

The Test Performance of Hudson Avenue's Most Recent Steam-Generating Units

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This paper presents the results of an acceptance test on one of the largest stokers in operation at the present time. The main purpose of the paper, however, is to illustrate the procedures developed for measuring those losses which are commonly allowed to appear in the unaccounted-for item of the energy balance. These losses are the hydrogen and hydrocarbon losses, and the carbon-monoxide loss which is in excess of that indicated by the conventional type of Orsat apparatus. Usually, part of the cinder loss appears in the "unaccounted-for" because it is seldom determined with the accuracy which the magnitude of this loss as determined from the method described would seem to warrant. The completeness with which the losses in the present test have been measured is evident from the low value obtained for the radiation and unaccounted-for item of the energy balance.

A high rate of combustion (75 lb per hr per sq ft) was carried for 48 hr at an efficiency of 77 per cent. The superheater produced approximately constant steam temperature over the full range of loads.

DURING the field development of stokers for high rates of combustion with the minimum loss in efficiency, complete and accurate measurement of stoker and boiler losses has been found necessary. Some of the losses which are commonly allowed to appear in the unaccounted-for item of the energy balance have been found to be greater than previously expected. Special attention has been given by the Brooklyn Edison Company, Inc., to improving the accuracy of the usual measurements, and test scopes have been broadened to include the determination of hydrogen and hydrocarbon losses. A preliminary report of this work was made at the meeting of the A.S.M.E. Fuels Division

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Contributed by the Power Division for presentation at the Annual Meeting, New York, N. Y., December 3 to 7, 1934, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

Discussion of this paper should be addressed to the Secretary, A.S.M.E., 29 West 39th Street, New York, N. Y., and will be accepted until January 10, 1935, for publication in a later issue of Transactions.

NOTE: Statements and opinions advanced in papers are to be understood as individual expressions of their authors, and not those of the Society.

in Chicago in 1931.³ The test reported in this paper represents the culmination of this work.

DESCRIPTION OF UNIT

The unit designated as No. 74 boiler was selected for test because it is equipped as the test boiler of the group. Briefly, the boiler is of the Ladd type and has 24,450 sq ft of heating surface, 3846 sq ft of furnace water walls, 5740 sq ft of superheater surface, and 22,400 sq ft of economizer surface. The furnace volume is 14,000 cu ft.

The stoker installed under the boiler is a 15-retort, 69-tuyère-length, underfeed type having a projected grate area of 694 sq ft. The wind box is equipped with zoned air control which permits hand control of the rate at which air is supplied to the various sections of the grate. One forced-draft fan of 200,000 cfm capacity and two induced-draft fans of 155,000 cfm each serve this unit. The general layout and arrangement of the equipment is shown in Fig. 1. A more detailed description of the equipment is to be found in the companion paper, "Ten Years of Stoker Development at Hudson Avenue,"⁴ by J. M. Driscoll and W. H. Sperr, and also in *Power*, May 31, 1932.

OPERATING CONDITIONS

In preparation for the test the boiler, superheater, and economizer were thoroughly cleaned and the stoker was put in prime operating condition. The setting was tested for leaks by closing the flue damper and operating the forced-draft fan while a dense smudge was produced in the furnace with titanium tetrachloride. All visible leaks were eliminated.

The fuel used was the regular station run of coal which was Pennsylvania semi-bituminous. Hot feedwater was supplied to the economizer for each run at a constant temperature corresponding to that specified in the contract.

Except for the two runs at the highest load the testing was continuous, i.e., without recess between runs. This procedure has the advantages that the testing period is reduced, and the influence on the results of possible differences in fuel-bed thickness between the beginning and end of runs is minimized. The latter holds because any difference on one run is compensated for by a corresponding difference in the opposite direction on other runs. Although the prescribed preliminary period at constant load was eliminated, the changes in load were small and required only about five minutes.

The automatic-control features on the boiler were shut off and all adjustments were made manually. The method of operation was left to the discretion of the stoker manufacturer's engineers. At all times there were one manufacturer's engineer, his assistant, and a station-stoker operator assigned to the operation of the stoker.

TEST PROCEDURE

Ten 24-hr runs were made at five loads from 170,000 to 500,000 lb of steam per hr. The first eight runs were conducted without

³ Report made to the Fuels Division by W. F. Davidson, Director of Research, Brooklyn Edison Company, Inc.

⁴ A paper which is also to be presented at the 1934 A.S.M.E. Annual Meeting.

