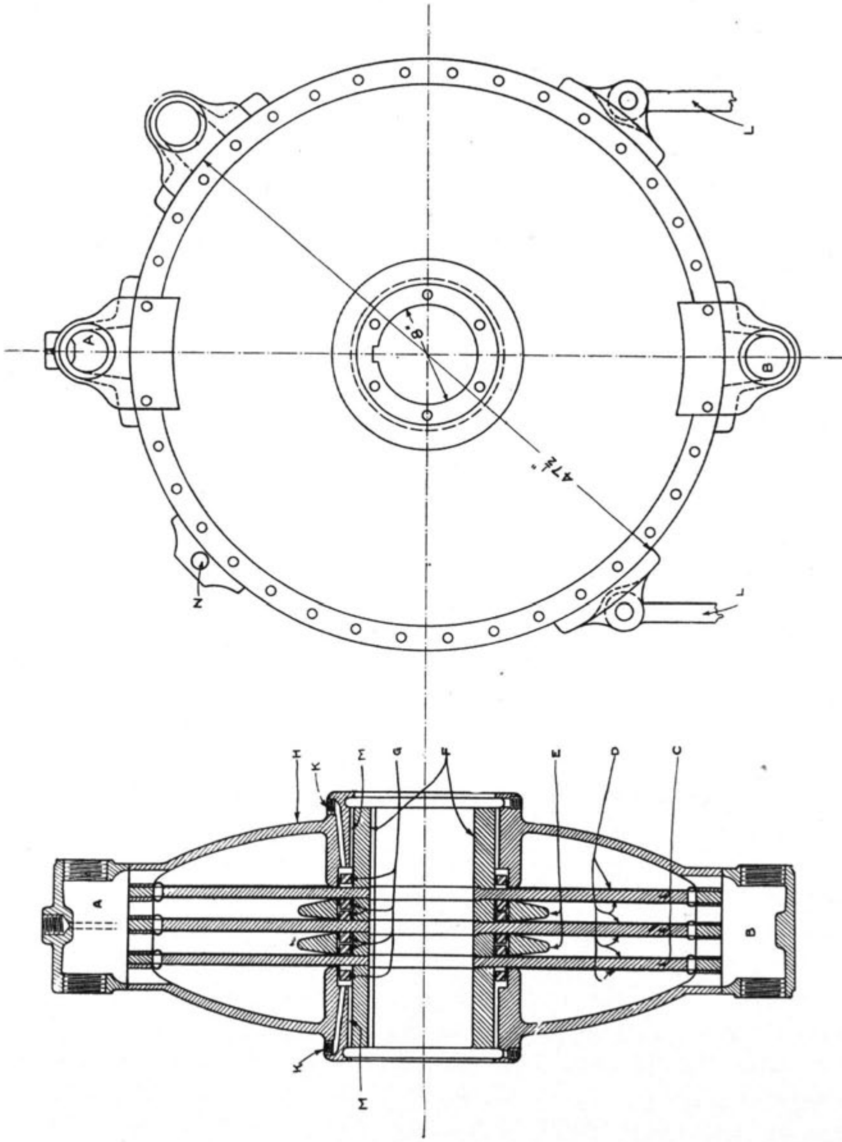

FIG. 52. ONE OF THE BRAKES.

shown in Fig. 47, 49, and 50. It is of the Emery type and consists essentially of two parts: the weighing head, carried on a pedestal and shown in Fig. 49, and the measuring and recording scale shown in Fig. 50. The weighing head may be raised or lowered to suit the height of the drawbar of any locomotive. Within the weighing head is an enclosed oil-chamber with a flexible wall or diaphragm, which receives and balances any force transmitted through the drawbar of the locomotive. The pressure within this oil-chamber varies with the load, and is transmitted through a copper tube of small bore to a smaller oil-chamber known as the reducing chamber, located in the case with the measuring apparatus. The pressure thus produced in the reducing chamber moves the beam of a substantial but sensitive scale which measures the tractive force of the locomotive.

In order to prevent undue shocks from taking place within the weighing head of the dynamometer on account of variations in the force in the drawbar, an initial load of 50 000 pounds is imposed upon the oil behind the diaphragm by means of the capstan and springs located at the rear of the weighing head and shown at the left in Fig. 49. The weighing head of the dynamometer is so designed that by an adjustment of the capstan the tractive effort may be measured whether the locomotive drivers are turning forward or backward. For the sake of accuracy in determining the drawbar pull it is essential that the locomotive drivers be placed and maintained with their centers precisely above the centers of the supporting-wheels. To satisfy this requirement the longitudinal travel of the dynamometer drawbar from no load to full load must be reduced to a minimum. In this instrument the range of movement is only three one-thousandths of an inch. The scale beam reads directly to 20 000 pounds in 100-pound divisions, and a vernier gives readings to ten pounds. For drawbar pulls of more than 20 000 pounds, weights may be added as required. The dynamometer will measure drawbar pulls as high as 125 000 pounds.

A feature of interest in the design of the scale lies in the fact that the adjustment of the poise weight on the scale beam may be made automatically. This is accomplished by means of a small motor which is mounted on the scale beam and geared to a screw which passes through the poise weight. Attached to the scale beam is a contact arm, and any movement of the beam in either direction causes a series of mercury-cup contacts; the number of contacts depending on the amount of deflection of the beam, which in turn is caused by a change in the load. When contact is made, an electrical circuit is closed and the motor runs in the direction required to bring the poise weight to a position of equilibrium. As soon as the load is balanced, the circuit is broken and the motor stops. This operation is repeated as often as the load changes, and is practically continuous. The action of the poise weight may also be controlled by a hand switch.

Water and Coal Supply.—The general water supply of the University is from driven wells, the demand upon which at times approaches their full capacity. In order therefore that the water which passes through the brakes shall not be wasted, provision has been made for collecting, cooling, and recirculating it. For this purpose a 100 000-gallon concrete storage reservoir (see Fig. 45) has been built in the ground outside of the building. A supply pump for the brakes draws water from this reservoir through a 6-inch main and pumps it through the main control valve to a header, whence it is distributed through auxiliary supply control valves to the several brakes; after which it flows back through another set of auxiliary back-pressure control valves to a sump located in the basement of the laboratory. (See Fig. 53). The water is drawn from the sump by another pump and forced through five 2-inch whirling-spray nozzles above the surface of the water in the reservoir. Water direct from the University mains may also be used in the brakes when desirable.

Water for the locomotive boiler may be drawn from the reservoir or direct from the University mains, and forced by a separate pump to two elevated tanks which are shown in Fig. 47 and 54. Each of these tanks has a capacity of 2000 pounds and rests permanently on a platform scale. At a supply pressure of 45 pounds, each tank can be filled, weighed, and emptied in two and one-half minutes. From the weighing tanks, the water falls into the 18 000-pound capacity feed tank below, and thence passes through two 4-inch supply pipes to the locomotive injectors. Water for the hydraulic elevator used in raising coal from the main floor to the firing platform may be taken from the University main or from the storage tank. In either case the pressure is maintained at 60 pounds by a throttle-control valve on the supply pump. By these provisions in the piping, reservoir water alone may be used for feed-water, brakes, and elevator.

The coal-room shown in Fig. 53 occupies the rear end of the building. It is 22 feet wide and 40 feet long, and has a storage capacity of 300 tons. Coal for the tests is loaded into 1000-pound capacity wagons, run out onto the scales, raised by the elevator to the firing plat-

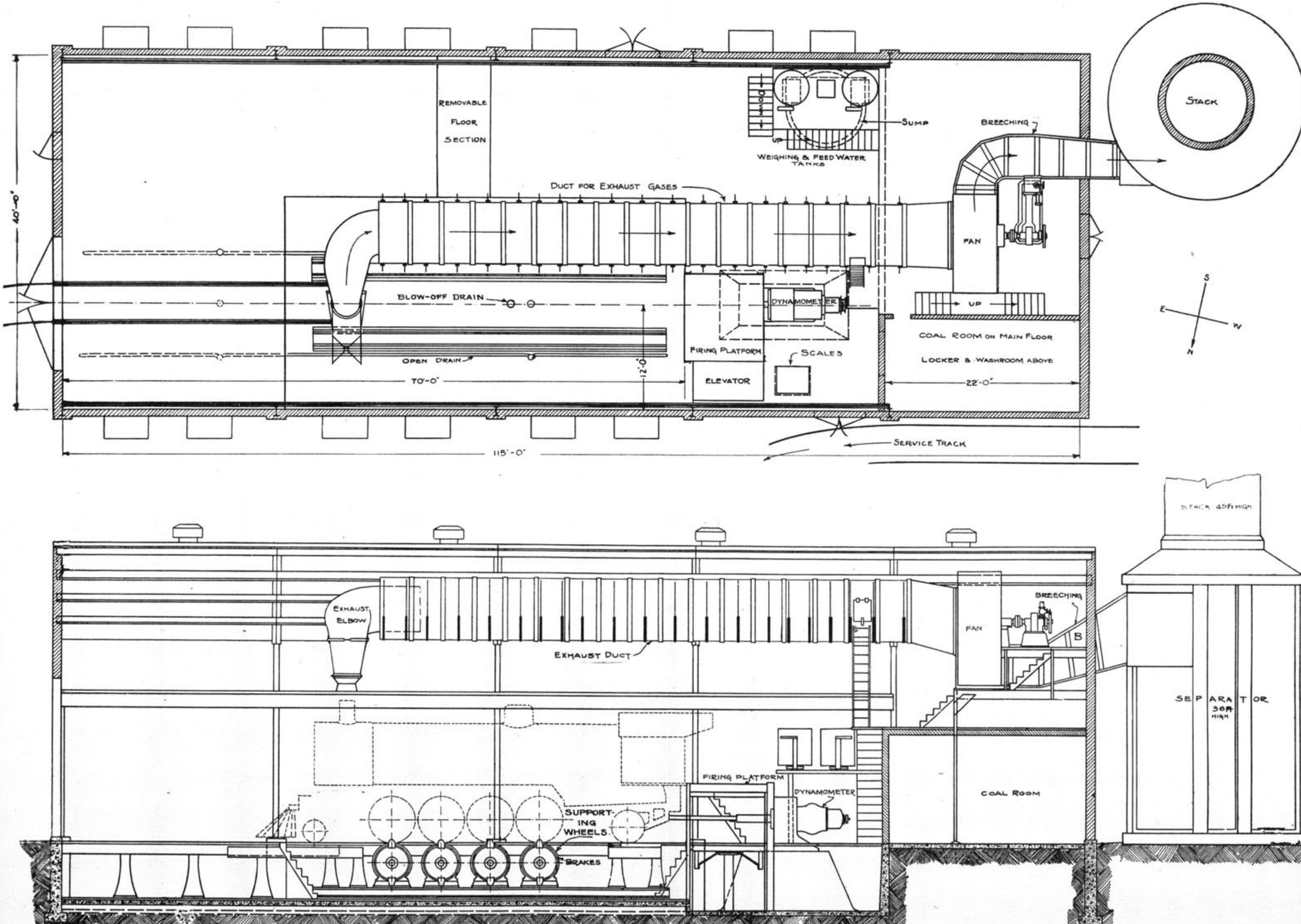

FIG. 53. SECTIONAL PLAN AND ELEVATION OF THE LABORATORY.

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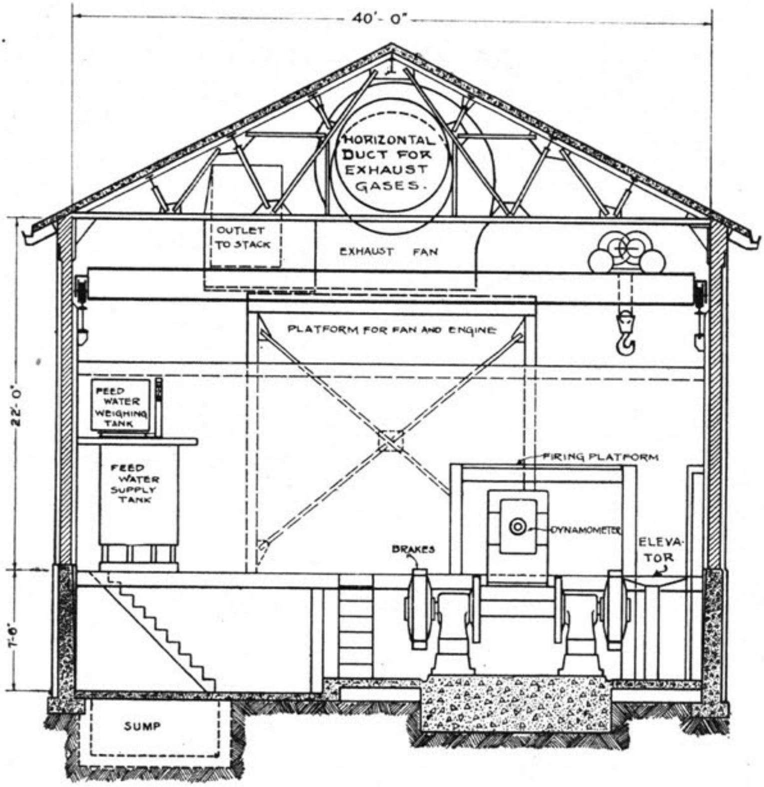

FIG. 54. A CROSS SECTION THROUGH THE MIDDLE OF THE LABORATORY.

form, and there dumped. The firing platform is adjustable in height so as to suit the deck of any locomotive cab. The elevator has a capacity of 2000 pounds. It is also used to raise ashes from the level of the basement.

The Exhaust System.—Recognizing the value of accurate determininations of the total amount of cinders lost through the stack of the locomotive, it was early decided that if possible some means should be incorporated in this plant to collect all of the solid matter which passes through the locomotive front end. Preliminary designs of a cinder catcher which should have sufficient capacity to pass the total volume of waste gas, exhaust steam, and entrained air, and at the same time collect all the cinders from the largest modern locomotive working at high power, made it clear that such a collector would be too

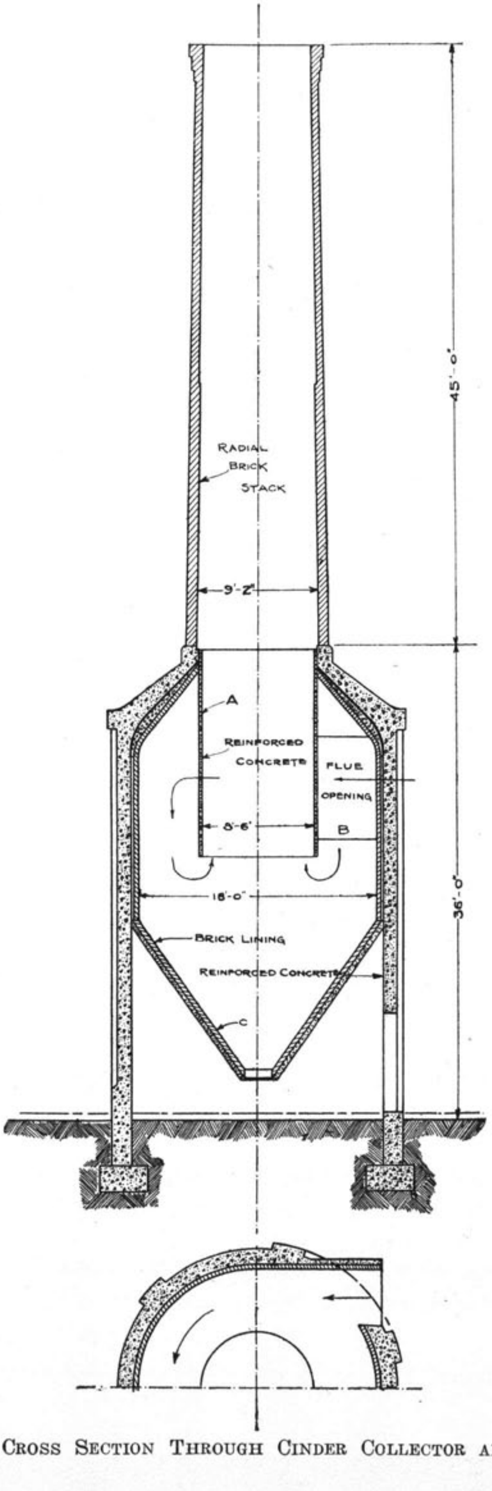

FIG. 55. CROSS SECTION THROUGH CINDER COLLECTOR AND STACK.

large to be located conveniently within the building. Another point considered in the design of the exhaust system was the necessity of a stack of sufficient height to insure that the exhaust gases would be discharged far enough above ground to prove inoffensive to occupants of neighboring residences and University buildings. For this purpose it was decided that a stack 8 feet in diameter and 80 feet high would be required. Further study made it apparent that these two decisions could be embodied in one structure combining the cinder separator and the stack. This has been accomplished in the construction represented in cross-section by Fig. 55, and which is located outside and at the rear of the laboratory.

The system will be most easily understood by following the course of the exhaust gases after they leave the locomotive stack. (Fig. 53 and 54.) The gases and exhaust steam are discharged across an open space above the locomotive stack into a steel exhaust elbow, which carries them up and over to a horizontal duct running through the center of the roof-trusses of the building. The gases, exhaust steam, and solid matter are drawn through this elbow and duct by the exhaust fan, located near the roof at the rear end of the building. They are then passed through a breeching or flue to the separator previously referred to, the action within which may be best explained by reference to Fig. 55. The cinder-laden gases enter the separator at B and in order to leave, they must pass downward and around the sleeve A. This operation gives them a whirling motion, which causes the cinders by centrifugal force to move toward the outside wall, along which they drop to the hopper below, while the gases pass downward and out through the mouth of the sleeve. The cinders collecting at the bottom of the hopper are drawn off, weighed, and analysed between tests. The separator is surmounted by a 45-foot radial brick stack, through which the gases and steam are finally discharged.

On account of the corrosive nature of the mixture of exhaust gases and steam, it was necessary to avoid the use of metal throughout the exhaust system, as far as it was possible to do so. The exhaust elbow which receives the gases from the locomotive stack is necessarily made of steel and needs occasionally to be renewed. The horizontal duct, running through the center of the roof-trusses, is made of a hard and tough asbestos board known as "Transite," which is proof against corrosion. This duct is seven feet in diameter, and is built up in sections so that its length may be varied to suit the position of the locomotive stack. The final adjustment of the elbow above the stack of the locomotive is obtained through the medium of a telescopic connection between the elbow and the duct. The fan has a runner six feet in diameter, and at a maximum speed of 300 revolutions per minute, will pass 140 000 cubic feet of gas per minute. The breeching between the fan and separator is also built of transite, and has a minimum cross-sectional area of about 24 square feet. The outer shell of the separator is built of reinforced concrete, and it is lined throughout with a course of hard red brick as protection from the corroding action of the gases. Between the lining and the shell is a 2-inch air space which acts as an insulator to protect the shell from overheating. Any leakage of gas through the lining into the air space is vented to the outside air through openings which are provided in the shell, and which serve also to circulate cool air through the air-space. Both the inside sleeve and the hopper are built of reinforced concrete. The stack itself is unlined, but is laid up with acid-proof cement. Provision was made in the design for traps in the bottom of the horizontal duct, whereby any solid matter that should accumulate within the duct could be removed and weighed. Experience has proved this to be unnecessary, as all portions of the duct and breeching have been self-cleaning under all test conditions thus far encountered.

APPENDIX 3.

Test Methods.

The test methods employed were, in general, those outlined in the "Method of Conducting Locomotive and Road Tests" published in the Proceedings of the American Railway Master Mechanics' Association, volume 47, page 538.

Each test was made under predetermined conditions of speed and cut-off. Throughout each test all conditions subject to control were maintained as nearly constant as possible. Variations between different tests, or groups of tests, relative to engine conditions and fuel used have been recorded and discussed.

The test methods employed were, with minor exceptions, the same throughout all tests. All instruments were known to be correct within reasonable limits or were calibrated at intervals and suitable corrections applied to the observed data. Observations were, in general, taken every ten minutes. Indicator diagrams, particularly on comparatively short tests, were often taken at five minute intervals. The locations of the more important instruments and apparatus are indicated in Fig. 40 in Appendix 1, and in the figures of Appendix 2. The methods of applying the load to the engine, of measuring the drawbar-pull, and of collecting the stack cinders are made clear by the description of the Locomotive Laboratory in Appendix 2.

Duration of Tests.—The tests reported in Appendix 4 varied in length from 30 minutes to 3 hours. Tests were in general of such duration that from 120 to 180 pounds of coal would be burned per square foot of grate during the test. This is equivalent to a coal consumption of approximately 6000 to 9000 pounds per test. An examination of the data shows that for 39 tests the coal consumption was within this range; for 15 tests it was less than 6000 pounds; and for 4 tests it was more than 9000 pounds per test.

Starting and Closing a Test.—In general, fires were built upon a clean grate for each test. With sufficient steam pressure the locomotive was started and gradually brought to the required conditions of speed and cut-off. The locomotive was operated for a short time under the required conditions and until a satisfactory fire and satisfactory boiler pressure were being maintained. On signal, the ash pan and cinder separator were closed, observations of water levels and steam pressure were made, and the test thereby started.

In closing a test, simultaneous observations were made upon water levels, steam pressure, and condition of fire. The locomotive was then stopped as quickly as conditions permitted. As soon as possible after stopping the locomotive, ashes were removed from the ash pan and cinders were removed from the front-end and from the cinder separator. In closing tests, it was sometimes advisable to remove some of the ash from the fire previous to the close of the test in order to bring the fire to the desired condition, and it was also occasionally advisable to remove some ash immediately after the close of the test. In all cases it was endeavored to have the same amount of combustible matter upon the grate at the close of the test as at the start. The removal of ash from the fire in connection with the closing of the test was primarily for the purpose of judging the amount of combustible upon the grate, not for the purpose of collecting the ash. The endeavor was made to have the boiler pressure and water level in the boiler substantially the same at the close as at the beginning of the test. Corrections were made for such irregularities as occurred.

Temperatures, Pressures, Gas Samples, Etc.—Temperatures in the fire-box were observed by means of a radiation pyrometer and temperatures in the front-end by means of a thermo-couple. Mercury thermometers were used at other points where temperature observations were made. Boiler pressure observations were taken from a gage located in the engine cab. Draft pressures were measured by means of U–tubes with water. Quality of steam was determined by means of a throttling calorimeter fitted with a suitable sampling tube. Front-end gas samples were collected through a sampling pipe provided with numerous small holes along the pipe, through which the gas was drawn. The time during which a single sample was collected varied from 20 to 60 minutes, depending mainly upon the total length of the test. The taking of samples usually covered the entire test period. Gas samples were analysed immediately after collection by means of the Orsat apparatus. Speed was measured by means of a stroke counter operated through the indicator reducing-motion.

Indicator Diagrams.—Four indicators were used, one at each end of each cylinder. During a majority of the tests, indicators were used which, through the operation of electrical attachments, took the four diagrams simultaneously. On account of minor accidents, it was sometimes necessary to use indicators where the pencil applications on some or all of the indicators were made by hand. In all cases, however, the applications were practically simultaneous.

Coal and Water.—Coal was delivered to the firing platform in lots of approximately 1000 pounds each. The time of firing the last shovelful of each lot was recorded. Water was weighed by means of two tanks upon platform scales. Each tank holds approximately 2000 pounds of water. The weighing tanks emptied into the feed-water supply-tank which has a capacity of 18 000 pounds. The height of water in the feed-water tank was maintained at an approximately constant level throughout a test. Observations were so taken that the amount of water furnished to the boiler could be calculated for intervals determined by the emptying of each weighing tank. Fig. 47 and 53 in Appendix 2 show the arrangement of the coal and water weighing apparatus.

Firing.—The locomotive was hand fired during all tests. The method of level firing was used, single shovelfuls of coal at a fairly constant rate being distributed uniformly over the grate. All large pieces of coal were broken, before firing, to lumps whose greatest dimension was from 3 to 4 inches. Two experienced firemen were employed. One of these men, however, was held entirely responsible and did practically all of the firing.

Samples of Coal, Ash, and Cinders.—Following the close of a test the ashes collected in the ash pan, the cinders collected in the front-end, and the cinders collected in the cinder separator were weighed and sampled.

A coal sample weighing from 200 to 500 lb. was collected during each test. This sample was collected while loading the cars taking coal to the firing platform, by placing about 50 lb. in the sampling can for each 1000-lb. car loaded. Care was exercised to make the sample representative.

The front-end cinders after being weighed were thoroughly mixed and about two pounds of cinders set aside as a sample. A sample of the stack cinders, weighing from 25 to 50 lb., was collected as the cinders were being weighed, a small amount being taken from each barrow load after passing over the scales. A sample of ash, weighing from 50 to 100 lb. was collected as the ash was being weighed, representative portions of the ash being selected.

The large samples of coal, ash, and stack cinders were ground or crushed as necessary to reduce them to a maximum size of 1/4 inch, then thoroughly mixed and reduced by "quartering" to samples weighing about two pounds. The two pound samples of coal, ash, front-end and stack cinders were submitted to the Chemical Laboratory for analysis.

