Characteristics of Large Hell Gate Direct-Fired Boiler Units

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Among the outstanding features which characterize this boiler installation is a capacity of each of the two units in excess of 1,000,000 lb per hr. The direct-fired, slag-tapped furnace with a twin arrangement of sectional header boilers above a single furnace is an innovation. The building that houses the two boilers, bunkers, and all auxiliaries is 78.7 ft by 106.5 ft and is 162 ft high, or a building volume of 680 cu ft per 1000 lb steaming capacity per hour. The steam conditions of 275 lb per sq in. pressure and 725 F temperature are the same as those prevailing in the remainder of the plant. The circulation of each half of the boiler unit, with its accompanying proportion of water walls, is independent. The superheater, economizer, and air heater of each half of the unit are also independent. The air-inlet end of the air heaters and similarly the gas-discharge end of the air heaters are connected to a common plenum chamber to eliminate the fan auxiliaries as a source of boiler outage. By this arrangement the unit may develop about 75 per cent of maximum capacity with half of the fan equipment idle. Aside from innovations regarding the twin arrangement, the boiler and furnace are of conservative design. Heat-release rates, absorption rate per unit of surface, and gas velocities entering the tube bank are moderate. Large boiler drums were provided in order to confine water-level fluctuations within safe limits regardless of the rapidity or range of load changes. The visible range within the water glass accommodates a 13 per cent change in the volume of water contained in the boiler and water walls up to the normal water level. This is equivalent to 4.5 per cent of the hourly output at maximum capacity on the basis of solid water.

THIS boiler installation at Hell Gate Station was erected as a boiler-room extension on land which was limited in area by existing structures and a street boundary. This limitation in area necessitated a design which would utilize the site to the greatest advantage without exceeding the height limit imposed by the city building code. The quantity of steam necessary to satisfy the installed turbine capacity was greater than could be produced by the boiler-plant extension. This consideration rendered necessary an installation capable of developing the maximum rational capacity in the available space in order to reduce the extent of revamping of the older boilers which otherwise would be necessary. As a railroad siding which enters the turbine-room basement passes across one side of the chosen site, it was necessary to arrange the design to accommodate this sidetrack below the boiler level.

Among the outstanding features which characterize this installation consisting of two units is a capacity of each unit in excess of 1,000,000 lb per hr. Direct-fired, slag-tapped furnaces with a twin arrangement of sectional header boilers above the common furnace is somewhat of an innovation. The furnace is the largest so far installed, and this is the first application of sectional header boilers with the twin-setting or end-to-end arrangement.

The building is 78.7 ft by 106.5 ft and is 162 ft high, housing two units, and the ratio of building volume to boiler capacity is 680 cu ft per 1000 lb steaming capacity per hour. Correcting the building volume for the space devoted to railroad tracks and court entry, the ratio becomes 636 cu ft per 1000 lb per hr capacity.

With the limited space conditions, the flat-bottom slagging type of furnace became almost a necessity. In the absence of space for an ash hopper of the dry-bottom type, careful thought was given to the slagging furnace for the grades of coal and type of load to be encountered. Earlier problems with slagging furnaces at Sherman Creek Station had been experienced, and this pioneering work left little doubt as to the attractive possibilities of the system.

The four mills and their auxiliaries are directly below each furnace, while the forced- and induced-draft fans are immediately above the air heaters. The coal bunkers are below the fan platform, from which coal is fed by gravity through vertical chutes to the mill feeders. Each chute supplies one mill and is provided with a Richardson automatic scale ahead of the feeder, with remote indication at the control board. These scales facilitate accounting and control, as well as testing. There are two drag-conveyer feeders per mill located on the operating floor and accessible from the control board. The feeders are driven by direct-current motors from motor-generator sets with Ward Leonard speed control.

Boilers

The steam conditions, 275 lb per sq in. pressure and 725 F temperature, are the same as those in the remainder of the plant.

With the end-to-end arrangement of boilers over the common furnace, access space was necessary between the headers, and a seal had to be provided between the furnace and this opening. This was accomplished by bringing the bottom slag-screen tubes under the bottom of the high-end headers and entering the op-

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posite side of the header by a wide-sweep return bend in the tube. This arrangement provides a water-cooled support for the protecting tile beneath the headers and also the baffle between header access space and furnace. The circulation of the two boilers is not interconnected, and each supplies its half of the furnace water walls, so that the circulation of each half of the units is entirely independent. The superheater, economizer, and air heater of each half of the unit are also independent, although the discharge end of the air heaters is connected to a common plenum chamber. This common-plenum-chamber arrangement renders the installation more independent of induced-draft fan outage, since the unit may develop about 75 per cent capacity with half of the fan equipment idle. The same general practise is applied to the forced-draft connection to obtain the same benefits of diversity and availability. This combination was obtained by a slight inclination of the air preheaters and by the elimination of separating partitions.

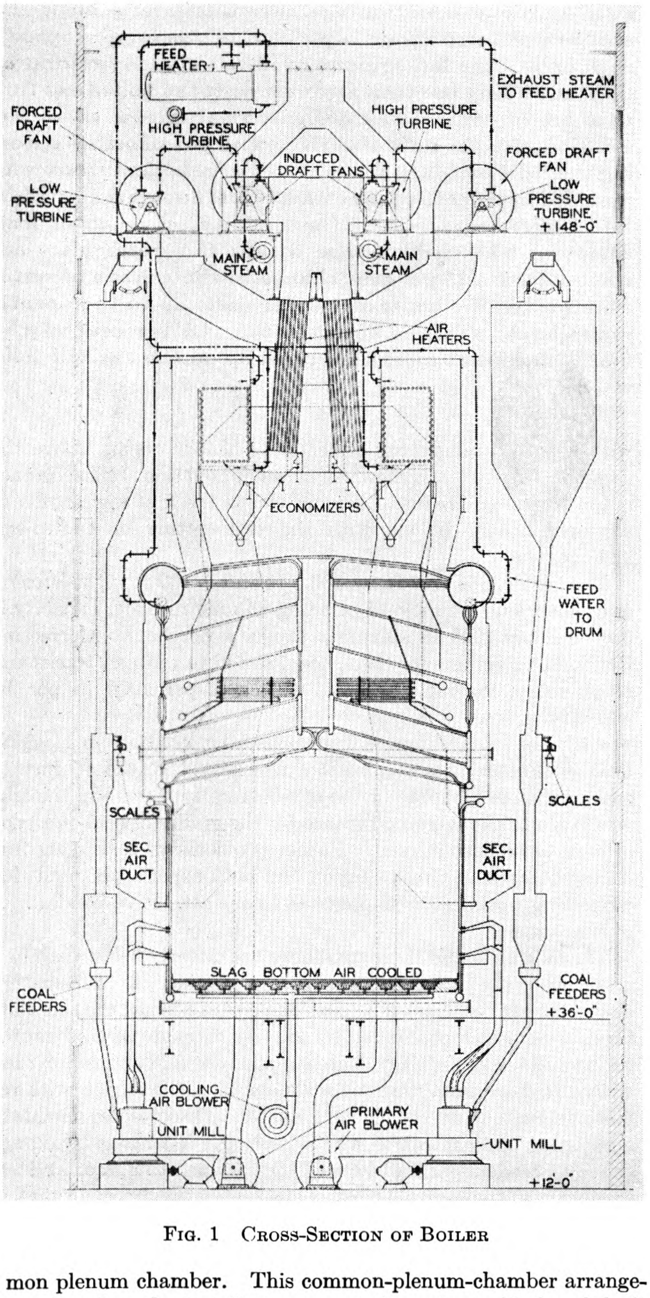

Fig. 1 Cross-Section of Boiler

Aside from innovations regarding the twin arrangement, the boiler and furnace are of conservative design. Heat-release rates, absorption rate per unit of surface, and gas velocities entering the tube bank are moderate. The water capacity of the boiler and economizer is rather large, and while the resulting accumulator effect renders the unit somewhat slow in response to changes of rating, it has a very desirable stabilizing influence with fluctuating loads. The 72-in. boiler drums are adequate to permit wide changes in rating without danger of carry-over from the drum. Large drum capacity is especially important with the moderate pressure and relatively high specific steam volumes prevailing, in order to accommodate the swelling contents of the boiler with wide increase in rating. This removes one of the possible limitations to flexibility and responsiveness, since water-level fluctuations are confined within safe limits regardless of the rapidity and range of load changes. With adequate drum capacity, the feed-control problem is simplified and the attention required by the operators is reduced to a minimum.

The visible range within the water glass accommodates a 13 per cent change in the volume of water contained in the boiler and water walls up to the normal water level. This is equivalent to 4.5 per cent of the hourly output at maximum capacity, on the basis of solid water.

The boilers are provided with three horizontal circulator tubes per section, arranged to minimize discharge friction and insuring an effective hydraulic head on all tubes. This lessens the likelihood of stagnant circulation, with the accompanying problems, and is of benefit from the standpoint of boiler maintenance and availability. The boiler drum is fitted with shutter-type baffles for moisture separation. Saturated steam is distributed to the superheater by means of a number of off-take tubes distributed along the length of the boiler drum and connected with the saturated-steam header on the superheater. This arrangement assures uniform steam distribution through the superheater, with a minimum of pressure drop. The economizer is of the conventional hairpin type, while the air heater is the standard tubular type, both being arranged for countercurrent flow.

Burners and Furnaces

Each mill delivers to three cross-tube burners in a horizontal row, distributed across the furnace width, there being two rows at each end of the furnace, one above the other. This provides well-balanced furnace conditions with almost any combination of mills. Individual burners may be cut out by closing a valve in the top of the mill, which diverts the coal and primary air from that burner to the remaining outlets and burners. There is an oil burner just below each coal burner, for ignition purposes only. The Bailey water-cooled furnaces are, roughly, 41 ft long between burners, with a width of 34 ft and a mean height of 30 ft. The furnace volume is 40,770 cu ft, giving a heat liberation of about 35,000 Btu per cu ft, at 1,000,000 lb per hr evaporation.

The furnace bottom is provided with air cooling by forced circulation from a centrifugal compressor delivering air at about 1 lb pressure. Immediately below the slag bed is an impervious layer of crushed magnesite supported on a porous layer of chrome ore. The cooling air is distributed by transverse ducts in the layer of chrome ore, from which it is discharged into the furnace at the side walls above the slag bed. The quantity of air used for cooling is determined from the Bailey air-flow meters which form a part of the regular operating equipment.

The preheated-air temperature being moderate, permits normal operation without the use of tempering air and the attendant manipulation required where higher preheat is used. With a direct-fired system there are many adjustments which must be readily coordinated, and in the interest of reliability these were kept to the minimum.

Fans

There are four induced-draft fans per boiler unit and two forced-draft fans. The induced-draft fans are connected in pairs and driven through reduction gears by a high-pressure, high-speed turbine, the exhaust steam from which is used to operate the low-pressure turbine driving the forced-draft fan.

Local conditions of plant expansion constituted a factor in the selection of fan drives. With the existing conditions evaluated, the differences between various types of drives were small, and the turbine drives were chosen for convenience. The exhaust steam from the low-pressure turbines which drive the forced-draft fans is discharged through short con-

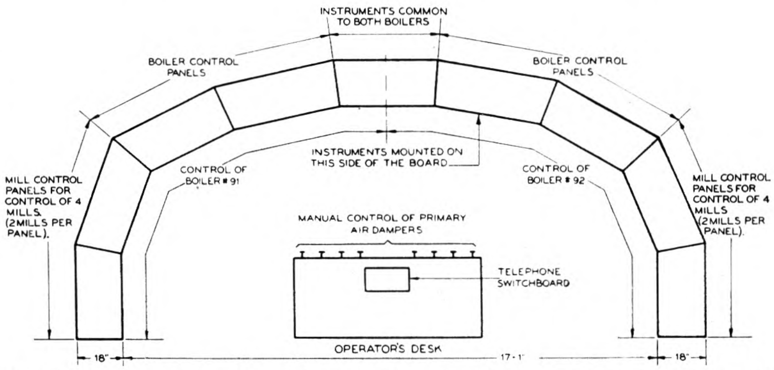

Fig. 5 Diagrammatic Plan View of Control Board for Boilers 91 and 92

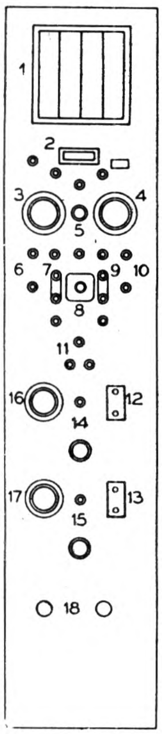

Fig. 3

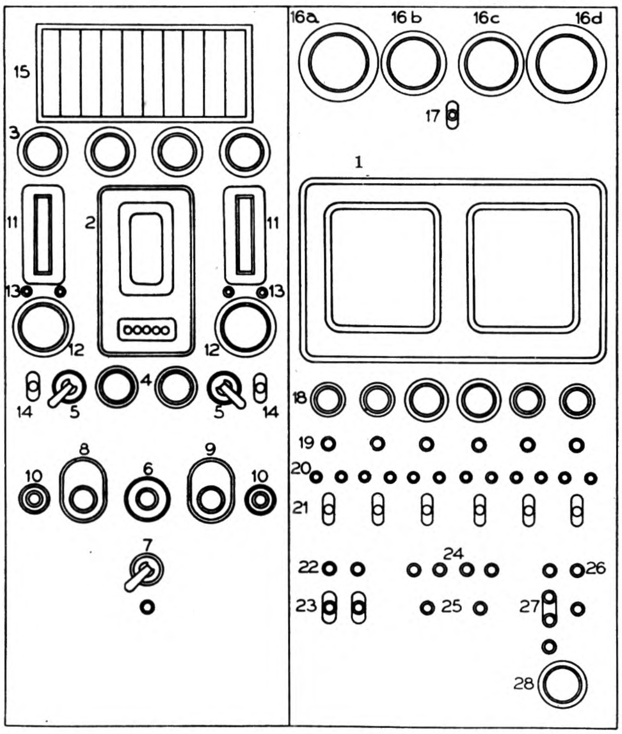

Fig. 2

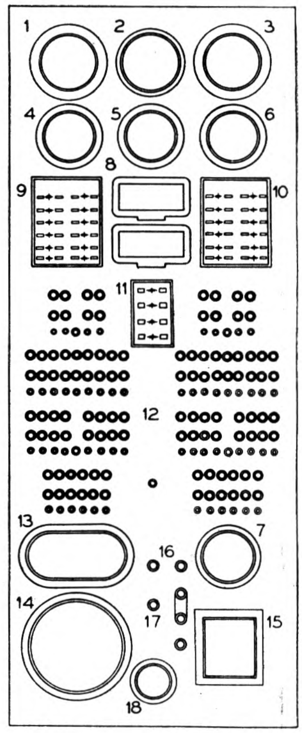

Fig. 4

Figs. 2, 3, and 4 Control Boards for the 90-Row Boilers, the Mills, and the Instruments

[Fig. 2. Section of the Control Board Showing Control for Each Boiler. Legend: 1, Bailey steam-flow–air-flow meter. 2, Smoot control panel (individual boiler control). 3, air- and oil-line pressure gages. 4, control air-pressure gages. 5, transfer cocks (from manual to pressure control), two valves. 6, control wheel (manual control). 7, transfer valve (coal-feed safety device). 8, maximum-rating-limit valve. 9, minimum-rating-limit valve. 10, control air-supply valve, two valves. (Nos. 2 to 10 are in the Smoot control.) 11, drum-water-level indicator. 12, feedwater-valve position indicator. 13, indicating lights for feedwater valve. 14, switch controlling feedwater valve. (There are two sets of 11, 12, 13, and 14 for each boiler.) 15, draft gages, 10 points (boiler, economizer, air heater). 16, pressure gages: (a) drum pressure, west drum. (b) and (c) receiver pressure. (Pressure in receivers of two sets of compound steam turbines driving forced- and induced-draft fans.) (d) drum pressure, east drum. 17, emergency trip switch for coal feeders, mills, and mill blowers. 18, tachometers (four for fan turbines), voltmeters (two for Ward Leonard coal-feeder control). 19, transfer switches (four for fan turbines, two for coal feeders) from hand to automatic control. 20, regulator position indicating lights for use when changing from hand to automatic control (in connection with 19). 21, push-pull switches for hand control of fan turbines and coal feeders (four for fan turbines, two for Ward Leonard coal-feeder control). 22, damper control, position-indicating light (damper between economizer and air heater). 23, damper control, switch. (There are two sets of 22 and 23 per boiler.) 24, lights indicating the functioning of an alarm for failure of Ward Leonard motor-generator sets (two sets for two boilers). 25, switches for controlling bell alarm for failure of Ward Leonard motor-generator sets (two sets for two boilers). 26, indicating lights. 27, switch. 28, ammeter. (Instruments 26, 27, and 28 are for control of furnace-bottom cooling blower.)

Fig. 3 Section of the Control Board Showing Control for Each of the Four Mills for Each Boiler. Legend: 1, air suction, pressure, and differential gages, four points (for mill blower and mill). 2, coal-scale counter. 3, mill-motor ammeter. 4, mill-blower-motor ammeter. 5, sequence cut-out switch and indicating light (mill, blower, and feeder). 6, mill-motor alarm-signal switch and indicating light. 7, mill-motor control switch and indicating lights. 8, coal-scale switch and indicating light. 9, mill-blower-motor control switch and indicating lights. 10, mill-blower-motor alarm-signal switch and indicating light. 11, coal-flow indicating lights. 12 and 13, mill-feeder-motor-control switches (two feeders per mill). 14 and 15, mill-feeder-motor rheostats (two feeders per mill). 16 and 17, mill-feeder-motor tachometers (two feeders per mill). 18, line switches for mill-feeder-motor power supply, from Ward Leonard generators (two feeders per mill).

Fig. 4 Section of the Control Board Showing Instruments Common to Both Boilers. Legend: 1, pressure gage, steam-line pressure. 2, Telechron clock. 3, pressure gage, feedwater-line pressure. 4, pressure gage, suction head on heater condensate pump. 5, load indicator, total station load. 6, pressure gage steam pressure in feedwater heater. 7, pressure gage, fuel-oil pressure. 8, temperature indicators, two indicators, one for low-temperature range and one for high-temperature range, on boilers 91 and 92. 9, switches for temperature indicators, boiler 91. 10, switches for temperature indicators, boiler 92. 11, switches for temperature indicators, common to both boilers. 12, signal lights, signal sending and receiving stations to and from mills, mill blowers, and fans (left side, boiler 91; right side, boiler 92). 13, belt-coal-scale indicating counter, one for main belt conveyer serving both boilers. 14, water-flow-meter indicator. 15, water-flow-meter integrator. (Instruments 14 and 15 are for both boilers.) 16, indicating lights. 17, switch. 18, ammeter. (Instruments 16, 17, and 18 are for control of furnace-bottom cooling blower, a spare blower serving either of the two boilers.)]