LEGEND -

- GAS SAMPLING POINTS
- ⊠ TEMPERATURES
- AIR AND GAS PRESSURES
- △ STEAM AND WATER PRESSURES

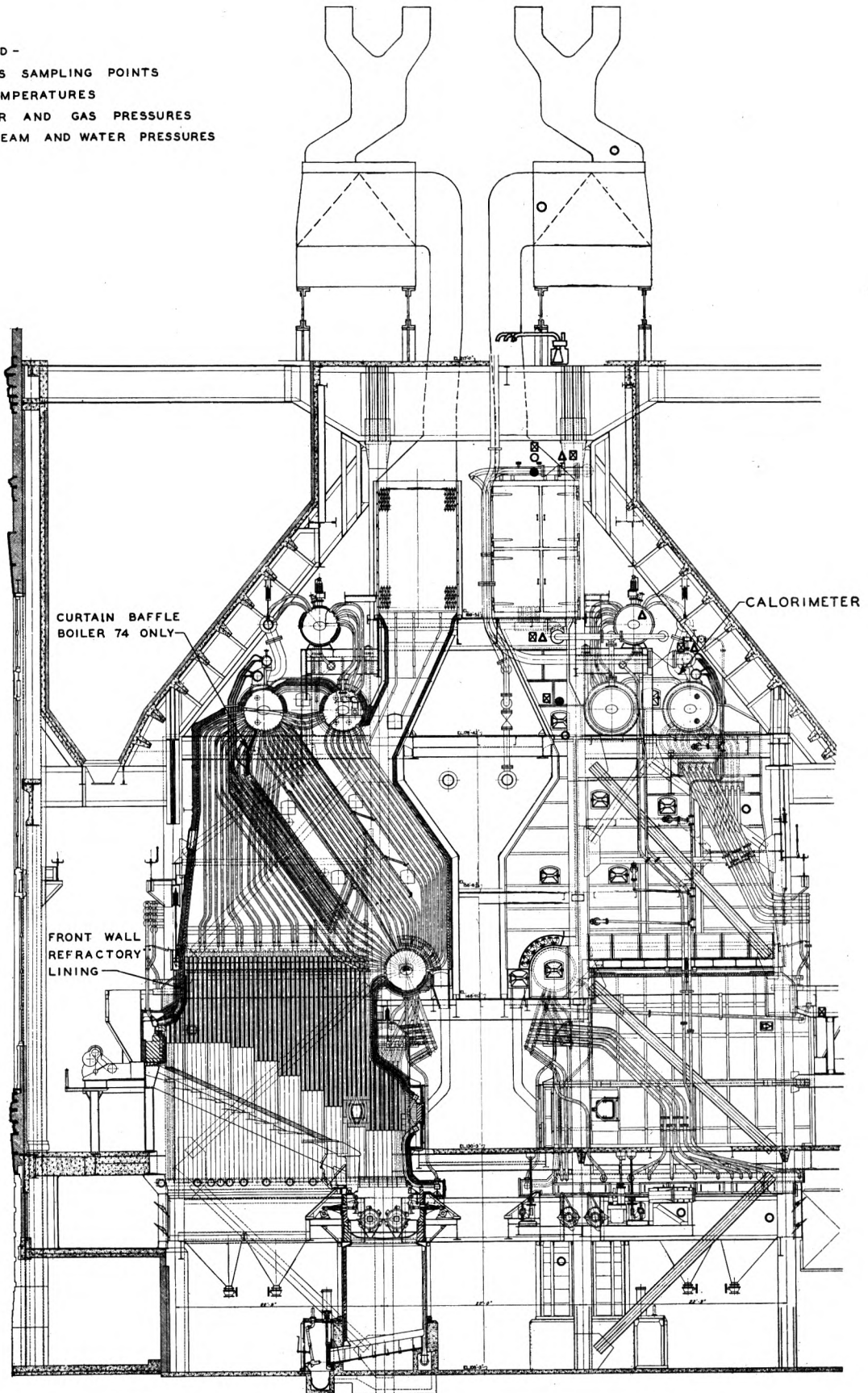


FIG. 1 STEAM-GENERATING UNIT SHOWING LOCATION OF TEST INSTRUMENTS

interruption, beginning at the lower steam flow and ascending to 400,000 lb per hr, then the same series of loads was repeated but in the reverse order. The two runs at 500,000 lb per hr were also made without interruption but not immediately following the other runs.

Feedwater. The boiler-feedwater circuit was completely isolated by means of double valves, and the feedwater flow was measured by means of the station weighing tanks. Fig. 2 is a line diagram showing this circuit. Feedwater was obtained from the boiler-feed suction header, the water having previously passed through the low-pressure stage of feed heating. After weighing, the water was returned to an isolated steam-driven boiler-feed pump in the turbine-room basement. From this feed pump the water passed through a specially isolated high-temperature regenerative heater of one of the turbine units. A load slightly in excess of that necessary was carried on this unit, while the feed temperature was regulated and maintained at the contract value for each load by means of a by-pass valve.

Fuel. The coal used during the test was weighed and supplied to the stoker hopper at regular intervals (15 to 30 min) from the station weigh lorry. After each filling a scoop of coal was taken from several sections of the hopper for chemical analysis and heat

grinding. Counters actuated from the driving ratchets on the clinker rolls served to indicate when samples should be taken. The refuse remaining in the hopper after sampling was sluiced out. After several samplings, the refuse retained (approximately 50 lb) was crushed and reduced by riffing to a laboratory-size sample. In assigning the refuse samples to their respective runs a time lag was allowed, based on the number of clinker-roll revolutions required for the refuse to pass from the top of the ash-pit through the rolls.