Chemical Analysis.—The chemical analyses and heat determinations were made by the Department of Chemistry of the University of Illinois. The methods employed were substantially those which have been recommended in the preliminary reports of the Joint Committee on Coal Analysis, of the American Society for Testing Materials and the American Chemical Society.

Proximate analyses and B.t.u. determinations were made for the coal sample for each test. Four ultimate analyses of coal were made —one for tests 2009 to 2019 inclusive, one for tests 2020 to 2045, one for tests 2046 to 2071, and one for tests 2072 to 2095. The ultimate analyses were made from composite samples. Each composite sample was made by combining from each air-dried sample of the tests to be represented, an amount proportional to the coal burned during the test. The ultimate analyses for the individual tests which appear in the tabulated results are based upon the percentages of moisture, ash, and sulphur as determined by the proximate analysis and upon the assumption that the carbon, hydrogen, oxygen, and nitrogen are proportional to the percentages as determined for the composite sample by ultimate analysis.

Each ash and cinder sample was subjected to analysis to determine carbon, earthy matter, and moisture. B.t.u. determinations for ash, front-end and stack cinders were estimated in the following manner. B.t.u. determinations were made upon ten ash samples of Series 1, upon three samples of Series 2, and upon one composite sample representing all tests 2072 to 2095 inclusive. Upon the assumptions that the heat content of the ash was entirely due to its carbon content, and that the heat content of the carbon was uniform in all of the ash, an average value for the heat content of one pound of carbon in the ash was computed. This value was determined as 14 672 B.t.u. per pound of carbon contained in the ash. Using this value as a basis the heat content per pound of ash was calculated for each test.

B.t.u. determinations were made for 10 front-end cinder samples of Series 1 and for one composite sample representing tests 2072 to 2095 inclusive. In a manner similar to that outlined in the case of the ash, it was computed that the average value for the heat content of one pound of carbon contained in the front-end cinders was 14 336 B.t.u. and with this value as a basis the heat content per pound of front-end cinders was calculated for each test.

B.t.u. determinations were made for 10 stack cinder samples of Series 1, for a composite sample representing 10 tests during which the draft ranged from 2.2 to 4.5 inches of water, for a composite sample representing 9 tests during which the draft ranged from 5.3 to 9.2 inches of water, for a composite sample representing 5 tests during which the draft ranged from 10 to 12.8 inches of water, and for 3 individual tests during which the drafts were respectively 2.9, 7.0, and 11.9 inches of water. The 24 tests represented by the composite samples were tests 2072 to 2095 inclusive. The 3 individual tests mentioned were 2087, 2079, and 2089. With these heat determinations and in a manner involving the same assumptions as were made in the case of the ash and front-end cinders, it was computed that the heat content of one pound of carbon contained in the stack cinders was equivalent to $(14\,932 - 44D)$ B.t.u. In this expression D is the draft in front of the diaphragm, expressed as inches of water. With the values determined by means of this formula the heat content per pound of stack cinders was calculated for each test.

APPENDIX 4.

Detailed Data and Results.

The purpose of this appendix is to present in detail the data and results of all the tests. It consists of 24 tables and 3 figures. Tables 13 to 35 inclusive contain the data and results for 61 tests, arranged in four groups. Table 36 contains information relating to the representative indicator diagrams which are shown in Fig. 56, 57, and 58 at the end of the appendix.

The first of the four groups of tests comprises tests 2009 to 2037 and has been designated as Series 1. The third group, designated as Series 2, comprises tests 2072 to 2098 (excepting No. 2090 and 2091). The results of Series 1 and 2 have been presented and discussed in sections VI to VIII in Part I. The data and results of the two remaining groups appear only in this appendix, and are elsewhere merely referred to incidentally.

Section IV of Part I defines these four groups of tests, and states the difference between them as regards the condition of the locomotive. The locomotive's condition has also been explained in Section II and in Appendix 1. The differences in condition as regards fuel are stated in Section V of Part I. The evaporative efficiencies recorded for tests 2024 and 2038 are enough higher than the corresponding results recorded for other tests to raise some question as to the correctness of their results. The conditions, however, under which they were made were such that high boiler efficiency was to be expected. The data and results for these tests have been included in the tables, and have been used throughout the discussion except as may have been specifically indicated.

The data and results are presented under 182 headings. The column-heading numbers are included between the numbers 344 and 900 and are arranged consecutively in the tables. Tables throughout the bulletin carry corresponding column-headings and numbers wherever the same data are presented. In general the column-headings and column-heading numbers are the same as used in the Code for Testing Locomotives published in the Proceedings of the American Railway Master Mechanics' Association, volume 47, page 538. The methods of calculation, unless entirely obvious, are given in detail in Appendix 5.

TABLE 13.
GENERAL CONDITIONS

Test No.	Laboratory Designation	Duration of Test, Hours	Speed				Position of Levers	
			Revolutions		Equivalent			
			Total	Average per Minute	Speed in Miles per Hour	Piston Speed in Feet per Minute	Reverse Lever, Notches from Center	Throttle
	Code Item ☞	345	351	352	353	354	360	363
2009	138–16–F	2.50	20 878	139.2	25.2	694.6	4	Full
2010	193–20–F	1.18	13 969	196.8	35.7	981.8	5	Full
2012	138–24–F	1.83	15 349	139.5	25.3	696.3	6	Full
2013	138–32–F	1.50	12 575	139.7	25.4	697.2	8	Full
2014	193–32–F	1.17	13 981	199.7	36.3	996.4	8	Full
2015	193–24–F	1.50	18 000	200.0	36.3	998.0	6	Full
2016	193–16–F	2.33	27 998	200.0	36.3	998.0	4	Full
2017	83–16–F	3.00	14 398	80.0	14.5	399.2	4	Full
2018	83–24–F	2.67	12 802	80.0	14.5	399.2	6	Full
2019	83–32–F	2.17	10 474	80.6	14.6	402.0	8	Full
2020	83–24–F	2.00	9 656	80.5	14.6	401.7	6	Full
2021	83–16–F	2.00	9 615	80.1	14.5	399.7	4	Full
2022	83–32–F	2.00	9 670	80.6	14.6	402.2	8	Full
2023	138–40–F	1.50	12 515	139.0	25.2	693.6	10	Full
2024	55–24–F	2.00	6 080	50.7	9.2	253.0	6	Full
2026	110–16–F	2.17	14 220	109.4	19.9	545.9	4	Full
2027	110–24–F	2.50	16 500	110.0	20.0	548.9	6	Full
2028	55–32–F	2.33	7 050	50.3	9.1	251.0	8	Full
2029	110–32–F	1.50	9 880	109.8	19.9	547.9	8	Full
2030	165–24–F	1.67	16 935	169.4	30.8	845.3	6	Full
2031	83–40–F	1.50	7 723	85.8	15.6	428.1	10	Full
2032	165–32–F	0.67	6 726	168.1	30.5	838.8	8	Full
2033	110–48–F	1.33	8 793	109.9	20.0	548.4	12	Full
2034	193–40–F	1.00	11 910	198.5	36.0	990.5	10	Full
2035	110–40–F	1.17	7 830	111.8	20.3	557.9	10	Full
2037	165–40–F	1.00	10 160	169.3	30.7	844.8	10	Full
2038	55–24–F	1.83	5 586	50.8	9.2	253.4	6	Full
2039	110–32–F	1.50	9 896	110.0	20.0	548.7	8	Full
2040	165–40–F	1.00	10 127	168.8	30.7	842.2	10	Full
2041	110–40–F	1.17	7 709	110.1	20.0	549.5	10	Full
2042	110–24–F	2.00	13 190	109.9	20.0	548.5	6	Full
2043	110–48–F	1.17	7 681	109.7	19.9	547.6	12	Full
2044	110–56–F	1.00	6 585	109.8	19.9	547.7	14	Full
2045	110–16–F	2.17	14 277	109.8	19.9	548.0	4	Full
2072	110–40–F	1.00	6 575	109.6	19.9	546.8	10	Full
2073	110–32–F	1.33	8 751	109.4	19.9	545.9	8	Full
2074	165–32–F	1.00	10 178	169.6	30.8	846.3	8	Full
2075	55–32–F	2.33	7 081	50.6	9.2	252.3	8	Full
2076	220–32–F	0.58	8 047	229.9	41.7	1147.2	8	Full
2077	110–24–F	1.83	12 174	110.7	20.1	552.2	6	Full
2078	165–24–F	1.17	11 830	169.0	30.7	843.3	6	Full
2079	220–24–F	1.00	13 914	231.9	42.1	1157.2	6	Full
2080	110–16–F	2.17	14 346	110.4	20.0	550.7	4	Full
2081	55–24–F	2.50	7 593	50.6	9.2	252.5	6	Full
2082	165–40–F	0.83	8 484	169.7	30.8	846.7	10	Full
2083	165–16–F	1.67	17 031	170.3	30.9	849.8	4	Full
2084	110–48–F	0.83	5 519	110.4	20.0	550.8	12	Full
2085	55–40–F	2.00	6 136	51.1	9.3	255.1	10	Full
2086	55–24–F	2.83	8 725	51.3	9.3	256.1	6	Full
2087	110–16–F	2.50	16 660	111.1	20.2	554.4	4	Full
2088	220–16–F	1.67	23 418	234.2	42.5	1168.6	4	Full
2089	220–40–F	0.58	8 075	230.7	41.9	1151.2	10	Full
2092	165–32–F	0.83	8 425	168.5	30.6	840.8	8	Full
2093	165–48–F	0.50	5 023	167.4	30.4	835.5	12	Full
2094	110–56–F	0.42	2 772	110.9	20.1	553.3	14	Full
2095	55–48–F	1.00	3 077	51.3	9.3	255.9	12	Full
2096	55–40–F	1.50	4 636	51.5	9.4	257.0	10	Full
2097	55–32–F	1.83	5 732	52.1	9.5	260.0	8	Full
2098	55–48–F	0.83	2 587	51.7	9.4	258.2	12	Full
2090	110–24–F	1.00	6 640	110.7	20.1	552.2	6	Full
2091	165–32–F	0.50	5 079	169.3	30.7	844.8	8	Full

Table 14.
Temperature and Pressure

Test No.	Laboratory Designation	Temperature, Deg. Fahr. Front-end	Laboratory Dry Bulb	Laboratory Wet Bulb	Feed Water	Fire Box	Pressure, lb. per sq. in. Boiler, Average	Laboratory Barometric
	Code Item	367	368	369	373	374	380	388
2009	138–16–F		93	75	64.1	1950	190.5	14.3
2010	193–20–F	761	62	57	59.3	2081	192.0	14.4
2012	138–24–F	712	86	69	61.7	1959	191.8	14.4
2013	138–32–F	754	87	70	62.2	1957	190.1	14.4
2014	193–32–F	751	94	75	62.9		191.5	14.4
2015	193–24–F	702	97	75	61.7		192.1	14.4
2016	193–16–F	671	94	75	63.4		193.9	14.4
2017	83–16–F	619	93	76	72.2		193.4	14.4
2018	83–24–F	649	92	71	64.0		194.2	14.3
2019	83–32–F	684	86	73	62.1		193.8	14.3
2020	83–24–F	499	70	61	64.9		190.7	14.4
2021	83–16–F	494	63	53	57.8	1552	193.7	14.5
2022	83–32–F	554	66	56	58.3	1808	189.9	14.5
2023	138–40–F	639	64	55	57.7	1898	190.8	14.4
2024	55–24–F	517	66	51	59.3	1829	196.3	14.5
2026	110–16–F	531	58	52	61.0	1748	196.9	14.5
2027	110–24–F	552	64	56	60.2	1677	196.8	14.4
2028	55–32–F	515	66	58	70.4	1700	198.1	14.4
2029	110–32–F	560	73	65	60.9	1690	197.1	14.4
2030	165–24–F	565	76	68	60.2	1636	196.5	14.3
2031	83–40–F	570	72	66	60.6	1811	196.4	14.3
2032	165–32–F	613	71	66	59.6	1630	196.8	14.3
2033	110–48–F	603	73	67	60.6	1806	196.0	14.3
2034	193–40–F	632	76	69	59.8	1879	192.1	14.3
2035	110–40–F	589	73	65	61.7	1663	194.3	14.3
2037	165–40–F	651	75	69	60.8	1800	196.1	14.4
2038	55–24–F	510	64	52	58.2	1544	198.3	14.5
2039	110–32–F	578	62	55	59.1	1815	197.1	14.5
2040	165–40–F	640	64	55	57.9	1828	190.3	14.5
2041	110–40–F	621	58	52	55.0	1800	192.3	14.5
2042	110–24–F	557	59	53	57.1	1758	196.8	14.5
2043	110–48–F	646	55	50	58.4	1856	194.4	14.5
2044	110–56–F	686	54	48	56.8	1871	190.1	14.4
2045	110–16–F	551	61	54	59.6	1775	197.1	14.4
2072	110–40–F	620	59	54	59.5	1643	196.7	14.4
2073	110–32–F	595	53	48	56.9	1662	197.6	14.5
2074	165–32–F	637	59	52	59.7	1662	197.1	14.4
2075	55–32–F	543	58	52	58.1	1661	198.1	14.4
2076	220–32–F	675	63	54	60.1	1785	196.0	14.4
2077	110–24–F	565	58	51	58.7	1570	196.0	14.3
2078	165–24–F	595	62	53	58.4	1597	196.4	14.5
2079	220–24–F	614	64	54	58.8	1688	197.4	14.5
2080	110–16–F	534	60	53	59.7	1418	198.8	14.6
2081	55–24–F	507	63	54	57.9	1407	198.2	14.6
2082	165–40–F	673	55	51	63.6	1458	195.2	14.3
2083	165–16–F	563	62	54	60.5	1267	198.7	14.4
2084	110–48–F	653	60	56	52.6		194.0	14.5
2085	55–40–F	545	62	55	44.7		197.9	14.4
2086	55–24–F	506	67	57	56.2		199.1	14.4
2087	110–16–F	524	69	59	59.5		199.2	14.3
2088	220–16–F	563	73	61	58.1		197.8	14.2
2089	220–40–F	703	59	50	58.4		194.9	14.4
2092	165–32–F	643	52	49	59.4		198.4	14.4
2093	165–48–F	702	60	52	59.3		191.5	14.3
2094	110–56–F	679	65	58	59.0		196.3	14.2
2095	55–48–F	567	60	53	60.0		198.1	14.2
2096	55–40–F	584			61.4		196.1	14.4
2097	55–32–F	573			58.6		198.8	14.4
2098	55–48–F	611			59.2		198.2	14.4
2090	110–24–F	552	67	58	60.1		199.0	14.4
2091	165–32–F	626	64	57	59.5		198.6	14.4

TABLE 15.

DRAFT, INJECTORS, QUALITY OF STEAM.

Test No.	Laboratory Designation	Draft, in. of Water: Front-end: Front of Diaphragm	Draft, in. of Water: Front-end: Back of Diaphragm	Draft, in. of Water: Fire Box	Draft, in. of Water: Ash Pan	Injectors in Action: Right, Total Hours	Injectors in Action: Left, Total Hours	Injectors in Action: Right, No. of Times	Injectors in Action: Left, No. of Times	Quality of Steam in Dome	Factor of Correction for Quality of Steam
	Code Item☞	394	395	396	397	403	404	405	406	407	412
2009	138–16–F	3.7	2.6	1.6						0.990	0.9919
2010	193–20–F	5.5	3.9	2.1						0.987	0.9908
2012	138–24–F	5.8	4.0	2.1						0.989	0.9918
2013	138–32–F	7.6	5.1	2.7						0.985	0.9888
2014	193–32–F	9.1	6.0	3.2						0.984	0.9883
2015	193–24–F	7.3	4.9	2.8						0.987	0.9908
2016	193–16–F	5.0	3.5	2.0						0.989	0.9919
2017	83–16–F	2.7	1.9	0.9						0.991	0.9935
2018	83–24–F	3.9	2.7	1.5						0.993	0.9949
2019	83–32–F	5.4	3.7	2.0						0.991	0.9935
2020	83–24–F	3.4	2.3	1.2		1.6	0.0	19	0	0.9929	0.9949
2021	83–16–F	2.2	1.4	0.7		1.3	0.0	29	0	0.9945	0.9961
2022	83–32–F	4.8	3.0	1.6		2.0	0.0	3	0	0.9956	0.9968
2023	138–40–F	9.0	5.6	2.1		0.5	1.5	26	1	0.9930	0.9950
2024	55–24–F	2.6	1.6	1.0		1.2	0.0	37	0	0.9950	0.9964
2026	110–16–F	2.9	1.9	1.0		1.4	0.0	50	0	0.9895	0.9925
2027	110–24–F	4.7	2.7	1.5		2.1	0.0	33	0	0.9914	0.9938
2028	55–32–F	3.2	2.2	1.1		2.1	0.0	32	0	0.9912	0.9936
2029	110–32–F	6.1	3.9	1.8		1.5	0.0	3	0	0.9902	0.9930
2030	165–24–F	6.2	3.9	2.0		1.7	0.0	1	0	0.9894	0.9924
2031	83–40–F	6.8	4.3	2.2		1.5	0.1	1	4	0.9896	0.9926
2032	165–32–F	8.4	4.9	2.3		0.7	0.1	1	5	0.9862	0.9901
2033	110–48–F	8.2	5.1	2.2		0.3	1.3	16	1	0.9867	0.9904
2034	193–40–F	10.7	6.6	2.3		0.6	1.0	17	1	0.9857	0.9898
2035	110–40–F	8.4	5.2	2.7		0.5	1.2	13	1	0.9833	0.9879
2037	165–40–F	10.2	6.2	3.2		0.5	0.0	24	0	0.9860	0.9900
2038	55–24–F	2.6	1.7	1.1	0.3	1.8	0.0	1	0	0.9934	0.9953
2039	110–32–F	6.9	4.5	2.4	0.6	1.5	0.0	1	0	0.9917	0.9941
2040	165–40–F	9.9	6.8	3.2	0.6	0.6	1.0	16	1	0.9917	0.9940
2041	110–40–F	8.7	5.5	2.2	0.5	0.3	1.2	20	1	0.9900	0.9852
2042	110–24–F	4.9	3.2	1.7	0.4	2.0	0.0	1	0	0.9932	0.9952
2043	110–48–F	9.7	5.9	2.4	0.7	0.6	1.2	24	1	0.9866	0.9904
2044	110–56–F	11.8	7.5	3.2	0.7	0.8	1.0	5	1	0.9900	0.9928
2045	110–16–F	3.2	2.2	1.1	0.3	2.2	0.0	1	0	0.9934	0.9953
2072	110–40–F	8.0	4.9	2.0	0.7	0.3	1.0	20	1	0.9895	0.9925
2073	110–32–F	5.7	3.5	1.6	0.5	1.3	0.0	1	0	0.9919	0.9942
2074	165–32–F	8.5	5.3	2.4	0.5	0.5	0.9	21	1	0.9861	0.9901
2075	55–32–F	2.8	1.8	0.9	0.3	2.3	0.0	1	0	0.9952	0.9970
2076	220–32–F	9.2	5.7	2.8	0.5	3.8	0.6	10	1	0.9844	0.9888
2077	110–24–F	4.1	2.5	1.3	0.4	1.8	0.0	3	0	0.9947	0.9963
2078	165–24–F	6.0	3.9	1.9	0.5	1.2	0.1	3	3	0.9915	0.9939
2079	220–24–F	7.0	4.8	2.3	0.4	0.1	1.0	13	1	0.9889	0.9921
2080	110–16–F	2.9	2.0	1.0	0.2	2.2	0.0	1	0	0.9956	0.9968
2081	55–24–F	2.2	1.5	0.7	0.2	2.5	0.0	4	0	0.9963	0.9974
2082	165–40–F	11.2	7.3	3.4	0.6	0.4	0.8	18	1	0.9886	0.9917
2083	165–16–F	4.3	2.7	1.6	0.4	1.7	0.0	1	0	0.9934	0.9953
2084	110–48–F	10.0	6.3	2.9	0.8	0.8	0.4	21	1	0.9896	0.9926
2085	55–40–F	4.0	2.5	1.1	0.3	2.0	0.0	1	0	0.9962	0.9973
2086	55–24–F	2.2	1.4	0.7	0.3	2.8	0.0	1	0	0.9963	0.9974
2087	110–16–F	2.9	1.9	0.9	0.2	2.5	0.0	1	0	0.9956	0.9968
2088	220–16–F	4.5	2.9	1.2	0.3	1.7	0.0	1	0	0.9919	0.9942
2089	220–40–F	11.9	7.1	3.5	0.7	0.6	0.6	3	1	0.9884	0.9917
2092	165–32–F	8.2	5.1	2.2	0.6	0.3	0.8	16	1	0.9894	0.9924
2093	165–48–F	12.8	7.8	3.4	0.9	0.3	0.5	3	1	0.9879	0.9913
2094	110–56–F	12.1	7.3	3.0	0.8	0.4	0.4	2	1	0.9887	0.9919
2095	55–48–F	5.3	3.0	1.5	0.4	1.0	0.0	1	0	0.9943	0.9959
2096	55–40–F	4.2	2.6	1.2	0.4	1.5	0.1	1	1	0.9891	0.9922
2097	55–32–F	3.2	2.3	1.0	0.5	1.8	0.0	1	0	0.9853	0.9895
2098	55–48–F	5.4	3.7	1.9	0.8	0.8	0.0	1	0	0.9840	0.9885
2090	110–24–F	4.2	2.9	1.1	0.3	1.0	0.0	1	0	0.9952	0.9966
2091	165–32–F	8.2	4.9	2.1	0.6	0.2	0.5	8	1	0.9911	0.9936

TABLE 16.

COAL, CINDERS, ASH, SMOKE, AND HUMIDITY.

Test No.	Laboratory Designation	Coal Fired Total, lb.	Dry Coal Fired Total, lb.	Combustible by Analysis Total, lb.	Ash by Analysis Total, lb.	Front-end Cinders Total, lb.	Stack Cinders Total, lb.	Front End and Stack Cinders Total, lb.
	Code Item ☞	418	419	420	421	422	423	424
2009	138–16–F	7497	6618	5786	832	26	413	439
2010	193–20–F	5147	4537	3943	593	10	507	517
2012	138–24–F	7657	6797	5835	962	9	648	657
2013	138–32–F	7832	7124	6119	1005	10	925	935
2014	193–32–F	7978	7230	6153	1077	9	1045	1054
2015	193–24–F	8298	7391	6365	1026	12	1092	1104
2016	193–16–F	8603	7595	6368	1228	11	681	692
2017	83–16–F	6535	5872	5079	793	12	187	199
2018	83–24–F	7589	6765	5795	970	29	380	409
2019	83–32–F	7793	6965	6096	865	14	586	600
2020	83–24–F	5416	4943	4318	625	16	286	302
2021	83–16–F	5040	4422	3837	585	22	243	265
2022	83–32–F	8198	7346	6222	1124	8	898	906
2023	138–40–F	11556	10031	8637	1394	7	2075	2082
2024	55–24–F	4104	3628	3171	456	20	115	135
2026	110–16–F	5693	4969	4265	704	25	279	304
2027	110–24–F	9322	8139	7075	1064	20	745	765
2028	55–32–F	6414	5615	4887	729	14	372	386
2029	110–32–F	7257	6363	5445	918	15	869	884
2030	165–24–F	7501	6689	5888	801	11	856	867
2031	83–40–F	7686	6366	5414	952	13	944	957
2032	165–32–F	4104	3568	3037	532	10	662	672
2033	110–48–F	7940	6835	5839	996	10	1219	1229
2034	193–40–F	8916	7767	6501	1266	10	1499	1509
2035	110–40–F	7590	6493	5575	918	6	934	940
2037	165–40–F	7625	6554	5631	923	11	1206	1217
2038	55–24–F	4202	3688	2985	703	19	126	145
2039	110–32–F	7678	6775	5639	1136	17	808	825
2040	165–40–F	8515	7482	6325	1157	10	1617	1627
2041	110–40–F	7957	6838	5851	987	6	1218	1224
2042	110–24–F	7771	6713	5720	992	6	663	669
2043	110–48–F	9979	8637	7431	1205	17	1829	1846
2044	110–56–F	9623	8361	7080	1282	10	1771	1781
2045	110–16–F	6061	5258	4369	889	23	453	476
2072	110–40–F	6802	5927	5103	824		1140	
2073	110–32–F	6703	5812	5116	694	12	736	748
2074	165–32–F	6766	6015	5206	805	3	949	952
2075	55–32–F	6236	5430	4791	639	13	385	398
2076	220–32–F	5394	4568	3983	585	14	1057	1071
2077	110–24–F	6896	6015	5240	775	14	449	463
2078	165–24–F	6332	5492	4786	706	16	758	774
2079	220–24–F	6332	5783	5121	662	14	873	887
2080	110–16–F	6031	5248	4666	581	15	210	225
2081	55–24–F	5591	4937	4355	582	18	155	173
2082	165–40–F	8506	7495	6624	871	19	1640	1659
2083	165–16–F	6453	5564	4847	717	21	432	453
2084	110–48–F	7592	6595	5633	963	20	1244	1264
2085	55–40–F	6991	6116	5353	763	17	434	451
2086	55–24–F	6660	5860	5082	778	17	310	327
2087	110–16–F	7004	6185	5337	847	18	296	314
2088	220–16–F	6445	5588	4688	900	17	456	473
2089	220–40–F	7401	6491	5558	933	13	1728	1741
2092	165–32–F	5491	4700	4128	572	12	698	710
2093	165–48–F	5933	5108	4444	664	10	1391	1401
2094	110–56–F	4095	3514	3055	459	13	811	824
2095	55–48–F	3799	3334	2854	480	10	250	260
2096	55–40–F							
2097	55–32–F							
2098	55–48–F							
2090	110–24–F	3605	3176	2772	404	14	312	326
2091	165–32–F	3028	2626	2302	324	12	431	443

TABLE 17.