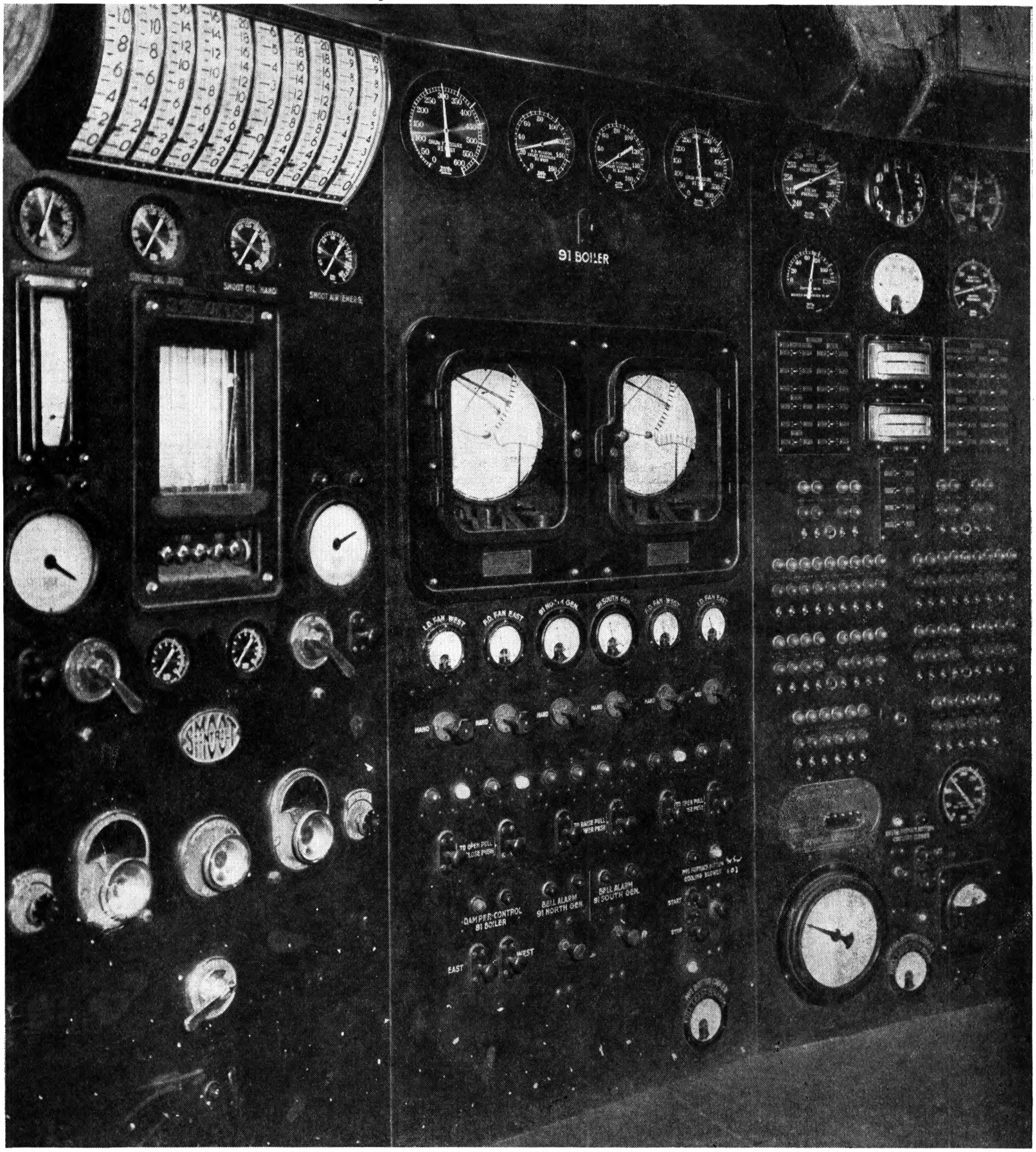

Fig. 6 Part of Boiler Control Board

necting piping to a closed heater in the feedwater supply to the boilers.

Control

Control of this installation has been brought to a central location, with the necessary instruments and devices provided so that operation is greatly simplified. The control board is illustrated in Figs. 2 to 7, inclusive. Practically all adjustments for starting, stopping, and changing the output are made from this control station. Sequence interlock relay protection is provided to guard against flarebacks or explosions due to mechanism failures or mishandling.

The installation is fitted with the same type of control mechanism as that on the earlier boilers and is designed to operate in conjunction with the other apparatus. Control may be changed from automatic to hand, or vice versa, at will. The importance of the control board is more apparent when the operations that must be closely coordinated in starting are considered. Figs. 8

and 9 depict graphically the sequence of operations followed in starting the boiler from the cold condition and also the method followed after a normal shutdown over the midnight watch.

The intent of this method of starting from cold is to apply heat very gradually about the furnace, so that proper circulation may be established throughout in order to avoid excessive temperature stresses. With the direct-firing arrangement, this necessitates operating the mills for short intervals in rotation and is conveniently accomplished from the central control board. The boilers are started each morning on weekdays, at which time the furnace is hot from the previous day's operation and there has been very little loss of steam pressure. Under these conditions

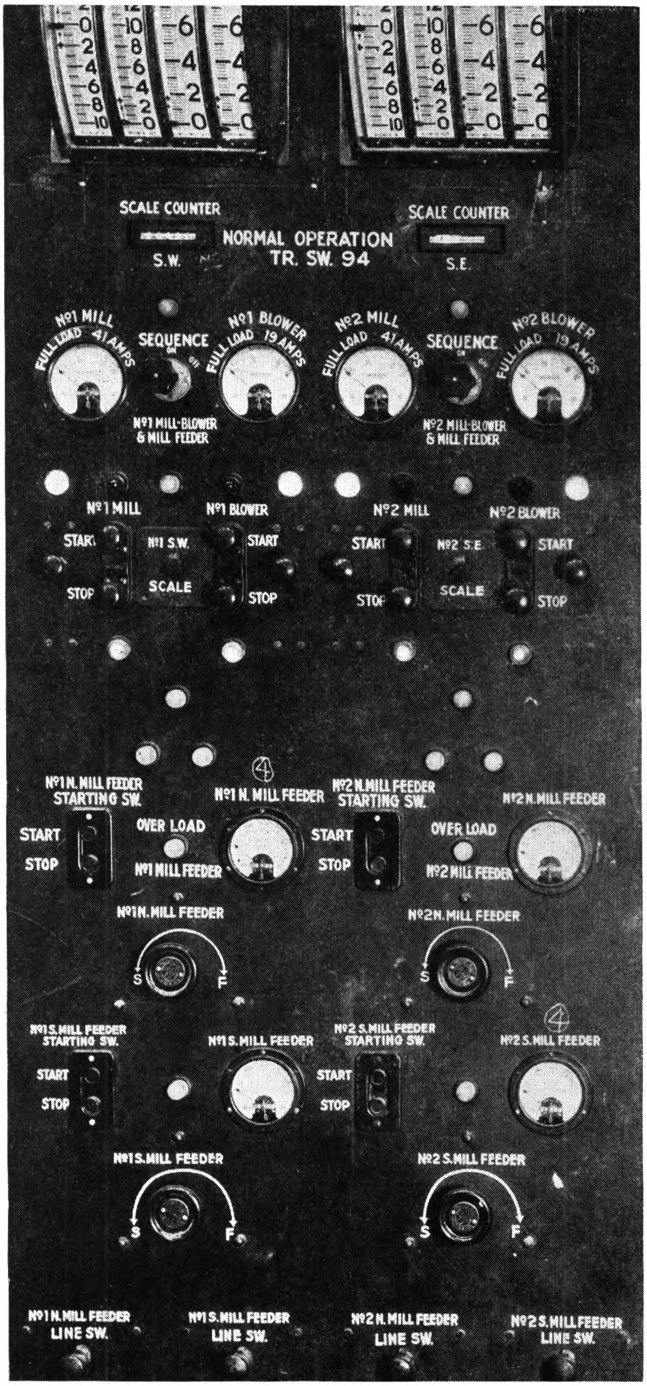

FIG. 7 ONE OF THE MILL CONTROL PANELS (2 MILLS)

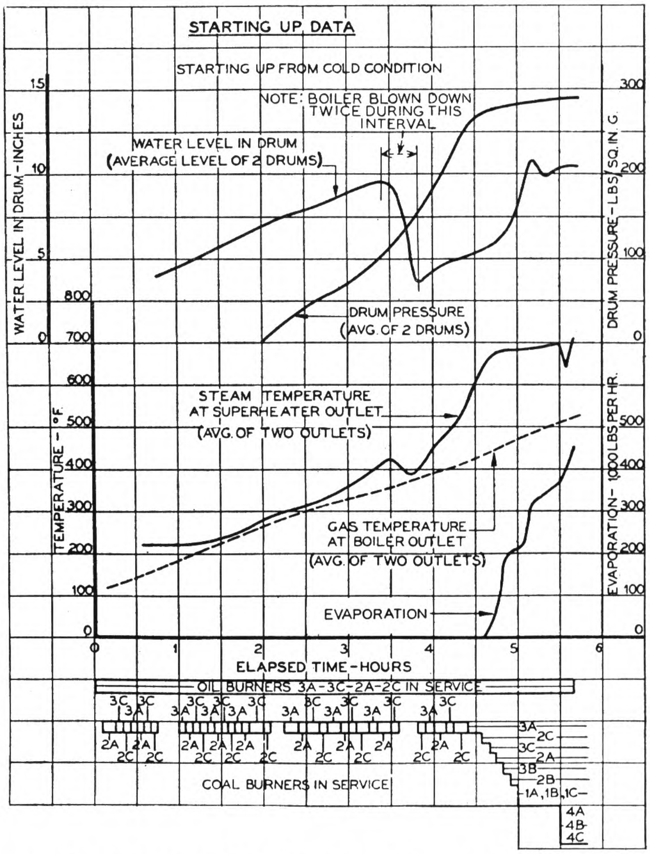

FIG. 8 STARTING UP FROM COLD CONDITION, BOILER 92

(During warming-up period, four corner burners, 2A, 3C, 2C, 3A, are operated alternately, one burner at a time.)

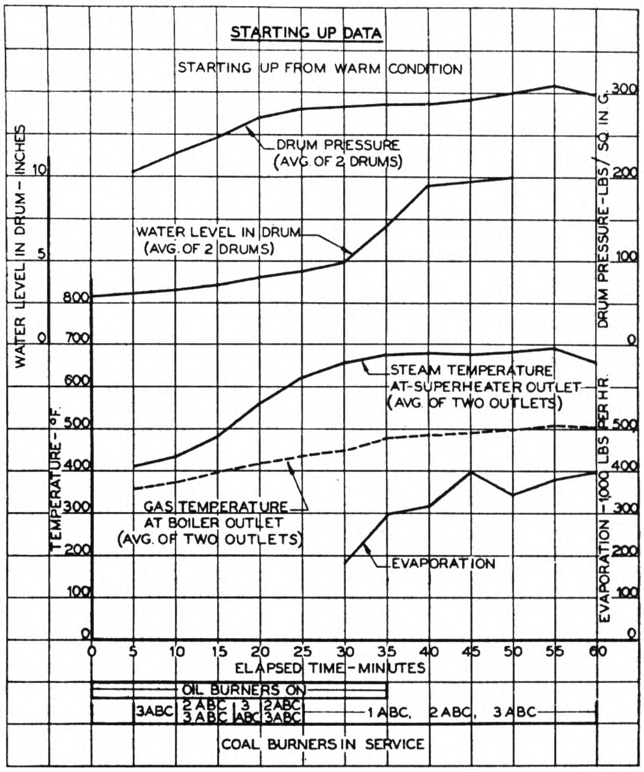

FIG. 9 STARTING UP FROM WARM CONDITION, BOILER 92

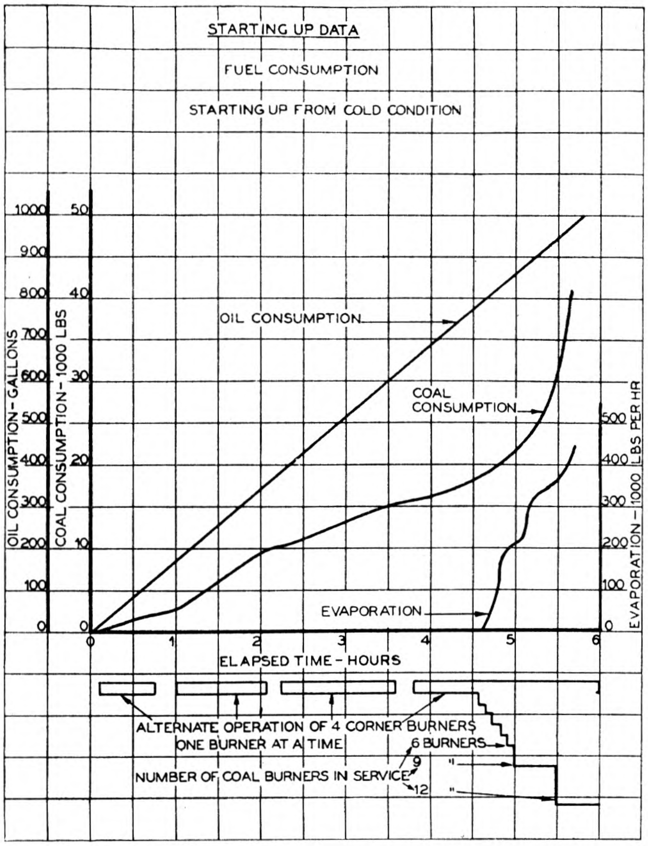

FIG. 10 FUEL CONSUMPTION, STARTING UP FROM COLD CONDITION, BOILER 92

the unit goes on the line within a few minutes after the first burner is lighted.

Capacity and Flexibility

The maximum capacity of the installation is limited by the fans and pressure drop through the superheater. With the average grade of coal used, the mill capacity is near the limit when other limiting conditions are approached. The lower limit of output is established by the minimum practical capacity of one mill, together with secondary-air leakage through the burner dampers of the idle mills. The heat radiated by the hot slag bottom provides strong ignition and minimizes the danger of flarebacks with one-mill operation or under unfavorable coal-feed conditions. The boiler has been operated for sustained periods at outputs as low as 200,000 lb per hr and as high as 1,080,000 lb per hr. Under test conditions these figures could be considerably bettered at both ends of the range by means well known to many operators. However, a more rational basis of rating for daily operation may be considered as from 300,000 lb per hr to 1,000,000 lb per hr.

Responsiveness

Tests were conducted under the supervision of the manufacturer's representatives to determine the rate of response of the mills for various changes in the feeder speed, together with the time effect on steam output from the boiler. These data are

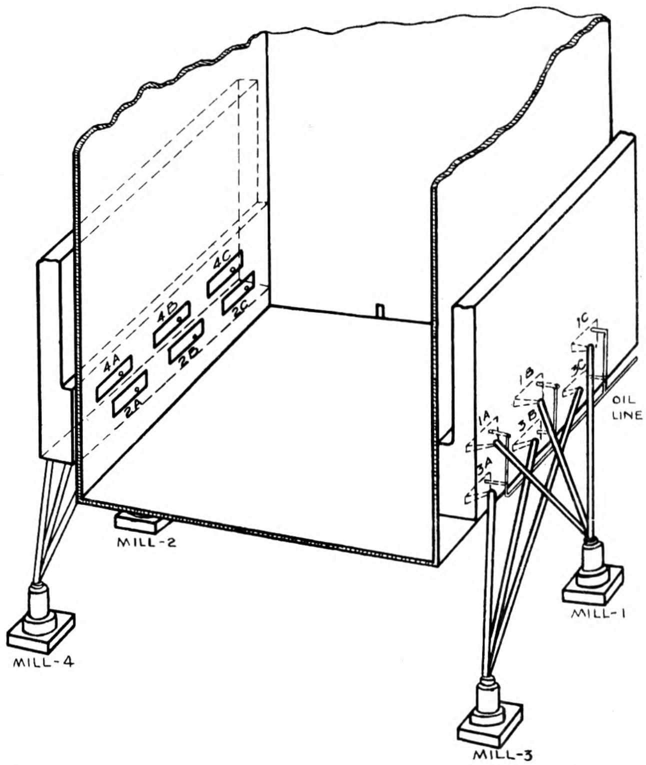

FIG. 11 ARRANGEMENT OF PIPING BETWEEN MILLS AND BURNERS

TABLE 1 TEST OF BOILER NO. 92, HELL GATE STATION—RESPONSIVENESS OF BOILER TO INCREASE IN LOAD

Steam flow, 1000 lb per hr: Before change in coal feed	After change in coal feed	Diff.	Increase in steam flow, per cent	Speed of coal-feeder motors, rpm: Initial	Maximum during change	Final	Increase in coal-feeder speed, per cent	Overtravel of coal feeders, per cent	Period of overtravel of coal feeders, min	Time lag, min[b]	Air supply[c]	Rate of change in steam flow, lb per hr per min: Per boiler	Per mill	Change in steam pressure, lb per sq in.	Change in water level, in.
600	725	125	20.8	637	832	832	31	0	0	3.25	FS	38,400	9,600	+ 5.3	+1.25
520	740	220	42.3	585	855	855	46	0	0	4.0	FC	55,000	13,750	+ 4.1	−2.25
530	810	280	52.8	587	959	959	63	0	0	4.5	FC	62,200	15,540	+ 6.0	−2.0
420	720	300	71.5	450	1005	806	79	25	3.0	4.75	FS	63,200	15,800	+ 3.3	−2.0
400	720	320	80.0	450	1200	800	78	50	3.0	4.25	FS	72,300	18,075	+ 8.7	−3.0
410	710	300	73.0	450	1400	800	78	75	3.0	3.75	FS	80,000	20,000	+ 5.5	+2.0
410	740	330	80.5	450	1500	800	78	87	3.0	4.5	FS	73,300	18,325	+12.5	−2.5
400	710	310	77.5	500	1250	925	85	35	2.5	2.75	FC	112,700	28,175	+ 0.5	−6.25
390	590	200	51.3	500	1250	800	60	56	1.5	2.25	FC	88,800	22,200	+ 7.0	+1.1
380	640	260	68.5	500	1350	800	60	69	1.5	3.25	FC	77,000	19,250	+ 5.0	−1.0
380[a]	660	280	73.7	500	1300	850	70	53	1.5	2.75	FC	102,000	25,500	+ 3.0	+3.5
410[a]	720	310	75.6	619	1341	1080	75	24	1.5	3.25	FC	95,400	23,850	+10.0	+3.25
350[a]	700	350	100.0	620	1350	1240	100	9	1.5	2.5	FC	140,000	35,000	+11.5	−0.5

[a] During these tests the speed of the coal feeders was increased in four steps, so as to approximate an automatic control; the period of the maximum overtravel was 1 min and that of the total overtravel 1.5 min. [b] Time lag represents the interval of time required for the stabilization of the steam flow after a change in the coal feed. [c] FS means the air supply follows the steam change; FC means the air supply follows the coal change.

NOTE: The actual tests for the last two runs indicated a temporary stabilization at a lower final speed of 850 rpm due to the accumulation of coal in the mills during the overtravel period, but since these runs were not sufficiently prolonged to establish the correct final speeds, the reported values for these final speeds were assumed to be in proportion to the increase in steam flow.

indicative only, since it was not convenient to carry out the tests with the precision of an evaporative test nor to entirely eliminate influences tending to affect the result of the observations.