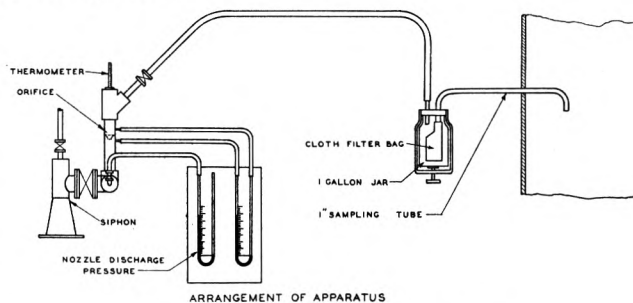


FIG. 3 CINDER-SAMPLING APPARATUS

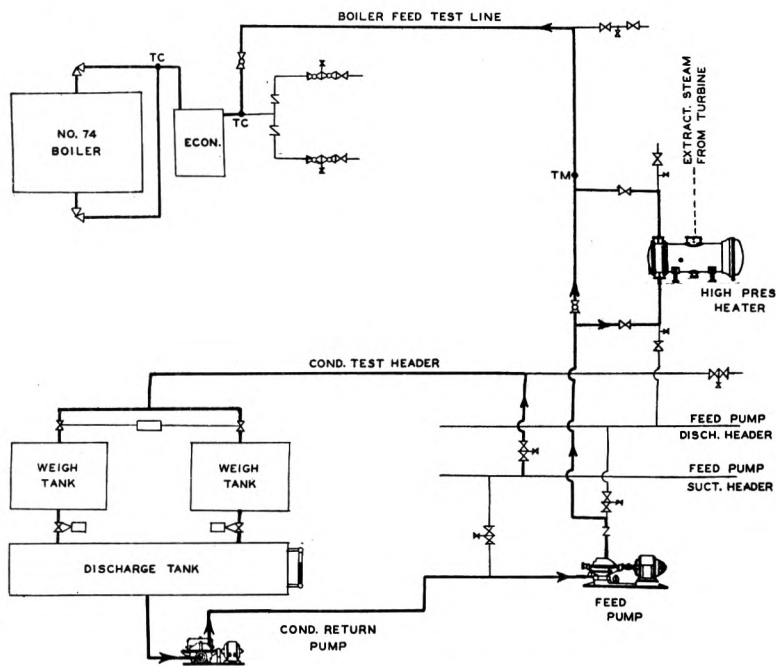


FIG. 2 DIAGRAM OF TEST-FEEDWATER CIRCUIT

value. The amount collected each time was sufficient to fill a pail (approximately 18 lb). To reduce the quantity to be saved after each collection, the coal was ground and reduced to one-tenth its original amount in a motor-driven crusher-sampler. The total amount thus collected during each of the runs was reduced to the volume of a quart fruit jar by riffing. For moisture determination, a separate and independent sample sufficient to fill a quart fruit jar was collected every hour. At the end of each four-hour period the coal in the four jars was mixed and reduced to one quart by means of a riffle. Special care was taken to make sure the moisture samples were sealed against leakage. The laboratory analysis of the coal was made in accordance with the A.S.T.M. standard procedure.

Refuse. The ash-pit refuse was sampled through three doors in the hopper under the clinker-grinder rolls at intervals such that the quantity of refuse collected was proportional to the amount of

Cinders. The lack of any standard procedure for, and difficulties encountered in measuring the cinder loss have often deprived this phase of boiler testing of the attention it should receive. The apparatus and procedure used on this test, while not new, represent the culmination of several years of experience. Much of this experience was gained in connection with dry cinder catchers where the total amount of cinders caught was weighed. These data provided a check on the sample determinations at the inlet and outlet ducts, and have demonstrated the accuracy of the method.

The cinder sampling on the present test was done in the vertical length of duct between the economizer outlet and the cinder-catcher inlet by means of 12 one-inch sampling tubes. (See Fig. 3.) The inlet ends of the tubes, which pointed against the direction of gas flow, were spotted at the centers of 12 equal areas into which the duct was divided. Each tube extended out of the duct into a large glass jar, and had attached to its end a wool filter bag. A second tube led out of each jar to a flow nozzle which discharged into a manifold connected to a steam ejector. U-tube manometers connected across the nozzle served the dual purpose of indicating

the gas flow, and of acting as a guide to the operator in maintaining a constant rate of flow.

The rate of flow for each sampler was regulated to give a velocity through the sampling-tube tip equal to the velocity in the duct at the respective points as determined by means of a pitot tube and thermocouple traverses made prior to the test. At the lower loads the samplers were kept in continuous operation except for the short time required for several changes of bags during each run. At high loads the outage time increased until at maximum load the samplers were in operation only ten minutes of each hour. The average cinder concentration (pounds of cinder per pound of gas) obtained in this manner multiplied by the total gas flow through the boiler gave the pounds of cinders leaving the boiler. The cinders collected for each run were reduced by riffing to a laboratory-size sample.

It might be noted at this point that some of the cinders pro-

duced were caught at the bottom of the third boiler pass rather than in the cinder catcher. These were then returned to the ash-put through four cinder return lines.

Gas Sampling. The flue gas was analyzed in the field using Williams' Orsat apparatus closely following accepted practise on these measurements. Samples were taken from the boiler outlet and economizer outlet through six lines equally spaced across the duct at each location. For the gas from the economizer outlet a bubbling bottle was used as a guide to regulate the flow and to