COAL, CINDERS, ASH, SMOKE, AND HUMIDITY.

Test No.	Laboratory Designation	Cinder Loss, Per cent of Total Dry Coal Fired	Stack Cinder Loss, Per cent of Total Dry Coal Fired	Ash from Ash Pan			Smoke	Humidity
				Total, lb.	Per cent of Total Dry Coal Fired	Per cent of Ash by Analysis	Per cent of Blackness by Ringlemann Chart	Moisture per lb. of Dry Air, lb.
	Code Item	426	427	428	429	430	431	435
2009	138–16–F	6.6	6.2	172	2.6	20.7		.014
2010	193–20–F	11.4	11.2	69	1.5	11.6		.008
2012	138–24–F	9.7	9.5	318	4.7	33.0		.011
2013	138–32–F	13.1	13.0	301	4.2	30.0		.011
2014	193–32–F	14.6	14.5	159	2.2	14.7		.014
2015	193–24–F	14.9	14.8	557	7.5	54.2		.014
2016	193–16–F	9.1	9.0	445	5.9	36.2		.014
2017	83–16–F	3.4	3.2	295	5.0	37.2		.015
2018	83–24–F	6.1	5.6	309	4.6	31.9		.011
2019	83–32–F	8.6	8.4	387	5.6	44.5		.014
2020	83–24–F	6.1	5.8	151	3.1	24.2		.010
2021	83–16–F	6.0	5.5	455	10.3	77.8		.006
2022	83–32–F	12.3	12.2	568	7.7	50.5		.010
2023	138–40–F	20.8	20.7	631	6.3	45.3		.007
2024	55–24–F	3.7	3.2	202	5.6	44.3		.005
2026	110–16–F	6.1	5.6	390	7.9	55.4	45	.007
2027	110–24–F	9.4	9.2	513	6.3	48.2	43	.008
2028	55–32–F	6.9	6.6	429	7.6	58.9	20	.009
2029	110–32–F	13.9	13.7	503	7.9	54.8	44	.011
2030	165–24–F	13.0	12.8	374	5.6	46.7	55	.013
2031	83–40–F	15.0	14.8	434	6.8	45.6		.012
2032	165–32–F	18.8	18.6	222	6.2	41.7	51	.013
2033	110–48–F	18.0	17.8	409	6.0	41.1		.013
2034	193–40–F	19.4	19.3	645	8.3	51.0		.014
2035	110–40–F	14.5	14.4	518	8.0	56.4		.011
2037	165–40–F	18.6	18.4	445	6.8	48.2		.014
2038	55–24–F	3.9	3.4	280	7.6	39.8		.006
2039	110–32–F	12.2	11.9	476	7.0	41.9		.008
2040	165–40–F	21.8	21.6	393	5.3	34.0		.007
2041	110–40–F	17.9	17.8	400	5.9	40.5		.007
2042	110–24–F	10.0	9.9	410	6.1	41.3		.007
2043	110–48–F	21.4	21.2	463	5.4	38.4		.006
2044	110–56–F	21.3	21.2	410	4.9	32.0		.006
2045	110–16–F	9.0	8.6	400	7.6	45.0	32	.007
2072	110–40–F		19.2	273	4.6	33.1	42	.008
2073	110–32–F	12.9	12.7	336	5.8	48.4	35	.006
2074	165–32–F	15.8	15.8	416	6.9	51.7	45	.007
2075	55–32–F	7.3	7.1	216	4.0	33.8	20	.007
2076	220–32–F	23.4	23.1	313	6.9	53.5		.007
2077	110–24–F	7.7	7.5	200	3.3	25.8		.006
2078	165–24–F	14.1	13.8	282	5.1	39.9		.007
2079	220–24–F	15.3	15.1	569	9.8	86.0		.007
2080	110–16–F	4.3	4.0	428	8.2	73.7		.007
2081	55–24–F	3.5	3.1	427	8.7	73.4		.007
2082	165–40–F	22.1	21.9	576	7.7	66.1		.007
2083	165–16–F	8.2	7.8	564	10.1	78.7		.007
2084	110–48–F	19.2	18.9	501	7.6	52.0		.008
2085	55–40–F	7.4	7.1	530	8.7	69.5		.008
2086	55–24–F	5.6	5.3	555	9.5	71.3		.008
2087	110–16–F	5.1	4.8	604	9.8	71.3		.008
2088	220–16–F	8.5	8.2	523	9.4	58.1		.008
2089	220–40–F	26.8	26.6	429	6.6	46.0		.006
2092	165–32–F	15.1	14.9	357	7.6	62.4		.006
2093	165–48–F	27.4	27.2	495	9.7	74.5		.006
2094	110–56–F	23.5	23.1	234	6.7	51.0		.008
2095	55–48–F	7.8	7.5	256	7.7	53.3		.007
2096	55–40–F							
2097	55–32–F							
2098	55–48–F							
2090	110–24–F	10.3	9.8	315	9.9	78.0		.008
2091	165–32–F	16.9	16.4	260	9.9	80.3		.008

Table 18.

Coal Analysis.

Test No.	Laboratory Designation	Proximate Analysis Coal as Fired: Fixed Carbon, per cent	Volatile Matter, per cent	Moisture, per cent	Ash, per cent	Sulphur Separately Determined, per cent	Calorific Value per lb. of Coal as Fired, B.t.u.	Ultimate Analysis Coal as Fired: Carbon, per cent	Hydrogen, per cent	Nitrogen, per cent	Oxygen, per cent
	Code Item☞	437	438	440	441	442	443	449	450	451	452
2009	138–16–F	38.21	38.97	11.72	11.10	2.33	11 083	61.68	4.48	0.85	7.84
2010	193–20–F	37.71	38.90	11.86	11.53	3.54	10 959	60.22	4.37	0.83	7.65
2012	138–24–F	38.08	38.12	11.23	12.57	3.43	10 901	59.97	4.36	0.83	7.62
2013	138–32–F	38.92	39.21	9.04	12.83	3.56	11 135	61.45	4.46	0.85	7.81
2014	193–32–F	38.14	38.99	9.37	13.50	3.43	11 042	60.74	4.41	0.84	7.72
2015	193–24–F	38.16	38.55	10.92	12.37	3.51	10 963	60.32	4.38	0.83	7.66
2016	193–16–F	36.86	37.16	11.71	14.27	4.16	10 588	57.57	4.18	0.79	7.31
2017	83–16–F	38.80	38.92	10.15	12.13	3.50	11 179	61.17	4.44	0.84	7.72
2018	83–24–F	38.25	38.11	10.86	12.78	3.12	10 932	60.36	4.38	0.83	7.67
2019	83–32–F	37.68	40.55	10.62	11.15	3.13	11 192	61.89	4.43	0.85	7.86
2020	83–24–F	39.40	40.33	8.73	11.54	3.86	11 228	62.42	3.80	1.61	8.03
2021	83–16–F	37.59	38.54	12.27	11.60	3.69	10 768	59.60	3.63	1.54	7.67
2022	83–32–F	37.57	38.33	10.39	13.71	4.36	10 642	58.86	3.59	1.52	7.57
2023	138–40–F	36.41	38.33	13.20	12.06	4.38	10 686	57.89	3.53	1.50	7.45
2024	55–24–F	37.02	40.25	11.61	11.12	3.41	11 236	60.77	3.70	1.57	7.82
2026	110–16–F	35.94	38.98	12.72	12.36	3.68	10 743	58.61	3.57	1.51	7.54
2027	110–24–F	37.38	38.52	12.69	11.41	3.42	11 078	59.64	3.63	1.54	7.67
2028	55–32–F	37.11	39.08	12.45	11.36	3.21	11 077	60.05	3.66	1.55	7.72
2029	110–32–F	35.06	39.97	12.32	12.65	3.67	10 948	58.71	3.58	1.52	7.55
2030	165–24–F	38.03	40.46	10.83	10.68	3.61	11 376	61.61	3.75	1.59	7.92
2031	83–40–F	34.11	36.33	17.18	12.38	3.15	9 929	55.36	3.37	1.43	7.12
2032	165–32–F	35.55	38.44	13.05	12.96	4.36	10 644	57.29	3.49	1.48	7.37
2033	110–48–F	35.99	37.55	13.92	12.54	4.16	10 539	57.08	3.48	1.48	7.34
2034	193–40–F	34.86	38.05	12.89	14.20	3.99	10 309	56.71	3.45	1.47	7.29
2035	110–40–F	34.41	39.04	14.46	12.09	4.09	10 547	57.07	3.48	1.48	7.34
2037	165–40–F	35.69	38.10	14.05	12.10	4.31	10 693	57.22	3.49	1.48	7.36
2038	55–24–F	34.50	36.54	12.24	16.72	3.63	10 041	55.46	3.38	1.43	7.13
2039	110–32–F	35.80	37.65	11.76	14.79	4.36	10 355	56.85	3.46	1.47	7.31
2040	165–40–F	35.58	38.70	12.13	13.59	4.19	10 688	57.67	3.51	1.49	7.42
2041	110–40–F	35.64	37.89	14.06	12.41	3.55	10 550	57.58	3.51	1.49	7.41
2042	110–24–F	36.24	37.37	13.62	12.77	3.73	10 602	57.50	3.50	1.49	7.39
2043	110–48–F	36.48	37.99	13.45	12.08	3.50	10 841	58.39	3.56	1.51	7.51
2044	110–56–F	36.25	37.32	13.11	13.32	3.56	10 594	57.60	3.51	1.49	7.41
2045	110–16–F	35.43	36.66	13.25	14.66	4.55	10 310	55.57	3.39	1.44	7.15
2072	110–40–F	37.21	37.81	12.87	12.11	4.28	10 857	57.75	4.27	2.10	6.62
2073	110–32–F	38.60	37.72	13.33	10.35	3.78	11 051	59.21	4.38	2.15	6.79
2074	165–32–F	38.79	38.16	11.15	11.90	3.36	11 173	60.07	4.44	2.19	6.89
2075	55–32–F	38.85	37.98	12.93	10.24	3.59	11 074	59.79	4.42	2.18	6.86
2076	220–32–F	35.81	38.03	15.31	10.85	2.79	10 602	58.00	4.29	2.11	6.65
2077	110–24–F	37.94	38.04	12.78	11.24	3.64	11 019	59.05	4.37	2.15	6.77
2078	165–24–F	37.88	37.71	13.26	11.15	3.66	10 858	58.72	4.34	2.14	6.73
2079	220–24–F	40.44	40.44	8.67	10.45	3.56	11 660	63.12	4.67	2.30	7.24
2080	110–16–F	36.71	40.66	12.99	9.64	3.32	11 178	60.45	4.47	2.20	6.93
2081	55–24–F	38.17	39.72	11.70	10.41	3.29	11 214	60.90	4.51	2.22	6.98
2082	165–40–F	37.92	39.95	11.89	10.24	3.27	11 125	60.90	4.51	2.22	6.98
2083	165–16–F	36.71	38.41	13.77	11.11	3.16	10 916	58.74	4.35	2.14	6.74
2084	110–48–F	35.11	39.08	13.13	12.68	3.51	10 689	57.70	4.27	2.10	6.62
2085	55–40–F	37.53	39.04	12.52	10.91	3.13	11 042	59.95	4.44	2.18	6.87
2086	55–24–F	36.86	39.45	12.01	11.68	3.58	11 075	59.37	4.39	2.16	6.81
2087	110–16–F	36.77	39.43	11.70	12.10	3.68	10 836	59.20	4.38	2.15	6.79
2088	220–16–F	35.86	36.88	13.30	13.96	4.04	10 487	56.08	4.15	2.04	6.43
2089	220–40–F	36.54	38.56	12.30	12.60	3.33	10 837	58.59	4.33	2.13	6.72
2092	165–32–F	37.35	37.83	14.40	10.42	3.02	10 802	58.90	4.36	2.14	6.75
2093	165–48–F	37.16	37.74	13.90	11.20	2.69	10 807	58.95	4.36	2.14	6.76
2094	110–56–F	36.92	37.68	14.20	11.20	3.41	10 662	58.11	4.30	2.11	6.66
2095	55–48–F	37.26	37.87	12.24	12.63	2.89	10 808	58.97	4.36	2.15	6.76
2096	55–40–F										
2097	55–32–F										
2098	55–48–F										
2090	110–24–F	36.99	39.90	11.91	11.20	3.51	11 094	59.90	4.43	2.18	6.87
2091	165–32–F	37.15	38.87	13.28	10.70	3.99	10 965	58.80	4.35	2.14	6.74

Table 19.

Calorific Value of Coal and Cinders, Analysis of Front-end Gases.

Test No.	Laboratory Designation	Calorific Value, B.t.u. per lb. Dry Coal	Combustible	Front-end Cinders	Stack Cinders	Ash	Analysis of Front-end Gases Oxygen O_2	Carbon Monoxide CO	Carbon Dioxide CO_2	Nitrogen N_2
	Code Item	458	459	461	462	463	466	467	468	469
2009	138–16–F	12 553	14 360	7796	6685	5069	10.9	0.0	8.1	81.0
2010	193–20–F	12 433	14 305	5544	8947	4587	13.7	0.0	6.0	80.3
2012	138–24–F	12 280	14 306	6242	8042	4515	13.7	0.0	5.7	80.7
2013	138–32–F	12 242	14 252	5312	8779	4785	13.5	0.1	6.0	80.6
2014	193–32–F	12 184	14 316	5611	9704	4046	11.4	0.0	7.4	81.1
2015	193–24–F	12 307	14 291	2586	9438	5297	11.9	0.0	7.3	80.8
2016	193–16–F	11 992	14 304	6104	8359	4844	12.1	0.0	7.1	80.7
2017	83–16–F	12 422	14 384	4821	6112	4624	11.3	0.1	8.0	80.5
2018	83–24–F	12 265	14 316	6155	7515	4134	11.0	0.2	8.3	80.6
2019	83–32–F	12 523	14 307	6523	8218	3272	10.3	0.2	8.9	80.6
2020	83–24–F	12 302	14 083	5342	6850	6528	10.7	0.0	8.7	80.6
2021	83–16–F	12 274	14 144	6573	7659	5267	11.8	0.0	7.7	80.5
2022	83–32–F	11 875	14 021	3907	9492	3850	11.8	0.0	8.0	80.2
2023	138–40–F	12 311	14 298	7357	10341	4842	6.6	0.0	11.2	82.2
2024	55–24–F	12 712	14 541	5657	6459	4261	10.9	0.0	8.0	81.1
2026	110–16–F	12 309	14 339	7003	8311	6064	11.6	0.0	7.7	80.7
2027	110–24–F	12 688	14 596	6996	8274	4853	10.8	0.0	8.1	81.1
2028	55–32–F	12 653	14 539	7109	7864	4032	10.4	0.0	8.1	81.5
2029	110–32–F	12 486	14 591	4841	8914	5429	9.5	0.0	9.4	81.1
2030	165–24–F	12 757	14 494	7007	9867	5618	8.9	0.0	9.7	81.4
2031	83–40–F	11 989	14 096	2985	9677	4262	8.2	0.2	9.8	81.8
2032	165–32–F	12 242	14 386	7539	4922	6021				
2033	110–48–F	12 243	14 331	2798	9888	4685	7.6	0.0	10.2	82.2
2034	193–40–F	11 835	14 139	6172	10324	5327	7.0	0.0	10.4	82.6
2035	110–40–F	12 329	14 359	5839	9698	5547	8.5	0.0	8.3	83.2
2037	165–40–F	12 441	14 479	6543	10098	5942	6.0	0.0	10.8	83.2
2038	55–24–F	11 442	14 134	6650	5772	6168	10.0	0.0	8.4	81.6
2039	110–32–F	11 734	14 098	6127	8557	4341	8.1	0.0	10.2	81.7
2040	165–40–F	12 164	14 389	4986	10227	5659	6.7	0.1	11.5	81.7
2041	110–40–F	12 276	14 348	6656	9634	5122	8.1	0.1	10.5	81.3
2042	110–24–F	12 273	14 403	6850	8425	5361	9.3	0.0	9.7	81.0
2043	110–48–F	12 523	14 558	1512	10046	4840	7.0	0.4	11.7	80.9
2044	110–56–F	12 192	14 400	3755	10654	4400	5.5	0.4	11.1	83.0
2045	110–16–F	11 885	14 302	7518	6890	4862	11.5	0.0	7.3	81.2
2072	110–40–F	12 460	14 472	4659	9926	3920	7.4	0.3	10.4	81.9
2073	110–32–F	12 751	14 480	4934	9485	5216	7.7	0.1	9.8	82.4
2074	165–32–F	12 575	14 520	5873	9780	4331	7.4	0.5	10.3	81.8
2075	55–32–F	12 718	14 414	6273	6914	4450	10.7	0.1	8.0	81.2
2076	220–32–F	12 519	14 358	6331	11014	4871	6.8	0.2	11.0	82.0
2077	110–24–F	12 633	14 502	8064	8289	7618	9.1	0.1	9.2	81.7
2078	165–24–F	12 517	14 364	6129	9454	4168	9.2	0.0	9.1	81.7
2079	220–24–F	12 767	14 416	6024	9867	5587	8.1	0.0	9.9	82.0
2080	110–16–F	12 848	14 448	6337	5522	4451	10.7	0.2	7.9	81.2
2081	55–24–F	12 700	14 398	5995	6097	4697	11.5	0.0	7.1	81.3
2082	165–40–F	12 626	14 287	6573	10548	4792	6.3	0.0	11.2	82.5
2083	165–16–F	12 660	14 531	7740	9157	5126	9.5	0.0	9.2	81.3
2084	110–48–F	12 305	14 408	3484	10655	4604	7.0	0.0	9.8	83.1
2085	55–40–F	12 622	14 421	7364	9496	4865	9.4	0.0	8.9	81.7
2086	55–24–F	12 586	14 513	3244	5777	4358	11.0	0.1	8.1	80.8
2087	110–16–F	12 272	14 220	5656	6711	4393	10.1	0.0	8.6	81.3
2088	220–16–F	12 095	14 418	2770	8456	4132	8.7	0.0	9.6	81.7
2089	220–40–F	12 356	14 431	5914	10926	3691	4.3	0.4	12.2	83.1
2092	165–32–F	12 620	14 368	5266	10165	5022	6.0	0.1	11.5	82.5
2093	165–48–F	12 551	14 429	5928	10295	6473	4.7	0.2	12.4	82.7
2094	110–56–F	12 426	14 292	6159	10447	5525	6.0	0.1	11.8	82.1
2095	55–48–F	12 315	14 385	8983	8508	4670	9.4	0.0	9.7	80.9
2096	55–40–F									
2097	55–32–F									
2098	55–48–F									
2090	110–24–F	12 594	14 429	7406	8440	5118	8.9	0.1	9.8	81.3
2091	165–32–F	12 626	14 423	7885	9831	5370	7.2	0.0	10.5	82.3

TABLE 20.
WATER AND DRAWBAR PULL.

Test No.	Laboratory Designation	Water						Drawbar Pull, lb.
		Delivered to Boiler by Injectors, lb.	Weight of Water in Boiler at Start of Test Minus Weight in Boiler at Close of Test, lb.	Correction for Change of Water Level and Steam Pressure in Boiler, Start to Close, lb.	Loss From Boiler, lb.	Loss From Boiler Corrected, lb.	Presumably Evaporated, lb.	
	Code Item☞	476	477	478	479	480	481	487
2009	138–16–F	45 314	+294	+122			45 436	
2010	193–20–F	28 122	+142	+147			28 269	
2012	138–24–F	43 727	+ 47	+ 34			43 761	10 140
2013	138–32–F	43 335	+317	+277			43 612	12 772
2014	193–32–F	38 210	–185	–114			38 096	8 823
2015	193–24–F	41 286	+140	+136			41 422	6 469
2016	193–16–F	48 590	– 94	– 76			48 514	4 320
2017	83–16–F	44 488	–182	–149			44 339	9 222
2018	83–24–F	47 725	–279	–184			47 542	13 215
2019	83–32–F	48 834	–313	–224			48 610	17 522
2020	83–24–F	35 196	+ 94	+104			35 300	13 072
2021	83–16–F	28 176	– 50	– 44			28 132	8 931
2022	83–32–F	43 759	0	– 18			43 741	17 292
2023	138–40–F	52 634	+141	+165			52 799	15 911
2024	55–24–F	30 466	–144	–111			30 355	14 528
2026	110–16–F	35 634	+ 49	+ 43			35 677	7 839
2027	110–24–F	52 496	+ 47	+ 60			52 556	11 903
2028	55–32–F	39 512	+ 51	+ 37			39 549	20 048
2029	110–32–F	40 044	+250	+179			40 223	15 444
2030	165–24–F	43 818	+ 47	+ 59			43 876	8 852
2031	83–40–F	41 688	+ 49	+ 17			41 704	20 947
2032	165–32–F	20 484	+144	+138			20 622	11 343
2033	110–48–F	42 984	+203	+137			43 121	18 946
2034	193–40–F	38 656	+193	+186			38 842	10 009
2035	110–40–F	38 650	+288	+152			38 802	17 426
2037	165–40–F	38 911	–659	–471			38 440	12 756
2038	55–24–F	27 068	–203	–129			26 939	14 998
2039	110–32–F	41 779	+ 51	+ 87			41 886	15 477
2040	165–40–F	37 933	+152	+197			38 130	13 869
2041	110–40–F	39 277	–152	– 5			39 272	18 895
2042	110–24–F	45 085	+ 50	– 7			45 078	12 680
2043	110–48–F	44 973	+355	+341			45 314	21 800
2044	110–56–F	43 838	+101	+260			44 098	23 666
2045	110–16–F	37 376	– 51	– 37			37 339	8 212
2072	110–40–F	33 886	0	+ 24			33 910	20 877
2073	110–32–F	37 169	+260	+203			37 372	16 961
2074	165–32–F	34 914	0	– 18			34 896	13 486
2075	55–32–F	38 781	–156	–111			38 670	20 483
2076	220–32–F	23 011	–153	–109			22 902	10 396
2077	110–24–F	40 308	–106	– 45			40 263	12 512
2078	165–24–F	33 546	–102	– 98			33 448	10 188
2079	220–24–F	32 074	–253	–225			31 849	8 270
2080	110–16–F	37 696	0	– 10			37 686	
2081	55–24–F	35 815	0	0			35 815	
2082	165–40–F	34 198	0	+ 34			34 232	14 783
2083	165–16–F	36 739	– 50	– 36			36 703	7 078
2084	110–48–F	32 266	+260	+177			32 443	22 403
2085	55–40–F	41 387	+102	+ 72			41 459	24 833
2086	55–24–F	40 553	+ 51	+ 46			40 599	15 532
2087	110–16–F	43 365	–102	– 79			43 286	8 135
2088	220–16–F	37 413	0	+ 18			37 431	5 568
2089	220–40–F	26 703	+102	+ 73			26 776	11 831
2092	165–32–F	28 808	+360	+247			29 055	13 701
2093	165–48–F	23 767	+675	+441			24 208	17 660
2094	110–56–F	18 810	+ 51	+ 88			18 898	25 225
2095	55–48–F	23 813	0	– 8			23 805	28 922
2096	55–40–F	31 887	–102	– 55			31 832	24 980
2097	55–32–F	33 084	+197	+140			33 224	20 820
2098	55–48–F	20 353	+ 60	+ 62			20 415	29 240
2090	110–24–F	21 688	0	0			21 688	11 477
2091	165–32–F	16 786	– 51	– 19			16 767	12 024

Table 21.

Events of Stroke from Indicator Cards—Cut-off and Release.