Some of these tests are recorded in Tables 1 and 2 and are also shown in Figs. 12, 13, and 14. The tests covered both increase and decrease in output, with observations recorded on 15-sec intervals. The time lag between the coal-feeder change and the change in heat input to the furnace was determined by ascertaining the variation in CO_2 in the flue gas while maintaining a constant supply of primary and secondary air. The change in CO_2 at the boiler outlet commenced within 15 sec from the start of the change in coal feed, and the stabilized condition was reached in about 2 min. The beginning of the change in the steam flow commenced from 12 to 18 sec after the change in coal feed, and it reached the final value in from 2.5 to 4.5 min. The shortest lag was obtained by giving considerable overtravel to the coal feeders and by adjusting the secondary-air supply to follow the change in coal supply instead of following the steam flow. The most rapid increase in output was 350,000 lb per hr in a period of 2.5 min. The rate of the increase was 35,000 lb of steam per hour per mill per minute, or 140,000 lb of steam per hour per minute for the boiler. This increase in evaporation represents 100 per cent change if referred to the load at the beginning of the change, and 14 per cent change if referred to the maximum capacity.

Very little change is required in the primary-air control for the full range of mill capacity, and this may be accomplished with one or two adjustments for the complete range. It is probable that a simple automatic control could be provided which would independently maintain constant air flow through the mill for practically all conditions. This would lessen the probability of a mill plugging up and would simplify operation somewhat, but operating conditions thus far have not warranted this refinement.

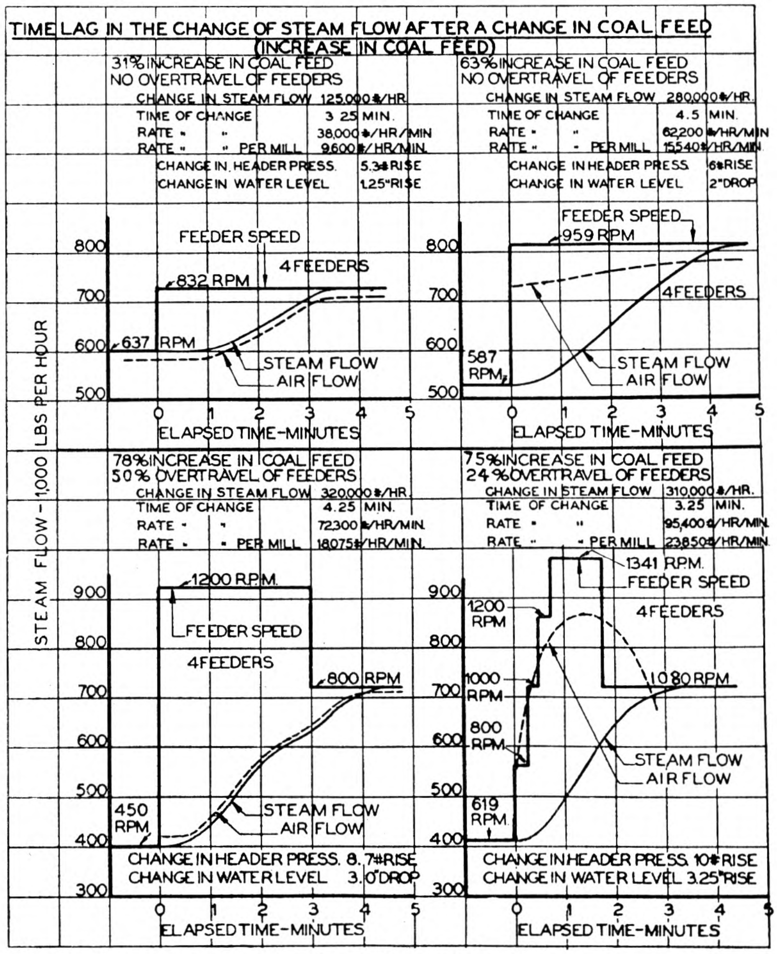

Fig. 12 Time Lag in the Change of Steam Flow After a Change in Coal Feed (Increase in Coal Feed), Boiler 92

(Note: The Rate of Change, at top of diagram, should be 38,400, instead of 38,000.)

Slagging

With the load conditions necessitating shutting down these boilers about eight hours daily on the midnight watch, a problem was introduced in slag removal. This was somewhat aggravated by the occasional delivery of coal having a high fusion ash and the necessity for running a rather high furnace draft to protect the upper seal in the furnace against the furnace-stack effect and consequent gas pressure. The high furnace draft greatly inconvenienced slag removal, due to the chilling effect of the air drawn against the slag stream at high velocity through the slag-tap opening. The chilling of the slag necessitated almost continuous use of bars and hooks to keep the slag flowing, at the expense of much physical labor.

The situation was improved somewhat by the substitution of water-cooled slag liners, to which the slag did not adhere so tenaciously. This rendered the labor of clearing the slag spout much easier, but still required, with normal grades of fuel, constant attendance to insure a continuous flow. Tests were made with fluxes, and some improvement in slag removal resulted.

TABLE 2 TEST OF BOILER NO. 92, HELL GATE STATION—RESPONSIVENESS OF BOILER TO DECREASE IN LOAD

Steam flow, 1000 lb per hr: Before change in coal feed	After change in coal feed	Diff.	Decrease in steam flow, per cent	Speed of coal-feeder motors, rpm: Initial	Minimum during change	Final	Decrease in coal-feeder speed, per cent	Undertravel of coal feeders, per cent	Period of undertravel of coal feeders, min	Time lag, min[b]	Air supply[c]	Rate of change in steam flow, lb per hr per min: Per boiler	Per mill	Change in steam pressure, lb per sq in.	Change in water level, in.
750	540	210	28.0	855	587	587	31.0	0	0	4.75	FS	44,300	11,075	− 7.3	+1.0
690	410	280	40.6	800	450	450	44.0	0	0	4.25	FS	65,900	16,475	− 3.0	−3.5
680	490	190	28.0	925	500	700	24.0	29	2.0	4.0	FS	47,500	11,875	−14.0	−1.5
590	400	190	32.2	800	250	500	37.5	50	1.5	3.75	FS	50,800	12,700	− 6.7	−1.7
620	410	210	33.8	800	250	500	37.5	50	1.5	3.5	FS	60,000	15,000	− 5.8	−2.3
630	400	230	36.5	800	250	500	37.5	50	2.0	4.0	FS	57,500	14,375	− 6.2	−1.5
690	400	290	42.0	950	250	500	47.0	50	2.0	4.5	FS	64,400	16,100	+ 9.0	−2.0
690[a]	400	290	42.0	850	606	606	29.0	0	0	3.75	LS	77,400	19,350	− 7.3	−0.5

[a] During this test the speed of the coal feeders was decreased in three steps, so as to approximate an automatic control. [b] Time lag represents the interval of time required for the stabilization of the steam flow after a change in the coal feed. [c] FS means the air supply follows the steam change; LS means the air supply leads the steam change.

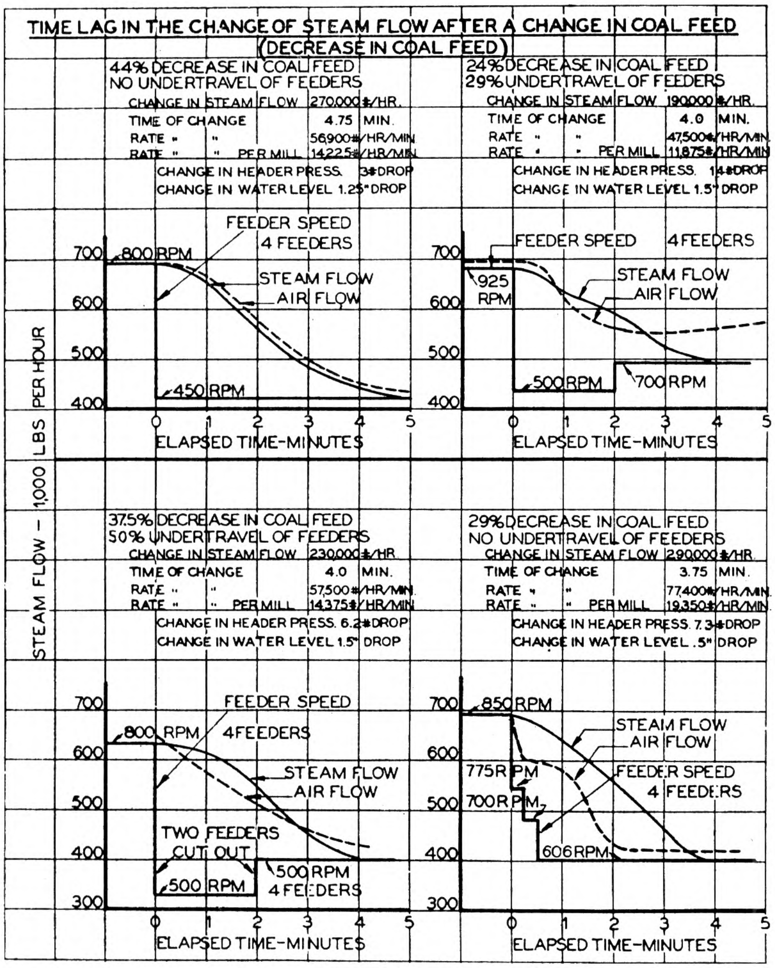

FIG. 13 TIME LAG IN THE CHANGE OF STEAM FLOW AFTER A CHANGE IN COAL FEED (DECREASE IN COAL FEED), BOILER 92

ambient temperature conditions prevailing are reproduced in Fig. 15. The decline in pressure has been used as a measure of radiation, and while this is not a strictly accurate method, it is an indication of relative value for comparison purposes. The pressure in one of the boilers of the unit declined more rapidly than the other, due to the fact that damper leakage on that half was somewhat greater. Immediately after shutting down there was a slight delay in closing the dampers, after which, it may be observed, the pressure in the boiler increased due to the absorption of heat from the hot slag bottom.

After about six hours the rate of change in heat content of water in the boiler became nearly constant, and this may be regarded as a rough indication of the radiation rate. This rate of radiation is equivalent to about 0.2 per cent of the heat input at maximum capacity. This method of accounting presupposes water temperature throughout the boiler corresponding to the pressure and includes the water equivalent of the metal parts in contact with the boiler water. Undoubtedly, a large proportion of the heat loss is due to unavoidable infiltration and damper leakage, and it is probable that the hot slag bed acts as a heat accumulator in reducing the rate of pressure loss in the boilers. In any event, the characteristic is advantageous in this installation, since it simplifies the problem of starting the boiler daily after an overnight shutdown.

Primary Air

The primary-air fans are located on the inlet side of the mills with the mills operating under pressure. The primary-air supply to the fans is taken from the main air duct and protected against possible backflow by light unbalanced non-return dampers. In addition, the primary-air supply pipe is extended

The fluxes, however, did not seem to combine chemically with the ash, but appeared to form an insulating scum on the surface which protected the underlying slag against the chilling effect of the inrush air. The method of introducing the fluxes was rather crude, but the benefit appeared to be physical rather than chemical. This also seemed to be borne out by the fact that fluxes which should be expected to have little effect in depressing the melting point appeared to have a pronounced influence in preventing chilling of the slag stream.

As a final corrective measure one slag opening and its receiving chamber were encased, and means were provided for inducing draft in this chamber during the slagging period. By inducing draft in this chamber greater than that existing in the furnace hot gases from the furnace are withdrawn with the slag instead of permitting cool air to exert a countercurrent effect on the slag stream during its passage. This resulted in a marked improvement in the slagging operation, eliminating the frequent use of hooks and shortening the time required for slag removal. With this improvement, slag which is fluid enough in the furnace to approach the opening may be readily withdrawn.

Cooling Rate

The boilers have a low radiation loss due to tight, well-insulated settings, with slag bottoms and tight-fitting uptake dampers. Observations made during a shutdown in winter with low

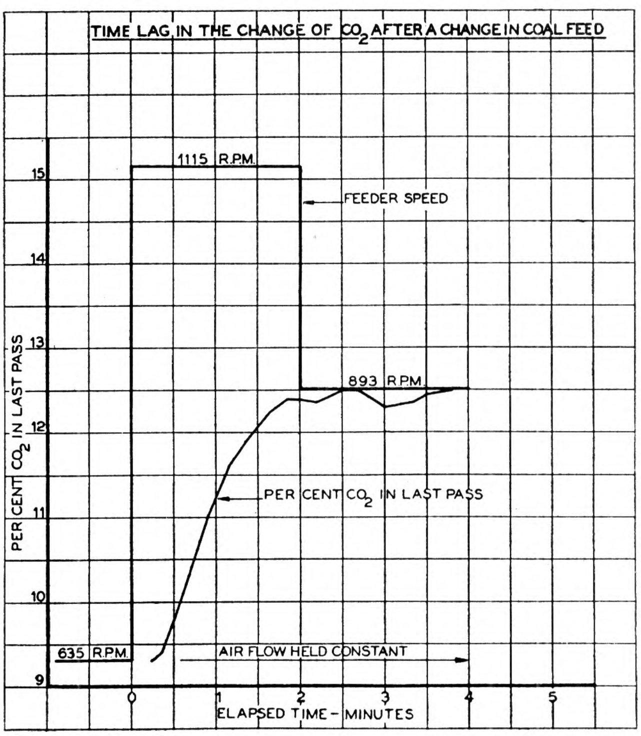

FIG. 14 TIME LAG IN THE CHANGE OF CO_2 AFTER A CHANGE IN COAL FEED, BOILER 92

vertically a substantial distance within the air duct, so that it does not communicate with any part of the plenum chamber adjacent to the burner openings into the furnace. As an additional precaution a balanced relay is provided to cut out the mills and other apparatus in the event the furnace pressure exceeds the air-duct pressure for an appreciable time interval.

TEST PROCEDURE

The tests were conducted by a staff of experienced engineers under the direction of the engineer of tests, with the cooperation of the manufacturer's representatives. Special care was exercised in preparations and arrangements for the evaporative tests to render the results accurate and reliable. Means of measurements of some of the quantities are indicated by illustrations and diagrams, and reference will be made only to some of the more important items.

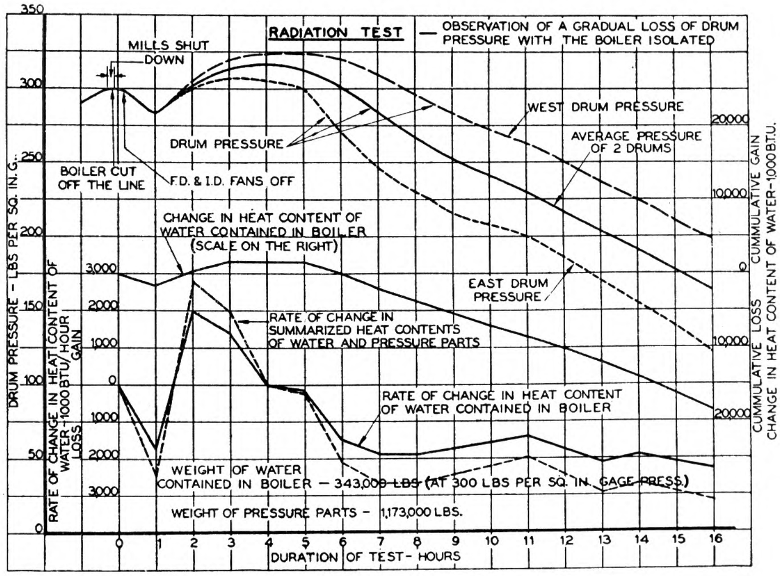

Fig. 15 Radiation Test, Boiler 91

Coal

The weight of coal was obtained from Richardson dump scales, with which each mill is provided. These scales are adjusted to deliver 400 lb at each dump, which rendered checking very convenient by the use of eight 50-lb test weights. Frequent checks were made on the balance of the scale during the test, and adjustment for impact was found unnecessary due to the uniform texture of the slack coal which was used. At the beginning of a run for a chosen rate of evaporation the exact time of a scale dump to each mill was noted and the reading of the counter was taken by individual observers. Thereafter, the counters were read hourly and so continued until the end of the run, when they were taken in the same manner as at the beginning.

The hopper and chute capacity between the scales and mills is about 5 tons per mill, or 20 tons per boiler. With the uniform grade of fuel used, there was little likelihood of appreciable error introduced by this intermediate storage due either to differences in composition or density. Variations in moisture and ash were small throughout the series of tests.

Samples of raw coal for moisture and Btu values were taken every hour, simultaneously. The moisture sample was collected in two 2-qt Mason jars, which were carefully sealed. One jar was delivered to the company laboratory and the other to the manufacturer. The Btu sample was collected in a large can equipped with a cover. At the end of each run the coal from the can was quartered, and a sample was taken again in two 2-qt Mason jars, one for the company laboratory and the other for the manufacturer. A sample of the pulverized coal at each burner was taken hourly. A graded traverse of the coal pipe was made with a sampling tube through which the coal sample was discharged into the pail. The tube was connected to the pail with a conical sleeve made of 10-oz canton flannel, selected for its ability to retain the finest coal. Pains were taken to make this apparatus leakproof against coal dust. At the conclusion of a run a careful sample was drawn from each of the three pails serving a single mill and was collected in two 2-qt Mason jars, sealed and labeled, one for the company and the other for the manufacturer. Thus the fineness samples for each run were contained in eight Mason jars.

Feedwater

Feedwater was measured by means of venturi tubes and manometers. Two tubes were used—one of 600,000 lb per hr capacity in the east section and the other of 400,000 lb per hr capacity in the west section. In order to maintain steady flow for accurate measurement with the venturi meters, boiler 92 was shut down and blanked off, so that the feedwater loop serving this boiler could be utilized in passing the feedwater to the west side section of boiler 91.

The manner in which the feedwater measurement in each section was taken care of was as follows: A venturi manometer in each section was placed at the boiler-drum floor level close to the station of the operator, who, by the manipulation of a chain-operated feed valve, maintained the reading of the manometer constant as long as the water in the nearby gage glass remained at the allowable level near the center of the gage glass. At the beginning of each run it was aimed to have the level in the gage glass in the middle, and the exact level was marked so that at the end of the run it could be properly reestablished. Drum pressures at termination of each run were maintained as close as possible to those existing at the start to obviate errors due to changes in heat quantities in the boiler contents. Both venturi tubes had been calibrated, together with the manometers, before the test, and they were found accurate within one-fourth of 1 per cent.

For readings beyond 800,000 lb per hr, at which the capacity of the venturi manometer on the west side was exceeded, a similar manometer was employed to read the differential on the steam nozzle serving the west side Bailey steam flowmeter. A similar arrangement was also used on the east side, but was supplemented by reading the regular venturi manometer in the feedwater lines. Both steam-flow venturi manometers were calibrated with the feedwater venturi meters. Temperature of the feedwater at entrance and exit of both heater and economizer were read with accurate chemical thermometers.