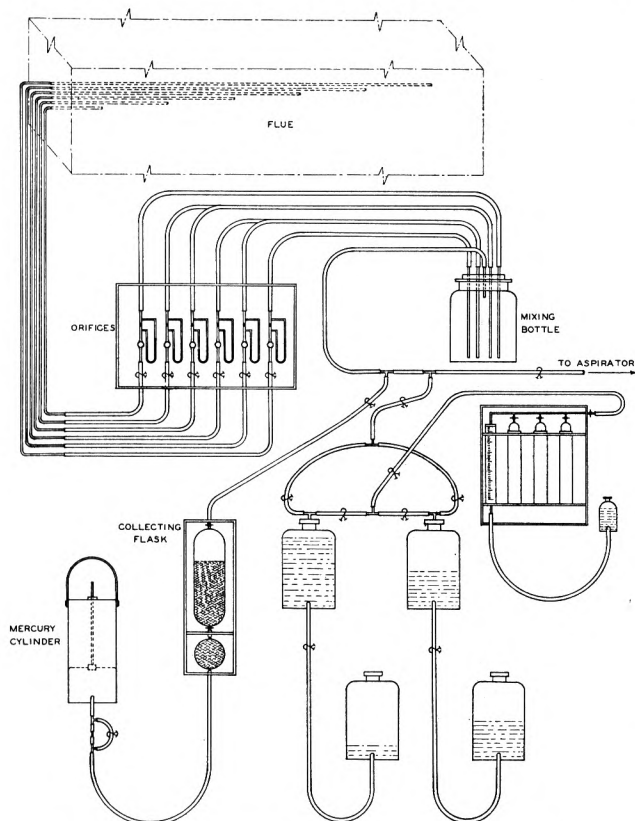


FIG. 4 GAS-SAMPLING APPARATUS AT BOILER OUTLET

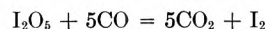
mix the gas from the six lines. An ejector maintained a continuous flow and a continuous sample was drawn by means of aspirating bottles every 15 minutes.

For sampling the gas at the boiler outlet, the same frequency and method as the foregoing were used with the following exception: Instead of using a bubbling bottle for indicating the uniformity of the gas flow from each sampling line, the gas from each passed through a glass orifice which had a U-tube manometer connected across it to indicate the flow rate. See Fig. 4. This possessed the advantage, over the use of a bubbling bottle, of freedom from solubility of the gas in water. The gas leaving all of the nozzles discharged into the bottom of a dry mixing bottle and the composite sample was drawn off at the top. Continuous gas flow was induced by an ejector. The Orsat apparatus was used in the field for analyzing these samples, but parallel samples were taken for laboratory analysis as described in the following.

Laboratory Gas Sample. The gas samples for laboratory determination were collected in 2000-cc glass flasks which were filled with mercury, then allowed to discharge at a constant rate, thereby drawing a continuous gas sample. The mercury in the glass flask was allowed to discharge into a steel leveling cylinder through a glass capillary serving as an orifice in the tube connecting flask with cylinder. The cylinder, which was suspended by

means of a differential hoist, was lowered at such a rate as to maintain a 5-in. differential across the capillary. In this manner, the gas flask and bulb below were filled with gas in four hours. Before disconnecting the flask the gas in the bulb was compressed into the flask thereby producing a slightly positive pressure which prevented contamination from leakage.

Special Gas Analysis. The laboratory determination of carbon monoxide (CO) in each sample was made separately with an iodine-pentoxide train. This was done by first passing the gas sample through a tube containing ascariite to remove CO₂ and other acidic gases, such as SO₂, H₂S, etc; then through a liquid-oxygen trap to freeze out other contaminants; then through a preheater filled with glass beads maintained at a temperature of 150 C (302 F); and finally through a tube containing iodine pentoxide (I₂O₅). The iodine liberated as indicated in the equation



was led into a flask where it was absorbed in a 10 per cent potassium-iodide solution. The amount of iodine liberated was determined by titrating the solution with sodium thiosulfate, using starch as the indicator. With the amount of iodine known, the amount of CO in the sample was computed from the foregoing equation.

A modified Burrell-Oberfell Orsat apparatus was used for the determination of hydrocarbons. The sample of gas, after introduction into the precision burette, was passed through the first pipette containing a 30 per cent solution of potassium-hydroxide to remove CO₂ and the other acidic gases. The oxygen in the sample was removed by passing it through the second pipette containing sodium hyposulphite (Na₂S₂O₄) solution. After several passes through the latter solution, the remainder of the sample was temporarily stored in this pipette while purified oxygen, stored in the third pipette, was passed over into the burette and its volume measured. The sample in the second pipette was next returned to the burette and the increase in volume read. This mixture was then passed four times over a heated platinum spiral in a combustion chamber. During this operation all combustibles, including carbon monoxide, were oxidized to carbon dioxide and water. The resulting gas was then passed back to the burette and the shrinkage due to combustion read. The CO₂ formed was determined by finally passing the gas again through the potassium-hydroxide solution. Some of this CO₂ resulted from the CO in the original sample, but since this gas was separately determined in the pentoxide train, the amount of CO₂ due to the combustion of the total hydrocarbons was found by difference. From these data the hydrogen and total hydrocarbons in the original sample were computed.⁵ While several hydrocarbons probably existed in the flue gas, their individual identity was unknown with the present technique of analysis. In this paper, the hydrocarbons have been assumed to be entirely methane gas (CH₄). The error in this assumption is not significant because the heats of combustion of all the probable constituent (gaseous) hydrocarbons per volume of CO₂ formed by combustion are nearly the same.

The dry-gas loss and gas-flow rates have been computed from the gas analysis at the boiler outlet using the laboratory analysis.

Temperatures and Pressures. All temperatures were read every 15 minutes by means of iron-constantan thermocouples all of which were connected to a single selector switch by iron-constantan leads. A compensated temperature indicator was used. The chief advantage of using thermocouples is that a single observer can take all temperature readings, and further, that the

⁵ For complete description see "Modified Flue-Gas Analysis," by Dr. R. N. Evans, to be published in *Journal of Industrial and Engineering Chemistry*.