Test No.	Laboratory Designation	Cut Off, Per cent of Stroke					Release, Per cent of Stroke				
		Right Side		Left Side		Average	Right Side		Left Side		Average
		Head End	Crank End	Head End	Crank End		Head End	Crank End	Head End	Crank End	
	Code Item☞	495	496	497	498	499	510	511	512	513	514
2009	138–16–F	14.0	19.0	17.4	17.8	17.1	51.1	57.4	54.0	59.7	55.6
2010	193–20–F	20.1	20.6	18.0	18.0	19.2	55.4	62.3	61.0	61.9	60.2
2012	138–24–F	24.4	22.7	22.4	23.8	23.3	63.9	66.9	63.7	65.9	65.1
2013	138–32–F	29.6	33.5	30.5	29.7	30.8	67.1	69.6	67.8	70.8	68.8
2014	193–32–F	33.4	33.1	29.0	30.1	31.4	67.0	71.2	67.3	68.0	68.4
2015	193–24–F	22.2	24.0	21.8	22.9	22.7	61.1	64.9	59.1	65.8	62.7
2016	193–16–F	16.1	17.6	14.2	17.8	16.4	53.6	60.8	55.9	60.5	57.7
2017	83–16–F	15.0	17.1	16.3	19.2	16.9	49.9	56.4	52.4	57.5	54.1
2018	83–24–F	20.7	22.9	22.7	23.9	22.6	56.4	63.2	59.3	60.3	59.8
2019	83–32–F	28.3	32.3	28.7	33.2	30.6	67.6	66.7	65.2	65.2	66.2
2020	83–24–F	18.3	25.5	21.4	24.4	22.4	57.1	62.6	60.4	61.8	60.5
2021	83–16–F	12.3	15.2	14.3	17.6	14.9	48.9	54.3	50.9	54.6	52.2
2022	83–32–F	27.0	31.7	28.0	34.5	30.3	62.9	66.8	66.0	70.4	66.5
2023	138–40–F	34.0	43.1	39.3	41.2	39.4	72.1	74.5	73.2	74.9	73.7
2024	55–24–F										
2026	110–16–F	15.2	24.3	18.1	18.7	19.1	52.6	55.5	56.1	59.3	55.9
2027	110–24–F	22.0	25.4	22.6	27.0	24.3	62.3	64.5	63.8	66.9	64.4
2028	55–32–F	28.6	32.1	31.4	34.8	31.7	65.6	66.7	68.9	69.9	67.8
2029	110–32–F	28.3	30.9	30.0	33.7	30.7	69.4	70.1	68.3	72.8	70.2
2030	165–24–F	20.8	22.9	23.3	26.4	23.4	57.8	65.0	68.0	64.8	63.9
2031	83–40–F	35.9	40.4	39.1	42.4	39.5	71.6	73.9	73.9	73.9	73.3
2032	165–32–F	28.5	31.4	27.9	33.0	30.2	65.1	71.1	70.8	72.9	70.0
2033	110–48–F	37.7	40.4	40.8	43.8	40.7	73.9	76.4	75.3	74.9	75.1
2034	193–40–F	38.3	44.9	39.1	43.4	41.4	77.0	78.2	78.3	79.3	78.2
2035	110–40–F	36.3	39.6	41.8	41.9	39.9	73.7	75.0	76.4	75.6	75.2
2037	165–40–F	38.9	41.6	36.7	43.0	40.1	74.5	75.3	75.7	77.2	75.7
2038	55–24–F										
2039	110–32–F	29.9	34.9	31.8	33.4	32.5	65.9	70.7	68.8	70.3	68.9
2040	165–40–F	41.1	41.4	41.9	41.4	41.5	75.2	76.7	76.1	76.8	76.2
2041	110–40–F	39.6	42.2	41.9	40.8	41.1	73.6	76.9	75.8	75.5	75.5
2042	110–24–F	23.6	23.5	27.9	24.3	24.8	59.5	62.8	63.5	63.8	62.4
2043	110–48–F	47.6	49.6	48.0	48.7	48.5	79.5	79.3	83.0	79.5	80.3
2044	110–56–F	56.2	56.9	60.5	56.5	57.5	81.6	82.2	86.3	81.2	71.8
2045	110–16–F	18.4	16.8	23.5	18.2	19.2	52.0	55.5	56.5	55.6	54.9
2072	110–40–F	41.5	41.5	41.8	41.0	41.5	75.1	74.8	75.0	75.6	75.1
2073	110–32–F	25.6	29.8	31.6	31.5	29.6	73.4	68.5	70.4	69.8	70.5
2074	165–32–F	20.3	32.7	32.5	29.7	28.8	67.7	70.8	72.3	69.5	70.1
2075	55–32–F	29.9	33.9	33.7	31.0	32.1	66.7	68.5	70.5	69.2	68.7
2076	220–32–F	29.3	33.3	31.4	34.9	32.2	68.3	68.1	63.2	67.3	66.7
2077	110–24–F	21.5	24.4	25.5	24.4	24.0	56.1	61.7	63.0	63.1	61.0
2078	165–24–F	22.0	24.7	26.6	22.8	24.0	58.9	64.6	64.5	65.4	63.4
2079	220–24–F	24.1	23.6	22.7	23.1	23.4	69.7	67.3	66.8	63.5	66.8
2080	110–16–F	15.3	16.6	18.9	16.8	16.9	50.6	53.0	61.0	59.3	56.0
2081	55–24–F	23.1	24.8	26.2	22.4	24.1	57.8	60.1	62.2	61.8	60.5
2082	165–40–F	36.0	45.3	41.9	42.3	41.4	74.2	72.9	76.9	75.7	74.9
2083	165–16–F	16.2	18.2	21.8	17.4	18.4	51.4	57.5	60.8	58.7	57.1
2084	110–48–F	47.9	49.9	48.9	47.0	48.4	79.2	79.8	80.9	78.4	79.6
2085	55–40–F	39.7	42.0	43.3	40.2	41.3	70.3	74.4	77.6	74.6	74.2
2086	55–24–F	22.0	23.8	25.7	22.0	23.4	58.5	61.3	63.2	62.3	61.3
2087	110–16–F	15.9	15.7	17.4	17.4	16.6	49.3	54.0	56.5	54.2	53.5
2088	220–16–F	16.4	16.9	14.9	15.3	15.9	59.3	58.7	57.4	56.3	57.9
2089	220–40–F	41.2	45.4	42.0	45.4	43.5	74.5	77.8	78.4	77.4	77.0
2092	165–32–F	30.1	31.1	30.8	29.5	30.4	70.0	70.2	70.8	70.3	70.3
2093	165–48–F	45.9	50.5	48.4	49.7	48.6	78.5	79.6	79.7	77.1	78.7
2094	110–56–F	55.7	56.3	61.1	54.7	57.0	83.1	84.5	86.9	82.5	84.3
2095	55–48–F	47.8	50.1	51.5	47.5	49.2	80.0	79.8	81.8	79.6	80.3
2096	55–40–F	38.1	41.3	43.2	39.1	40.4	73.2	74.0	77.6	74.7	74.9
2097	55–32–F	30.6	33.2	35.0	30.5	32.3	66.4	69.4	71.0	69.0	69.0
2098	55–48–F	47.7	50.1	51.5	47.2	49.1	79.5	80.2	82.7	80.2	80.7
2090	110–24–F	20.9	22.3	23.4	24.6	22.8	56.5	66.1	64.2	64.2	62.8
2091	165–32–F	27.5	34.0	27.6	26.0	28.8	68.5	70.5	71.8	71.3	70.5

Table 22.

Events of Stroke and Pressure from Indicator Cards—Beginning of Compression and Initial Pressure.

Test No.	Laboratory Designation	Beginning of Compression, Per cent of Stroke: Right Side, Head End	Right Side, Crank End	Left Side, Head End	Left Side, Crank End	Average	Initial Pressure, lb. per sq. in.: Right Side, Head End	Right Side, Crank End	Left Side, Head End	Left Side, Crank End	Average
	Code Item☞	525	526	527	528	529	540	541	542	543	544
2009	138–16–F	56.0	58.3	56.7	56.2	56.8	170.9	188.6	173.0	186.2	179.7
2010	193–20–F	57.5	66.8	71.1	59.7	63.8	150.5	159.6	144.5	162.6	154.3
2012	138–24–F	50.2	59.5	48.2	55.8	53.4	166.4	182.3	170.8	180.8	175.1
2013	138–32–F	47.4	58.7	50.4	49.1	51.4	165.0	177.9	167.7	173.1	170.9
2014	193–32–F	77.5	76.0	80.8	59.1	73.4	156.4	154.3	166.8	173.0	162.5
2015	193–24–F	79.7	73.9	78.2	76.9	77.2	159.7	155.7	162.9	160.9	159.8
2016	193–16–F	64.0	71.2	68.5	67.2	67.7	156.1	163.6	150.1	165.1	158.7
2017	83–16–F	50.4	58.1	49.4	56.5	53.6	177.3	187.4	177.1	181.8	180.9
2018	83–24–F	43.9	50.8	43.3	53.1	47.8	178.8	179.4	176.4	190.2	181.2
2019	83–32–F	38.2	42.4	35.8	37.6	38.5	178.3	178.6	176.5	178.7	178.0
2020	83–24–F	39.2	43.6	39.2	42.8	41.2	175.1	177.0	177.6	180.0	177.4
2021	83–16–F	46.2	51.5	46.1	51.6	48.9	182.9	182.9	181.8	185.5	183.3
2022	83–32–F	31.2	42.6	29.0	35.5	34.6	175.5	156.6	178.7	182.1	173.2
2023	138–40–F	33.7	35.8	30.8	34.9	33.8	168.7	178.6	169.9	178.8	174.0
2024	55–24–F										
2026	110–16–F	51.5	54.6	51.6	55.8	53.4	191.1	181.1	187.5	175.9	183.9
2027	110–24–F	44.9	47.6	44.6	44.8	45.5	185.4	174.5	189.2	176.2	181.3
2028	55–32–F	32.1	35.0	35.6	36.6	34.8	186.1	184.7	192.2	191.7	188.7
2029	110–32–F	38.3	45.1	35.6	41.0	40.0	181.8	180.4	186.8	192.2	185.3
2030	165–24–F	43.6	63.4	48.3	53.6	52.2	161.3	171.9	167.4	179.7	170.1
2031	83–40–F	28.7	32.3	30.0	31.9	30.7	183.7	177.9	187.7	186.9	184.1
2032	165–32–F	42.1	48.4	77.5	68.3	59.1	185.8	166.2	162.6	166.0	170.2
2033	110–48–F	29.7	33.7	30.5	34.1	32.0	185.6	178.4	184.2	189.3	184.4
2034	193–40–F	62.0	70.0	71.8	71.6	68.9	168.7	172.9	179.7	170.8	173.0
2035	110–40–F	33.5	36.7	30.0	33.1	33.3	178.7	172.9	183.3	187.7	180.7
2037	165–40–F	61.6	68.5	67.4	66.5	66.0	176.7	161.4	159.3	179.8	169.3
2038	55–24–F										
2039	110–32–F	41.2	46.3	40.0	39.8	41.8	175.0	194.2	181.8	189.6	185.2
2040	165–40–F	73.9	75.5	74.5	74.6	74.6	184.5	195.7	192.1	184.6	189.2
2041	110–40–F	34.5	37.3	36.2	32.8	35.2	175.5	186.1	179.6	183.1	181.1
2042	110–24–F	46.3	51.8	47.2	46.9	48.1	180.9	176.1	188.0	173.9	179.7
2043	110–48–F	28.2	30.2	30.4	25.7	28.6	191.7	188.2	181.1	194.7	188.9
2044	110–56–F	23.8	23.3	25.7	22.4	23.8	180.1	190.8	191.4	187.4	187.4
2045	110–16–F	54.9	56.7	52.8	53.4	54.5	185.9	181.1	193.4	195.9	189.1
2072	110–40–F	30.5	30.7	31.3	29.3	30.5	183.8	187.4	185.5	186.7	185.9
2073	110–32–F	36.8	41.4	37.7	35.5	37.9	184.8	190.3	189.7	190.2	188.8
2074	165–32–F	43.3	43.0	41.2	44.2	42.9	178.9	173.7	178.1	173.9	176.2
2075	55–32–F	31.5	36.6	37.8	33.2	34.8	192.6	195.7	193.8	197.1	194.8
2076	220–32–F	51.4	50.5	47.4	48.9	49.6	182.7	184.5	193.1	186.5	186.7
2077	110–24–F	48.6	47.2	48.5	47.1	47.9	185.5	193.9	190.8	191.1	190.3
2078	165–24–F	49.5	51.3	48.6	50.4	50.0	179.9	177.5	168.7	173.6	175.0
2079	220–24–F	52.2	54.7	52.3	53.5	53.2	185.1	166.4	179.6	186.1	179.3
2080	110–16–F	54.6	54.6	53.1	52.6	53.7	190.3	178.5	176.4	179.2	181.1
2081	55–24–F	41.3	45.5	44.8	41.8	43.4	193.0	192.8	190.3	197.3	193.4
2082	165–40–F	33.2	36.4	34.0	33.0	34.2	191.9	170.6	163.6	171.6	174.4
2083	165–16–F	51.6	59.7	48.5	54.3	53.5	169.8	182.1	173.9	176.9	175.7
2084	110–48–F	25.7	24.8	16.4	22.8	24.9	179.4	181.8	179.8	187.1	182.0
2085	55–40–F	27.3	28.1	29.6	23.7	27.2	189.4	193.6	192.9	194.2	192.5
2086	55–24–F	39.2	41.7	39.8	37.4	39.2	192.7	192.1	189.4	193.4	191.9
2087	110–16–F	53.1	51.1	50.7	49.1	51.0	176.3	175.3	174.2	177.8	175.9
2088	220–16–F	54.9	52.5	52.1	52.4	53.0	136.4	134.0	160.9	159.9	147.8
2089	220–40–F	44.0	43.7	42.9	41.2	43.0	163.2	162.0	160.2	170.8	164.1
2092	165–32–F	39.1	41.5	39.9	41.3	40.5	163.3	172.5	162.7	171.8	167.6
2093	165–48–F	27.6	26.2	25.5	24.8	26.0	165.4	165.4	157.2	166.7	163.7
2094	110–56–F	19.5	17.7	20.7	15.5	18.4	172.4	171.3	170.6	178.9	173.3
2095	55–48–F	20.4	22.0	22.5	19.2	21.0	187.3	189.9	187.9	190.7	189.0
2096	55–40–F	25.1	27.1	27.8	23.6	25.9	187.8	187.9	189.1	190.2	188.8
2097	55–32–F	30.4	33.6	34.3	29.9	32.1	192.9	191.9	192.4	192.4	192.4
2098	55–48–F	21.6	22.0	23.3	19.5	21.6	188.7	191.4	191.8	192.9	191.2
2090	110–24–F	44.4	46.1	41.4	42.6	43.6	184.7	172.4	171.2	173.4	175.4
2091	165–32–F	39.4	43.0	36.1	39.6	39.5	164.4	174.1	165.4	175.5	169.9

Table 23.

Pressure from Indicator Cards—Cut-off and Release.

Test No.	Laboratory Designation	Pressure at Cut-Off, lb. per sq. in.					Pressure at Release, lb. per sq. in.				
		Right Side		Left Side		Aver-age	Right Side		Left Side		Aver-age
		Head End	Crank End	Head End	Crank End		Head End	Crank End	Head End	Crank End	
	Code Item☞	566	567	568	569	570	581	582	583	584	585
2009	138–16–F	146.6	129.7	130.6	132.0	134.7	44.0	45.7	46.4	42.8	44.7
2010	193–20–F	108.5	129.0	119.5	131.0	122.0	40.5	45.5	39.5	43.5	42.3
2012	138–24–F	130.7	138.0	131.3	136.8	134.2	45.6	54.0	48.4	53.4	50.4
2013	138–32–F	123.8	134.6	122.0	139.4	130.0	52.9	64.9	55.3	63.3	59.1
2014	193–32–F	101.3	123.5	114.0	125.0	116.0	49.3	57.8	48.2	57.0	53.1
2015	193–24–F	114.8	123.6	114.0	131.8	121.1	42.8	49.4	47.2	49.1	47.1
2016	193–16–F	113.9	133.0	114.6	132.0	123.4	38.8	41.3	34.8	42.2	39.3
2017	83–16–F	152.0	162.7	146.0	155.3	154.0	51.7	55.5	52.6	54.5	53.6
2018	83–24–F	148.0	157.7	142.0	156.7	151.1	57.9	60.5	59.1	66.4	61.0
2019	83–32–F	150.3	158.0	145.9	155.1	152.3	58.9	75.0	66.6	79.6	70.0
2020	83–24–F	156.2	147.3	154.1	155.6	153.3	58.0	61.6	60.8	66.4	61.7
2021	83–16–F	162.0	168.9	164.5	167.0	165.6	51.1	56.3	52.6	61.7	56.7
2022	83–32–F	149.1	129.2	151.4	154.7	146.1	65.6	66.0	70.2	77.7	69.9
2023	138–40–F	136.9	133.6	121.1	146.2	134.5	65.7	76.8	66.3	81.3	72.5
2024	55–24–F										
2026	110–16–F	145.6	123.6	133.2	151.6	138.4	45.1	54.7	45.1	51.6	49.1
2027	110–24–F	139.7	146.8	143.9	144.3	143.7	49.0	58.1	51.1	57.3	53.9
2028	55–32–F	154.9	165.3	161.7	167.3	162.3	67.4	80.1	72.2	81.7	75.4
2029	110–32–F	135.3	150.7	143.7	154.5	141.1	52.0	67.9	62.7	74.0	64.2
2030	165–24–F	122.0	139.7	129.1	136.4	131.8	48.4	56.1	43.4	61.2	52.3
2031	83–40–F	149.0	150.5	149.5	154.6	150.9	72.5	80.5	77.0	85.8	79.0
2032	165–32–F	126.2	131.8	133.0	134.7	131.4	56.4	62.5	52.6	61.8	58.3
2033	110–48–F	139.7	146.0	141.0	145.6	143.1	70.0	75.3	75.3	82.3	75.7
2034	193–40–F	111.5	112.2	111.1	123.4	114.5	51.8	62.1	53.1	64.1	57.8
2035	110–40–F	139.5	141.4	133.9	148.2	140.8	66.1	74.7	71.0	80.3	73.0
2037	165–40–F	117.9	124.2	125.3	132.2	124.9	58.2	69.5	60.5	72.1	65.1
2038	55–24–F										
2039	110–32–F	135.4	152.6	139.7	150.3	146.8	60.8	73.2	62.4	70.6	66.8
2040	165–40–F	119.7	134.9	120.3	127.4	125.6	63.7	71.2	63.6	66.8	66.3
2041	110–40–F	136.3	150.8	141.0	149.7	144.5	71.6	80.3	75.3	78.0	76.3
2042	110–24–F	140.7	158.6	135.7	149.6	146.2	55.5	62.6	56.7	56.5	57.8
2043	110–48–F	146.5	156.1	149.8	153.0	151.4	85.1	94.5	83.8	91.9	88.8
2044	110–56–F	144.8	154.4	139.5	152.8	147.9	96.8	103.9	92.8	105.9	99.9
2045	110–16–F	136.5	164.1	121.3	146.7	142.2	47.4	54.4	47.4	51.6	50.2
2072	110–40–F	139.2	149.1	145.2	149.4	145.7	73.1	80.9	79.4	79.7	78.3
2073	110–32–F	155.4	157.7	149.4	148.1	152.7	51.6	70.9	68.1	67.1	64.2
2074	165–32–F	153.4	135.2	129.1	139.7	139.4	56.8	63.5	56.2	62.4	59.7
2075	55–32–F	166.3	167.0	166.1	163.8	165.8	77.1	79.9	79.8	75.4	78.1
2076	220–32–F	116.7	117.4	113.2	116.2	115.9	51.1	58.8	55.5	57.5	55.7
2077	110–24–F	142.3	148.9	142.3	145.7	144.8	57.4	59.5	57.1	58.4	58.1
2078	165–24–F	135.2	139.0	125.8	135.9	134.0	51.7	56.0	50.5	51.1	52.3
2079	220–24–F	112.9	121.6	124.3	119.9	119.7	36.0	47.3	44.5	43.7	42.9
2080	110–16–F	147.9	161.2	146.3	148.8	151.1	48.9	54.1	45.2	43.3	47.9
2081	55–24–F	163.2	169.9	164.6	170.6	167.1	68.8	70.5	72.0	65.1	69.1
2082	165–40–F	134.3	124.3	123.6	124.8	126.8	64.1	76.3	64.3	68.6	68.3
2083	165–16–F	139.3	142.1	129.1	132.7	135.8	46.2	47.0	43.2	41.5	44.5
2084	110–48–F	139.1	147.6	145.8	149.1	145.4	83.8	88.6	85.6	87.1	86.3
2085	55–40–F	162.1	169.1	164.4	165.0	165.2	91.4	90.5	90.6	85.3	89.5
2086	55–24–F	167.3	173.7	167.2	175.4	170.9	67.4	68.2	72.0	65.3	68.2
2087	110–16–F	145.9	164.8	152.6	147.8	152.8	50.9	53.4	49.6	51.6	51.4
2088	220–16–F	99.6	108.0	126.6	130.4	116.2	25.5	32.6	34.3	35.2	31.9
2089	220–40–F	107.3	112.0	107.8	108.2	108.8	57.7	63.1	54.5	60.6	59.0
2092	165–32–F	128.3	138.9	132.7	139.8	134.9	52.4	63.6	57.7	59.3	58.3
2093	165–48–F	128.5	131.7	127.2	129.8	129.3	73.9	82.5	75.4	81.7	78.4
2094	110–56–F	148.6	154.6	144.9	156.4	151.1	98.9	99.9	98.1	102.8	99.9
2095	55–48–F	170.2	170.6	169.3	171.3	170.4	101.0	102.7	105.2	101.2	102.5
2096	55–40–F	169.9	171.0	168.2	172.6	170.4	90.8	93.4	92.7	89.9	91.7
2097	55–32–F	165.4	171.4	165.9	172.9	168.9	81.2	81.0	83.2	78.2	80.9
2098	55–48–F	168.9	176.5	171.9	175.5	173.2	100.5	105.2	106.1	100.6	103.1
2090	110–24–F	145.1	155.8	151.2	143.4	148.9	55.8	53.4	54.4	55.0	54.7
2091	165–32–F	133.8	129.8	143.4	147.9	138.7	54.2	63.9	56.7	58.8	58.4

Table 24.

Pressure from Indicator Cards—Beginning of Compression and Least Back Pressure.