Fly Ash

In the measurement of fly ash, efforts were made to obtain accurate measurement of losses without necessitating an elaborate arrangement. At the boiler outlet of each section a suitable horizontal lane for sampling fly ash was chosen, as shown in Fig. 16. This lane contained equidistant holes, through each of which normally was inserted a movable tube drawing a sample of cinder-laden gas in three different positions, as illustrated in Fig. 17. Care was exercised in drawing this sample at the same velocity as that of the gas at the point of sampling. This velocity was determined at the beginning of the run with a pitot-tube

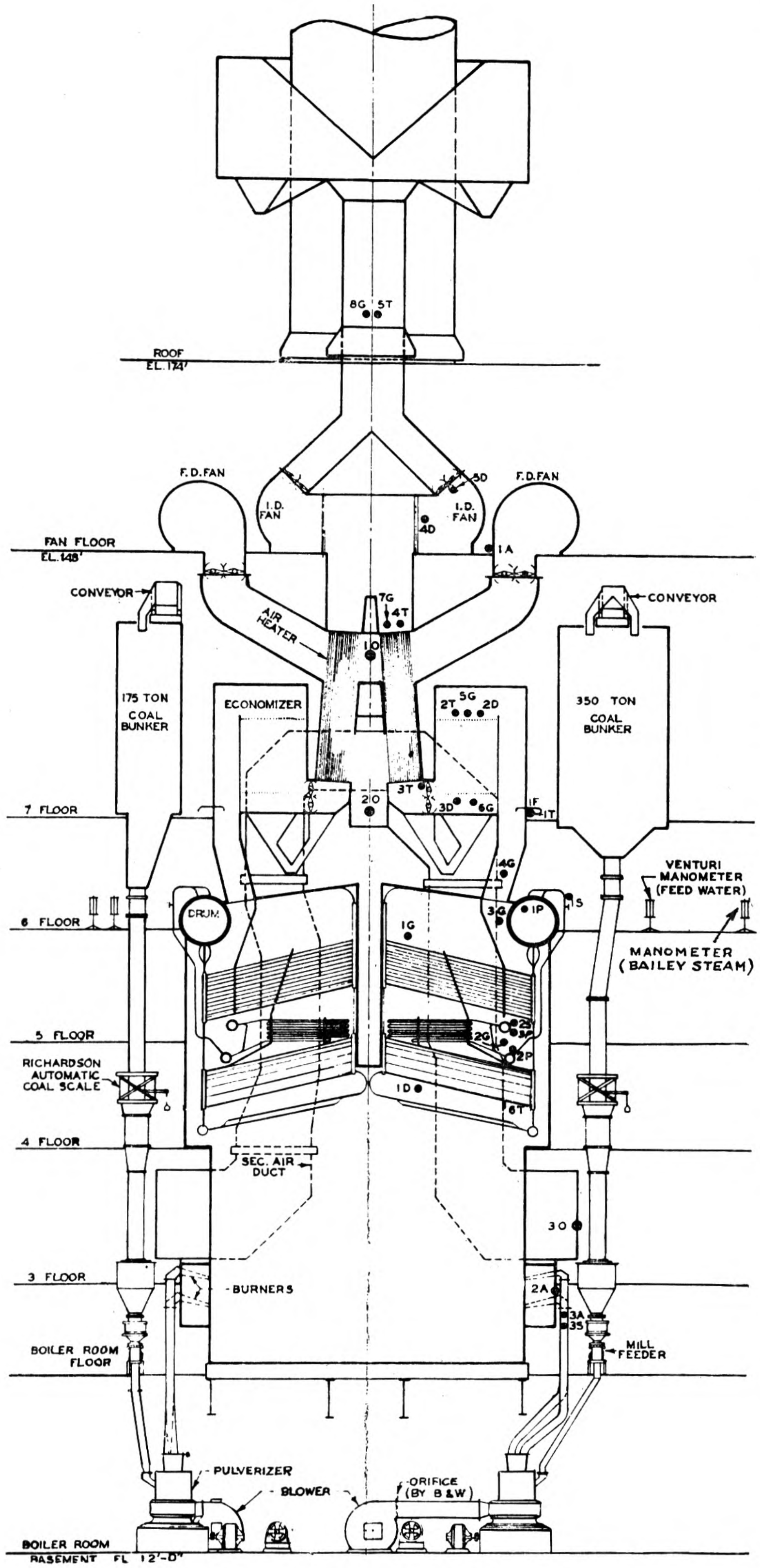

Fig. 16 Section Through Boiler 91, Looking South

(For key to Fig. 16, see bottom of next column)

traverse and was checked occasionally during and at the end of the run. Temperatures of the gas at the points of sampling were measured with a thermocouple at the same time the pitot-tube traverse was made. For the values of velocity and temperature thus obtained a rate of gas sampling was read from a calibration curve for the individual orifices serving each sampling tube. This rate was determined by the pressure differential across the orifice and was maintained constant throughout the run as long as the gas velocity, temperature, and suction remained unchanged. Orifices were calibrated with commercial gas meters, which in turn were standardized with a standard gas meter provided by the gas company. In this calibration actual flue gas was employed. The gas sample was drawn by means of an air-actuated aspirator, as shown in Fig. 17.

This gas, on leaving the sampling tube, was filtered through a bag, contained in a carefully sealed Mason jar. The material of the bag was 10-oz canton flannel chosen from a selection of other weights as the most suitable for its ability to retain finest cinders without offering undue resistance to the gas flow. The bags were weighed before each run, the tare weight being subtracted from the gross weight of bags containing cinders at the end of the run, after a preliminary drying. The resulting net weight of cinders divided by the measured quantity of gas, corrected to standard

---

Operating Connections:

Pressure (Air):
1O Air-heater inlet, 1 point
2O Air-heater outlet, 1 point
3O Secondary-air duct, 1 point
(Note: The regular operating connections were used in obtaining test results.)

Test Connections:

Thermocouple:
1T Boiler outlet, 8 points
2T Economizer inlet, 3 points
3T Air-heater inlet, 3 points
4T Air-heater outlet, 3 points
5T After induced-draft fan, 3 points
6T Secondary-air duct, 2 points

Gas Sampling:
1G Top of first pass, 3 points
2G Bottom of second pass, 3 points
3G Top of last pass, 6 points
4G Boiler outlet, 6 points
5G Economizer inlet, 3 points
6G Economizer outlet, 3 points
7G Air-heater outlet, 3 points
8G After induced-draft fan, 3 points

Draft (Gas):
1D Furnace, 1 point
2D Economizer inlet, 1 point
3D Economizer outlet, 1 point
4D Induced-draft-fan inlet, 2 points
5D Induced-draft-fan outlet, 2 points

Pressure (Air):
1A Forced-Draft-fan outlet, 1 point
2A Secondary air at burner chamber, 3 points
3A Primary air and coal mixture at burners, 6 points

Temperature:
1S Calorimeter, 4 points
2S Superheater outlet, 2 points
3S Primary air and coal mixture, 6 points

Pressure (Steam):
1P Drum, 1 point
2P Superheater inlet, 1 point
3P Superheater outlet, 2 points

Fly Ash:
IF Boiler outlet, 8 points

(Note: Dampers were open during tests, although shown closed in the drawing. Test connections are symmetrical about the center line of the boiler, except for 5T and 8G. The number of points refers to one side of the boiler only.)

conditions, gave the density of cinders in the flue gas. Fineness tests and combustible determinations were made on the cinder samples that were obtained.

Flue Gas

Owing to the great width of the boiler-outlet connections, six gas-sampling tubes were employed. To simplify the problem of gas analysis, an average sample was drawn from every three sampling positions of a given region and passed through a common bubbling bottle to an Orsat apparatus. Gas temperatures were measured chiefly with calibrated thermocouples. Gas temperatures in the furnace were obtained by the manufacturer's representative with an optical pyrometer.

Steam

The quality of steam entering the superheater at each section was determined with four steam-jacketed calorimeters about equally spaced. The normal correction for this type of calorimeter is very small, and since tests indicated a blank correction of less than one-tenth of 1 per cent, no correction was applied to the observations. Temperatures of the superheated steam were read with accurate chemical thermometers. Steam pressures at the drum outlet and the superheater inlet and outlet in each section were read with the same calibrated gages connected to a common manifold which served all the pressure points.

General

During the tests observations were made covering the performance of all major auxiliaries as well as the feedwater heater.

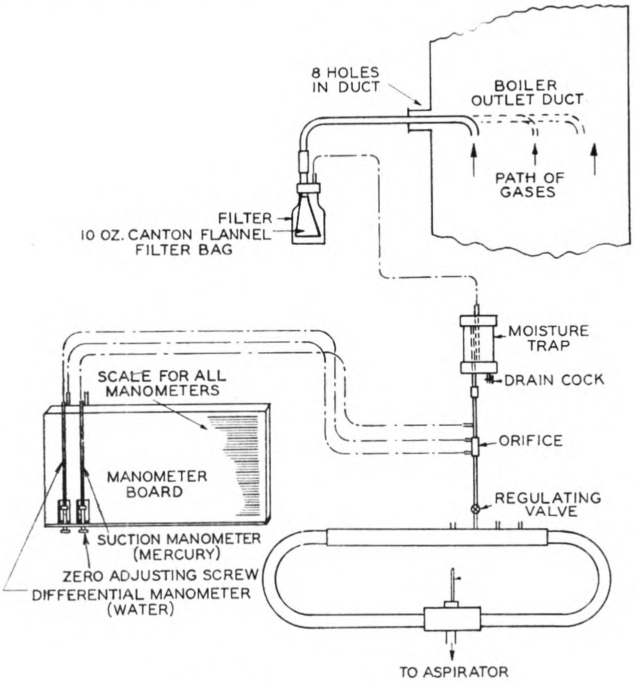

Fig. 17 Fly-Ash Test Layout

All gages were calibrated before and after the test, while the potentiometer used with the thermocouples was calibrated before the test. The tests here reported consisted of six runs, conducted in the following order:

Run No.	Rating, lb per hr	Duration, hr	Number of mills
1	402,700	10	3
2	542,100	8	4
3	689,800	10	4
3a..........	688,100	8	4
4	791,300	8	4
5	923,200	6	4
6	1,078,000 (max)	2	4

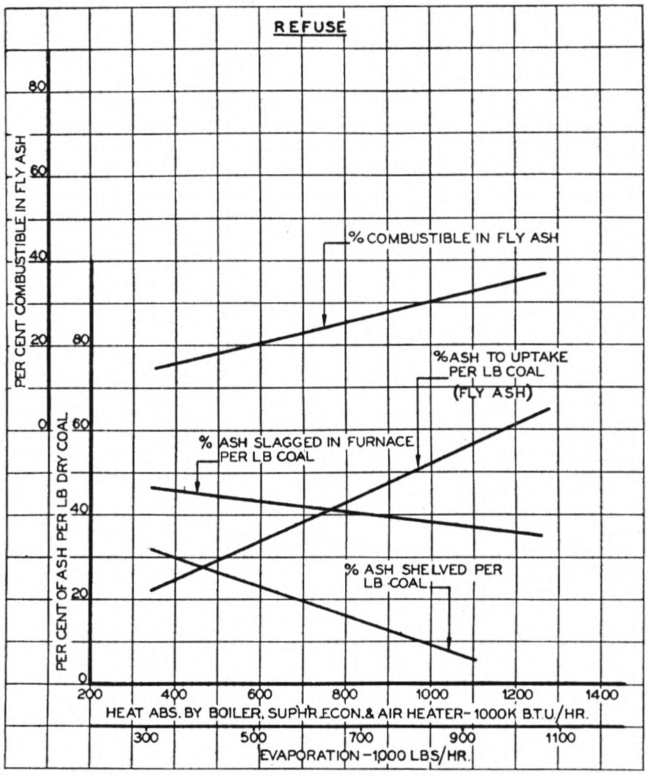

Fig. 18 Refuse, Boiler 91

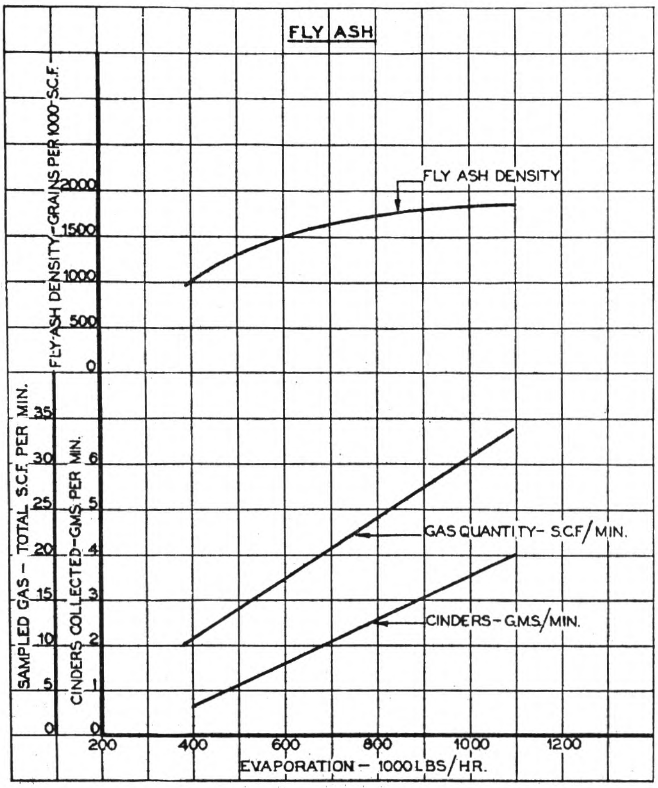

Fig. 19 Fly Ash, Boiler 91

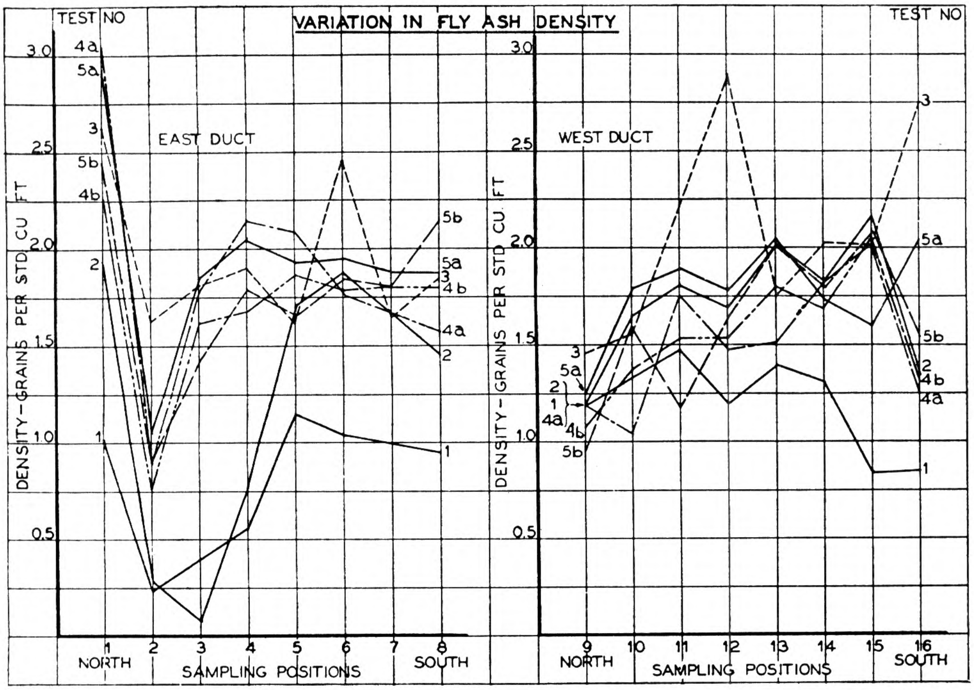

Fig. 20 Variation in Fly-Ash Density, Boiler 91

Prior to each test run the tubes of the boiler, economizer, and air heater were blown by means of soot blowers. Before starting any test, the boiler was operated at the chosen rating for several hours, and secondary air was adjusted to give approximately 15 per cent CO_2 about $^1/_2$ hr before actual testing commenced.

In the case of run No. 3, which was scheduled for 8 hr duration, it was observed that during the first two hours, evaporation was improving steadily. This observation led to the belief that for this higher rating than the previous ones the boiler needed longer time to reach stable conditions. As a result the original run was prolonged by two hours, and test No. 3a is therefore the official run.

Pulverizing characteristics and mill limitations at the time of the test made it necessary to employ only three mills during run No. 1. It was also these limitations that made operation at substantially lower rating somewhat uncertain. The maximum rating test was run in the evening, and to avoid an unnecessary hazard the manual control of the feedwater was dispensed with, recourse being made to the standard automatic water regulation.

The venturi manometers were read every 2 min. Excess air was reduced to maintain about 17 per cent CO_2 for the purpose of reducing the duty on the induced-draft fans. Smoke at the stack for this rating did not appear to be of a prohibitive density and differed very little from that observed during the preceding run.

The entire series of tests were conducted in close cooperation with representatives of the manufacturer. Aided by their assistants, they made supplementary observations on the primary-air supply to the mills, on the temperatures of the Bailey blocks on the furnace walls, and on the temperature of the furnace.

Computations

Results of the tests were calculated in accordance with the latest issue (January, 1930) of the Test Code for stationary steam-generating units, use being made of Table S-4-b for heat balance. To render the heating value of the coal more truly representative in the computations of the heat balance for each run and by agreement with the manufacturer's representatives, an average of the following three values was used:

- That determined by the manufacturer for his sample
- That determined by the United company for its sample
- That from the analysis by the United company of the manufacturer's sample.

This method of averaging was applied to the complete coal analysis, both for the proximate and the ultimate.