TABLE 1 SUMMARY OF DATA AND RESULTS

Item	1	2	3	4	5	6	7	8	9	10
1 Run No.										
2 Date, 1934	4-2	4-3	4-4	4-5	4-6	4-7	4-8	4-9	4-25	4-26
3 Duration of run, hr.	24	24	24	24	24	24	24	24	24	24
<i>Load</i>										
4 Energy output, million Btu per hr.	207.0	277.0	364.8	454.3	460.3	372.0	279.8	202.8	566.0	567.2
5 Steam generated, thousand lb per hr.	174.4	237.3	318.1	399.1	405.8	324.5	240.3	171.9	501.3	504.2
6 Coal fired, thousand lb per hr.	16.50	22.61	31.76	38.92	38.87	30.69	22.68	16.32	52.83	52.24
<i>Fuel, Proximate Analysis (as Fired)</i>										
7 Volatile matter, per cent.	18.7	18.4	16.9	15.6	16.2	15.8	16.2	16.3	20.6	21.2
8 Fixed carbon, per cent.	70.4	71.3	72.2	73.7	73.9	74.4	73.7	73.6	69.1	68.4
9 Ash, per cent.	7.6	6.6	7.2	7.7	6.8	6.6	7.0	7.0	6.9	6.9
10 Moisture, per cent.	3.3	3.7	3.7	3.0	3.1	3.2	3.1	3.1	3.4	3.5
11 Heating value, Btu per lb.	13940	14060	13920	13990	14050	14120	14050	14020	14060	14000
<i>Fuel, Ultimate Analysis (as Fired)</i>										
12 Carbon, per cent.	78.7	79.8	79.3	79.7	79.8	80.6	79.5	80.2	80.6	80.0
13 Hydrogen, per cent.	4.3	4.2	4.0	4.1	4.0	4.2	4.2	4.2	3.9	4.0
14 Oxygen, per cent.	3.6	3.4	3.3	2.9	3.8	2.9	3.9	3.2	2.7	2.8
15 Nitrogen, per cent.	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
16 Sulphur, per cent.	1.2	1.0	1.2	1.3	1.2	1.2	1.0	1.0	1.2	1.5
<i>Flue Gas, Boiler Outlet</i>										
17 CO ₂ , per cent.	14.8	15.0	14.9	14.5	14.8	14.5	14.4	14.5	14.6	15.1
18 O ₂ , per cent.	3.7	3.4	3.6	4.0	3.7	4.0	4.1	4.0	3.8	3.4
19 CO, per cent.	0.05	0.20	0.13	0.09	0.05	0.03	0.05	0.08	0.12	0.26
20 H ₂ , per cent.	0.03	0.03	0.04	0.03	0	0	0.05	0.04	0.04	0.06
21 Hydrocarbons, per cent.	0.09	0.21	0.04	0.03	0.07	0.06	0.07	0.07	0.07	0.02
22 N ₂ , per cent.	81.3	81.2	81.3	81.4	81.4	81.4	81.3	81.3	81.4	81.2
23 Dry gas, lb per lb coal	13.3	13.0	12.9	13.3	13.0	13.8	13.8	13.9	12.5	11.9
24 Wet gas, lb per lb coal	13.8	13.5	13.4	13.8	13.5	14.3	14.2	14.3	12.9	12.3
25 Dry air, lb per lb coal	13.0	12.7	12.6	13.0	12.7	13.5	13.4	13.5	12.2	11.6
26 Dry air required for ideal combustion, lb per lb coal	10.4	10.5	10.4	10.5	10.4	10.7	10.5	10.6	10.6	10.5
27 Dilution coefficient	1.24	1.20	1.21	1.23	1.22	1.26	1.28	1.28	1.16	1.10
<i>Flue Gas, Economizer Outlet</i>										
28 CO ₂ , per cent.	14.4	14.7	14.5	14.5	14.8	14.7	14.6	14.8	14.3	14.5
29 O ₂ , per cent.	3.6	3.2	3.4	3.6	3.5	3.8	3.8	3.6	4.3	4.0
30 CO, per cent.	0.05	0.08	0.04	0.03	0.03	0.02	0.04	0.07	0.04	0.06
31 N ₂ , per cent.	82.0	82.0	82.1	81.9	81.7	81.5	81.6	81.5	81.4	81.4
<i>Pressures and Drafts</i>										
32 Moisture in steam leaving drum, per cent.	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7
33 Steam pressure in drum, lb per sq in. abs.	426	430	436	447	447	438	429	422	466	466
34 Steam pressure of superheater outlet, lb per sq in. abs.	421	422	425	428	428	426	423	420	431	431
35 Pressure drop in superheater, lb per sq in.	5	8	11	19	19	12	6	2	35	35
36 Pressure drop in economizer, lb per sq in.	13	19	31	45	45	30	17	10	66	68
37 Air pressure in stoker plenum, in water	1.8	3.0	3.5	4.4	4.2	3.6	3.1	1.6	5.7	6.0
38 Air pressure under extension grate, in water	0.7	1.4	1.8	2.7	2.3	2.2	2.0	1.4	3.4	3.5
39 Air pressure under ashpit, in water	0.3	0.5	1.0	1.9	1.2	0.9	0.7	0.4	1.7	1.4
40 Draft in furnace, in water	0.10	0.11	0.30	0.53	0.59	0.24	0.19	0.07	0.88	1.03
41 Draft at boiler outlet, in water	0.7	1.4	2.9	4.7	4.7	2.7	1.3	0.6	7.9	7.8
42 Draft at economizer outlet, in water	1.1	2.0	4.3	7.1	7.1	4.3	2.1	0.9	11.9	11.7
43 Draft at cinder catcher outlet, in water	1.2	2.2	4.8	7.9	7.9	4.8	2.3	1.0	14.3	14.3
<i>Temperatures</i>										
44 Air temperature, F.	64	58	52	53	50	54	55	60	55	60