Test No.	Laboratory Designation	Pressure at Beginning of Compression, lb. per sq. in.					Least Back Pressure, lb. per sq. in.				
		Right Side		Left Side		Average	Right Side		Left Side		Average
		Head End	Crank End	Head End	Crank End		Head End	Crank End	Head End	Crank End	
	Code Item☞	596	597	598	599	600	611	612	613	614	615
2009	138–16–F	7.2	9.3	10.9	9.1	9.1	3.9	3.8	7.0	6.4	5.3
2010	193–20–F	10.4	11.5	9.0	13.3	11.1	7.3	7.6	9.0	9.0	8.2
2012	138–24–F	11.5	12.2	14.0	10.4	12.0	7.0	7.8	7.8	8.2	7.7
2013	138–32–F	15.0	16.8	16.4	16.0	16.1	9.8	12.7	10.4	13.4	11.6
2014	193–32–F	15.8	17.5	16.8	17.3	16.9	15.4	17.9	16.6	18.3	17.1
2015	193–24–F	11.6	13.0	13.8	13.3	12.9	10.2	13.5	11.3	13.4	12.1
2016	193–16–F	9.2	8.8	10.5	10.8	9.8	6.3	6.7	5.8	6.9	6.4
2017	83–16–F	2.8	4.6	4.1	3.1	3.7	2.7	2.1	2.4	3.2	2.6
2018	83–24–F	4.5	6.6	5.9	4.8	5.5	4.6	3.4	3.1	4.7	4.0
2019	83–32–F	7.1	10.6	9.1	8.0	8.7	4.5	5.6	5.1	5.4	5.2
2020	83–24–F	5.3	8.0	9.3	8.4	7.8	3.6	2.4	6.6	7.8	5.1
2021	83–16–F	4.0	5.9	8.8	5.1	6.0		2.2	6.1	5.3	4.4
2022	83–32–F	6.7	9.4	13.3	11.2	10.2	4.1	7.2	8.2	9.4	7.2
2023	138–40–F	22.4	27.3	28.2	28.4	26.6	17.1	18.5	20.0	22.3	19.5
2024	55–24–F										
2026	110–16–F	5.8	8.1	9.6	5.7	7.3	2.3	2.8	4.1	3.2	3.1
2027	110–24–F	8.2	11.3	11.0	9.4	10.0	4.7	5.9	6.3	7.4	6.1
2028	55–32–F	2.2	5.5	5.9	1.5	3.8					
2029	110–32–F	8.2	12.7	16.5	16.0	13.4	8.1	10.4	10.0	13.6	10.5
2030	165–24–F	13.4	13.7	16.6	20.6	16.1	10.5	12.1	9.0	14.2	11.5
2031	83–40–F	10.5	11.7	14.4	13.4	12.5	9.6	10.0	10.6	10.8	10.3
2032	165–32–F	18.8	20.0	16.2	18.7	18.4					
2033	110–48–F	15.4	19.9	21.4	18.8	18.9	13.8	15.3	16.9	14.6	15.2
2034	193–40–F	21.6	23.8	24.7	26.7	24.2	22.8	24.0	24.1	25.6	24.1
2035	110–40–F	14.9	17.2	22.1	18.5	18.2	11.9	15.7	16.0	15.0	14.7
2037	165–40–F	21.1	22.8	22.1	25.1	22.8	21.8	23.4	22.5	24.7	18.1
2038	55–24–F										
2039	110–32–F	12.6	16.8	15.8	14.4	14.9	8.5	11.5	8.4	11.1	9.9
2040	165–40–F	24.4	24.8	23.8	23.5	24.1	22.5	24.8	22.9	24.7	23.7
2041	110–40–F	18.5	21.1	21.4	18.0	19.8	12.4	16.0	14.0	15.3	14.4
2042	110–24–F	10.4	10.7	11.2	9.6	10.5	5.0	7.0	5.4	6.4	6.0
2043	110–48–F	23.0	26.8	26.8	25.1	25.4	18.5	22.0	20.0	21.4	20.5
2044	110–56–F	27.9	30.6	29.9	28.7	29.3	22.5	24.9	22.9	22.4	23.2
2045	110–16–F	5.9	7.2	7.6	7.1	7.0	3.0	3.8	3.1	3.3	3.3
2072	110–40–F	12.8	15.1	14.9	13.7	14.1	8.3	10.1	8.9	10.0	9.3
2073	110–32–F	9.1	10.9	11.6	10.0	10.4	5.9	7.1	5.6	7.2	6.5
2074	165–32–F	15.5	19.5	20.5	18.5	18.5	11.4	13.9	11.3	13.5	12.5
2075	55–32–F	4.1	3.1	2.1	2.4	2.9	2.2	1.9	1.2	1.6	1.7
2076	220–32–F	18.3	21.9	21.5	22.5	21.1	14.5	17.9	14.0	16.9	15.8
2077	110–24–F	5.6	8.5	6.6	6.5	6.8	3.0	3.4	2.8	3.5	3.2
2078	165–24–F	10.3	14.2	12.5	12.0	12.3	5.1	8.8	7.1	8.4	7.4
2079	220–24–F	12.3	15.9	15.7	15.3	14.8	8.3	12.0	8.2	10.7	9.8
2080	110–16–F	4.3	5.6	5.6	4.5	5.0	2.0	2.1	2.0	2.0	2.0
2081	55–24–F	2.5	2.4	1.9	2.1	2.2	2.0	0.3	0.3	0.3	0.7
2082	165–40–F	21.6	24.4	26.6	25.1	24.4	17.2	20.0	17.7	18.2	18.3
2083	165–16–F	7.7	8.9	11.5	9.1	9.3	3.3	4.9	3.3	4.2	3.9
2084	110–48–F	15.4	17.9	18.4	17.0	17.2	12.6	13.3	10.0	13.0	12.2
2085	55–40–F	3.5	4.1	4.2	3.8	3.9	1.5	1.2	2.6	1.9	1.8
2086	55–24–F	2.7	2.3	2.1	2.8	2.5	1.6	0.4	0.0	0.5	0.6
2087	110–16–F	4.1	6.2	6.0	4.9	5.3	2.2	2.2	2.2	2.7	2.3
2088	220–16–F	7.5	9.4	10.4	11.2	9.6	4.8	7.5	3.4	4.7	5.1
2089	220–40–F	25.2	30.3	30.2	29.7	28.9	19.8	24.5	20.8	23.0	22.0
2092	165–32–F	15.5	18.0	18.3	17.2	17.3	9.6	14.0	10.8	12.0	11.6
2093	165–48–F	28.7	29.9	31.7	29.5	30.0	20.4	24.0	21.1	23.0	22.1
2094	110–56–F	21.9	22.1	22.9	22.3	22.3	16.0	17.1	16.3	15.8	16.3
2095	55–48–F	5.2	4.1	4.2	4.2	4.4	2.3	1.7	1.1	2.0	1.8
2096	55–40–F	6.2		4.2	3.8		2.8	1.0	1.4	1.5	1.7
2097	55–32–F	5.4	3.0	3.8	3.6	4.0	3.1	1.9	2.1	1.2	2.1
2098	55–48–F	4.6	4.8	5.1	4.0	4.6	1.7	2.0	2.3	1.9	2.0
2090	110–24–F	8.7	11.5	11.3	10.0	10.4	5.4	6.0	5.0	5.4	5.5
2091	165–32–F	21.7	24.4	26.5	23.4	24.0	14.2	17.1	14.7	16.4	15.6

TABLE 25.
BOILER PERFORMANCE—COAL AND EVAPORATION.

Test No.	Laboratory Designation	Dry Coal Fired, lb.		Evaporation					Steam Used at Calorimeter, Safety Valve, Leaks etc., lb.	Dry Steam to Engine per Hour, lb.	Factor of Evaporation
					Dry Steam, lb.						
		Per Hour	Per Hour per sq. ft. of Grate Surface	Moist Steam per Hour, lb.	Per Hour	Per Hour per sq. ft. of Heating Surface	Per lb. of Dry Coal	Per lb. of Coal as Fired			
	Code Item	626	627	633	634	635	636	637	638	639	641
2009	138–16–F	2647	53.4	18 174	18 027	5.49	6.80	6.01	183	18 023	1.192
2010	193–20–F	3834	77.4	23 887	23 668	7.21	6.17	5.44	39	23 631	1.196
2012	138–24–F	3707	74.8	23 869	23 674	7.21	6.39	5.67	89	23 632	1.194
2013	138–32–F	4749	95.8	29 076	28 751	8.76	6.05	5.51	50	28 742	1.190
2014	193–32–F	6199	125.1	32 648	32 272	9.83	5.21	4.72	39	32 173	1.189
2015	193–24–F	4927	99.5	27 617	27 363	8.33	5.55	4.95	50	27 330	1.193
2016	193–16–F	3255	65.7	20 792	20 623	6.28	6.34	5.59	183	20 538	1.193
2017	83–16–F	1957	39.5	14 778	14 683	4.47	7.50	6.74	246	14 590	1.186
2018	83–24–F	2537	51.2	17 828	17 737	5.40	6.99	6.23	157	17 643	1.195
2019	83–32–F	3215	64.9	22 429	22 288	6.79	6.93	6.20	150	22 173	1.196
2020	83–24–F	2472	49.9	17 650	17 560	5.35	7.10	6.48	64	17 523	1.195
2021	83–16–F	2211	44.6	14 066	14 011	4.27	6.34	5.56	502	13 758	1.204
2022	83–32–F	3673	74.1	21 871	21 801	6.64	5.94	5.32	64	21 778	1.204
2023	138–40–F	6687	135.0	35 199	35 025	10.67	5.24	4.54	623	34 594	1.202
2024	55–24–F	1814	36.6	15 178	15 123	4.61	8.34	7.37	265	14 974	1.203
2026	110–16–F	2293	46.3	16 461	16 341	4.98	7.13	6.22	71	16 313	1.196
2027	110–24–F	3256	65.7	21 022	20 892	6.36	6.42	5.60	92	20 850	1.198
2028	55–32–F	2406	48.6	16 950	16 841	5.13	7.00	6.13	169	16 775	1.188
2029	110–32–F	4242	85.6	26 815	26 629	8.11	6.28	5.50	52	26 640	1.197
2030	165–24–F	4013	81.0	26 326	26 126	7.96	6.51	5.80	63	26 081	1.197
2031	83–40–F	4244	85.6	27 804	27 598	8.41	6.50	5.39	303	27 419	1.197
2032	165–32–F	5352	108.0	30 933	30 627	9.33	5.72	4.98	105	30 480	1.195
2033	110–48–F	5126	103.5	32 341	32 030	9.76	6.25	5.38	389	31 791	1.194
2034	193–40–F	7767	156.8	38 841	38 445	11.71	4.95	4.31	414	38 330	1.194
2035	110–40–F	5565	112.3	33 253	32 856	10.01	5.90	5.05	38	32 940	1.190
2037	165–40–F	6554	132.3	38 440	38 056	11.59	5.81	4.99	102	37 769	1.193
2038	55–24–F	2012	40.6	14 967	14 625	4.45	7.27	6.38	709	14 199	1.203
2039	110–32–F	4517	91.2	27 927	27 762	8.46	6.15	5.42	109	27 663	1.201
2040	165–40–F	7482	151.0	38 130	37 901	11.54	5.07	4.45	70	37 787	1.201
2041	110–40–F	5861	118.3	33 656	33 163	10.10	5.66	4.86	290	32 794	1.193
2042	110–24–F	3356	67.7	22 539	22 431	6.83	6.68	5.77	425	22 247	1.204
2043	110–48–F	7403	149.4	38 840	38 468	11.72	5.20	4.50	314	38 213	1.196
2044	110–56–F	8361	168.7	44 098	43 780	13.34	5.23	4.55	242	43 382	1.201
2045	110–16–F	2427	49.0	17 228	17 151	5.22	7.07	6.13	388	16 968	1.201
2072	110–40–F	5927	119.6	33 910	33 656	10.25	5.68	4.95	78	33 554	1.197
2073	110–32–F	4359	87.9	28 029	27 866	8.49	6.39	5.54	238	27 731	1.203
2074	165–32–F	6015	121.3	34 896	34 551	10.52	5.74	5.11	216	34 354	1.195
2075	55–32–F	2327	47.0	16 574	16 523	5.03	7.10	6.18	171	16 431	1.204
2076	220–32–F	7831	158.0	39 261	38 820	11.82	4.96	4.20	82	38 608	1.193
2077	110–24–F	3281	66.2	21 959	21 878	6.64	6.67	5.82	141	21 770	1.203
2078	165–24–F	4707	95.0	28 668	28 493	8.68	6.05	5.25	101	28 404	1.201
2079	220–24–F	5783	116.7	31 849	31 597	9.62	5.46	4.99	224	31 347	1.198
2080	110–16–F	2422	48.9	17 392	17 336	5.28	7.16	6.23	214	17 244	1.203
2081	55–24–F	1975	39.9	14 326	14 289	4.35	7.24	6.39	211	14 205	1.206
2082	165–40–F	8994	181.5	41 078	40 738	12.41	4.53	3.99	60	40 625	1.193
2083	165–16–F	3338	67.4	22 022	21 918	6.68	6.57	5.66	425	21 656	1.201
2084	110–48–F	7914	159.7	38 932	38 646	11.77	4.88	4.24	60	38 671	1.205
2085	55–40–F	3058	61.7	20 730	20 674	6.30	6.76	5.91	146	20 616	1.219
2086	55–24–F	2068	41.7	14 329	14 290	4.35	6.91	6.08	213	14 219	1.208
2087	110–16–F	2474	49.9	17 314	17 259	5.26	6.98	6.16	189	17 175	1.204
2088	220–16–F	3353	67.7	22 459	22 328	6.80	6.66	5.77	142	22 233	1.202
2089	220–40–F	11127	224.5	45 902	45 521	13.87	4.09	3.59	42	45 498	1.198
2092	165–32–F	5640	113.8	34 866	34 601	10.54	6.13	5.25	64	34 660	1.198
2093	165–48–F	10216	206.2	48 416	47 994	14.62	4.70	4.04	36	48 387	1.197
2094	110–56–F	8434	170.2	45 355	44 988	13.71	5.33	4.58	80	44 709	1.198
2095	55–48–F	3334	67.3	23 805	23 707	7.22	7.11	6.24	73	23 643	1.202
2096	55–40–F			21 222	21 057	6.41			285	20 837	1.196
2097	55–32–F			18 124	17 933	5.46			291	17 807	1.196
2098	55–48–F			24 498	24 216	7.38			303	23 843	1.194
2090	110–24–F	3176	64.1	21 688	21 614	6.58	6.80	6.00	73	21 542	1.203
2091	165–32–F	5252	106.0	33 534	33 320	10.15	6.34	5.50	39	33 178	1.200

TABLE 26.

BOILER PERFORMANCE—EQUIVALENT EVAPORATION, HORSE POWER, AND EFFICIENCY.

Test No.	Laboratory Designation	Dry Steam Loss per Hour Due to Calorimeter, Leaks, Corrections etc., lb.	Dry Coal Loss per Hour Equivalent to Steam Loss, lb.	Equivalent Evaporation From and at 212°F., lb.						Boiler Horse Power	Efficiency of Boiler, per cent
				Per Hour	Per Hour per sq. ft. of Total Heating Surface	Per Hour per sq. ft. of Grate Area	Per lb. of Coal as Fired	Per lb. of Dry Coal	Per lb. of Combustible		
	Code Item	642	643	645	648	656	657	658	659	660	666
2009	138–16–F	4	1	21 669	6.60	437.3	7.23	8.19	9.36	628.1	63.30
2010	193–20–F	37	6	28 564	8.71	576.5	6.57	7.45	8.57	827.9	57.63
2012	138–24–F	42	6	28 514	8.69	575.4	6.83	7.69	8.96	826.5	60.80
2013	138–32–F	9	1	34 612	10.54	698.5	6.63	7.29	8.48	1003.3	57.78
2014	193–32–F	99	18	38 820	11.83	783.5	5.68	6.27	7.36	1125.2	49.92
2015	193–24–F	33	6	32 958	10.04	665.2	5.97	6.69	7.77	955.3	52.84
2016	193–16–F	85	14	24 804	7.56	500.7	6.73	7.62	9.09	719.1	61.68
2017	83–16–F	93	12	17 513	5.33	353.4	8.05	8.96	10.35	507.6	69.88
2018	83–24–F	94	13	21 326	6.50	430.4	7.49	8.41	9.81	618.1	66.49
2019	83–32–F	115	16	26 834	8.17	541.6	7.46	8.35	9.54	777.8	64.68
2020	83–24–F	37	5	21 092	6.42	425.7	7.79	8.53	9.77	611.4	67.33
2021	83–16–F	253	40	16 934	5.16	341.8	6.72	7.66	8.83	490.8	60.56
2022	83–32–F	123	4	26 332	8.02	531.4	6.42	7.17	8.46	763.3	58.54
2023	138–40–F	431	82	42 329	12.89	854.3	5.49	6.33	7.35	1226.9	49.86
2024	55–24–F	149	18	18 258	5.56	368.5	8.90	10.07	11.52	529.2	76.87
2026	110–16–F	28	4	19 700	6.00	397.6	7.50	8.59	10.01	571.0	67.75
2027	110–24–F	42	7	25 206	7.68	508.7	6.76	7.74	8.91	730.6	59.22
2028	55–32–F	66	9	20 143	6.14	406.5	7.33	8.37	9.62	583.9	64.21
2029	110–32–F	−11	− 2	32 108	9.78	648.0	6.64	7.57	8.84	930.7	58.85
2030	165–24–F	45	7	31 517	9.60	636.1	7.00	7.85	8.92	913.5	59.71
2031	83–40–F	179	28	33 281	10.14	671.7	6.49	7.84	9.22	964.7	63.43
2032	165–32–F	147	26	36 967	11.26	746.1	6.01	6.91	8.11	1071.5	54.79
2033	110–48–F	239	38	38 624	11.77	779.5	6.49	7.54	8.82	1119.5	59.76
2034	193–40–F	115	23	46 380	14.13	936.0	5.20	5.97	7.13	1344.4	48.95
2035	110–40–F	−84	−14	39 578	12.06	798.8	6.08	7.11	8.28	1147.2	55.94
2037	165–40–F	287	49	45 859	13.97	925.5	6.01	7.00	8.14	1329.3	54.54
2038	55–24–F	426	59	17 676	5.38	356.7	7.71	8.79	10.86	512.4	74.51
2039	110–32–F	99	16	33 529	10.21	676.7	6.55	7.42	8.90	971.9	61.38
2040	165–40–F	114	23	45 802	13.95	824.4	5.38	6.12	7.24	1327.6	48.84
2041	110–40–F	369	65	40 168	12.24	810.7	5.89	6.85	8.01	1164.3	54.18
2042	110–24–F	184	27	27 132	8.26	547.6	6.98	8.08	9.49	787.0	63.89
2043	110–48–F	255	49	46 472	14.16	937.9	5.43	6.28	7.30	1347.0	48.60
2044	110–56–F	398	76	52 948	16.13	1068.6	5.50	6.33	7.48	1534.7	50.38
2045	110–16–F	183	26	20 704	6.31	417.9	7.40	8.53	10.27	600.1	69.65
2072	110–40–F	102	18	40 590	12.36	819.2	5.97	6.85	7.95	1176.5	53.36
2073	110–32–F	135	21	33 719	10.27	680.5	6.71	7.74	8.79	977.4	58.92
2074	165–32–F	197	34	41 701	12.70	841.6	6.16	6.93	8.01	1208.7	53.50
2075	55–32–F	92	13	19 954	6.08	402.7	7.47	8.57	9.72	578.4	65.46
2076	220–32–F	212	43	46 838	14.27	945.3	5.07	5.98	6.86	1357.6	46.41
2077	110–24–F	108	16	26 417	8.05	533.1	7.02	8.05	9.24	765.7	61.82
2078	165–24–F	89	15	34 431	10.49	694.9	6.34	7.31	8.39	998.0	56.66
2079	220–24–F	250	46	38 155	11.62	770.0	6.03	6.60	7.45	1105.9	50.18
2080	110–16–F	92	13	20 923	6.37	422.3	7.52	8.64	9.72	606.5	65.28
2081	55–24–F	84	12	17 277	5.26	348.7	7.73	8.75	9.92	500.8	66.89
2082	165–40–F	113	25	49 007	14.93	989.0	4.80	5.45	6.15	1420.5	41.87
2083	165–16–F	262	40	26 448	8.06	533.8	6.83	7.92	9.09	766.6	60.72
2084	110–48–F	−25	− 5	46 913	14.29	946.7	5.15	5.93	6.94	1359.8	46.76
2085	55–40–F	58	9	25 270	7.70	509.9	7.23	8.26	9.44	732.5	63.54
2086	55–24–F	71	10	17 308	5.27	349.3	7.36	8.37	9.65	501.7	64.49
2087	110–16–F	84	12	20 846	6.35	420.7	7.44	8.43	9.77	604.2	66.63
2088	220–16–F	95	14	26 995	8.22	544.8	6.99	8.05	9.60	782.5	64.58
2089	220–40–F	23	6	54 989	16.75	1109.7	4.33	4.94	5.77	1593.9	38.77
2092	165–32–F	−59	−10	41 770	12.72	842.9	6.34	7.41	8.43	1210.7	56.95
2093	165–48–F	−393	−84	57 954	17.65	1169.5	4.88	5.67	6.52	1678.8	43.82
2094	110–56–F	279	52	54 336	16.55	1096.5	5.53	6.44	7.41	1575.0	50.33
2095	55–48–F	64	9	28 614	8.72	577.4	7.53	8.58	10.03	829.4	67.61
2096	55–40–F	220		25 382	7.73	512.2				735.7	
2097	55–32–F	126		21 676	6.60	437.4				628.3	
2098	55–48–F	373		29 251	8.91	590.3				847.9	
2090	110–24–F	72	11	26 091	7.95	526.5	7.24	8.22	9.41	756.3	63.33
2091	165–32–F	142	23	40 240	12.26	812.0	6.64	7.66	8.74	1166.4	58.76

Table 27.

Engine Performance—Mean Effective Pressure and Number of Expansions.

Test No.	Laboratory Designation	Mean Effective Pressure, lb. per sq. in.					Number of Expansions			
		Right Side		Left Side		Aver-age	Right Side		Left Side	
		Head End	Crank End	Head End	Crank End		Head End	Crank End	Head End	Crank End
	Code Item☞	674	675	676	677	678	697	698	699	700
2009	138–16–F	32.8	32.9	32.9	37.7	34.1	2.51	2.34	2.35	2.50
2010	193–20–F	28.3	36.9	29.0	36.4	32.6	2.18	2.38	2.55	2.56
2012	138–24–F	45.5	53.1	48.0	53.7	50.1	2.15	2.36	2.29	2.24
2013	138–32–F	56.8	65.5	57.4	65.9	61.4	1.95	1.84	1.93	2.03
2014	193–32–F	44.7	52.2	41.6	49.7	47.1	1.78	1.89	1.99	1.94
2015	193–24–F	33.8	40.3	32.8	40.3	36.8	2.21	2.21	2.18	2.30
2016	193–16–F	23.0	28.4	21.1	29.3	25.5	2.44	2.58	2.74	2.53
2017	83–16–F	42.9	46.8	45.8	50.8	46.6	2.40	2.47	2.39	2.31
2018	83–24–F	59.5	65.4	63.7	69.7	64.6	2.17	2.24	2.18	2.07
2019	83–32–F	76.2	85.1	79.9	89.6	82.7	2.03	1.82	1.95	1.74
2020	83–24–F	58.2	63.5	62.4	68.6	63.2	2.38	2.05	2.25	2.08
2021	83–16–F	42.2	43.8	47.3	52.7	46.5	2.65	2.57	2.53	2.34
2022	83–32–F	77.2	86.7	80.6	89.5	83.5	1.97	1.85	2.01	1.80
2023	138–40–F	70.2	76.4	69.8	81.3	74.4	1.87	1.59	1.69	1.66
2024	55–24–F	69.8	74.8	72.5	78.8	74.0				
2026	110–16–F	36.5	40.6	38.1	48.7	41.0	2.49	1.92	2.37	2.41
2027	110–24–F	55.3	59.3	57.3	65.2	59.3	2.26	2.11	2.28	2.08
2028	55–32–F	88.2	93.2	94.2	103.9	94.9	1.96	1.83	1.91	1.78
2029	110–32–F	71.8	76.6	73.8	84.7	76.7	2.08	1.97	1.96	1.89
2030	165–24–F	42.4	47.5	45.5	49.4	46.2	2.21	2.29	2.35	2.05
2031	83–40–F	91.9	95.8	95.3	104.6	96.9	1.78	1.67	1.71	1.60
2032	165–32–F	53.8	56.8	53.6	62.5	56.7	1.95	1.97	2.14	1.93
2033	110–48–F	88.9	91.6	88.1	93.1	90.4	1.75	1.72	1.68	1.58
2034	193–40–F	54.7	56.4	52.2	60.6	56.0	1.80	1.61	1.80	1.67
2035	110–40–F	83.3	85.0	86.8	93.2	87.1	1.81	1.72	1.67	1.65
2037	165–40–F	63.1	65.4	62.9	71.2	65.7	1.73	1.66	1.84	1.64
2038	55–24–F	66.6	73.6	73.1	80.3	73.4				
2039	110–32–F	69.3	77.0	71.9	79.4	74.4	1.87	1.78	1.87	1.83
2040	165–40–F	61.8	66.2	62.1	68.1	64.5	1.65	1.67	1.65	1.68
2041	110–40–F	83.3	90.4	85.8	91.1	87.7	1.67	1.65	1.65	1.67
2042	110–24–F	54.3	60.7	60.8	63.8	59.9	2.03	2.14	1.92	2.12
2043	110–48–F	97.4	101.3	98.3	102.5	99.9	1.54	1.49	1.60	1.52
2044	110–56–F	103.0	107.0	104.8	108.7	105.9	1.38	1.37	1.36	1.37
2045	110–16–F	37.2	42.0	40.3	45.0	41.1	2.13	2.39	1.97	2.28
2072	110–40–F	94.1	99.3	96.9	100.2	97.6	1.64	1.63	1.63	1.67
2073	110–32–F	77.4	81.7	80.4	83.6	80.8	2.29	1.95	1.92	1.90
2074	165–32–F	61.7	67.8	61.8	67.5	64.7	2.50	1.87	1.92	1.98
2075	55–32–F	93.8	99.9	101.7	100.3	98.9	1.89	1.77	1.83	1.91
2076	220–32–F	53.0	53.2	47.1	52.6	51.5	1.96	1.79	1.76	1.71
2077	110–24–F	56.0	63.9	61.9	67.6	62.4	2.05	2.05	2.04	2.09
2078	165–24–F	48.2	55.6	50.0	54.0	52.0	2.10	2.12	2.02	2.26
2079	220–24–F	40.9	43.2	40.2	41.8	41.5	2.28	2.26	2.32	2.18
2080	110–16–F	38.8	45.5	43.5	47.7	43.9	2.32	2.32	2.43	2.53
2081	55–24–F	72.1	78.1	80.8	77.6	77.1	2.01	1.99	1.98	2.18
2082	165–40–F	71.7	78.3	71.9	75.9	74.5	1.81	1.49	1.67	1.63
2083	165–16–F	33.2	39.3	39.0	37.3	37.2	2.28	2.35	2.20	2.45
2084	110–48–F	103.3	108.1	103.5	107.8	105.7	1.53	1.49	1.54	1.54
2085	55–40–F	112.7	120.0	120.3	118.1	117.8	1.60	1.61	1.64	1.67
2086	55–24–F	71.9	77.2	81.1	78.0	77.1	2.09	2.08	2.03	2.22
2087	110–16–F	39.2	44.5	43.7	47.6	43.7	2.22	2.43	2.40	2.30
2088	220–16–F	28.0	27.1	29.7	27.5	28.1	2.54	2.50	2.67	2.56
2089	220–40–F	57.8	60.8	56.2	60.1	58.7	1.63	1.57	1.69	1.57
2092	165–32–F	61.9	68.0	63.9	67.3	65.3	1.96	1.93	1.97	2.01
2093	165–48–F	81.1	86.9	82.0	86.6	84.2	1.57	1.47	1.53	1.45
2094	110–56–F	115.8	120.8	118.5	121.3	119.1	1.41	1.42	1.36	1.42
2095	55–48–F	131.8	136.7	136.7	136.2	135.4	1.54	1.49	1.49	1.55
2096	55–40–F	115.1	121.2	123.2	121.3	120.2	1.72	1.63	1.64	1.71
2097	55–32–F	97.0	103.7	103.2	102.2	101.5	1.85	1.82	1.79	1.93
2098	55–48–F	133.0	138.1	141.3	137.7	137.5	1.54	1.49	1.50	1.57
2090	110–24–F	52.7	59.1	59.2	61.4	58.1	2.10	2.32	2.20	2.11
2091	165–32–F	54.2	60.2	58.1	60.9	58.3	2.05	1.81	2.16	2.22

TABLE 28.