Curves shown in Fig. 18 give, in a graphic form, the approximate relationship between the three components of the total ash

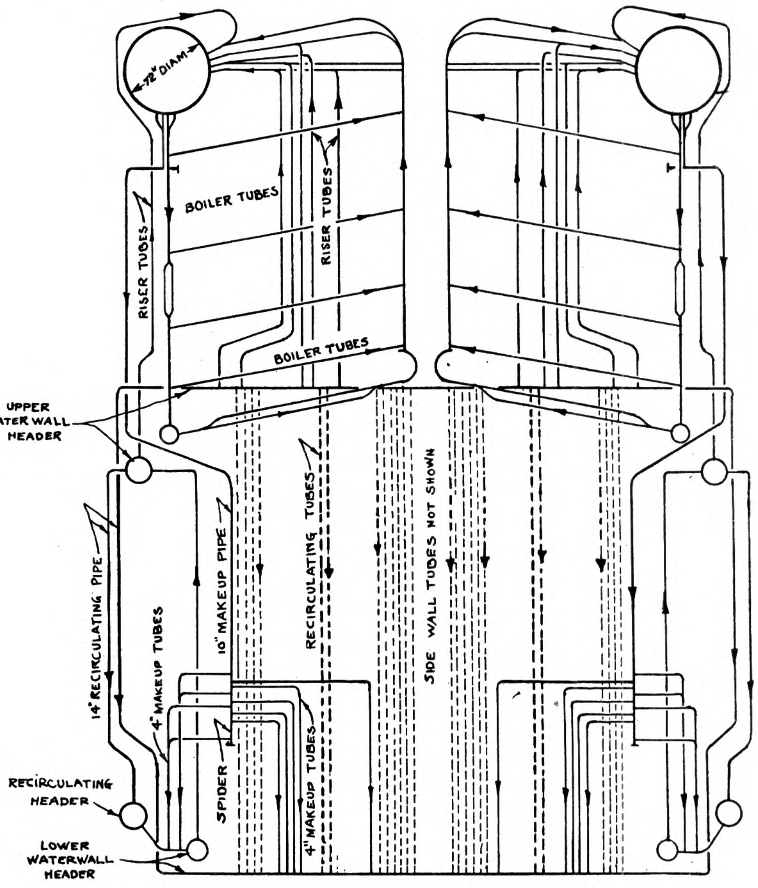

Fig. 21 Recirculation Diagram, Boiler 91

at various ratings. The "fly ash to uptake" component was determined at all ratings by measurements. The other two components were determined on the following basis: For the low rating, the "ash slagged in furnace" component was estimated 45 per cent, this figure being substantiated by the experience of the manufacturer, and the "ash shelved" component was determined by the difference; for the high rating, it was observed that the "ash shelved" component was zero, due to high gas

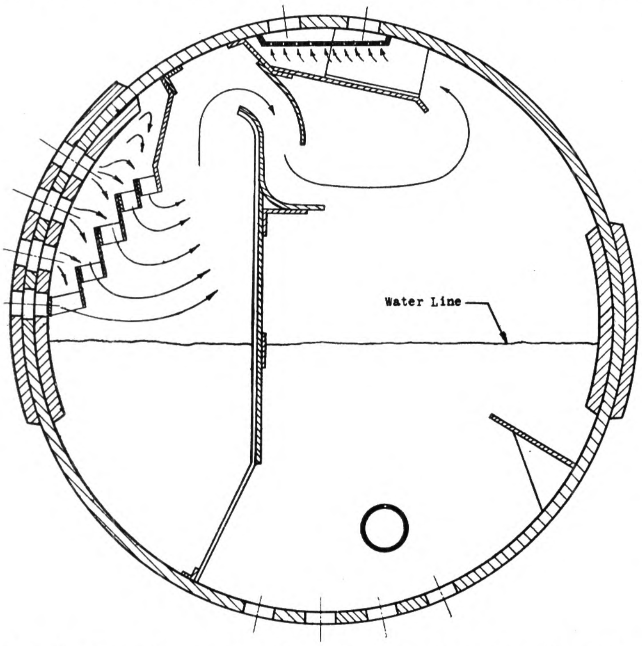

FIG. 22 CROSS-SECTION OF DRUM SHOWING SYSTEM OF BAFFLING (Diameter of drum, 72 in.; thickness of wall, 1⅞ in.)

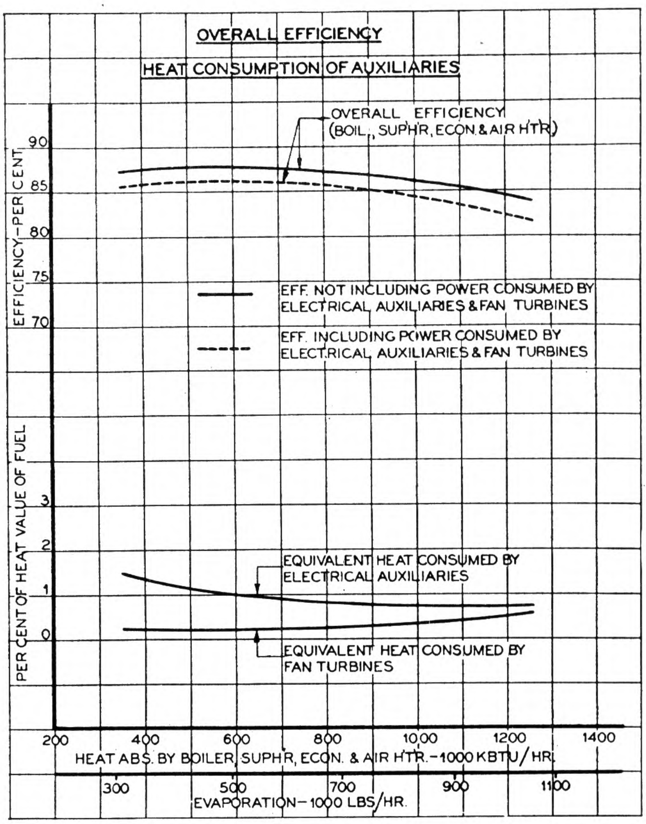

FIG. 24 OVERALL EFFICIENCY, HEAT CONSUMPTION OF AUXILIARIES BOILER 91

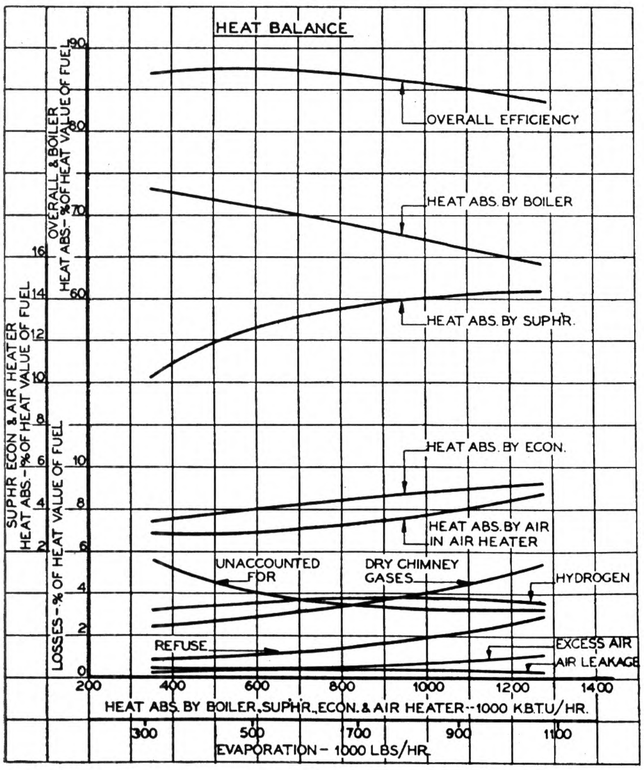

FIG. 23 HEAT BALANCE, BOILER 91

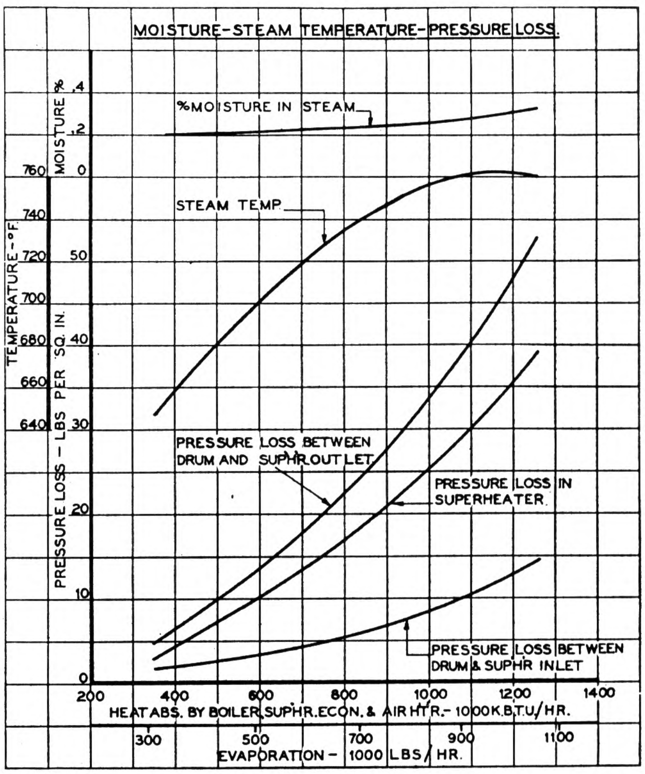

FIG. 25 MOISTURE, STEAM-TEMPERATURE, AND PRESSURE LOSS, BOILER 91

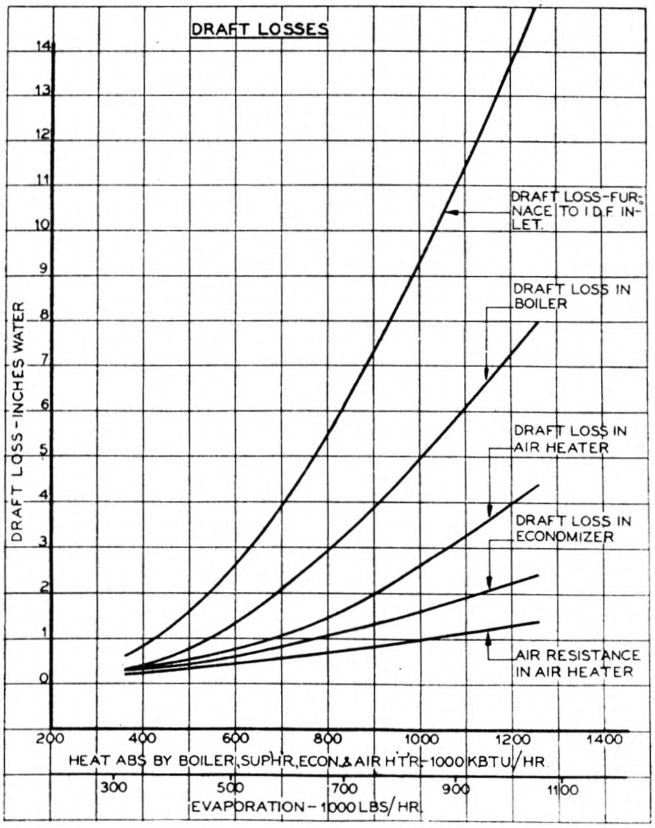

Fig. 26 Draft Losses, Boiler 91

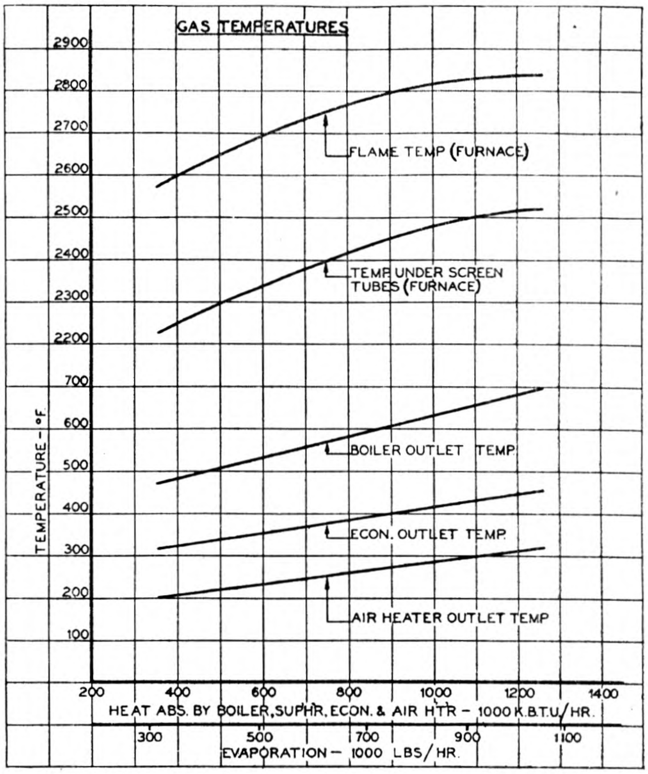

Fig. 27 Gas Temperatures, Boiler 91

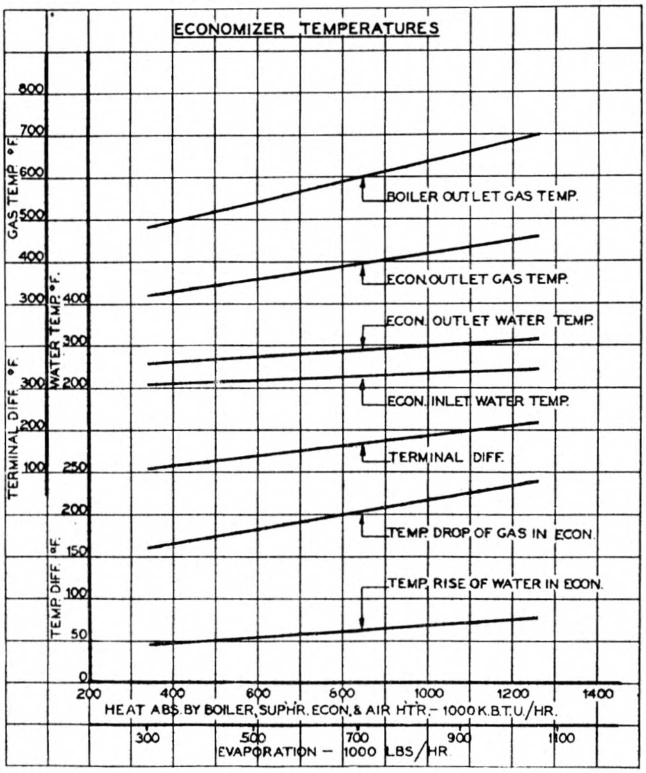

Fig. 28 Economizer Temperatures, Boiler 91

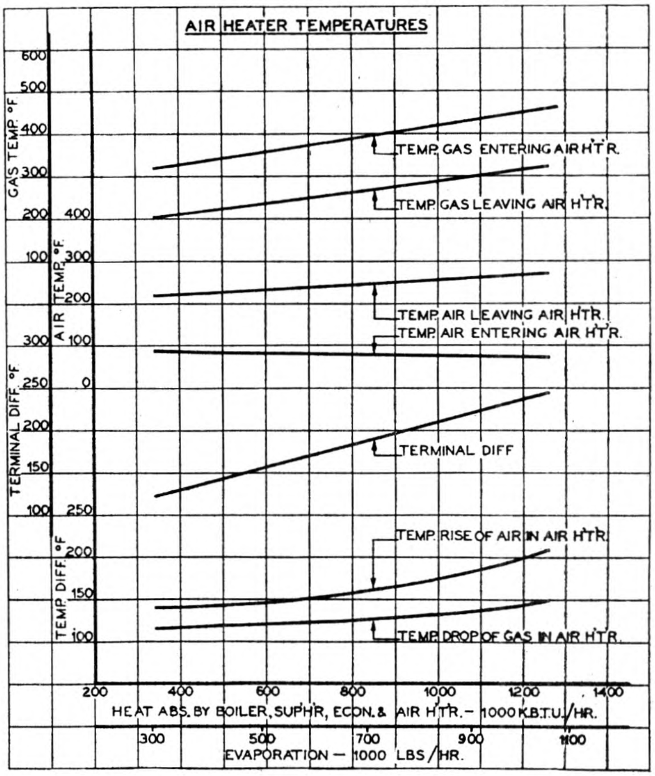

Fig. 29 Air-Heater Temperatures, Boiler 91

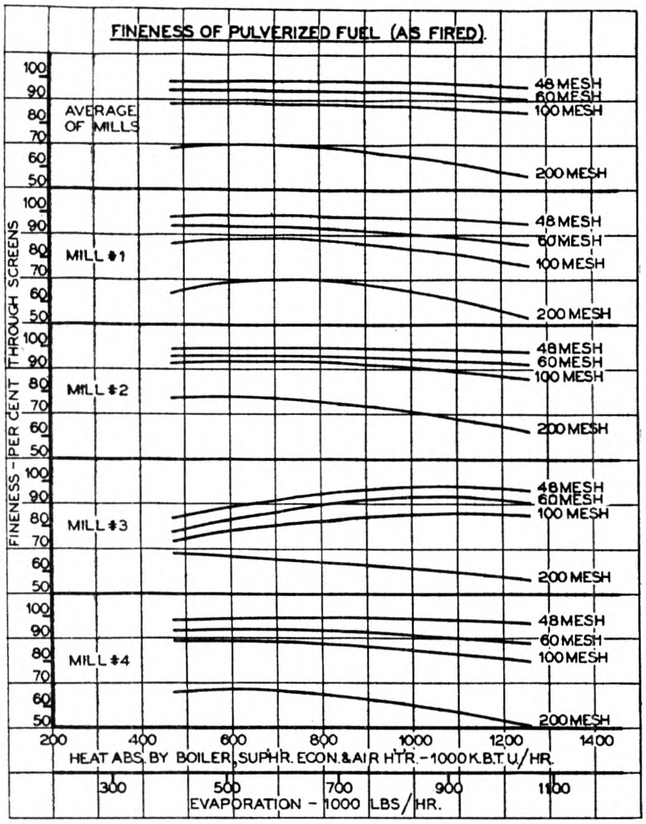

Fig. 30 Fineness of Pulverized Fuel (as Fired), Boiler 91

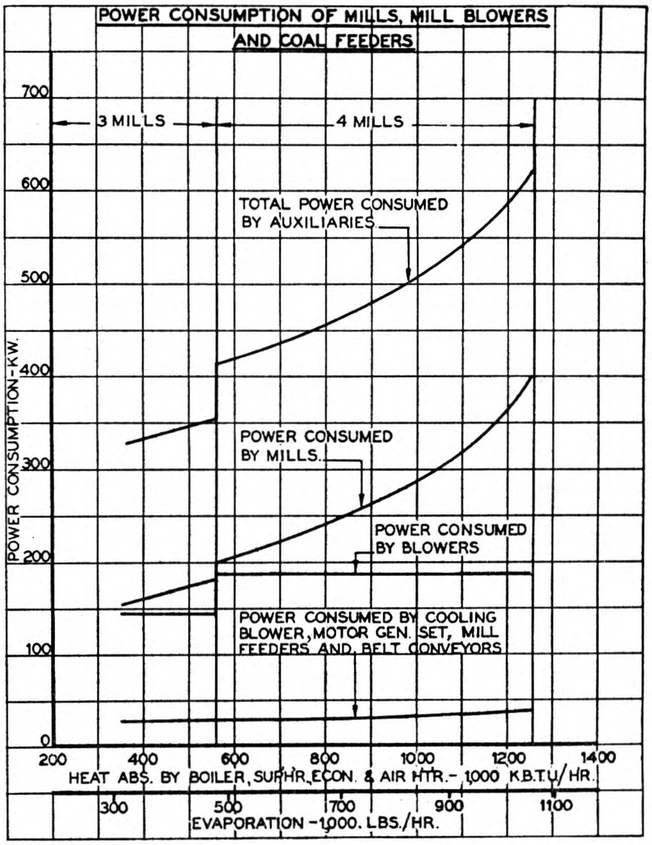

Fig. 31 Power Consumption of Mills, Mill Blowers, and Coal Feeders, Boiler 91 (Total Consumption)