45 Relative humidity of air, per cent.	46	48	53	40	46	53	42	51	48	53
46 Coal temperature, F.	66	63	70	76	76	83	80	94	73	70
47 Flue-gas temperature at boiler outlet, F.	594	657	713	768	767	728	668	613	817	812
48 Flue-gas temperature at economizer outlet, F.	274	317	358	389	386	360	323	287	425	421
49 Feedwater temperature entering economizer, F.	212	232	249	263	263	253	232	212	273	274
50 Feedwater temperature leaving economizer, F.	318	345	366	386	384	371	348	321	399	399
51 Steam temperature at superheater outlet, F.	711	711	706	716	708	714	706	697	719	712
<i>Refuse and Cinders</i>										
52 Combustible in ashpit refuse, per cent.	0.6	5.0	10.2	4.8	3.9	4.2	4.0	2.3	3.4	3.7
53 Cinder concentration, lb cinders per thousand lb dry gas	0.59	1.25	2.37	3.15	3.20	1.40	0.85	0.45	7.63	8.32
54 Cinders per thousand lb of coal, lb.	7.8	16.3	30.6	41.9	41.8	19.3	11.7	6.2	95.4	98.9
55 Combustible in cinders, per cent.	35.7	43.6	54.6	64.0	67.3	53.0	44.1	37.9	79.0	80.9
56 Heating value of cinders, Btu per lb.	4990	6090	7750	9140	9730	7550	5960	5120	11520	11710
57 Carbon burned, lb per lb of coal	0.779	0.777	0.766	0.765	0.764	0.790	0.783	0.794	0.725	0.716
<i>Unit Quantities</i>										
58 Rate of combustion, lb coal per hr per sq ft of grate area	23.8	32.6	45.8	56.1	56.0	44.2	32.7	23.5	76.2	75.3
59 Rate of energy development in furnace, thousand Btu per hr per cu ft.	16.2	21.7	30.4	37.4	37.4	30.3	22.3	16.2	48.0	47.2
60 Steam-fuel ratio	10.6	10.5	10.0	10.3	10.4	10.6	10.6	10.5	9.5	9.7
61 Rate of steam generation, lb per hr per sq ft of boiler surface ¹	7.1	9.7	13.0	16.3	16.6	13.3	9.8	7.0	20.5	20.6
62 Rate of energy transfer, Btu per hr per sq ft of boiler surface ¹	6490	8560	11180	13680	13950	11330	8630	6380	16930	17010
63 Rate of energy transfer, Btu per hr per sq ft of superheater surface	5120	6970	9230	11920	11830	9640	6970	4810	15070	14830
64 Rate of energy transfer, Btu per hr per sq ft of economizer surface	840	1230	1710	2290	2290	1770	1280	850	2920	2960
65 Increase in enthalpy in steam-generating unit, Btu per lb.	1187.0	1167.4	1146.7	1138.3	1134.3	1146.5	1164.3	1179.5	1129.1	1125.0
<i>Efficiency and Energy Balance</i>										
66 Efficiency of steam-generating unit, per cent.	90.0	87.1	82.5	83.4	84.3	85.9	87.8	88.6	76.2	77.5
67 Energy loss due to moisture in air, per cent.	0.1	0.1	0.1	0	0	0.1	0	0.1	0.1	0.1
68 Energy loss due to moisture in coal, per cent.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.3
69 Energy loss due to moisture formed by burning of H ₂ , per cent.	3.0	2.9	3.0	3.1	3.0	3.1	3.0	2.9	2.9	3.1
70 Energy loss due to incomplete combustion of carbon (CO), per cent.	0.2	0.7	0.5	0.3	0.2	0.1	0.2	0.3	0.4	0.9
71 Energy loss due to unburned hydrogen, per cent.	0.1	0.1	0.2	0.1	0	0	0.2	0.2	0.1	0.2
72 Energy loss due to unburned hydrocarbons, per cent.	1.1	2.4	0.5	0.4	0.8	0.7	0.9	0.9	0.8	0.2
73 Energy loss due to combustible in ashpit refuse, per cent.	0	0.4	0.8	0.4	0.3	0.3	0.3	0.2	0.3	0.3
74 Energy loss due to combustible in cinders, per cent.	0.3	0.7	1.7	2.7	2.9	1.0	0.5	0.2	7.8	8.3
75 Energy loss due to dry gas, per cent.	4.9	5.9	6.9	7.9	7.6	7.3	6.4	5.5	8.1	7.6
76 Energy loss due to radiation, and unaccounted for, per cent.	0	-0.6	3.5	1.4	0.6	1.2	0.4	0.9	3.0	1.5
<i>Power Consumption of Auxiliaries</i>										
77 Stoker and clinker grinder, kw.	10	12	13	14	14	12	11	9	19	19
78 Forced-draft fan, kw.	188	203	281	297	297	288	228	210	331	338
79 Induced-draft fans, kw.	33	78	284	408	399	313	101	37	926	928
80 Total, kw.	231	293	578	719	710	613	340	256	1276	1285

¹ Water-wall surface not included.