ENGINE PERFORMANCE—INDICATED HORSE POWER.

Test No.	Laboratory Designation	Indicated Horse Power					
		Right Side		Left Side		Total	Maximum
		Head End	Crank End	Head End	Crank End		
	Code Item☞	707	708	709	710	711	721
2009	138–16–F	131.9	128.8	135.1	149.7	545.5	687.5
2010	193–20–F	161.2	203.4	167.9	204.5	737.0	902.5
2012	138–24–F	183.9	207.4	197.3	214.2	802.8	1023.7
2013	138–32–F	229.6	256.5	237.0	263.2	986.3	1224.6
2014	193–32–F	258.4	292.0	245.0	283.6	1079.0	1374.9
2015	193–24–F	195.8	225.9	193.4	230.5	845.6	1051.3
2016	193–16–F	133.1	158.9	124.6	167.2	583.8	774.8
2017	83–16–F	99.3	104.8	107.9	116.1	428.1	624.5
2018	83–24–F	137.6	146.6	150.3	159.3	593.8	742.0
2019	83–32–F	177.6	192.1	189.7	206.3	765.7	948.8
2020	83–24–F	135.4	143.2	148.1	157.7	584.4	596.3
2021	83–16–F	97.8	98.3	111.7	120.8	428.6	441.7
2022	83–32–F	180.0	195.9	191.8	206.2	773.9	797.9
2023	138–40–F	282.4	297.5	286.0	322.8	1188.7	1217.6
2024	55–24–F	102.3	106.2	108.3	114.2	431.0	450.9
2026	110–16–F	115.5	124.5	122.7	152.3	515.0	527.6
2027	110–24–F	175.9	182.7	185.7	204.8	749.1	
2028	55–32–F	128.4	131.3	139.7	149.3	548.7	557.6
2029	110–32–F	228.1	235.8	238.9	265.8	968.6	974.7
2030	165–24–F	208.0	225.2	227.1	239.3	899.6	924.4
2031	83–40–F	226.9	229.5	241.1	256.4	953.9	992.4
2032	165–32–F	261.4	267.3	265.7	300.2	1094.6	1125.8
2033	110–48–F	282.6	282.0	285.4	292.3	1142.3	1155.3
2034	193–40–F	314.0	313.6	305.3	343.8	1276.7	1299.0
2035	110–40–F	269.4	266.1	285.9	297.7	1119.1	1148.6
2037	165–40–F	309.1	310.1	313.9	344.6	1277.7	1307.5
2038	55–24–F	97.8	104.7	109.4	116.5	428.4	442.6
2039	110–32–F	220.5	237.1	233.0	249.4	940.0	967.5
2040	165–40–F	301.4	312.8	308.7	328.1	1251.0	1294.3
2041	110–40–F	265.4	279.3	278.7	287.0	1110.4	1133.7
2042	110–24–F	172.8	186.5	197.0	197.4	753.9	799.9
2043	110–48–F	309.0	311.3	318.1	321.2	1259.6	1284.3
2044	110–56–F	326.7	328.7	338.7	340.6	1334.7	1391.1
2045	110–16–F	118.2	129.2	130.5	141.2	519.1	534.7
2072	110–40–F	299.3	305.9	313.8	314.8	1233.8	1253.2
2073	110–32–F	245.8	251.3	260.1	262.1	1019.3	1047.8
2074	165–32–F	303.7	322.9	309.7	328.0	1264.3	1282.6
2075	55–32–F	137.9	142.3	152.7	145.7	578.6	597.2
2076	220–32–F	353.5	344.0	320.0	346.8	1364.3	1390.0
2077	110–24–F	179.9	198.8	202.7	214.3	795.7	813.9
2078	165–24–F	236.4	263.8	249.5	261.5	1011.2	1023.2
2079	220–24–F	275.4	281.1	275.3	278.1	1109.9	1152.3
2080	110–16–F	124.3	141.3	142.0	150.9	558.5	576.0
2081	55–24–F	105.9	111.2	120.9	112.5	450.5	467.6
2082	165–40–F	353.1	373.7	361.1	369.4	1457.3	1484.1
2083	165–16–F	163.9	188.0	196.4	182.1	730.4	756.1
2084	110–48–F	331.6	336.0	338.5	341.4	1347.5	1366.2
2085	55–40–F	167.2	172.4	181.7	173.0	694.3	705.6
2086	55–24–F	106.5	111.4	123.2	114.9	456.0	466.4
2087	110–16–F	126.5	138.9	143.5	151.4	560.3	574.9
2088	220–16–F	189.5	177.7	204.9	184.0	756.1	791.4
2089	220–40–F	386.6	393.6	382.6	397.1	1559.9	1588.6
2092	165–32–F	302.2	321.4	319.6	324.1	1267.3	1427.0
2093	165–48–F	396.0	411.5	408.3	417.7	1633.5	1654.2
2094	110–56–F	372.2	375.9	388.3	385.0	1521.4	1570.1
2095	55–48–F	196.2	197.1	211.4	200.2	804.9	822.7
2096	55–40–F	172.0	175.3	187.4	178.9	713.6	733.1
2097	55–32–F	146.7	152.0	159.0	152.8	610.6	621.0
2098	55–48–F	200.0	201.1	216.6	204.5	822.2	837.5
2090	110–24–F	169.7	184.2	194.2	195.0	743.1	757.3
2091	165–32–F	266.6	286.6	291.0	295.8	1140.0	1170.8

TABLE 29.

ENGINE PERFORMANCE—COAL, STEAM, AND B.T.U. PER INDICATED HORSE POWER HOUR.

Test No.	Laboratory Designation	Consumed per Indicated Horse Power per Hour			
		Dry Coal, lb.	B.t.u. in Coal	Dry Steam, lb.	B.t.u. in Steam Above 32°F.
	Code Item☞	734	735	736	737
2009	138–16–F	4.85	60 882	33.06	
2010	193–20–F	5.19	64 527	32.07	
2012	138–24–F	4.61	56 611	29.44	
2013	138–32–F	4.81	58 884	29.14	
2014	193–32–F	5.72	69 692	29.82	
2015	193–24–F	5.82	71 627	32.32	
2016	193–16–F	5.55	66 556	35.18	
2017	83–16–F	4.54	56 396	34.08	
2018	83–24–F	4.25	52 126	29.71	
2019	83–32–F	4.18	52 346	28.96	
2020	83–24–F	4.22	51 914	29.99	35 943
2021	83–16–F	5.07	62 229	32.10	38 478
2022	83–32–F	4.75	56 406	28.14	33 723
2023	138–40–F	5.56	68 449	29.10	34 876
2024	55–24–F	4.17	53 009	34.74	41 650
2026	110–16–F	4.44	54 652	31.67	37 969
2027	110–24–F	4.34	55 066	27.84	33 377
2028	55–32–F	4.37	55 294	30.57	36 653
2029	110–32–F	4.38	55 188	27.51	32 984
2030	165–24–F	4.45	56 769	28.99	34 756
2031	83–40–F	4.42	52 991	28.75	34 468
2032	165–32–F	4.87	59 619	27.84	33 365
2033	110–48–F	4.45	54 481	27.83	33 363
2034	193–40–F	6.07	71 838	30.02	35 982
2035	110–40–F	4.99	61 522	29.43	35 278
2037	165–40–F	5.09	63 325	29.56	35 439
2038	55–24–F	4.56	52 176	33.14	39 745
2039	110–32–F	4.79	56 206	29.43	35 287
2040	165–40–F	5.96	72 497	30.21	36 206
2041	110–40–F	5.22	64 081	29.54	35 407
2042	110–24–F	4.42	54 247	29.52	35 391
2043	110–48–F	5.84	73 134	30.34	36 372
2044	110–56–F	6.21	75 712	32.50	38 948
2045	110–16–F	4.63	55 028	32.69	39 195
2072	110–40–F	4.79	59 683	27.19	32 601
2073	110–32–F	4.26	54 319	27.20	32 586
2074	165–32–F	4.73	59 480	27.17	32 574
2075	55–32–F	4.00	50 872	28.40	34 052
2076	220–32–F	5.71	71 483	28.30	33 929
2077	110–24–F	4.10	51 795	27.36	32 788
2078	165–24–F	4.63	57 954	28.09	33 677
2079	220–24–F	5.17	66 005	28.25	33 869
2080	110–16–F	4.31	55 375	30.87	37 016
2081	55–24–F	4.36	55 372	31.53	37 808
2082	165–40–F	6.15	77 650	27.88	33 423
2083	165–16–F	4.52	57 223	29.65	35 553
2084	110–48–F	5.88	72 353	28.69	34 391
2085	55–40–F	4.39	55 411	29.69	35 598
2086	55–24–F	4.51	56 763	31.18	37 388
2087	110–16–F	4.39	53 383	30.65	36 752
2088	220–16–F	4.42	53 460	29.40	35 251
2089	220–40–F	7.10	87 728	29.18	34 978
2092	165–32–F	4.46	56 285	27.34	32 783
2093	165–48–F	6.31	79 197	29.62	35 500
2094	110–56–F	5.58	69 337	29.39	35 233
2095	55–48–F	4.15	51 107	29.37	35 215
2096	55–40–F				35 005
2097	55–32–F				34 978
2098	55–48–F				34 783
2090	110–24–F	4.26	53 650	28.99	34 762
2091	165–32–F	4.58	58 080	29.10	34 894

TABLE 30.

GENERAL PERFORMANCE—DRAWBAR HORSE POWER AND MILLIONS OF FOOT POUNDS AT DRAWBAR.

Test No.	Laboratory Designation	Drawbar Horse Power	Consumed per D.H.P. Hour			Millions of Foot Pounds at Drawbar per Hour	Per Million Ft. lb. at Drawbar		
			Dry Coal, lb.	Dry Steam, lb.	B.t.u.		Dry Coal, lb.	Dry Steam, lb.	B.t.u.
	Code Item☞	743	744	745	746	750	752	753	754
2009	138–16–F								
2010	193–20–F								
2012	138–24–F	684.9	5.40	34.50	66 312	1357	2.73	17.4	33 524
2013	138–32–F	863.7	5.50	33.28	67 331	1711	2.77	16.8	33 910
2014	193–32–F	853.1	7.25	37.71	88 334	1689	3.66	19.0	44 593
2015	193–24–F	626.2	7.86	43.64	96 733	1240	3.97	22.0	48 859
2016	193–16–F	418.2	7.75	49.11	92 938	828	3.92	24.8	47 009
2017	83–16–F	357.1	5.45	40.85	67 700	707	2.75	20.6	34 161
2018	83–24–F	511.7	4.93	34.48	60 466	1014	2.49	17.4	30 540
2019	83–32–F	683.1	4.68	32.46	58 608	1353	2.36	16.4	29 554
2020	83–24–F	508.9	4.85	34.46	59 665	1009	2.44	17.4	30 017
2021	83–16–F	346.3	6.27	39.72	76 958	686	3.16	20.0	38 786
2022	83–32–F	674.6	5.44	32.29	64 600	1336	2.75	16.3	32 656
2023	138–40–F	1070.5	6.16	32.31	75 836	2120	3.11	16.3	38 287
2024	55–24–F	355.6	5.05	42.34	64 196	706	2.54	21.2	32 288
2026	110–16–F	415.1	5.51	39.31	67 823	822	2.78	19.8	34 219
2027	110–24–F	633.6	5.13	32.92	65 089	1255	2.59	16.6	32 862
2028	55–32–F	488.1	4.91	34.37	62 126	967	2.48	17.3	31 379
2029	110–32–F	820.8	5.17	32.50	64 553	1626	2.61	16.4	32 588
2030	165–24–F	725.8	5.52	35.95	70 419	1438	2.79	18.1	35 592
2031	83–40–F	869.7	4.85	31.52	58 147	1723	2.45	15.9	29 373
2032	165–32–F	922.8	5.77	33.22	70 636	1828	2.91	16.7	35 624
2033	110–48–F	1007.9	5.05	31.54	61 827	1996	2.55	15.9	31 220
2034	193–40–F	961.7	8.05	39.86	95 272	1905	4.07	20.1	48 168
2035	110–40–F	942.9	5.92	34.99	72 988	1868	2.99	17.6	36 864
2037	165–40–F	1045.3	6.22	36.09	77 383	2070	3.14	18.2	39 065
2038	55–24–F	368.4	5.30	38.54	60 643	730	2.68	19.4	30 665
2039	110–32–F	824.2	5.46	33.56	64 068	1631	2.76	17.0	32 386
2040	165–40–F	1133.6	6.58	33.33	80 039	2244	3.32	16.8	40 384
2041	110–40–F	1007.7	5.75	32.54	70 587	1995	2.91	16.4	35 723
2042	110–24–F	674.8	4.93	32.97	60 506	1336	2.49	16.7	30 560
2043	110–48–F	1158.5	6.35	32.98	79 521	2293	3.21	16.7	40 199
2044	110–56–F	1257.7	6.59	34.49	80 345	2490	3.33	17.4	40 599
2045	110–16–F	436.6	5.50	38.86	65 368	865	2.78	19.6	33 040
2072	110–40–F	1107.8	5.33	30.28	66 412	2193	2.69	15.3	33 517
2073	110–32–F	898.3	4.83	30.87	61 587	1779	2.44	15.6	31 112
2074	165–32–F	1107.3	5.40	31.03	67 905	2193	2.73	15.7	34 330
2075	55–32–F	501.4	4.62	32.76	58 757	993	2.33	16.5	29 633
2076	220–32–F	1157.1	6.73	33.36	84 253	2291	3.40	16.9	42 565
2077	110–24–F	670.2	4.87	32.48	61 523	1328	2.46	16.4	31 077
2078	165–24–F	833.8	5.62	34.06	70 346	1651	2.84	17.1	35 548
2079	220–24–F	928.5	6.18	33.84	78 900	1839	3.12	17.0	39 833
2080	110–16–F								
2081	55–24–F								
2082	165–40–F	1214.6	7.38	33.45	93 180	2405	3.73	16.9	47 095
2083	165–16–F	583.6	5.65	37.10	71 529	1156	2.85	18.7	36 081
2084	110–48–F	1197.2	6.62	32.30	81 459	2371	3.34	16.3	41 099
2085	55–40–F	614.5	4.96	33.55	62 605	1217	2.51	16.9	31 681
2086	55–24–F	386.0	5.33	36.83	67 083	764	2.69	18.6	33 856
2087	110–16–F	437.6	5.63	39.24	69 091	867	2.84	19.8	34 852
2088	220–16–F	631.3	5.29	35.21	63 983	1250	2.67	17.8	32 294
2089	220–40–F	1321.6	8.38	34.42	103 543	2617	4.25	17.4	52 513
2092	165–32–F	1117.6	5.06	31.01	63 857	2213	2.55	15.7	32 181
2093	165–48–F	1431.6	7.19	33.80	90 242	2835	3.63	17.1	45 560
2094	110–56–F	1354.1	6.27	33.02	77 911	2681	3.17	16.7	39 390
2095	55–48–F	718.0	4.66	32.92	57 388	1422	2.35	16.6	28 940
2096	55–40–F	622.8		33.46		1234		16.9	
2097	55–32–F	525.2		33.91		1040		17.1	
2098	55–48–F	732.2		32.56		1450		16.4	
2090	110–24–F	614.9	5.15	35.03	64 859	1218	2.60	17.7	32 744
2091	165–32–F	985.6	5.31	33.66	67 044	1952	2.68	17.0	33 838

TABLE 31.

GENERAL PERFORMANCE—INDICATED HORSE POWER, DRAWBAR HORSE POWER, AND TRACTIVE FORCE.

Test No.	Laboratory Designation	Indicated Horse Power Per sq. ft. of Heating Surface	Indicated Horse Power Per sq. ft. of Grate Surface	Drawbar Horse Power Per sq. ft. of Heating Surface	Drawbar Horse Power Per sq. ft. of Grate Surface	Tractive Force Based on M.E.P., lb.
	Code Item ☞	755	756	757	758	764
2009	138–16–F	0.17	11.01			8 096
2010	193–20–F	0.22	14.89			7 745
2012	138–24–F	0.24	16.23	0.21	13.84	11 876
2013	138–32–F	0.30	19.91	0.26	17.43	14 581
2014	193–32–F	0.33	21.84	0.26	17.27	11 153
2015	193–24–F	0.26	17.09	0.19	12.65	8 736
2016	193–16–F	0.18	11.83	0.13	8.48	6 031
2017	83–16–F	0.13	8.69	0.11	7.25	11 050
2018	83–24–F	0.18	12.04	0.16	10.39	15 325
2019	83–32–F	0.23	15.53	0.21	13.86	19 621
2020	83–24–F	0.18	11.81	0.16	10.29	14 994
2021	83–16–F	0.13	8.81	0.11	7.12	11 050
2022	83–32–F	0.24	15.64	0.21	13.62	19 827
2023	138–40–F	0.37	24.29	0.33	21.87	17 659
2024	55–24–F	0.13	8.79	0.11	7.25	17 555
2026	110–16–F	0.16	10.41	0.13	8.39	9 728
2027	110–24–F	0.23	15.15	0.19	12.82	14 065
2028	55–32–F	0.17	11.11	0.15	9.89	22 533
2029	110–32–F	0.29	19.54	0.25	16.56	18 216
2030	165–24–F	0.27	18.19	0.22	14.67	10 967
2031	83–40–F	0.29	19.38	0.27	17.66	22 967
2032	165–32–F	0.34	22.20	0.28	18.71	13 445
2033	110–48–F	0.35	23.22	0.31	20.49	21 459
2034	193–40–F	0.39	25.85	0.29	19.47	13 280
2035	110–40–F	0.34	22.53	0.29	18.98	20 674
2037	165–40–F	0.39	25.99	0.32	21.26	15 593
2038	55–24–F	0.13	8.91	0.12	7.66	17 431
2039	110–32–F	0.29	19.04	0.25	16.69	17 659
2040	165–40–F	0.38	25.33	0.35	22.95	15 304
2041	110–40–F	0.34	22.65	0.31	20.57	20 819
2042	110–24–F	0.23	15.33	0.21	13.73	14 148
2043	110–48–F	0.39	25.59	0.36	23.54	23 710
2044	110–56–F	0.41	27.22	0.39	25.63	25 115
2045	110–16–F	0.16	10.59	0.13	8.91	9 769
2072	110–40–F	0.38	24.97	0.34	22.43	23 256
2073	110–32–F	0.31	20.67	0.27	18.22	19 249
2074	165–32–F	0.39	25.67	0.34	22.48	15 387
2075	55–32–F	0.18	11.75	0.15	10.18	23 627
2076	220–32–F	0.42	27.68	0.35	23.48	12 247
2077	110–24–F	0.24	16.14	0.21	13.60	14 850
2078	165–24–F	0.31	20.47	0.25	16.88	12 351
2079	220–24–F	0.34	22.58	0.29	18.89	9 893
2080	110–16–F	0.17	11.33			10 451
2081	55–24–F	0.14	9.14			18 382
2082	165–40–F	0.45	29.49	0.37	24.58	17 741
2083	165–16–F	0.23	14.92	0.18	11.92	8 860
2084	110–48–F	0.41	27.19	0.36	24.16	25 218
2085	55–40–F	0.21	14.05	0.19	12.43	28 047
2086	55–24–F	0.14	9.25	0.12	7.83	18 361
2087	110–16–F	0.17	11.37	0.13	8.87	10 409
2088	220–16–F	0.23	15.33	0.19	12.79	6 671
2089	220–40–F	0.48	31.50	0.40	26.68	13 962
2092	165–32–F	0.39	25.53	0.34	22.51	15 531
2093	165–48–F	0.49	32.69	0.43	28.66	20 158
2094	110–56–F	0.47	30.89	0.42	27.50	28 336
2095	55–48–F	0.25	16.28	0.22	14.53	32 426
2096	55–40–F	0.22	14.55	0.19	12.70	28 605
2097	55–32–F	0.19	12.41	0.16	10.68	24 205
2098	55–48–F	0.25	16.85	0.23	15.01	32 818
2090	110–24–F	0.23	15.05	0.19	12.45	13 879
2091	165–32–F	0.35	23.10	0.30	19.98	13 900

TABLE 32.

GENERAL PERFORMANCE—MACHINE FRICTION, EFFICIENCIES, AND RATIOS.

Test No.	Laboratory Designation	Machine Friction of Locomotive in Terms of				Machine Efficiency of Locomotive, per cent	Efficiency of Locomotive per cent	Ratios	
		Horse Power	Mean Effective Pressure, lb. per sq. in.	Draw-bar Pull, lb.	Per cent of Indicated Horse Power			Total Weight of Locomotive to Maximum I.H.P.	Total Heating Surface to Maximum I.H.P.
	Code Item☞	770	771	772	773	778	779	785	786
2009	138–16–F							324.4	4.8
2010	193–20–F							247.1	3.6
2012	138–24–F	117.9	7.35	1746	14.7	85.3	3.84	217.8	3.2
2013	138–32–F	122.6	7.63	1812	12.4	87.6	3.78	182.1	2.7
2014	193–32–F	225.9	9.86	2337	20.9	79.1	2.88	162.2	2.4
2015	193–24–F	219.4	9.56	2267	26.0	74.1	2.63	212.1	3.1
2016	193–16–F	165.6	7.22	1711	28.4	71.6	2.74	287.8	4.2
2017	83–16–F	71.0	7.72	1837	16.6	83.4	3.76	357.1	5.3
2018	83–24–F	82.1	8.93	2120	13.8	86.2	4.21	300.5	4.4
2019	83–32–F	82.6	8.92	2118	10.8	89.2	4.35	235.0	3.5
2020	83–24–F	75.5	8.16	1938	12.9	87.1	4.27	374.0	5.5
2021	83–16–F	82.3	8.93	2123	19.2	80.8	3.31	504.9	7.4
2022	83–32–F	99.3	10.71	2545	12.8	87.2	3.94	279.5	4.1
2023	138–40–F	118.2	7.40	1757	9.9	90.1	3.36	183.2	2.7
2024	55–24–F	75.4	12.94	3073	17.5	82.5	3.97	494.6	7.3
2026	110–16–F	99.9	7.95	1887	19.4	80.6	3.75	422.7	6.2
2027	110–24–F	115.5	9.14	2169	15.4	84.6	3.91		
2028	55–32–F	60.6	10.47	2489	11.0	89.0	4.10	399.9	5.9
2029	110–32–F	147.8	11.71	2781	15.3	84.7	3.94	235.3	3.4
2030	165–24–F	173.8	8.93	2118	19.3	80.7	3.62	241.2	3.6
2031	83–40–F	84.2	8.56	2023	8.8	91.2	4.38	224.7	3.3
2032	165–32–F	171.8	8.90	2112	15.7	84.3	3.61	198.1	2.9
2033	110–48–F	134.4	10.64	2527	11.8	88.2	4.12	193.0	2.8
2034	193–40–F	315.0	13.81	3279	24.7	75.3	2.67	171.7	2.5
2035	110–40–F	176.2	13.70	3256	15.7	84.3	3.49	194.2	2.9
2037	165–40–F	232.4	11.94	2836	18.2	81.8	3.29	170.6	2.5
2038	55–24–F	60.0	10.28	2440	14.0	86.0	4.20	503.8	7.4
2039	110–32–F	115.8	9.17	2175	12.3	87.7	3.97	230.5	3.4
2040	165–40–F	117.4	6.05	1437	9.4	90.6	3.18	172.3	2.5
2041	110–40–F	102.7	8.11	1923	9.3	90.8	3.61	196.8	2.9
2042	110–24–F	78.9	6.27	1483	10.5	89.5	4.21	278.9	4.1
2043	110–48–F	101.1	8.02	1903	8.0	92.0	3.20	173.7	2.6
2044	110–56–F	77.0	6.10	1449	5.8	94.2	3.17	160.3	2.4
2045	110–16–F	82.5	6.53	1551	15.9	84.1	3.90	417.1	6.1
2072	110–40–F	126.0	9.97	2375	10.2	89.8	3.83	177.9	2.6
2073	110–32–F	121.0	9.59	2284	11.9	88.1	4.13	212.8	3.1
2074	165–32–F	157.0	8.04	1913	12.4	87.6	3.75	173.9	2.6
2075	55–32–F	77.2	13.20	3154	13.3	86.7	4.33	373.4	5.5
2076	220–32–F	207.2	7.81	1861	15.2	84.8	3.02	160.4	2.4
2077	110–24–F	125.5	9.83	2342	15.8	84.2	4.14	274.0	4.0
2078	165–24–F	177.4	9.10	2169	17.5	82.5	3.62	217.9	3.2
2079	220–24–F	181.4	6.78	1615	16.3	83.7	3.23	193.5	2.9
2080	110–16–F							387.2	5.7
2081	55–24–F							476.9	7.0
2082	165–40–F	242.7	12.40	2954	16.7	83.4	2.73	150.3	2.2
2083	165–16–F	146.8	7.46	1780	20.1	79.9	3.56	294.9	4.3
2084	110–48–F	150.3	11.79	2813	11.2	88.9	3.13	163.2	2.4
2085	55–40–F	79.8	13.54	3224	11.5	88.5	4.07	316.0	4.7
2086	55–24–F	70.0	11.83	2817	15.4	84.7	3.80	478.1	7.0
2087	110–16–F	122.7	9.57	2280	21.9	78.1	3.69	387.9	5.7
2088	220–16–F	124.8	4.64	1101	16.5	83.5	3.98	281.8	4.2
2089	220–40–F	238.3	8.97	2134	15.3	84.7	2.46	140.4	2.1
2092	165–32–F	149.7	7.71	1834	11.8	88.2	3.99	156.3	2.3
2093	165–48–F	201.9	10.41	2491	12.4	87.6	2.82	134.8	2.0
2094	110–56–F	167.3	13.10	3117	11.0	89.0	3.27	142.0	2.1
2095	55–48–F	86.9	14.62	3501	10.8	89.2	4.44	271.1	4.0
2096	55–40–F	90.8	15.28	3641	12.7	87.3		304.2	4.5
2097	55–32–F	85.4	14.20	3385	14.0	86.0		359.1	5.3
2098	55–48–F	90.0	15.06	3592	11.0	89.1		266.3	3.9
2090	110–24–F	128.2	10.02	2394	17.3	82.8	3.93	294.5	4.3
2091	165–32–F	154.4	7.89	1884	13.5	86.5	3.80	190.5	2.8

TABLE 33.