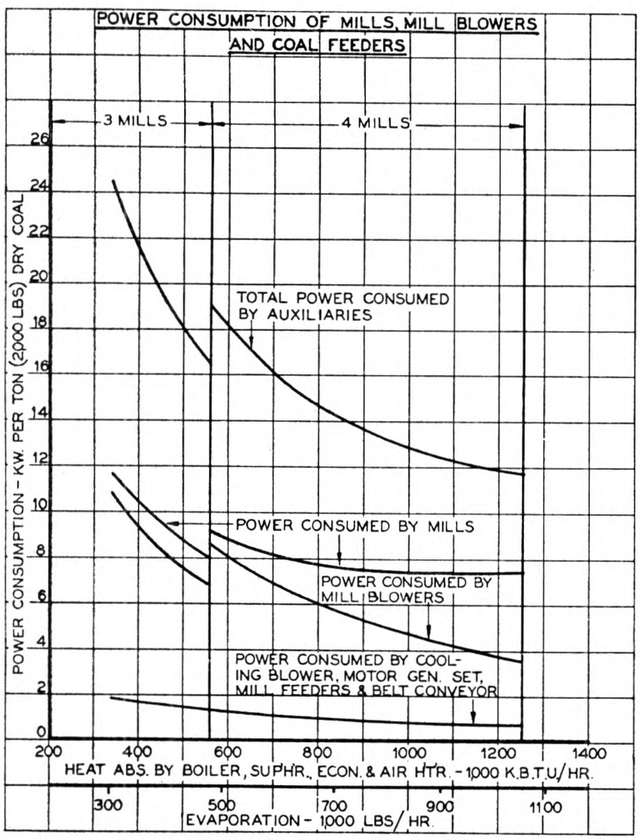

Fig. 32 Power Consumption of Mills, Mill Blowers, and Coal Feeders, Boiler 91 (Consumption per Ton)

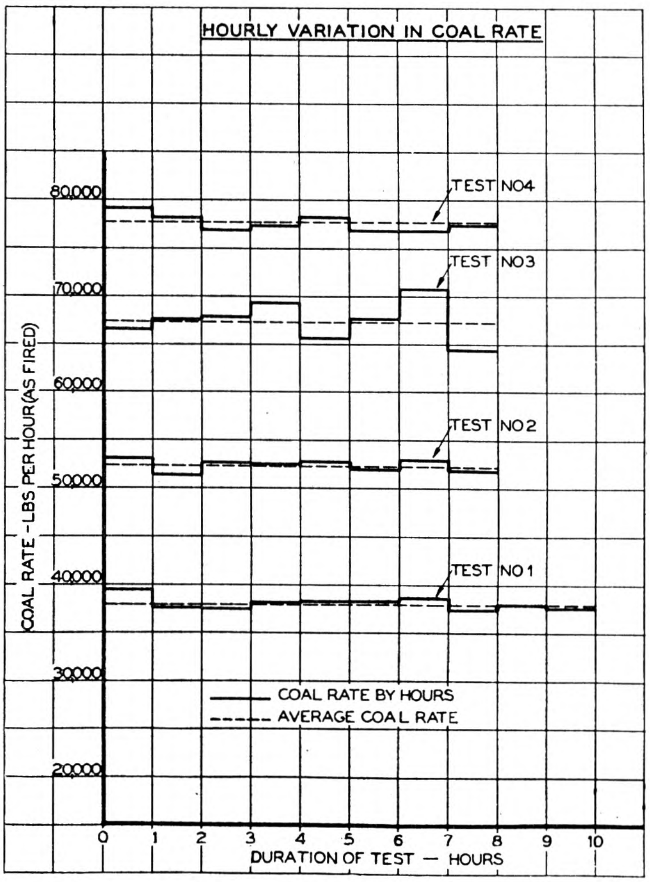

Fig. 33 Hourly Variation in Coal Rate, Boiler 91

velocity, and the "ash slagged in furnace" component was determined by the difference. Although the "ash shelved" component could not be accurately measured, its content of combustible was determined from the samples taken from various baffles. The content of combustible in the fly ash to uptake was determined by measurements, and the ash slagged in the furnace was assumed to contain practically no combustible.

Figs. 21 and 22 illustrate various features of this installation. The results of the test are given in a graphic form in a series of curves and also in Table 3.

The general data on the major boiler equipment are included in the Appendix.

The author gratefully acknowledges the assistance rendered by his associates and the manufacturer's representatives in the preparation of this paper.

Appendix

DATA ON THE MAJOR EQUIPMENT OF THE 90-ROW BOILERS, HELL GATE STATION

Number of boilers, two

Year of installation, 1930

Boiler: Babcock & Wilcox sectional, twin, cross-drum, water-tube type

Drums: Two drums (one for each half) 72 in. diam, $1\frac{7}{8}$ in. thick, 40 ft 9 in. long

Tubes: 58 sections of 18 tubes 4 in. o.d. No. 6 Bwg, 20 ft long in each half of the boiler

Heating surface: 53,926 sq ft

Water walls: Bailey blocks mounted on 4-in. o.d. No. 6 Bwg tubes, spaced on 6 in. centers; manufactured by Fuller Lehigh Company. (The Bailey blocks are of three types, the refrac-

TABLE 3 TEST OF BOILER NO. 91, HELL GATE STATION, THE UNITED ELECTRIC LIGHT AND POWER COMPANY

Item							
1	Test No.	1	2	3	4	5	6
2	Date of test, 1931	12–2	12–3	12–4	12–7	12–8	12–9
3	Duration of test, hr	10	8	8	8	6	2
	Fuel, Proximate Analysis (Dry):						
4	Volatile matter, per cent	22.46	22.57	22.37	21.94	21.39	23.01
5	Fixed carbon, per cent	70.17	71.28	72.37	71.62	73.18	71.33
6	Ash, per cent	7.36	6.15	5.26	6.44	5.43	5.65
7	Moisture (as fired), per cent	3.90	4.15	4.15	4.55	4.20	4.90
8	Heating value per lb (as fired), Btu	14,012	14,200	14,350	14,055	14,265	14,130
9	Heating value per lb (dry), Btu	14,581	14,814	14,967	14,734	14,899	14,855
10	Fusion temperature of ash, F	2,405	2,425	2,435	2,428	2,448	2,445
	Fuel, Ultimate Analysis (dry):						
11	Carbon, per cent	83.05	84.35	84.78	84.10	84.83	84.54
12	Hydrogen, per cent	4.45	4.49	4.77	4.59	4.54	4.49
13	Oxygen, per cent	3.36	3.29	3.50	3.15	3.41	3.57
14	Nitrogen, per cent	1.08	1.17	1.16	1.15	1.16	1.21
15	Sulphur, per cent	0.70	0.55	0.54	0.57	0.59	0.53
16	Ash, per cent	7.36	6.15	5.26	6.44	5.43	5.65
	Pulverized-Fuel, Proximate Analysis (Dry):						
17	Volatile matter, per cent	22.30	22.00	23.00	22.40	22.60	22.50
18	Fixed carbon, per cent	71.76	72.38	71.44	72.05	72.26	71.97
19	Ash, per cent	5.94	5.62	5.56	5.55	5.14	5.53
20	Sulphur, per cent	0.58	0.60	0.55	0.55	0.56	0.60
21	Heating value per lb, Btu	14,767	14,842	14,811	14,808	14,889	14,808
	Fineness of Pulverized Fuel (as Fired):						
22	Mill No. 1:						
	Through 48 mesh, per cent	98.5	99.0	97.5	98.5	97.5	96.5
	Through 60 mesh, per cent	93.5	95.0	92.5	91.0	90.0	90.0
	Through 100 mesh, per cent	86.0	89.5	88.5	85.0	82.0	83.0
	Through 200 mesh, per cent	63.0	70.5	74.0	59.0	63.0	63.0
23	Mill No. 2:						
	Through 48 mesh, per cent	99.0	99.5	99.0	99.5	99.0	98.0
	Through 60 mesh, per cent	96.0	96.0	95.0	96.0	93.0	91.5
	Through 100 mesh, per cent	93.0	93.5	92.0	93.0	87.5	85.5
	Through 200 mesh, per cent	77.0	78.0	74.0	76.0	68.0	65.0
24	Mill No. 3:						
	Through 48 mesh, per cent	.....[a]	91.5	95.0	96.5	98.5	96.5
	Through 60 mesh, per cent	.....[a]	85.0	89.5	91.5	94.0	91.0
	Through 100 mesh, per cent	.....[a]	81.0	81.0	85.5	86.0	85.0
	Through 200 mesh, per cent	.....[a]	66.0	63.5	60.5	60.0	63.5
25	Mill No. 4:						
	Through 48 mesh, per cent	98.0	99.0	97.5	98.0	97.0	97.5
	Through 60 mesh, per cent	93.5	94.5	93.0	91.0	89.5	91.5
	Through 100 mesh, per cent	87.5	89.0	87.5	84.5	83.0	86.5
	Through 200 mesh, per cent	64.5	69.0	66.0	61.0	58.0	68.0
	Gas Analysis, Furnace:						
26	CO_2, per cent	15.6	15.9	15.8	15.8	15.8	17.9
27	O_2, per cent	3.4	3.0	3.2	2.9	3.3	0.3
28	CO, per cent	0.0	0.0	0.0	0.0	0.0	0.0
29	N_2, per cent	81.0	81.1	81.0	81.3	80.9	81.8
	Gas Analysis, Boiler Outlet:						
30	CO_2, per cent	15.2	15.0	15.1	15.1	14.9	16.6
31	O_2, per cent	3.9	4.1	4.0	4.0	4.3	2.4
32	CO, per cent	0.0	0.0	0.0	0.0	0.0	0.0
33	N_2, per cent	80.9	80.9	80.9	80.9	80.8	81.0
	Gas Analysis, Economizer Outlet:						
34	CO_2, per cent	14.9	14.8	14.8	14.7	14.5	16.0
35	O_2, per cent	4.1	4.3	4.3	4.4	4.8	2.9
36	CO, per cent	0.0	0.0	0.0	0.0	0.0	0.0
37	N_2, per cent	81.0	80.9	80.9	80.9	80.7	81.1
	Gas Analysis, Air-Heater Outlet:						
38	CO_2, per cent	14.4	14.2	14.3	14.2	14.2	16.0
39	O_2, per cent	4.7	5.0	4.9	5.0	5.0	2.9
40	CO, per cent	0.0	0.0	0.0	0.0	0.0	0.0
41	N_2, per cent	80.9	80.8	80.8	80.8	80.8	81.1
	Gas Analysis, Induced-Draft-Fan Outlet:						
42	CO_2, per cent	13.9	13.8	13.8	13.6	13.4	15.2
43	O_2, per cent	5.1	5.3	5.3	5.6	5.8	3.7
44	CO, per cent	0.0	0.0	0.0	0.0	0.0	0.0
45	N_2, per cent	81.0	80.9	80.9	80.8	80.8	81.1

[a] Not in operation.

TABLE 3 TEST OF BOILER NO. 91, HELL GATE STATION, THE UNITED ELECTRIC LIGHT AND POWER COMPANY—*Continued*

Item	Test No.	1	2	3	4	5	6
	Dry Gas per Pound of Fuel (Dry):						
46	Furnace, lb	13.40	13.47	13.43	13.34	13.43	10.86
47	Boiler outlet, lb	13.74	14.10	13.95	13.86	14.17	11.71
48	Economizer outlet, lb	14.10	14.32	14.30	14.29	14.57	12.10
49	Air-heater outlet, lb	14.46	14.87	14.75	14.77	14.87	12.10
50	Theoretical, lb	11.48	11.53	11.69	11.58	11.65	10.70
	Air Supplied per Pound of Fuel (Dry):						
51	Furnace, lb	12.89	12.84	12.93	12.83	12.91	10.41
52	Boiler outlet, lb	13.23	13.57	13.45	13.35	13.65	11.26
53	Economizer outlet, lb	13.59	13.79	13.80	13.78	14.05	11.65
54	Air-heater outlet, lb	13.95	14.34	14.25	14.26	14.35	11.65
55	Air supplied by cooling blower, lb	0.42	0.29	0.23	0.20	0.18	0.14
56	Moisture in air, lb per lb air	0.0048	0.0063	0.0102	0.0073	0.0104	0.0177
	Pressures and Drafts:						
57	Water pressure economizer inlet, lb per sq in. gage[b]	391.1	390.6	386.5	402.4	401.8	427.5
58	Water pressure economizer outlet, lb per sq in. gage[b]	387.4	384.2	375.5	387.0	380.5	399.0
59	Steam pressure boiler, lb per sq in. gage[b]	279.9	291.4	302.2	310.1	315.0	325.7
60	Steam pressure superheater inlet, lb per sq in. gage[b]	277.7	287.5	296.3	302.6	304.7	310.5
61	Steam pressure superheater outlet, lb per sq in. gage[b]	271.3	275.8	278.5	279.3	273.6	269.5
62	Pressure loss in economizer, lb per sq in.[b]	3.7	6.4	11.0	15.4	21.3	28.5
63	Pressure loss in superheater, lb per sq in.[b]	6.4	11.7	17.8	23.3	31.1	41.0
64	Pressure loss between drum and superheater outlet, lb per sq in.[b]	8.6	15.6	23.7	30.8	41.4	56.2
65	Draft in furnace, in water	0.09	0.10	0.10	0.09	0.10	0.12
66	Draft at economizer inlet, in water	0.7	1.8	3.4	4.6	6.4	6.7
67	Draft at economizer outlet, in water	1.1	2.5	4.4	6.0	8.3	8.7
68	Draft at induced-draft-fan inlet, in water	1.5	3.3	6.0	8.3	11.6	12.3
69	Draft at induced-draft-fan outlet, in water	0.3	0.2	0.0	+0.1	0.0	+0.2
70	Draft loss, furnace to economizer inlet, in water	0.6	1.7	2.3	4.5	6.3	6.6
71	Draft loss, economizer inlet to economizer outlet, in water	0.4	0.7	1.0	1.4	1.9	2.0
72	Draft loss, economizer outlet to induced-draft-fan inlet, in water	0.4	0.8	1.6	2.3	3.3	3.6
73	Draft loss, furnace to induced-draft-fan inlet, in water	1.4	3.2	5.9	8.2	11.5	12.2
74	Draft loss, induced-draft-fan inlet to induced-draft-fan outlet, in water	1.2	3.1	6.0	8.4	11.6	12.5
75	Pressure at air-heater inlet, in water	3.0	4.58	5.94	7.30	8.40	8.60
76	Pressure at air-heater outlet, in water	2.74	4.14	5.11	6.40	7.30	7.20
77	Pressure loss in air heater, in water	0.26	0.44	0.83	0.90	1.10	1.40
	Pressure at burner (primary air), in water (3 burners per mill):						
78	Mill No. 1, A	1.40	1.30	1.92	1.80	2.00	2.50
	Mill No. 1, B	1.10	1.00	1.46	1.40	1.40	1.50
	Mill No. 1, C	1.30	1.20	1.77	1.60	2.00	2.60
79	Mill No. 2, A	1.20	1.10	1.62	1.60	1.59	2.40
	Mill No. 2, B	1.73	1.53	1.91	1.73	1.93	2.52
	Mill No. 2, C	1.65	1.37	1.98	1.89	2.04	2.62
80	Mill No. 3, A	.....[a]	1.30	1.67	1.60	1.60	2.10
	Mill No. 3, B	.....[a]	1.10	1.62	1.50	1.60	2.10
	Mill No. 3, C	.....[a]	1.20	1.59	1.40	1.60	2.10
81	Mill No. 4, A	1.13	1.22	1.65	1.46	1.72	2.04
	Mill No. 4, B	1.78	1.72	2.15	1.86	2.28	2.62
	Mill No. 4, C	1.42	1.37	1.85	1.52	1.83	2.18
	Secondary air pressure at burner, in water:						
82	East duct	1.92	2.54	2.68	3.31	2.76	2.93
83	West duct	2.00	2.50	2.80	2.90	2.90	2.79
	Temperatures:						
84	Steam temperature at superheater outlet, F[b]	663.2	718.3	739.1	752.5	761.8	713.0
85	Moisture in steam, per cent[b]	0.20	0.23	0.27	0.23	0.28	0.47
86	Superheat, F[b]	250.2	303.9	323.9	337.0	348.1	300.6
87	Temperature of coal-and-air mixture at burners, F[b]	131	131	131	120	110	108
88	Temperature of air entering air heater, wet, F[b]	57	60	67	61	59	75
89	Temperature of air entering air heater, dry, F[b]	80	82	85	78	60	76
90	Temperature of air leaving air heater, F[b]	215	232	246	246	253	267
91	Temperature of furnace (optical pyrometer), F:						
	Furnace temperature, floor	2470	2408	2400	2460	2450	2655
	Furnace temperature, flame	2600	2741	2793	2580	2773	2873
	Furnace temperature under first row of tubes[b]	2250	2372	2440	2450	2496	2500
92	Temperature of gases leaving boiler, F[b]	504	554	596	625	660	652
93	Temperature of gases leaving economizer, F[b]	334	366	396	412	436	448
94	Temperature of gases leaving air heater, F[b]	217	247	269	280	300	306
95	Temperature of feedwater entering boiler, F[b]	262.0	278.0	280.7	292.4	303.7	294.8
96	Temperature of feedwater entering economizer, F[b]	212.5	222.8	219.4	229.1	237.5	239.8
97	Temperature of fuel, F	60	59	70	60	64	62
98	Temperature of air surrounding boiler, F	115	115	115	115	115	115
99	Temperature of air surrounding economizer, F	125	125	125	125	125	125
100	Temperature of air surrounding air heater, F	125	125	125	125	125	125
	Primary-air temperature at burners, F (three burners per mill):						
101	Mill No. 1, A	125	121	133	118	113	105
	Mill No. 1, B	126	120	131	118	113	105
	Mill No. 1, C	125	121	132	118	113	106

[a] Not in operation.
[b] Average reading for east and west boilers.