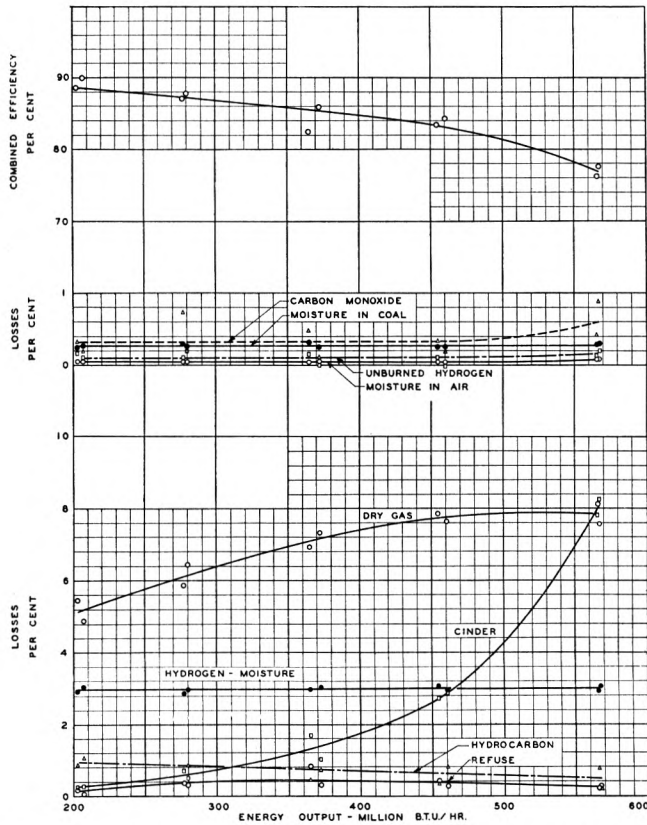


FIG. 5 TEST-PERFORMANCE CURVES, EFFICIENCY AND ENERGY BALANCE

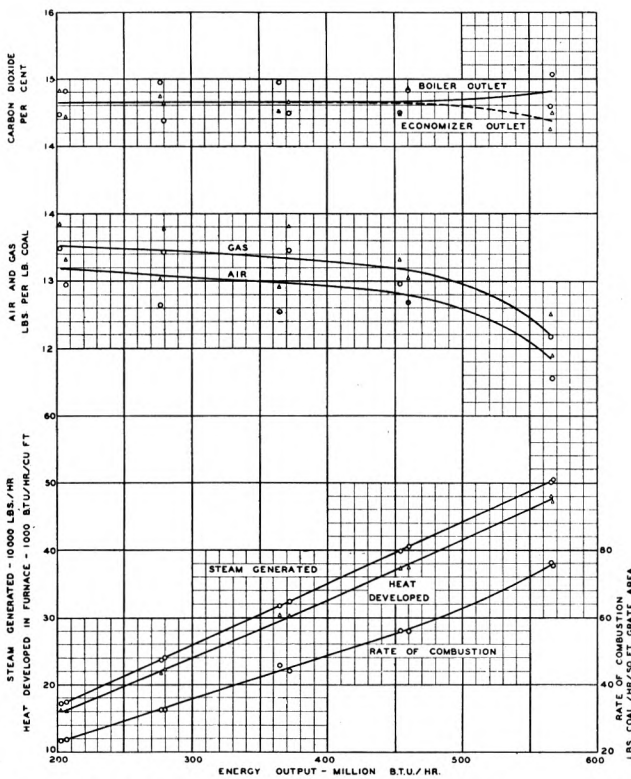


FIG. 6 TEST-PERFORMANCE CURVES, COAL, STEAM, AND AIR QUANTITIES

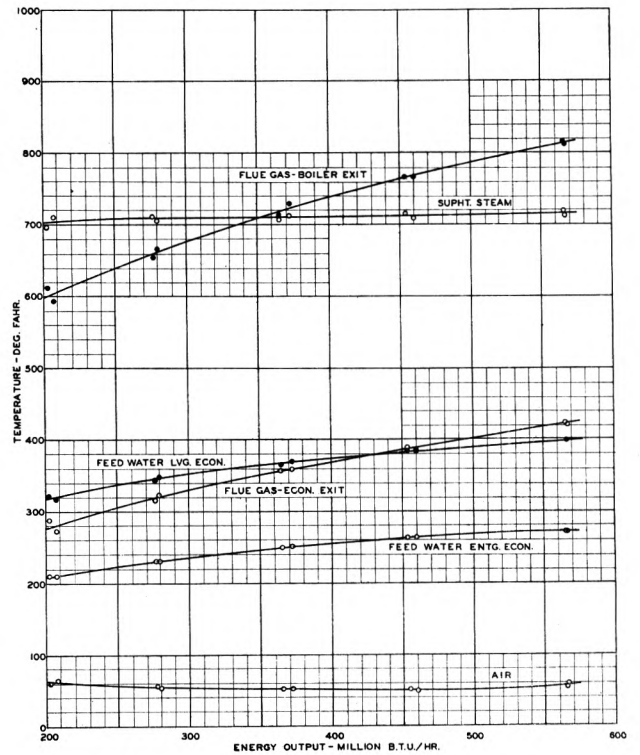


FIG. 7 TEST-PERFORMANCE CURVES, TEMPERATURES

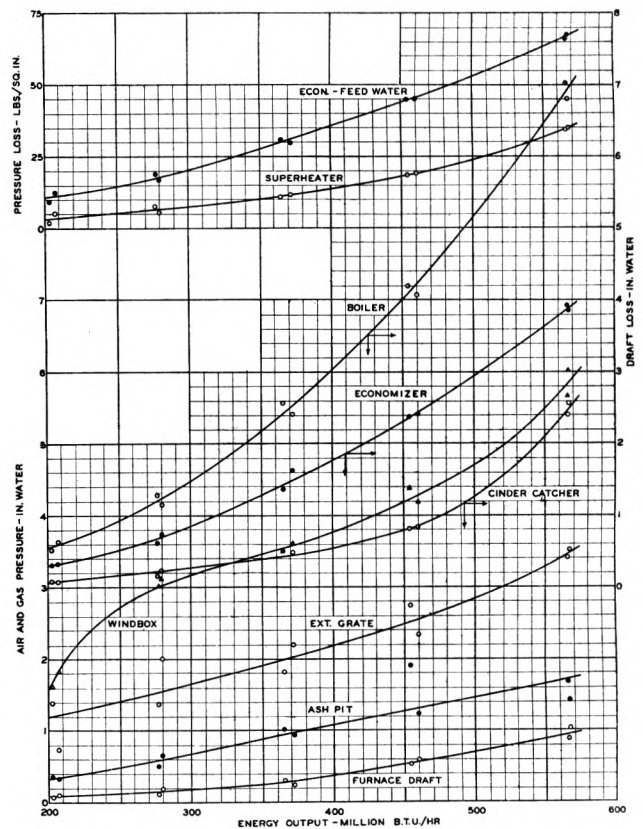


FIG. 8 TEST-PERFORMANCE CURVES, PRESSURES AND DRAFTS

indicator can be located where working conditions are conducive to careful readings.

Independent pressure and draft gages rather than the station instruments were observed during the test. Duplicate gages, one on each side of the boiler, were provided for all readings which were observed every 15 minutes.

Calibrations. Weigh tanks, coal lorry, and all pressure gages and thermocouples were calibrated and corrections applied to the data reported.

TEST DATA AND RESULTS

The principal test data and computed results are given in Table 1, and are also shown in curve form plotted against output in Figs. 5, 6, 7, and 8.

The completeness with which the losses have been measured is evident from the energy balance. The radiation and "un-accounted-for," while varying for the different runs, is consistently low. The zero value for the first run and negative value for the second run followed by the high value for run 3 seems to indicate a reduction of fuel-bed thickness during the first two runs which was restored to normal on run 3. The foregoing is further substantiated by the high efficiency obtained on run 2 even though the carbon monoxide and hydrocarbon losses were considerably above the average.

With the exception of run 3 the efficiencies obtained are quite consistent giving a gradually dropping curve when plotted against output as shown in Fig. 5. The dry-gas and cinder losses are the only two which vary appreciably with load, and are the ones that cause the reduction of efficiency with increase in load. At the maximum load during test (565 million Btu per hr), these two losses were approximately equal. Small increase in load, however, would be required for the cinder loss to exceed the sum of all the other losses, yet no procedure for this measurement is included in the 1930 edition of the A.S.M.E. Power Test Code for Stationary Steam-Generating Units.

While the unburned hydrogen loss was consistently negligible on this test, the hydrocarbon loss was sufficiently large on all runs to justify its measurement. The maximum average value of the hydrocarbon loss was 2.4 per cent for run 2.