ANALYSIS OF ASH, FRONT-END CINDERS, AND STACK CINDERS.

Test No.	Laboratory Designation	Analysis of Ash			Analysis of Front-end Cinders			Analysis of Stack Cinders		
		Carbon, per cent	Earthy Matter, per cent	Moisture, per cent	Carbon, per cent	Earthy Matter, per cent	Moisture, per cent	Carbon, per cent	Earthy Matter, per cent	Moisture, per cent
	Code Item☞	831	832	833	841	842	843	846	847	848
2009	138–16–F	34.90	51.97	10.92	57.47	35.56	4.50	44.35	51.75	0.84
2010	193–20–F	30.26	60.22	7.33	42.75	54.85	0.58	61.97	34.90	0.54
2012	138–24–F	29.34	63.97	4.21	42.52	54.33	0.73	52.71	43.88	0.84
2013	138–32–F	31.53	62.82	2.86	37.46	59.41	0.66	60.26	37.00	0.54
2014	193–32–F	25.41	66.84	4.66	38.60	57.42	1.50	66.76	28.48	2.23
2015	193–24–F	33.03	58.52	4.48	18.19	79.68	0.62	63.90	32.16	1.26
2016	193–16–F	30.75	59.56	6.43	39.95	55.40	0.74	56.47	40.76	0.81
2017	83–16–F	30.12	63.55	3.78	29.99	65.99	1.34	40.17	50.54	7.02
2018	83–24–F	27.49	67.01	3.28	44.08	52.97	0.88	50.62	44.44	2.64
2019	83–32–F	24.59	71.63	1.58	45.95	48.93	2.71	55.30	40.83	1.27
2020	83–24–F	44.49	50.94	4.57	37.26	44.31	18.43	46.34	52.40	1.26
2021	83–16–F	35.90	62.95	1.15	45.85	53.00	1.15	51.63	46.90	1.47
2022	83–32–F	26.24	72.63	1.13	27.25	72.05	0.70	64.48	33.95	1.57
2023	138–40–F	33.00	64.76	2.24	51.32	47.83	0.85	71.14	28.56	0.30
2024	55–24–F	29.04	68.25	2.70	39.46	38.60	21.94	43.59	55.04	1.37
2026	110–16–F	41.33	51.24	7.43	48.85	50.37	0.78	56.14	42.77	1.09
2027	110–24–F	33.08	63.71	3.21	48.80	50.38	0.82	56.19	43.24	0.57
2028	55–32–F	27.48	70.63	1.89	49.59	49.88	0.53	53.17	44.05	2.78
2029	110–32–F	37.00	60.61	2.39	33.77	65.56	0.67	60.79	38.27	0.94
2030	165–24–F	38.29	56.74	4.97	48.88	51.11	0.01	67.31	32.34	0.35
2031	83–40–F	29.05	69.49	1.46	20.82	78.66	0.52	66.13	32.96	0.91
2032	165–32–F	41.04	55.71	3.25	52.59	46.76	0.65	33.80	65.28	0.92
2033	110–48–F	31.93	66.04	2.03	19.52	79.89	0.59	67.86	31.48	0.66
2034	193–40–F	36.31	61.59	2.10	43.05	56.35	0.60	71.39	28.04	0.57
2035	110–40–F	37.81	60.00	2.19	40.73	58.72	0.55	66.60	32.69	0.71
2037	165–40–F	40.50	56.91	2.59	45.64	53.40	0.96	69.72	29.61	0.67
2038	55–24–F	42.04	57.58	0.38	46.39	52.05	1.56	38.95	60.16	0.89
2039	110–32–F	29.59	69.28	1.13	42.74	55.44	1.82	58.50	40.89	0.61
2040	165–40–F	38.57	59.98	1.45	34.78	64.71	0.51	70.55	28.96	0.49
2041	110–40–F	34.91	63.69	1.40	46.43	52.35	1.22	66.22	33.30	0.48
2042	110–24–F	36.54	62.11	1.35	47.78	51.63	0.59	57.25	42.08	0.67
2043	110–48–F	32.99	64.35	2.66	10.55	89.37	0.08	69.26	30.14	0.60
2044	110–56–F	29.99	67.45	2.56	26.19	73.50	0.31	73.92	25.64	0.44
2045	110–16–F	33.14	65.06	1.80	52.44	47.41	0.15	46.58	53.03	0.39
2072	110–40–F	26.72	70.98	2.30	32.50	67.18	0.32	68.08	31.37	0.55
2073	110–32–F	35.55	60.82	3.63	34.42	65.08	0.50	64.61	34.96	0.43
2074	165–32–F	29.52	68.03	2.45	40.97	58.68	0.35	67.18	32.41	0.41
2075	55–32–F	30.33	69.36	0.31	43.76	56.18	0.06	46.69	52.84	0.47
2076	220–32–F	33.20	64.08	2.72	44.16	55.50	0.34	75.82	23.79	0.39
2077	110–24–F	51.92	40.16	7.92	56.25	43.34	0.41	56.19	43.00	0.81
2078	165–24–F	28.41	69.20	2.39	42.75	56.88	0.37	64.45	34.98	0.57
2079	220–24–F	38.08	60.98	0.94	42.02	57.69	0.29	67.47	32.03	0.50
2080	110–16–F	30.34	67.79	1.87	44.20	53.12	2.68	37.30	61.96	0.74
2081	55–24–F	32.01	66.82	1.17	41.82	57.98	0.20	41.10	58.37	0.53
2082	165–40–F	32.66	64.62	2.72	45.85	53.65	0.50	73.05	26.41	0.54
2083	165–16–F	34.94	61.87	3.19	53.99	45.66	0.35	62.11	37.19	0.70
2084	110–48–F	31.38	66.85	1.97	24.30	53.52	22.18	73.52	25.92	0.56
2085	55–40–F	33.16	66.19	0.65	51.37	48.42	0.21	64.35	35.23	0.42
2086	55–24–F	29.70	69.64	0.66	22.63	54.43	22.94	38.94	53.81	7.25
2087	110–16–F	29.94	69.47	0.59	39.45	60.35	0.20	45.33	53.70	0.97
2088	220–16–F	28.16	71.15	0.69	19.32	74.04	6.64	57.39	41.93	0.68
2089	220–40–F	25.16	72.85	1.99	41.25	58.48	0.27	75.83	23.84	0.33
2092	165–32–F	34.23	63.49	2.28	36.73	62.95	0.32	69.76	29.65	0.59
2093	165–48–F	44.12	54.79	1.09	41.35	58.42	0.23	71.65	28.01	0.34
2094	110–56–F	37.66	61.46	0.88	42.96	55.06	1.98	72.55	26.94	0.51
2095	55–48–F	31.83	67.47	0.70	62.66	37.00	0.34	57.88	41.66	0.46
2096	55–40–F									
2097	55–32–F									
2098	55–48–F									
2090	110–24–F	34.88	64.52	0.60	51.66	48.03	0.31	57.23	41.93	0.84
2091	165–32–F	36.60	61.98	1.42	55.00	44.32	0.68	67.47	31.79	0.74

TABLE 34.

HEAT BALANCE—BRITISH THERMAL UNITS.

Test No.	Laboratory Designation	B.t.u. Absorbed by Boiler per lb. of Coal as Fired	B.t.u. Loss Per Pound of Coal as Fired								
			Due to Moisture in Coal	Due to Moisture in Air	Due to Hydrogen in Coal	Due to Escaping Gases	Due to Incomplete Combustion	Due to Combustible in Front-end Cinders	Due to Combustible in Stack Cinders	Due to Combustible in Ash	Due to Radiation, and Unaccounted-for
	Code Item☞	851	852	853	854	855	856	857	858	860	869
2009	138–16–F	7007	143	46	491	1691	0	27	368	116	1194
2010	193–20–F	6376	163	57	542	3688	0	11	882	61	–821
2012	138–24–F	6618	150	77	522	3525	30	7	681	187	–896
2013	138–32–F	6435	122	78	542	3506	47	7	1036	184	–821
2014	193–32–F	5512	126	75	532	2698	22	7	1272	81	713
2015	193–24–F	5638	144	64	518	2171	0	4	1243	355	826
2016	193–16–F	6531	153	68	490	2323	15	8	662	250	87
2017	83–16–F	7812	130	64	512	2213	106	9	175	209	– 50
2018	83–24–F	7269	141	49	510	2220	106	24	377	168	268
2019	83–32–F	7239	140	62	532	2211	124	11	618	162	93
2020	83–24–F	7560					0	16	362	182	
2021	83–16–F	6521	154	22	409	1786	0	28	370	476	1003
2022	83–32–F	6231	133	34	412	1811	0	4	1039	267	711
2023	138–40–F	5317	174	19	419	1336	0	4	1856	264	1297
2024	55–24–F	8637	146	18	419	1942	0	28	181	210	–345
2026	110–16–F	7278	162	26	409	1928	0	31	408	415	85
2027	110–24–F	6550	162	29	418	1908	0	15	661	267	1069
2028	55–32–F	7113	157	30	414	1812	0	16	457	270	808
2029	110–32–F	6414	157	33	410	1512	0	10	1068	376	968
2030	165–24–F	6793	138	40	429	1566	0	10	1127	280	993
2031	83–40–F	6299	220	33	388	1360	96	5	1188	240	91
2032	165–32–F	5822	171		411	1431	0	19	794	326	
2033	110–48–F	6289	180	35	405	1400	0	3	1519	241	467
2034	193–40–F	5045	168	36	405	1347	0	7	1736	386	1180
2035	110–40–F	5900	186	39	403	1707	0	4	1191	379	738
2037	165–40–F	5813	185	39	413	1400	0	9	1599	347	889
2038	55–24–F	7482	154	18	383	1622	0	29	173	411	–231
2039	110–32–F	6356	152	22	402	1478	0	13	900	269	762
2040	165–40–F	5180	160	18	417	1271	38	6	1941	261	1396
2041	110–40–F	5716	185	20	416	1455	45	5	1477	258	974
2042	110–24–F	6774	175	22	405	1557	0	5	719	283	662
2043	110–48–F	5231	179	16	426	1299	154	2	1838	225	1471
2044	110–56–F	5306	177	17	427	1408	156	4	1961	187	551
2045	110–16–F	7180	170	21	391	1474	0	3	515	321	236
2072	110–40–F	5793	169		505			0	1664	157	
2073	110–32–F	6511	175	19	516	1638	56	9	1042	261	824
2074	165–32–F	5978	148	21	529	1568	229	2	1372	266	1061
2075	55–32–F	7249	166	28	509	1981	69	13	427	154	478
2076	220–32–F	4920	205	18	516	1352	74	16	2159	283	1059
2077	110–24–F	6812	165	22	507	1765	29	16	540	221	941
2078	165–24–F	6152	172	22	508	1738	0	16	1132	185	932
2079	220–24–F	5851	113	22	549	1676	0	13	1361	502	1573
2080	110–16–F	7297	166	28	512	1982	142	16	193	316	527
2081	55–24–F	7501	147	29	511	2121	0	19	169	359	358
2082	165–40–F	4658	160	20	545	1468	0	14	2034	324	1902
2083	165–16–F	6629	177	23	504	1672	0	26	613	448	824
2084	110–48–F	4998	175	26	510	1566	0	9	1746	304	1354
2085	55–40–F	7016	160	26	510	1725	0	18	590	369	628
2086	55–24–F	7142	151	26	495	1750	68	8	269	363	803
2087	110–16–F	7220	147	28	496	1725	0	14	284	379	543
2088	220–16–F	6773	169	25	476	1517	0	7	599	335	586
2089	220–40–F	4202	167	14	528	1207	126	10	2551	214	1819
2092	165–32–F	6152	192	18	522	1475	22	11	1292	326	792
2093	165–48–F	4736	188	15	530	1187	62	10	2414	540	1125
2094	110–56–F	5666	190	21	517	1282	35	20	2069	315	847
2095	55–48–F	7307	158	23	505	1656	0	24	560	315	260
2096	55–40–F										
2097	55–32–F										
2098	55–48–F										
2090	110–24–F	7026	152	25	508	1524	26	29	730	447	627
2091	165–32–F	6443	174	23	514	1470	0	31	1399	461	449

Table 35.
Heat Balance—Percentage.

Test No.	Laboratory Designation	Per cent of Heat of Coal as Fired: Absorbed by Boiler	To Moisture in Coal	To Moisture in Air	To Hydrogen in Coal	To Escaping Gases	To Incomplete Combustion	To Combustible in Front-end Cinders	To Combustible in Stack Cinders	To Combustible in Ash	To Radiation, and Unaccounted-for
	Code Item	881	882	883	884	885	886	887	888	890	899
2009	138–16–F	63.2	1.3	0.4	4.4	15.3	0.0	0.2	3.3	1.1	10.8
2010	193–20–F	58.2	1.5	0.5	5.0	33.7	0.0	0.1	8.1	0.6	– 7.5
2012	138–24–F	60.7	1.4	0.7	4.8	32.3	0.3	0.1	6.3	1.7	– 8.2
2013	138–32–F	57.8	1.1	0.7	4.9	31.5	0.4	0.1	9.3	1.7	– 7.4
2014	193–32–F	49.9	1.1	0.7	4.8	24.4	0.2	0.1	11.5	0.7	6.5
2015	193–24–F	51.4	1.3	0.6	4.7	19.8	0.0	0.0	11.3	3.2	7.5
2016	193–16–F	61.7	1.4	0.6	4.6	21.9	0.1	0.1	6.3	2.4	0.8
2017	83–16–F	69.9	1.2	0.6	4.6	19.8	1.0	0.1	1.6	1.9	– 0.4
2018	83–24–F	66.5	1.3	0.5	4.7	20.3	1.0	0.2	3.4	1.5	2.5
2019	83–32–F	64.7	1.3	0.6	4.8	19.8	1.1	0.1	5.5	1.5	0.8
2020	83–24–F	67.3					0.0	0.1	3.2	1.6	
2021	83–16–F	60.6	1.4	0.2	3.8	16.6	0.0	0.3	3.4	4.4	9.3
2022	83–32–F	58.6	1.3	0.3	3.9	17.0	0.0	0.0	9.8	2.5	6.7
2023	138–40–F	49.8	1.6	0.2	3.9	12.5	0.0	0.0	17.4	2.5	12.1
2024	55–24–F	76.9	1.3	0.2	3.7	17.3	0.0	0.3	1.6	1.9	– 3.1
2026	110–16–F	67.8	1.5	0.2	3.8	18.0	0.0	0.3	3.8	3.9	0.8
2027	110–24–F	59.1	1.5	0.3	3.8	17.2	0.0	0.1	6.0	2.4	9.7
2028	55–32–F	64.2	1.4	0.3	3.7	16.4	0.0	0.1	4.1	2.4	7.3
2029	110–32–F	58.6	1.4	0.3	3.8	13.8	0.0	0.1	9.8	3.4	8.8
2030	165–24–F	59.7	1.2	0.4	3.8	13.8	0.0	0.1	9.9	2.5	8.7
2031	83–40–F	63.4	2.2	0.3	3.9	13.7	1.0	0.1	12.0	2.4	0.9
2032	165–32–F	54.7	1.6		3.9		0.0	0.2	7.5	3.1	
2033	110–48–F	59.7	1.7	0.3	3.8	13.3	0.0	0.0	14.0	2.3	4.4
2034	193–40–F	48.9	1.6	0.4	3.9	13.1	0.0	0.1	16.8	3.7	11.5
2035	110–40–F	55.9	1.8	0.4	3.8	16.2	0.0	0.0	11.3	3.6	7.0
2037	165–40–F	54.4	1.7	0.4	3.9	13.1	0.0	0.1	15.0	3.2	8.3
2038	55–24–F	74.5	1.5	0.2	3.8	16.2	0.0	0.3	1.7	4.1	– 2.3
2039	110–32–F	61.4	1.5	0.2	3.9	14.3	0.0	0.1	8.7	2.6	7.4
2040	165–40–F	48.5	1.5	0.2	3.9	11.9	0.4	0.1	18.2	2.5	13.1
2041	110–40–F	54.2	1.8	0.2	3.9	13.8	0.4	0.0	14.0	2.4	9.2
2042	110–24–F	63.9	1.7	0.2	3.8	14.7	0.0	0.1	6.8	2.7	6.3
2043	110–48–F	48.3	1.7	0.2	3.9	12.0	1.4	0.0	17.0	2.1	13.6
2044	110–56–F	50.1	1.7	0.2	4.0	13.3	1.5	0.0	18.5	1.8	5.2
2045	110–16–F	69.6	1.7	0.2	3.8	14.3	0.0	0.0	5.0	3.1	2.3
2072	110–40–F										
2073	110–32–F	58.9	1.6	0.2	4.7	14.8	0.5	0.1	9.4	2.4	7.4
2074	165–32–F	53.5	1.3	0.2	4.7	14.0	2.1	0.0	12.3	2.4	9.5
2075	55–32–F	65.5	1.5	0.3	4.6	17.9	0.7	0.1	3.9	1.4	4.3
2076	220–32–F	46.4	1.9	0.2	4.9	12.8	0.7	0.1	20.4	2.7	10.0
2077	110–24–F	61.8	1.5	0.2	4.6	16.0	0.3	0.1	4.9	2.0	8.5
2078	165–24–F	56.7	1.6	0.2	4.7	16.0	0.0	0.1	10.4	1.7	8.6
2079	220–24–F	50.2	1.0	0.2	4.7	15.0	0.0	0.1	11.7	4.3	13.5
2080	110–16–F	65.3	1.5	0.3	4.6	17.7	1.3	0.1	1.7	2.8	4.7
2081	55–24–F	66.9	1.3	0.3	4.6	18.9	0.0	0.2	1.5	3.2	3.2
2082	165–40–F	41.9	1.4	0.2	4.9	13.2	0.0	0.1	18.3	2.9	17.1
2083	165–16–F	60.7	1.6	0.2	4.6	15.3	0.0	0.2	5.6	4.1	7.6
2084	110–48–F	46.8	1.6	0.3	4.8	14.6	0.0	0.1	16.3	2.8	12.7
2085	55–40–F	63.5	1.5	0.2	4.6	15.6	0.0	0.2	5.3	3.3	5.7
2086	55–24–F	64.5	1.4	0.2	4.5	15.8	0.6	0.1	2.4	3.3	7.2
2087	110–16–F	66.6	1.4	0.3	4.6	15.9	0.0	0.1	2.6	3.5	5.0
2088	220–16–F	64.6	1.6	0.2	4.5	14.5	0.0	0.1	5.7	3.2	5.6
2089	220–40–F	38.8	1.5	0.1	4.9	11.1	1.2	0.1	23.5	2.0	16.8
2092	165–32–F	57.0	1.8	0.2	4.8	13.7	0.2	0.1	12.0	3.0	7.3
2093	165–48–F	43.8	1.7	0.1	4.9	11.0	0.6	0.1	22.3	5.0	10.4
2094	110–56–F	50.3	1.8	0.2	4.9	12.0	0.3	0.2	19.4	3.0	7.9
2095	55–48–F	67.6	1.5	0.2	4.7	15.3	0.0	0.2	5.2	2.9	2.4
2096	55–40–F										
2097	55–32–F										
2098	55–48–F										
2090	110–24–F	63.3	1.4	0.2	4.6	13.7	0.2	0.3	6.6	4.0	5.6
2091	165–32–F	58.8	1.6	0.2	4.7	13.4	0.0	0.3	12.8	4.2	4.1

TABLE 36.

INFORMATION CONCERNING THE INDICATOR DIAGRAMS SHOWN IN FIG. 56, 57, and 58.

Diagram No.	Right or Left Side	Head or Crank End	Test No.	Laboratory Designation	Nominal Speed, M. P. H.	Speed, R. P. M.
1	R	H	2086	55–24–F	10	51.3
2	R	C	"	"	"	"
3	L	H	"	"	"	"
4	L	C	"	"	"	"
5	R	H	2077	110–24–F	20	110.7
6	R	C	"	"	"	"
7	L	H	"	"	"	"
8	L	C	"	"	"	"
9	R	H	2083	165–16–F	30	170.3
10	R	C	"	"	"	"
11	L	H	"	"	"	"
12	L	C	"	"	"	"
13	R	H	2088	220–16–F	40	234.2
14	R	C	"	"	"	"
15	L	H	"	"	"	"
16	L	C	"	"	"	"
17	R	H	2095	55–48–F	10	51.3
18	R	C	"	"	"	"
19	L	H	"	"	"	"
20	L	C	"	"	"	"
21	R	H	2084	110–48–F	20	110.4
22	R	C	"	"	"	"
23	L	H	"	"	"	"
24	L	C	"	"	"	"
25	R	H	2093	165–48–F	30	167.4
26	R	C	"	"	"	"
27	L	H	"	"	"	"
28	L	C	"	"	"	"
29	R	H	2089	220–40–F	40	230.7
30	R	C	"	"	"	"
31	L	H	"	"	"	"
32	L	C	"	"	"	"
33	R	H	2028	55–32–F	10	50.3
34	R	C	"	"	"	"
35	L	H	"	"	"	"
36	L	C	"	"	"	"
37	R	H	2029	110–32–F	20	109.8
38	R	C	"	"	"	"
39	L	H	"	"	"	"
40	L	C	"	"	"	"
41	R	H	2030	165–24–F	30	169.4
42	R	C	"	"	"	"
43	L	H	"	"	"	"
44	L	C	"	"	"	"
45	R	H	2034	193–40–F	35	198.5
46	R	C	"	"	"	"
47	L	H	"	"	"	"
48	L	C	"	"	"	"

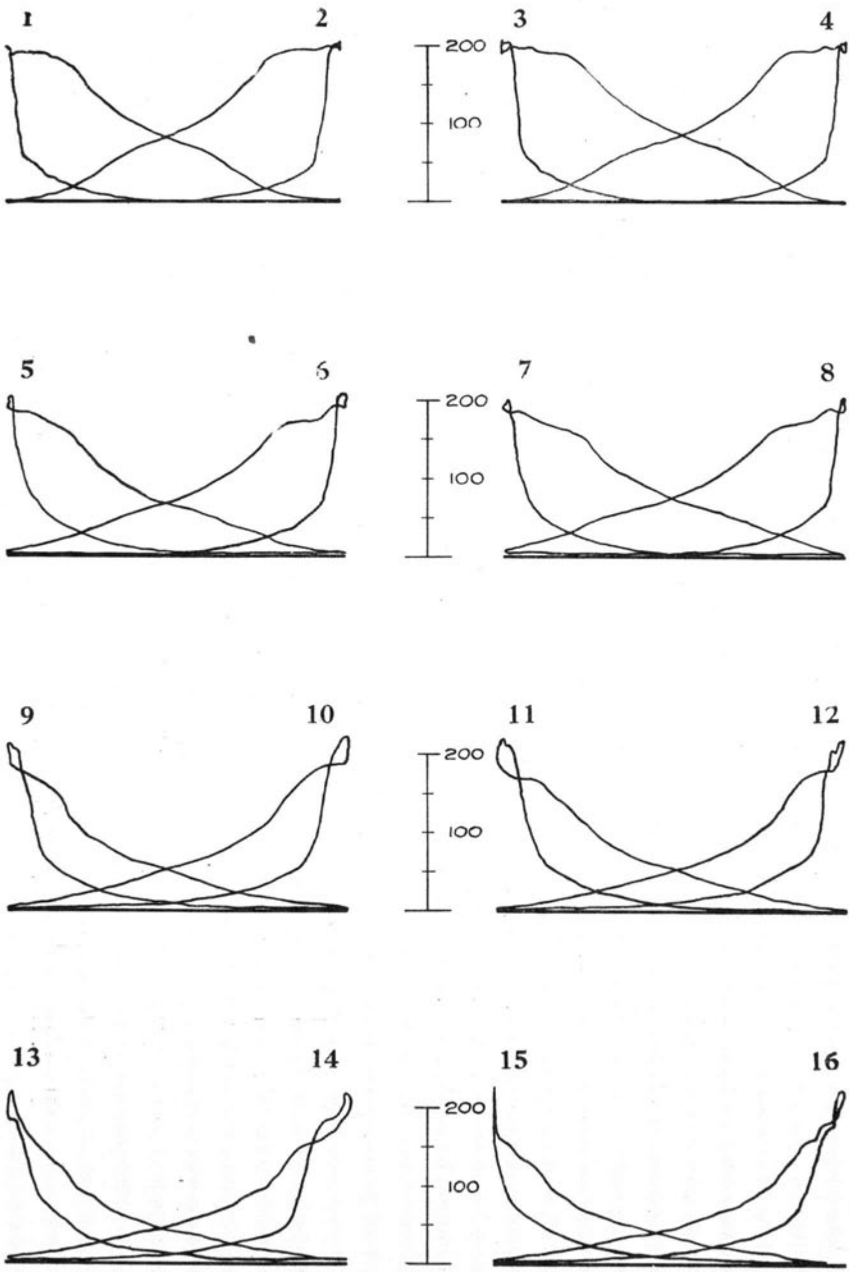

FIG. 56. REPRESENTATIVE INDICATOR DIAGRAMS FOR SERIES 2.
For Data, See Table 36.