TABLE 3 TEST OF BOILER NO. 91, HELL GATE STATION, THE UNITED ELECTRIC LIGHT AND POWER COMPANY—*Continued*

Item	Test No.	1	2	3	4	5	6
	Temperatures:—Continued						
102	Mill No. 2, A	139	131	130	124	106	107
	Mill No. 2, B	142	133	133	126	111	108
	Mill No. 2, C	137	132	130	123	110	109
103	Mill No. 3, A	.....[a]	135	129	122	113	109
	Mill No. 3, B	.....[a]	136	128	119	112	110
	Mill No. 3, C	.....[a]	136	128	119	112	110
104	Mill No. 4, A	134	135	131	118	105	107
	Mill No. 4, B	136	135	133	117	106	108
	Mill No. 4, C	133	133	130	116	103	105
	Hourly Quantities:						
105	Duration of test, hr (repetition of item 3)	10	8	8	8	6	2
	Fuel per hour (as fired), lb:						
106	Mill No. 1	12,748	13,860	16,263	19,183	22,733	29,097
107	Mill No. 2	12,534	13,273	16,868	19,689	22,662	29,400
108	Mill No. 3	.....[a]	12,254	16,820	18,605	21,998	27,105
109	Mill No. 4	12,577	12,865	17,300	20,131	23,200	28,161
110	Total	37,859	52,252	67,251	77,608	90,593	113,763
	Fuel per hour (dry), lb:						
111	Mill No. 1	12,251	13,285	15,588	18,310	21,778	27,671
112	Mill No. 2	12,045	12,722	16,168	18,793	21,710	27,959
113	Mill No. 3	.....[a]	11,745	16,122	17,758	21,074	25,777
114	Mill No. 4	12,086	12,332	16,582	19,216	22,226	26,782
115	Total	36,382	50,084	64,460	74,077	86,788	108,189
116	Combustion space per lb coal per hr (dry), cu ft	1.123	0.815	0.634	0.550	0.47	0.377
117	Refuse per hour, lb	3,113	3,656	4,565	5,971	6,203	15,713
	Actual water per hour, lb:						
118	East boiler	202,600	264,900	341,000	400,500	455,200	515,000
119	West boiler	200,100	277,200	347,100	390,800	468,000	563,000
120	Total	402,700	542,100	688,100	791,300	923,200	1,078,000
	Unit Quantities:						
	Heat absorbed by water in economizer, Btu per lb:						
121	East boiler	49.6	57.0	62.4	64.2	67.4	55.8
122	West boiler	50.6	54.8	62.6	65.0	67.9	56.0
	Heat absorbed by water and steam in boiler, Btu per lb:						
123	East boiler	970.0	952.9	950.7	939.9	927.7	935.2
124	West boiler	970.0	955.0	951.0	939.1	927.6	936.0
	Heat absorbed by steam in superheater, Btu per lb:						
125	East boiler	150.9	180.6	188.2	194.6	201.9	176.3
126	West boiler	145.2	174.2	188.8	195.9	199.5	175.7
127	Rate of heat absorption in economizer, kB per hr	20,174	30,290	43,006	51,114	62,457	60,265
128	Rate of heat absorption in boiler, kB per hr	390,619	517,149	654,281	743,430	856,406	1,008,236
129	Rate of heat absorption in superheater, kB per hr	60,140	96,129	129,708	154,495	185,271	189,714
130	Total rate of heat absorption by steam generating unit, kB per hr	470,933	643,568	826,995	949,039	1,104,134	1,258,215
	Refuse:						
131	Refuse, per cent of fuel (dry), per cent	8.56	7.30	7.08	8.06	7.15	14.53
132	Combustible in refuse, per cent	14.0	15.7	25.6	20.0	24.0	61.1
133	Carbon burned per lb fuel (dry), lb	0.8185	0.8320	0.8297	0.8249	0.8312	0.7566
	Evaporation:						
134	Rate of heat absorption per lb fuel (as fired), kB	12.44	12.32	12.30	12.23	12.19	11.06
135	Rate of heat absorption per lb fuel (dry), kB	12.94	12.85	12.83	12.81	12.72	11.63
136	Rate of heat absorption per sq ft of steam-generating unit surface per hr, kB	5.35	7.30	9.39	10.75	12.54	14.30
	Efficiency:						
137	Efficiency of steam generating unit, per cent	88.7	86.7	85.7	86.9	85.4	78.3
138	Efficiency of boiler and superheater, per cent	85.0	82.7	81.2	82.2	80.4	74.6
	Heat Balance:						
139	Heating value of fuel (dry) { Btu	14,581	14,814	14,967	14,734	14,899	14,855
	{ per cent	100	100	100	100	100	100
140	Heat absorbed by water in economizer { Btu	555	605	667	690	720	557
	{ per cent	3.8	4.1	4.5	4.7	4.8	3.7
141	Heat absorbed by water and steam in boiler { Btu	10,736	10,326	10,150	10,036	9,868	9,319
	{ per cent	73.6	69.6	67.7	68.0	66.3	62.8
142	Heat absorbed by steam in superheater { Btu	1,653	1,919	2,012	2,086	2,135	1,754
	{ per cent	11.3	13.0	13.5	14.2	14.3	11.8
143	Heat absorbed by steam-generating unit { Btu	12,944	12,850	12,829	12,812	12,723	11,630
	{ per cent	88.7	86.7	85.7	86.9	85.4	78.3
144	Heat loss due to combustible in refuse { Btu	175	168	266	237	251	1,296
	{ per cent	1.2	1.1	1.8	1.6	1.7	8.7
145	Heat loss due to incomplete combustion of carbon, { Btu	0.0	0.0	0.0	0.0	0.0	0.0
	{ per cent	0.0	0.0	0.0	0.0	0.0	0.0
146	Heat loss due to theoretical dry gases { Btu	376	456	516	560	670	591
	{ per cent	2.6	3.1	3.4	3.8	4.5	4.0
147	Heat loss due to moisture in coal, moisture accompanying theoretical air, and water from combustion of hydrogen, { Btu	495	515	548	538	537	548
	{ per cent	3.4	3.5	3.7	3.7	3.6	3.7

[a] Not in operation.

TABLE 3 TEST OF BOILER NO. 91, HELL GATE STATION, THE UNITED ELECTRIC LIGHT AND POWER COMPANY—*Continued*

Item	Test No.	1	2	3	4	5	6
148	Heat loss due to excess air and accompanying moisture entering furnace { Btu	64	74	79	87	105	9
	per cent	0.4	0.5	0.5	0.6	0.7	0.1
149	Heat loss due to air and moisture leaking through boiler, economizer, and air-heater setting { Btu	24	46	48	56	64	58
	per cent	0.2	0.3	0.3	0.4	0.4	0.4
150	Heat loss due to unconsumed hydrogen and hydrocarbons, radiation, and unaccounted for { Btu	503	705	681	444	549	723
	per cent	3.5	4.8	4.6	3.0	3.7	4.8
	Economizer:						
151	Heat available to economizer, Btu per lb fuel (dry)	1030	1203	1368	1420	1554	1284
152	Efficiency of economizer, per cent	53.9	50.3	48.8	48.6	46.3	43.4
153	Coefficient of heat transfer, Btu per sq ft per deg F per hr	6.26	8.13	9.76	11.0	12.58	11.87
	Air Heater:						
154	Heat available to air heater, Btu per lb fuel (dry)	836	952	1051	1120	1294	1076
155	Heat absorbed by air heater, Btu per lb fuel (dry)	408	457	501	516	602	487
156	Efficiency of air heater, per cent	48.8	48.0	47.6	46.1	46.5	45.3
157	Coefficient of heat transfer, Btu per sq ft per deg F per hr	1.92	2.54	3.22	3.45	4.10	4.26
	Fly-Ash Data:						
158	Combustible in fly ash, per cent	17.50	22.50	29.96	27.95	33.13	66.68
159	Gas per lb coal, lb	13.61	14.17	14.06	13.62	14.16	11.68
160	Specific volume of gas, standard cu ft	12.56	12.57	12.69	12.69	12.79	12.71
161	Gas per lb coal, standard cu ft	170.94	178.12	178.42	172.84	181.11	148.45
162	Cinders per 1000 standard cu ft of gas, lb	0.1443	0.1934	0.2846	0.241	0.252	0.888
163	Cinders per lb coal, lb	0.0246	0.0344	0.0508	0.0415	0.0455	0.1318
164	Cinders per lb gas, lb	0.00181	0.00243	0.00361	0.00305	0.00321	0.01128
165	Heat loss due to fly ash, Btu per lb coal	60	110	220	170	220	1280
166	Fineness of flue dust:						
	Through 60 mesh, per cent	90.5	86.5	82.0	84.0	83.0	77.0
	Through 100 mesh, per cent	85.5	80.5	75.5	78.5	77.5	69.5
	Through 200 mesh, per cent	70.5	67.5	62.5	67.0	67.0	63.0
	Through 325 mesh, per cent	56.0	55.5	52.5	57.0	55.5	33.5
	Power Consumed by Pulverizers, Blowers, and Feeders (Electric Drive):						
	Power consumed by mills:						
167	Mill No. 1, kw	51.6	58.7	61.6	69.5	81.3	98.0
168	Mill No. 2, kw	59.8	59.0	63.7	66.5	82.0	98.0
169	Mill No. 3, kw	0.0	41.0	56.5	60.5	79.3	86.0
170	Mill No. 4, kw	57.6	56.3	66.2	74.0	92.7	102.0
171	Total for mills, kw	169.0	215.0	248.0	270.5	335.3	384.0
	Power consumed by mill blowers:						
172	Mill No. 1, kw	47.2	44.8	44.0	46.0	45.3	48.0
173	Mill No. 2, kw	50.8	49.2	49.5	49.0	49.3	50.0
174	Mill No. 3, kw	0.0	46.5	47.0	45.5	45.3	42.0
175	Mill No. 4, kw	47.6	46.0	48.8	43.0	49.3	46.0
176	Total for mill blowers, kw	145.6	186.5	189.3	183.5	189.2	186.0
177	Power consumed by motor-generator set, mill feeder, belt conveyer, and bottom cooling blower, kw	28.5	28.4	29.4	31.0	35.9	38.8
178	Total power consumed by electrically driven auxiliaries, kw	342.9	429.9	467.0	485.0	560.4	608.8
179	Power consumed by electrically driven auxiliaries in terms of heat per lb of coal { Btu	163	148	125	113	111	97
	per cent heating value	1.2	1.0	0.9	0.8	0.8	0.7

NOTE: Typical water analysis: Suspended solids, 1000 ppm; dissolved solids, 1030 ppm; total solids, 2030 ppm; NaOH, 44 ppm; Na_2CO_3, 106 ppm; NaCl, 412 ppm.

tory-faced blocks, the rough bare-metal blocks, and the smooth bare-metal blocks. The refractory-faced blocks are used in the lower section of the furnace about 12 ft high, followed up first by rough bare-metal blocks for the height of 3 ft, and then by the smooth bare-metal blocks extending 15.5 ft to a point within 2 ft of the top. The top section of the Bailey blocks is 2 ft wide and is made of refractory-faced blocks. Smooth bare-metal blocks are used in the vicinity of burners.)

Heating surfaces: Two downtake walls, 1880 sq ft; two side-walls, 2380 sq ft; total for water walls, 4260 sq ft

Total heating surface for the boiler and water walls, 58,186 sq ft

Furnace: Width, 34 ft; depth (between burner sides), 41 ft; height, 30 ft; furnace volume, 40,770 cu ft

Superheater: Babcock & Wilcox return-bend type; two superheaters per twin boiler unit. (Each superheater consists of five loops of 2-in. o.d. No. 9 Bwg tubes, 107 elements.)

Heating surface: 5800 sq ft each superheater; total, 11,600 sq ft

Economizer: Babcock & Wilcox return-bend type; two economizers per twin boiler unit (one for each half). (Each economizer consists of 2-in. o.d. No. 6 Bwg tubes, 24 tubes high, 24 tubes wide, 30 ft long.)

Heating surface: 9200 sq ft each economizer; total, 18,400 sq ft

Air heater: Babcock & Wilcox straight tubular type; two air heaters per twin boiler unit (one for each half). (Each air heater consists of 28 staggered rows of vertical tubes, $2^1/_2$ in. o.d. No. 11 Bwg, 22 ft long, 75 tubes in each row.)

Heating surface: On air side, 30,238 sq ft each air heater; total, 60,476 sq ft. On gas side, 27,350 sq ft each air heater; total, 54,700 sq ft

Burners: Fuller Lehigh, cross-tube type; 12 burners per twin boiler, six in each downtake wall, three burners per mill; 12 Babcock & Wilcox mechanical oil burners for lighting torches

Mills: Fuller Lehigh type-B pressure-type mills; four mills per twin boiler; capacity of each mill, 10 short tons

Mill blowers: B. F. Sturtevant single-inlet, paddle-wheel type, 18 in. static pressure; one blower per mill

Fans: Forced-draft fans, two fans per twin boiler; each fan 150,000 cfm capacity at 11.5 in. static pressure. Induced-draft fans, four fans per twin boiler; each fan 125,000 cfm capacity at 17 in. static pressure. (Forced- and induced-draft fans for each boiler unit are driven by two cross-compound steam turbines. Each high-pressure element drives two induced-draft fans through a reduction gear and is rated 974 hp at 7500 rpm. Each low-pressure element drives one forced-draft fan through a reduction gear and is rated 393 hp at 6000 rpm.)

Water-storage capacity: Volumetric contents of the boiler: Two drums (up to the normal water level), 1039 cu ft; boiler tubes, headers and nipples, 3756 cu ft; water walls (including downtake and uptake headers and recirculating tubes), 1713 cu ft; total 6508 cu ft

Weight of water and pressure parts: Weight of water contained in the boiler, water walls, and drums up to the normal water level at 421.7 F (300 lb per sq in. gage), 343,000 lb. Weight of water contained in the drums at 421.7 F within the water column connections, 58,000 lb; within the visible range of gage glass, 45,000 lb. Weight of pressure parts (in contact with water and steam), 953,000 lb. Weight of Bailey blocks in the furnace, 220,000 lb. Weight of pressure parts in terms of the equivalent weight of water on the basis of the ratio of the specific heats of steel and water, 112,000 lb. (Note: Weights of water and pressure parts are approximate.)

Ratios: Furnace volume per sq ft of water-heating surface, 0.7 cu ft. Superheater surface per sq ft of water-heating surface, 0.2 sq ft. Economizer surface per sq ft of water-heating surface, 0.317 sq ft. Total water-heating surface (boiler and water walls) per sq ft of boiler-room floor area (for both boilers, including aisles), 14.8 sq ft. Building volume per 1000 lb evaporation at maximum capacity, 636 cu ft.

Discussion

H. J. Kerr.[2] A full discussion of the paper would require more space than the paper itself, in which, like the installation described, little space has been wasted and much material to work with has been presented in a small volume. Although these units are the first twin B. & W. sectional-header boilers installed, we have in operation many single boilers of the same size and capacity as one of the halves of these twin units. The idea of the twin unit was not new, as units similar in principle but using Stirling boilers had been installed in several plants. In shape, these units are rectangular, with the mills and primary-air fans below the furnace and the economizers and air heaters above the boiler. They therefore permit maximum utilization of the building space. The design of these units is based on conservative values for heat release, gas velocities, and steam capacity.

Only a few of the main features of these units can be mentioned, such as the special slag-screen tubes, the large-diameter drums with shutter-type baffles, steam circulators, slag-tap furnaces with block-covered wall tubes, and pressure-type mills used for direct firing.

The general principle of the boiler slag-screen tubes used with these units was developed some years ago and has been used extensively since then. In this design of boiler unit they permit the placing of two boilers together over a single furnace, with an access space between the boilers that is definitely sealed from the furnace. At a million pounds of steam per hour, the heat-liberation rate per square foot of equivalent cold surface exposed to radiation from the furnace is approximately 300,000 Btu. With preheated air at approximately 250 F, the temperature of gases entering the first pass should be in the neighborhood of 2500 F, which is checked by the test data. The value of the boiler slag-screen tubes as a preventive of slag difficulties is therefore obvious, even when burning fuel having as high an ash-fusion temperature as that of the coal used at this station, approximately 2450 F. Without the boiler slag-screen tubes, a certain amount of slag trouble would be experienced. In other words, the boiler slag-screen permits of the maximum combustion rate in a single-stage furnace set by the limitation of slag on the boiler tubes. For capacities beyond those thus obtainable, it is necessary to use the two-stage furnace, with its furnace slag screen, such as those that have been installed by the State Line Generating Company and those that are now being installed by the Potomac Electric Power Company in Washington, D. C.

The large-diameter drums on this installation are of interest. By concentrating on the problem of moisture and carryover it has been possible to bring these down to such quantities as to be negligible. With the boilers described, operating at their comparatively low steam pressure, the moisture content is shown to be below $^1/_2$ of 1 per cent at the maximum rating. Further developments have permitted the reduction of this percentage, in later installations, to such a point that we now deal with two or three parts per million, and we are pressing the chemist as to his accuracy on one part per million. We have succeeded in obtaining steam containing less than 0.1 of 1 per cent of moisture at a rate of more than 16,000 lb of steam per foot length of 48-in.-diameter drum. Drum diameter will, in the future, no longer be set by the amount of moisture in the steam, but rather it will be decided by the amount of water storage required to handle the variation in load necessary for any particular installation. This requirement is well discussed in the paper, and the value of a large-diameter drum from the standpoint of water-level fluctuation is well covered. In the past there have been certain limitations in obtaining large-diameter drums. The development of welding processes and of material of higher tensile strength is expected to extend this limitation in the future.

[2] Chief Engineer, Service Department, Babcock & Wilcox Company, New York, N. Y. Mem. A.S.M.E.

The paper calls attention to the three rows of horizontal circulating tubes on these boilers. In this connection it might be well to point out that the number of circulators depends upon certain factors, one of which is the steam pressure. With some other designs, it would not be necessary to have this number of circulators, and, as a matter of fact, boilers are being constructed, of higher capacity per section than the units described, that are fitted with only one circulator per section.

The slag-tap furnace and block-covered tubes have been thoroughly discussed. Furnaces of this construction are in successful operation in so many plants that little need be said about them. Attention, however, is called to the fact that they are in successful operation in this plant with coal containing ash of high fusion temperature and in boilers that are off the line each night. In fact, it might be mentioned in this connection that, as compared with normal central stations, the starting up and shutting down each day of these large units constitutes very severe service. The value of this type of furnace is also to be observed in the extreme range in capacity, nearly five to one, as mentioned in the paper. Its value as it affects the cubical contents of the station is of course obvious.

The direct-firing pulverizers used at this plant are of the pressure type and were among the first of this type to be installed. The pressure type of mill was adopted for this installation to simplify various factors, and since then has been generally accepted as a standard because of simplification of coal distribution and piping, use of fans handling air only, instead of exhausters handling abrasive coal dust, reduction in fan power due to higher fan efficiency, and ease of control.

The test data show a high carbon loss with the boiler operating at a capacity of 1,078,000 lb of steam per hour. This was due to the fact that, at this capacity, the steam unit was operating 34 per cent above that contemplated in the mill design, with the result that the fineness was decreased. Subsequent changes in some of the mills have shown that even this capacity is obtainable, with high fineness from the mills and low carbon loss.

The ball-bearing principle of pulverizing as used in these mills is ideally suited to the art of pulverizing coal. The correctness of this principle of grinding has been demonstrated in many and varied applications.

Relative to the variation in superheat temperature from 700 tc 760 deg, with the rating changed from 500,000 to 1,000,000 lb of steam per hour, as shown by Fig. 25, this variation in superheat can be materially reduced by a variation from standard in the operation of the burners. This method of taking care of the natural drop in superheat that takes place with reduction in rating is being used extensively where superheaters are not fitted with desuperheaters. The author is requested to cover this point in his closure.

The success of these boiler units in developing their high capacity may suggest to some the question, "What is the limit in capacity?" Although present practise tends toward the use of high steam output per foot width of furnace in single boiler units, and we could today furnish a single unit having the same capacity as the twin units at Hell Gate, the capacity of single units can, presumably, always be doubled, as was done in this case. The possibilities in high-capacity boilers are therefore considerably in excess of any present or probable future requirements in the use of single boiler units to serve individual turbines. The capacity of the boiler units will be limited by the maximum burner capacity it is possible to install per foot of furnace width, by the volume and capacity of the furnace it is possible to construct under the boiler, the amount of steam it is possible to raise per section, the length, thickness, and diameter of the boiler drum, the length of tubes, available draft, quality of feedwater, and solids in steam to the turbine.

M. K. DREWRY.[3] Never have the design and the performance of large boiler units been reported so comprehensively as in this paper. It is a valuable contribution and deserves much study. Appropriate discussion is difficult because of the magnitude of the information afforded. A few of the most interesting points obtained from it were found as follows:

1 The 72-in. boiler drums emphasize the desirability of appreciable boiler-water storage.

2 Steam-turbine drives for fans were chosen for other reasons than their reliability, for the coal pulverizers are motor driven.

3 Direct firing does not afford direct response to coal-feed demands, for differences in coal storage in the mills cause 2 to 4 min lag in heat output.