The gas data reported for the boiler outlet are based on laboratory analysis and those for the economizer outlet on Orsat analy-

sis. The percentages of CO by field Orsat apparatus at the boiler outlet are not reported but since they were the same as the values measured at the economizer outlet, the later values can be used in comparing the difference between the field and laboratory measurements for CO. The difference between laboratory and field analyses is not appreciable except on a few of the runs where the true values of CO were in excess of one-tenth of one per cent by volume. Based on this test one might reasonably conclude that the use of an iodine-pentoxide train is not justifiable. On the other hand previous tests have shown the reverse to be true. Since cuprous chloride is noted for its unreliability as an absorbent for CO and other substitute absorbents have been found equally unreliable, the iodine-pentoxide method for CO determination should be included as a check on the Orsat determinations.

From Fig. 7 it can be seen that a nearly constant steam temperature was obtained over the full range of test loads.

It seems worthy of note that an output of a half-million pounds of steam per hour at an efficiency of 77 per cent could be maintained by this unit, as it was, for 48 hours. At the end of this period the fire was still in good condition. Apparently, once a good start has been made this load can be maintained for even longer periods.

The efficiencies reported are gross, not net, in that auxiliary power has not been deducted. The auxiliary energy consumed, based on the coal which was required for its generation, varies from 1.3 per cent at the lowest test load to 2.3 per cent at the higher test load.

ACKNOWLEDGMENTS

The authors desire to acknowledge the assistance of K. W. Bondurant in supervising the third shift and computing the results, and of W. J. Roberts in keeping the field log and computing results. Coal, cinder, and refuse analyses were made under the direction of J. W. Snyder of the Station Efficiency Bureau. The laboratory gas analyses were made under the direction of Dr. R. N. Evans of the Research Bureau using apparatus specially adapted by him for this purpose.

The authors also wish to acknowledge the cooperation of the field engineers of the following interested companies, the American Engineering Company, the Combustion Engineering Company, Inc., and the Superheater Company.