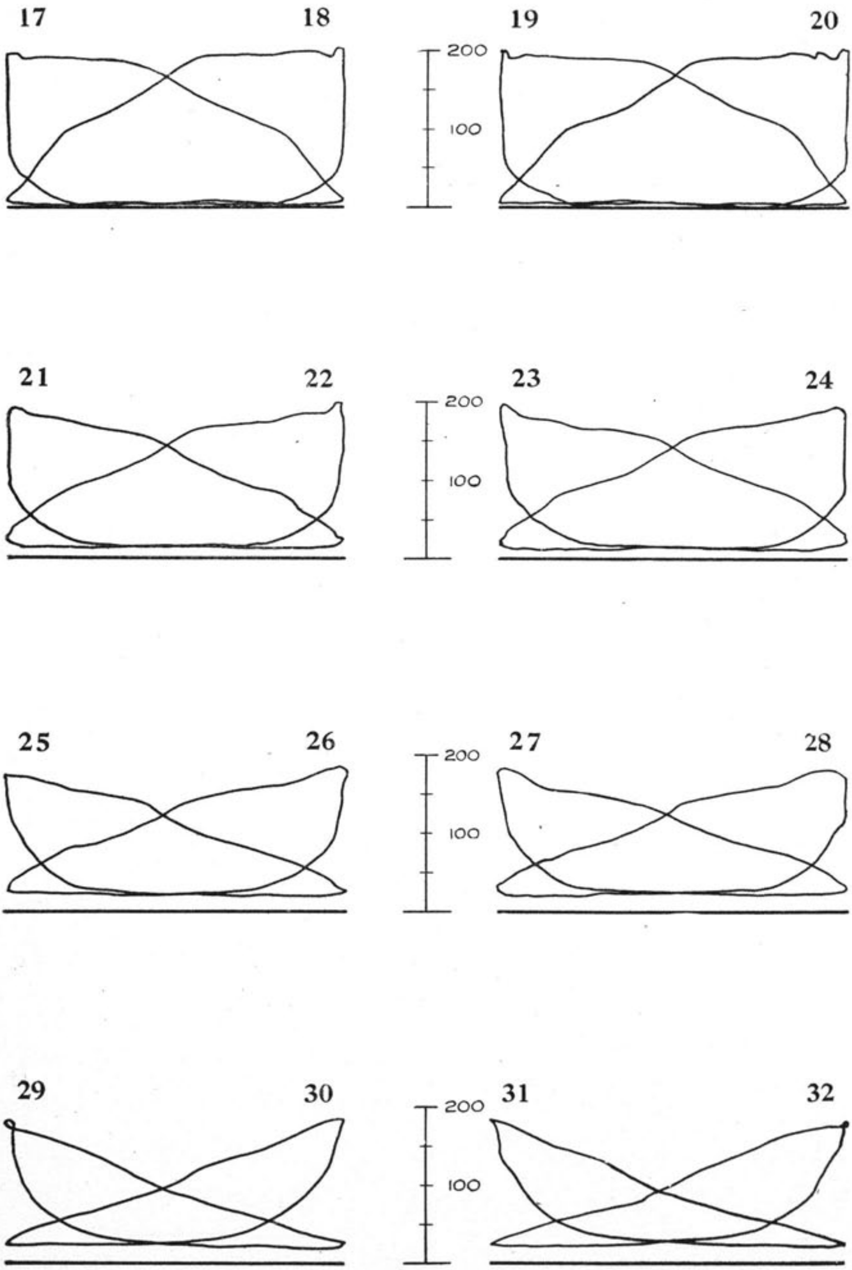

FIG. 57. REPRESENTATIVE INDICATOR DIAGRAMS FOR SERIES 2.
For Data, See Table 36.

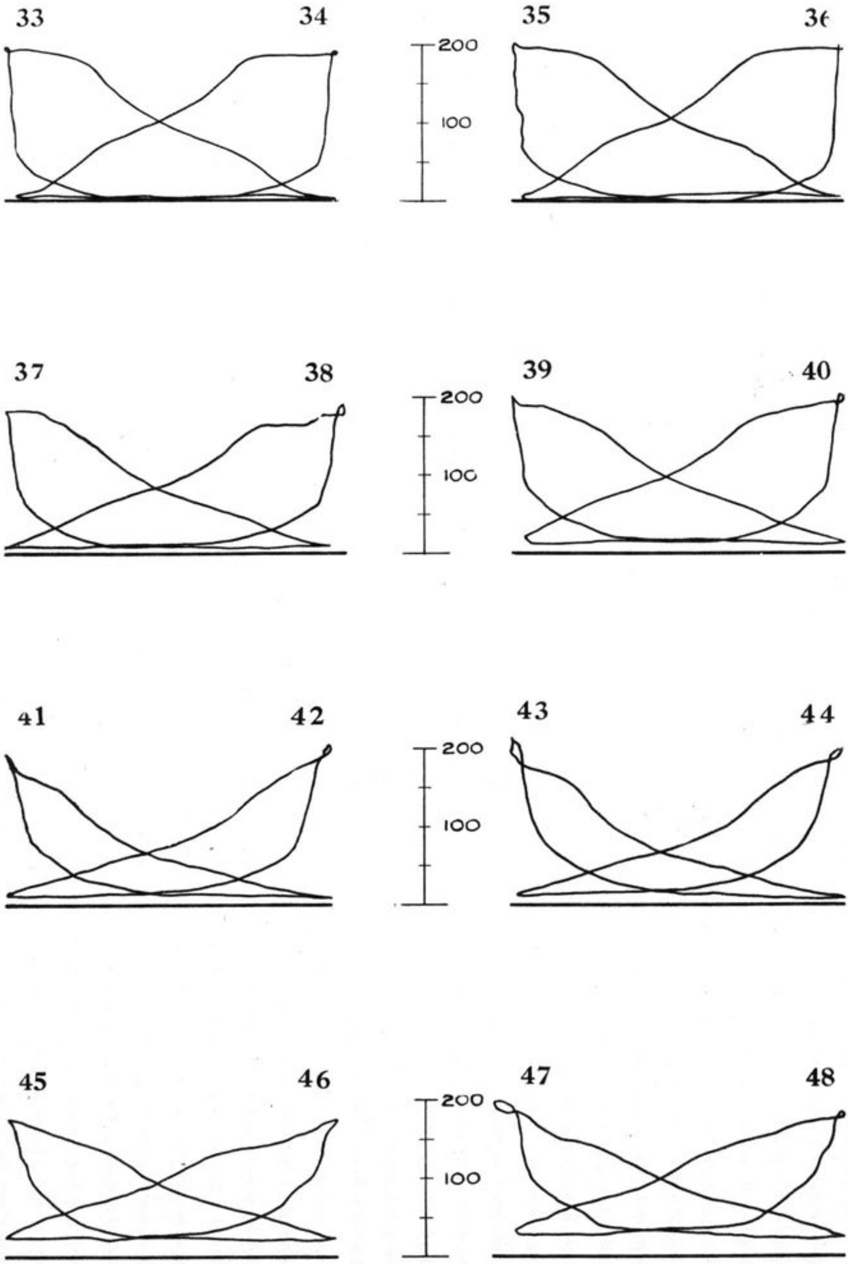

FIG. 58. REPRESENTATIVE INDICATOR DIAGRAMS FOR SERIES 1.
For Data, See Table 36.

APPENDIX 5.

METHODS OF CALCULATION.

Appendix 5 presents in detail the methods of calculation used in determining all results except for those items whose determination is self-evident.

The Marks and Davis steam tables for saturated and superheated steam have been used in all calculations pertaining to the properties of steam.

The events of the stroke and the corresponding pressures were determined for each indicator diagram by inspection and measurement. Horse power calculations were made, in like manner, for each indicator diagram. The values tabulated in Appendix 4 are averages of the determinations made from the individual diagrams.

Methods of estimating the ultimate analyses for the individual coal samples and of estimating the calorific values for the samples of ash and cinders have been presented in Appendix 4 in the consideration of Test Methods.

Item 318. Constant for dynamometer horse power.

$$\frac{\text{Item 19}}{33\,000}$$

Item 319. Constant for indicated horse power. Right, head end.

$$.000001983 \times (\text{Item 68})^2 \times \text{Item 77}$$

Item 320. Constant for indicated horse power. Right, crank end.

$$.000001983 \times [\,(\text{Item 68})^2 - (\text{Item 135})^2] \times \text{Item 77}$$

Item 321. Constant for indicated horse power. Left, head end.

$$.000001983 \times (\text{Item 69})^2 \times \text{Item 78}$$

Item 322. Constant for indicated horse power. Left, crank end.

$.000001983 \times [(\text{Item } 69)^2 - (\text{Item } 136)^2 \times \text{Item } 78$

Item 332. Constant for piston displacement. Right, head end.

$229.17 \times \text{Item } 319$

Item 333. Constant for piston displacement. Right, crank end.

$229.17 \times \text{Item } 320$

Item 334. Constant for piston displacement. Left, head end.

$229.17 \times \text{Item } 321$

Item 335. Constant for piston displacement. Left, crank end.

$229.17 \times \text{Item } 322$

Item 352. Average revolutions per minute.

$$\frac{\text{Item } 351}{60 \times \text{Item } 345}$$

Item 353. Equivalent speed, miles per hour.

$$\frac{\text{Item } 352 \times \text{Item } 19}{88}$$

Item 354. Equivalent piston speed in feet per minute.

$$\text{Item } 352 \times \left[\frac{\text{Item } 77 + \text{Item } 78}{12}\right]$$

Item 388. Barometric pressure in laboratory. The observed value has been corrected for the expansion of the mercury and brass by means of the formula:

$H = h_1 [1.0026 - 0.000091\ t_1]$.

This method is in accordance with that of the United States Weather Bureau as described in Bulletin No. 472, page 29.

Item 407. Quality of steam, average.

Quality of steam in the dome has been determined by means of a throttling calorimeter and the formula:

$$x_o = \frac{H_o + 0.47 \times [t_s - t_o] - q_o}{r_o}$$

x_o = quality of steam
t_s = observed temperature in calorimeter
t_o = temperature of saturated steam at pressure in calorimeter
q_o = heat of liquid due to boiler pressure
H_o = total heat of dry steam at calorimeter pressure
r_o = latent heat of dry steam due to boiler pressure

Item 412. Factor of correction for quality of steam.

$$\frac{q + xr - h}{q + r - h}$$

q = heat of liquid due to average boiler pressure
h = heat of liquid due to average feed water temperature
x = quality of steam, average
r = latent heat of dry steam due to average boiler pressure.

Item 419. Total pounds of dry coal fired.

$$\text{Item } 418 \times \left[\frac{100 - \text{Item } 440}{100}\right]$$

Item 420. Total pounds of combustible by analysis.

$$\text{Item } 418 \times \left[\frac{100 - (\text{Item } 440 + \text{Item } 441)}{100}\right]$$

Item 421. Total pounds of ash by analysis.

$$\text{Item } 418 \times \left[\frac{\text{Item } 441}{100}\right]$$

Item 424. Total pounds of front end and stack cinders.

Item 422 + Item 423.

Item 435. Pounds of moisture per pound of dry air has been obtained from item 368, item 369, and the psychrometric chart and formula described by W. H. Carrier in the November, 1911, Journal of the American Society of Mechanical Engineers.

Item 458. Calorific value of dry coal in B.t.u. per pound.

$$\left[\frac{\text{Item 443}}{100 - \text{Item 440}}\right] \times 100$$

Item 459. Calorific value of combustible in B.t.u. per pound.

$$\left[\frac{\text{Item 443}}{100 - [\text{Item 440} + \text{Item 441}]}\right] \times 100$$

Item 478. Correction for change of water level and pressure in the boiler from start to close of test has been calculated by the formula:

$$\frac{W_i\ [q + xr - q_i] - W_f\ [q + xr - q_f]}{q + xr - h}$$

W_i = initial weight of water in the boiler, pounds

W_f = final weight of water in the boiler, pounds

q = heat of liquid due to average boiler pressure

x = quality of steam, average

r = latent heat of dry steam due to average boiler pressure

q_i = heat of liquid at start of test

q_f = heat of liquid at close of test

h = heat of liquid due to average feed water temperature

Item 480. Total hot water losses, corrected, pounds.

$$\text{Item 479} \times \left[\frac{xr}{q + xr - h}\right]$$

Item 481. Water delivered to boiler and presumably evaporated, pounds.

Item 476 — Item 480 + Item 478

Item 626. Dry coal fired per hour, pounds.

$$\frac{\text{Item 419}}{\text{Item 345}}$$

Item 627. Dry coal fired per hour per square foot of grate surface, pounds.

$$\frac{\text{Item } 626}{\text{Item } 252}$$

Item 633. Moist steam evaporated per hour, pounds.

$$\frac{\text{Item } 481}{\text{Item } 345}$$

Item 634. Dry steam evaporated per hour, pounds.

$$\text{Item } 633 \times \text{Item } 412$$

Item 635. Dry steam evaporated per hour per square foot of heating surface, pounds.

$$\frac{\text{Item } 634}{\text{Item } 275}$$

Item 636. Dry steam evaporated per pound of dry coal, pounds.

$$\frac{\text{Item } 634}{\text{Item } 626}$$

Item 637. Dry steam evaporated per pound of coal as fired, pounds.

$$\text{Item } 634 \div \left[\frac{\text{Item } 418}{\text{Item } 345}\right]$$

Item 639. Dry steam to engine per hour, pounds.

$$[\text{Item } 476 + \text{Item } 477 - \text{Item } 479 - \text{Item } 638] \times \left[\frac{\text{Item } 412}{\text{Item } 345}\right]$$

Item 641. Factor of evaporation.

$$\frac{q + xr - h}{970.4}$$

Item 642. Dry steam loss per hour due to calorimeter, leaks, corrections, etc., pounds.

Item 634 — Item 639

Item 642. Dry coal loss per hour equivalent to steam loss, pounds.

$$\frac{\text{Item } 642}{\text{Item } 636}$$

Item. 645. Equivalent evaporation per hour from and at 212°F., pounds.

Item 633 × Item 641.

Item 648. Equivalent evaporation per hour per square foot of total heating surface, pounds.

$$\frac{\text{Item } 645}{\text{Item } 275}$$

Item 656. Equivalent evaporation per hour per square foot of grate surface, pounds.

$$\frac{\text{Item } 645}{\text{Item } 252}$$

Item 657. Equivalent evaporation per hour per pound of coal as fired, pounds.

$$\text{Item } 645 \div \left[\frac{\text{Item } 418}{\text{Item } 345}\right]$$

Item 658. Equivalent evaporation per hour per pound of dry coal, pounds.

$$\frac{\text{Item } 645}{\text{Item } 626}$$

Item 659. Equivalent evaporation per hour per pound of combustible, pounds.

$$\text{Item } 645 \div \left[\frac{\text{Item } 420}{\text{Item } 345}\right]$$

Item 660. Boiler horse power.

$$\frac{\text{Item } 645}{34.5}$$

Item 666. Efficiency of the boiler, per cent.

$$\frac{\text{Item } 657 \times 970.4 \times 100}{\text{Item } 443.}$$

Item 697. Number of expansions, right, head end.

$$\frac{\text{Item } 510 + \text{Item } 86}{\text{Item } 495 + \text{Item } 86}$$

Item 698. Number of expansions, right, crank end.

$$\frac{\text{Item } 511 + \text{Item } 87}{\text{Item } 496 + \text{Item } 87}$$

Item 699. Number of expansions, left, head end.

$$\frac{\text{Item } 512 + \text{Item } 88}{\text{Item } 497 + \text{Item } 88}$$

Item 700. Number of expansions, left, crank end.

$$\frac{\text{Item } 513 + \text{Item } 89}{\text{Item } 498 + \text{Item } 89}$$

Item 734. Dry coal used by engine per indicated horse power per hour, pounds.

$$\left[\frac{\text{Item } 639}{\text{Item } 636}\right] \div \text{Item } 711$$

Item 735. B.t.u. in dry coal per indicated horse power per hour.

$$\text{Item } 734 \times \text{Item } 458$$

Item 736. Dry steam per indicated horse power per hour, pounds.

$$\frac{\text{Item } 639}{\text{Item } 711}$$

Item 737. B.t.u. in steam above 32°F. per indicated horse power per hour.

$$\text{Item } 736 \times [q + r]$$

Item 743. Drawbar horse power.

$$\text{Item } 318 \times \text{Item } 352 \times \text{Item } 487$$

Item 744. Dry coal per drawbar horse power per hour, pounds.

$$\left[\frac{\text{Item } 639}{\text{Item } 636}\right] \div \text{Item } 743$$

Item 745. Dry steam per drawbar horse power per hour, pounds.

$$\frac{\text{Item } 639}{\text{Item } 743}$$

Item 746. B.t.u. per drawbar horse power per hour.

$$\text{Item } 744 \times \text{Item } 458$$

Item 750. Millions of foot pounds at drawbar per hour.

$$\frac{\text{Item } 487 \times \text{Item } 19 \times \text{Item } 351}{\text{Item } 345 \times 1\,000\,000}$$

Item 752. Dry coal per million foot pounds at drawbar, pounds.

$$\left[\frac{\text{Item } 639}{\text{Item } 636}\right] \div \text{Item } 750$$

Item 753. Dry steam per million foot pounds at drawbar, pounds.

$$\frac{\text{Item } 639}{\text{Item } 750}$$

Item 754. B.t.u. per million foot pounds at drawbar.

$$\text{Item } 752 \times \text{Item } 458$$

Item 755. Indicated horse power per square foot of heating surface.

$$\left[\frac{\text{Item } 711}{\text{Item } 275}\right] \times \left[\frac{\text{Item } 634}{\text{Item } 639}\right]$$

Item 756. Indicated horse power per square foot of grate surface.

$$\left[\frac{\text{Item } 711}{\text{Item } 252}\right] \times \left[\frac{\text{Item } 634}{\text{Item } 639}\right]$$

Item 757. Drawbar horse power per square foot of heating surface.

$$\left[\frac{\text{Item } 743}{\text{Item } 275}\right] \times \left[\frac{\text{Item } 634}{\text{Item } 639}\right]$$

Item 758. Drawbar horse power per square foot of grate surface.

$$\left[\frac{\text{Item } 743}{\text{Item } 252}\right] \times \left[\frac{\text{Item } 634}{\text{Item } 639}\right]$$

Item 764. Tractive force based on mean effective pressure, pounds.

$$\left[\frac{33\,000}{\text{Item } 19}\right] \times \left[\frac{\text{Item } 711}{\text{Item } 352}\right]$$

Item 770. Machine friction of the locomotive in terms of horse power.

Item 711 — Item 743

Item 771. Machine friction of the locomotive in terms of mean effective pressure, pounds.

$$\frac{\text{Item } 770}{\text{Item } 352 \times [\text{Item } 319 + \text{Item } 320 + \text{Item } 321 + \text{Item } 322]}$$

Item 772. Machine friction of the locomotive in terms of drawbar pull, pounds.

$$\left[\frac{33\,000}{\text{Item } 19}\right] \times \left[\frac{\text{Item } 770}{\text{Item } 352}\right]$$

Item 773. Machine friction of the locomotive in per cent of indicated horse power.

$$\left[\frac{\text{Item } 770}{\text{Item } 711}\right] \times 100$$

Item 778. Machine efficiency of the locomotive, per cent.

$$\left[\frac{\text{Item } 743}{\text{Item } 711}\right] \times 100$$

Item 779. Efficiency of the locomotive, per cent.

$$\frac{254\,655.8}{\text{Item } 746}$$

$$\text{Constant } 254\,655.8 = \left[\frac{33\,000 \times 60}{777.52}\right] \times 100$$

Item 785. Ratio of total weight of the locomotive to the maximum indicated horse power.

$$\frac{\text{Item } 63}{\text{Item } 721}$$

Item 786. Ratio of total heating surface to maximum indicated horse power.

$$\frac{\text{Item } 275}{\text{Item } 721}$$

Item 851. B.t.u. absorbed by the boiler per pound of coal as fired.

$$\text{Item } 657 \times 970.4$$

Items 852, 853, 854, 855, and 856 see next page.

Item 857. B.t.u. loss due to combustible in front-end cinders.

$$\frac{\text{Item } 422 \times \text{Item } 461}{\text{Item } 418}$$

Item 858. B.t.u. loss due to combustible in stack cinders.

$$\frac{\text{Item } 423 \times \text{Item } 462}{\text{Item } 418}$$

Item 860. B.t.u. loss due to combustible in ash.

$$\frac{\text{Item } 428 \times \text{Item } 463}{\text{Item } 418}$$

Item 869. B.t.u. loss due to radiation and unaccounted-for.

$$\text{Item } 443 - [\text{Item } 851 + \text{Item } 852 + \text{Item } 853 + \text{Item } 854 + \text{Item } 855 + \text{Item } 856 + \text{Item } 857 + \text{Item } 858 + \text{Item } 860]$$

Item 852. B.t.u. loss per pound of coal as fired due to moisture in the coal.

$$\frac{\text{Item 440}}{100} \times \left[(211 - \text{Item 368}) + 970.4 + 0.47 \times (\text{Item 367} - 211) \right]$$

Item 853. B.t.u. loss per pound of coal as fired due to moisture in the air.

$$\left[\frac{[\text{Item 418} \times \text{Item 449}] - [\text{Item 428} \times \text{Item 831}] - [\text{Item 422} \times \text{Item 841}] - [\text{Item 423} \times \text{Item 846}]}{\text{Item 418} \times 100} \right]$$

$$\times \left[\frac{3.032 \times \text{Item 469}}{\text{Item 468} + \text{Item 467}} \right] \times \left[0.47 \times (\text{Item 367} - \text{Item 368}) \right] \times \text{Item 435}$$

Item 854. B.t.u. loss per pound of coal as fired due to hydrogen in the coal.

$$9 \times \left[\frac{\text{Item 450}}{100} \right] \times \left[(211 - \text{Item 368}) + 970.4 + 0.47 \times (\text{Item 367} - 211) \right]$$

Item 855. B.t.u. loss per pound of coal as fired due to escaping gases.

$$\left[\frac{[\text{Item 418} \times \text{Item 449}] - [\text{Item 428} \times \text{Item 831}] - [\text{Item 422} \times \text{Item 841}] - [\text{Item 423} \times \text{Item 846}]}{\text{Item 418} \times 100} \right] \times$$

$$\left[\frac{[4 \times \text{Item 468}] + \text{Item 466} + 700}{3 \times [\text{Item 468} + \text{Item 467}]} \right] \times \left[0.24 \times [\text{Item 367} - \text{Item 368}] \right]$$

Item 856. B.t.u. loss per pound of coal as fired due to incomplete combustion.

$$\left[\frac{[\text{Item 418} \times \text{Item 449}] - [\text{Item 428} \times \text{Item 831}] - [\text{Item 422} \times \text{Item 841}] - [\text{Item 423} \times \text{Item 846}]}{\text{Item 418} \times 100} \right] \times$$

$$\left[\frac{\text{Item 467}}{\text{Item 468} + \text{Item 467}} \right] \times 10\,150$$

PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

Bulletin No. 1. Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904. *None available.*

Circular No. 1. High-Speed Tool Steels, by L. P. Breckenridge. 1905. *None available.*

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. *None available.*

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Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. *None available.*

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