4 Removing ash in the molten form under all conditions of plant operation is not readily accomplished.

5 Unusually low radiation loss of the boiler-unit equivalent to only 0.2 per cent of maximum output emphasizes one economy of large sizes.

6 The time of $5^1/_2$ hr is prudently used to start the units from cold and get them to normal rating. Each of the four mills is started and stopped 10 times during the starting procedure, and 8000 lb of oil is used for reliable ignition.

7 A drop of 100 deg fahr in superheat temperature occurs as output lowers from 1100 kB to 400 kB.

8 The reported boiler-unit efficiencies appear conservatively low because of the 3.5 per cent to 4.8 per cent "radiation and unaccounted" figure.

The author is thanked for his painstaking and intelligent reporting of a vital subject.

J. J. GROB.[4] This paper goes farther than the usual report of a boiler-performance test. The author gives an exceptionally broad and lucid explanation of the many-sided problems facing the designing engineer responsible for developing a huge block of steam-generating capacity from a limited available space. The various engineering factors discussed so clearly and the mass of test data covering the performance of the various elements of the boiler installation should be of immeasurable value to other engineers responsible for boiler-station design. A discussion of the various outstanding points of interest in this paper would require considerable space, and therefore it will be confined to a few of the many points of interest.

In the rapid development of higher pressures and capacities in power stations, a number of problems, heretofore little heard of, have been forced upon the operating engineers, and one of the most persistent of these is "carryover moisture" in the steam. Trouble from this carryover moisture manifests itself in a number of ways, among them being the plugging up of superheater elements with sediment carried over with the moisture and left in the superheater, fouling up of steam valves with the residue salts and phosphates, line gasket leaks, fouling up of turbine spindles and casings, and frequently sharp steam-temperature dips and moisture slugs passing through the turbines, resulting finally in reduced turbine capacities due to fouling, if not in serious blade troubles.

Some phases of this problem are controlled by the installation of purifiers or baffles in the steam drum, but the author raises an important point in his introduction of the factor of boiler-surge capacity.

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[4] Engineer of Tests, United Electric Light & Power Co., New York, N. Y. Mem. A.S.M.E.

In the old section of the boiler house at Hell Gate Station, nine of the stoker boilers have been revamped to carry a maximum rating of 250,000 lb per hr steam apiece. The 54-in. drums originally provided were standard practise at the time of installation and were not altered when the boilers were revamped. Tests to determine the speed of pick-up in these revamped boilers have indicated that the rate of pick-up is limited by the rapidity of water-level change. In these tests attempts were made to assist water-level control by hand control of the feedwater cut-off valves and with automatic regulators in operation. On boiler 62 a drop of rating from 230,000 lb per hr to 120,000 lb per hr rating was accomplished in 7 min. The gear-controlled feed valve was restricted at the start to three turns open.

In the first 4 min the water level dropped from the 5-in. level to the 1-in. level, and then rose rapidly, until at the end of 7 min it had risen to the 14-in. level, at which time the gear valve was further restricted. After stabilization of rating at 80,000 lb per hr, the water level was established at the 3-in. level and the gear valve was kept restricted to one turn open. The rating was then raised from 80,000 lb per hr to 153,000 lb per hr in a space of $7^1/_2$ min. In the first 4 min the rating rose to 115,000 lb per hr and the water level rose to 15 in., a gain of 12 in. The level then dropped off, until at the end of the $7^1/_2$-min period it had reached the 7-in. level.

In another such test on boiler No. 33, when the start was made without restriction of the gear-controlled feed valve, a reduction of rating from 254,000 lb per hr to 83,000 lb per hr was accomplished in a space of 7 min. In the first $4^1/_2$ min the water level dropped from the 5-in. level to the 2-in. level. It then rose to the 10-in. level on the rebound while the boiler was banked. Starting with a banked rating of 54,000 lb per hr and the gear-controlled feed valve one turn open, the rating was raised, as shown in the curves of Figs. 34 and 35, to 250,000 lb per hr. In the first $1^1/_2$ min the rating had reached the 94,000 lb per hr rate and the feed valve was closed tight. It was then opened slightly and closed at intervals during the rise in rating, until full capacity had been reached. The water-level surges, although dampened by this control, show a swing from the $7^1/_2$-in. level up to the 13-in., and then down to the $6^1/_2$-in., finally settling near the 6-in. level.

A study of these curves and log entries will yield interesting information and makes clear the reason for the prevailing water-level problems in many plants.

Many other such tests on the stoker boilers indicate that while the speed of pick-up can be increased sharply by overtraveling on air pressure, the violence of water-level change requires manual control of the feedwater to avoid troublesome carryover.

Carrying the thought a step farther, perhaps it should be asked whether limited drum capacities and rapid rating response are worth the price of carryover-moisture troubles. It is clear that the surge characteristics and limitations of a specific boiler design should be determined to assist in the control of "moisture carryover."

In this connection and because of the growing importance of water-carryover problems, further comments are desired as to whether future design trends should take into account this troublesome factor. This apparently was done in the case of the million-pound-capacity boiler under discussion by allowing ample surge capacity of the boiler drums.

The completeness of the performance data helps to visualize the growing importance of heat-balance checks at intervals. With complete heat-balance information showing changes in boiler losses, it should be possible to correct pulverization and combustion impairment, and thus realize the maximum performance possibilities of the equipment.

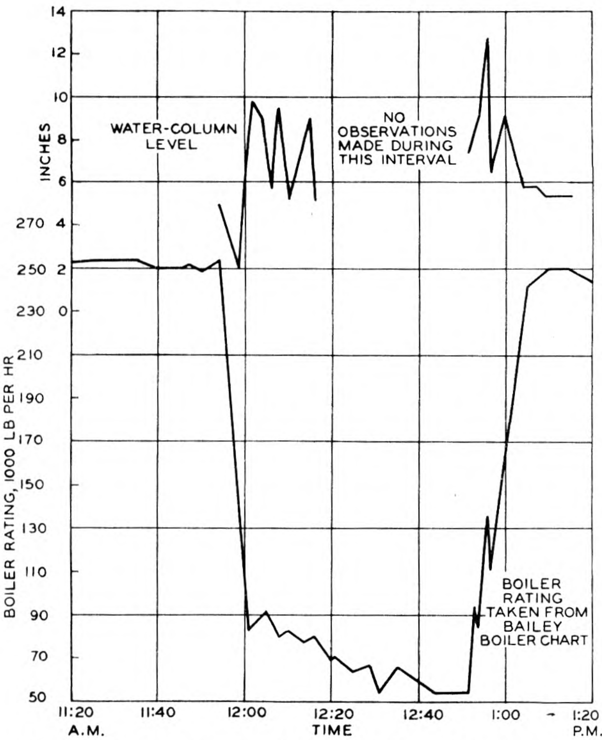

FIG. 34 SPECIAL TEST OF BOILER 33, HELL GATE STATION

(Log on boiler rating, boiler 33, tested Jan. 14, 1932: 11:54 a.m., start to drop; 11:57, no visible change in rating, boiler banked; 11:59$^{1}/_{2}$, reached 90,000 lb per hr; 12:50 p.m., one turn on gear valve; 12:51$^{1}/_{2}$, 54,000 lb per hr, end of banked period; 11:53, closed gear valve; 11:53$^{1}/_{2}$, opened gear valve to one turn; 11:56, closed gear valve; 11:56$^{1}/_{2}$, opened gear valve to one turn; 1:00 p.m., gear valve opened to 10 turns.)

GEORGE D. HETTRICK.[5] While the paper characterizes the two-unit boiler, fired with a common furnace and the single-unit capacity of 1,000,000 lb per hr, as the outstanding feature of the Hell Gate installation, it would seem that the engineering feat of producing 2,000,000 lb of steam per hour within a ground area of approximately 8400 sq ft, with a net ratio of building volume to boiler capacity of 636 cu ft per 1000 lb per hr capacity, is the outstanding accomplishment, when it is considered that with designs prevailing only three or four years ago this same capacity would occupy about 40,000 sq ft and require a building volume ratio of over 1700 cu ft. In the campaign for lower first costs, at least in the matter of space requirements, the Hell Gate installation is an excellent example of what can be accomplished.

An interesting feature is that these large boilers are shut down daily during night periods, demonstrating the operating flexibility of the units.

With two separate boilers served with one furnace, it would seem that difficulty would be encountered in maintaining a uniform temperature throughout the furnace and that physical conditions would tend toward a difference in superheat, feedwater, and air temperatures between the two units. The data presented make no reference to these conditions, so that it may be assumed that no appreciable difference in the performance of the dual installation is noticeable. However, with remote control it would be of interest to know how the action of each of the 12 burners is observed and adjusted to maintain uniform conditions. If one of the burners is not receiving its proper quota of fuel—a condition which occurs at times—how is the control operator notified of this condition?

It is not quite clear why relatively large drum capacity should in any way permit less vigilance on the part of the operators in the matter of attention to feedwater control. Certainly with a large drum, water-level fluctuation would be less noticeable, but the work to be done by the feed regulator is in no way lightened and water level is dependent on regulator performance.

Providing three circulator tubes per section is certainly a desirable arrangement, and should, as claimed, lessen the likelihood of stagnant circulation—a condition which has occurred in some high-pressure installations.

The information presented in the radiation test, Fig. 15, indicates the great value of the modern insulated furnace which makes possible quick starting of boilers after many hours of shutdown. The fact that these large boilers are in steaming service 30 min after lighting burners each morning after having been shut down during the night is a highly interesting operating condition, especially when we consider that the furnaces are of the slag-tap type. The slag probably remains in a molten state during the shutdown period and serves as a heat reservoir, which results in a much faster steaming schedule than would be the case with a water-cooling installation equipped with dry-ash hopper. It is of importance to observe that it takes less than five hours to put these boilers on the line from a cold condition.

The chilling of slag by air drawn through the slag-tap openings is information of value to the design engineer. The fact that it was necessary to install induced-draft equipment to reverse the air currents in the furnace adds not only to first cost but to operating costs also. This somewhat objectionable feature is of small consequence compared to the advantages of the slag-tap furnace, which include avoidance of slagging of ash on tubes, reduction to a large extent of the discharge of ash and dust from the

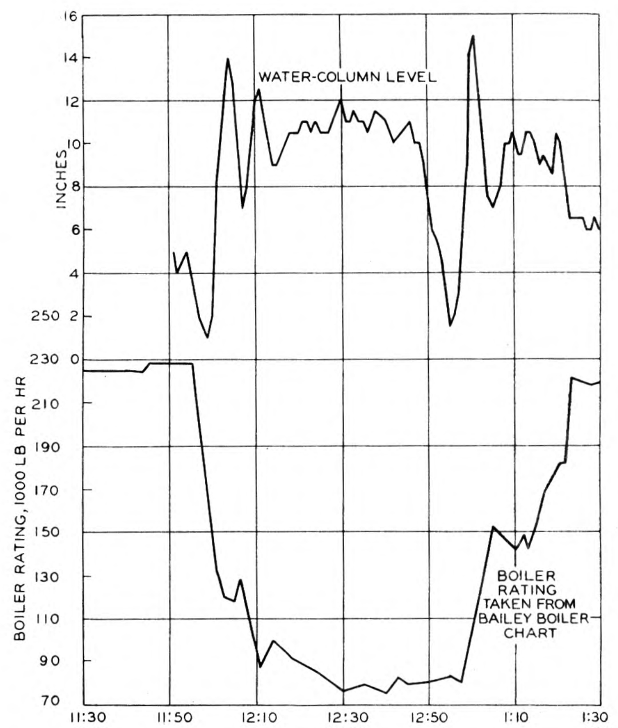

FIG. 35 SPECIAL TEST OF BOILER 62, HELL GATE STATION

(Log on boiler rating, boiler 62, tested Jan. 15, 1932: 11:30 a.m., rating at 225,000 lb per hr, east and west check valve open, three turns on gear valve, 3$^{1}/_{2}$ in. H_2O on forced-draft duct, induced-draft-fan vane opening 98 per cent, induced-draft fan overloaded, overfire draft −0.1; 11:55$^{1}/_{2}$, start to bring rating down; 12:03 p.m., gear valve closed to one turn open, fire in banked condition; 12:48, closed gear valve; 12:57$^{1}/_{2}$, opened gear valve to one turn open; 1:15, opened gear valve to three turns; 1:17, rating at 168,000 lb per hr, induced-draft fan put in high speed; 1:21 p.m., Smoot forced-draft damper stuck closed, and then opened.)

[5] General Superintendent, Montaup Electric Company, Somerset, Mass. Mem. A.S.M.E.

furnace, and an increase in furnace volume on property of limited area.

H. M. Cushing.[6] In connection with the load pick-up tests shown in Figs. 12, 13, and 14, data on a pick-up test in Buffalo might be of interest. As is normal during light-load periods, two boilers rated at 560,000 lb per hr were feeding 65,000 lb per hr, each to an 80,000-kw turbine carrying a 10-megawatt load. The boiler operator was notified that a pick-up would be made, but the time was not given. The electrical operator, when ready to increase, set the bulletin boards to 60 mw, and proceeded to build up the load at a uniform rate to that point in 2 min, and held at that point. The boiler pressure dropped from 460 lb to 390 lb at the 4-min mark, and then came back to normal. A 12-in. rise in boiler-drum level resulted from this pick-up.

Babcock & Wilcox cross-drum boilers, 60 sections wide, 22 tubes high, 24-ft tubes, with a 60-in. drum, were used.

A. G. Christie.[7] The paper is of timely interest, not only on account of the fact that the tests were made upon one of the largest-capacity boilers in the world, but particularly by reason of the great mass of valuable performance data contained in the tests. The twin setting of B. & W. boilers represents a new practise. Similar twin settings for 30,600 sq ft Stirling boilers were designed by McClellan and Junkersfeld, with whom the writer was then associated, for the Lake Shore Station of the Cleveland Electric Illuminating Company, and tests of these boilers were reported by John Wolff in a paper entitled, "Tests of Pulverized-Fuel-Fired Boilers at the Lake Shore Station, Cleveland." (A.S.M.E. Trans., Vol. 47, p. 1255, 1925.) The excellent performance of these boilers led to the use of similar twin boilers and furnaces at Avon Beach and Ashtabula Stations. Mr. Caldwell's boiler operates at a higher capacity than any of these Stirling boilers and appears to have a larger furnace.

The use of smaller boiler drums was advocated a few years ago, but experiences with the water-cooled furnaces at the Gould Street Station indicated the desirability of large water capacity in the boiler drums. When the India Basin Station at San Francisco was designed, the largest drums available (72 in. in diameter) were purchased. The use of this size of drum has since extended, and this size is employed in the Hell Gate boilers.

As Mr. Caldwell points out, these drums simplify control problems and decrease fluctuations of water level. He also refers to its accumulator effect, which may be of considerable value under certain conditions.

Many recent plants employing slag-bottom furnaces have provided water cooling for these bottoms. Mr. Caldwell uses air cooling, undoubtedly on account of the high fusing temperature of the ash, which, as shown in the data, exceeds 2400 F. This high fusing temperature undoubtedly adds to the difficulties experienced in tapping slag. Mr. Caldwell states that fluxes were tried to increase the fluidity of the slag. It would be interesting if he could add some further information on the chemical nature of the ash and the character of the fluxes that were tried. Many suggestions have been made regarding the use of fluxes, but specific data on the action of these are few.

Steam-turbine drives for both forced- and induced-draft fans represent a departure from the current practise of all-electric drive. Have the performances of small turbines been improved and first costs lowered to the point that these again are serious competitors of motors to drive power-plant auxiliaries?

The data upon the response of the boiler to increase in coal feed indicate a rather slow action. This was undoubtedly measured with constant pressure at the superheater outlet throughout the test. One would at first infer that this boiler would not respond quickly to large fluctuations in load on the given turbine. If, however, the steam pressure is allowed to drop when the sudden increase in load occurs, the accumulator effect of the large drum will come into play, and this will permit a sudden increase in the flow of steam to carry the increased load. The contrary effect occurs if pressure is allowed to rise on sudden decrease of load. One can therefore expect such large boilers to meet load swings satisfactorily in actual service.

The test results are unusually complete. One is impressed by the large pressure drop through the superheater at high capacities, and also with the sizeable draft required of the induced-draft fans. However, an overall efficiency of 85 per cent and above was maintained for outputs up to over 900,000 lb per hour, which in itself is a remarkable performance. Fig. 24 indicates that the total equivalent heat required by the boiler auxiliaries remains substantially constant at all loads. The total power consumed by the powdered-coal equipment shows much lower figures than indicated by earlier tests.

The experience gained on these large boilers and their auxiliary equipment must have led to certain ideas on the part of the author in regard to future installations. In the light of this performance, what modifications would Mr. Caldwell recommend in a new plant to meet similar load conditions?

Author's Closure

In regard to the variation in superheat referred to by Mr. Kerr, it should be noted that the tests were conducted with approximately constant excess air. In normal operation the amount of excess air is reduced as the rating increases due to practical considerations, and the resulting superheat curve is consequently flatter than that reported in the test.

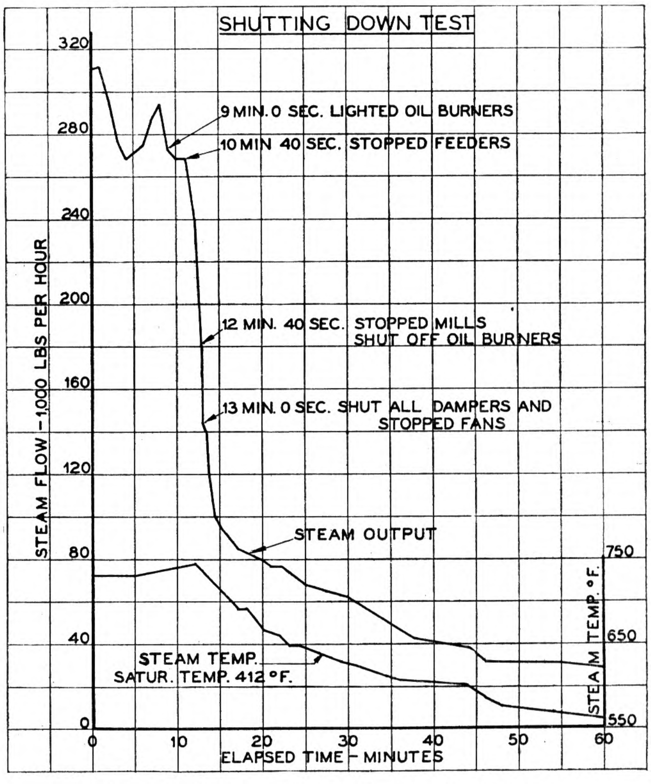

Fig. 36 Shutting-Down Test on Boiler 91

[6] Chief Engineer, Buffalo General Electric Company, Buffalo, N. Y. Mem. A.S.M.E.

[7] Professor of Mechanical Engineering, Johns Hopkins University, Baltimore, Md. Mem. A.S.M.E.

Mr. Drewry calls attention to some of the characteristics of the installation, and among other things mentions the lag in heat output associated with direct firing. Direct firing undoubtedly contributes somewhat to the time lag, but there are other factors which also have an influence. As an indication of the heat inertia of the installation, Fig. 36 is introduced from observations taken during a normal shutdown.

It may be observed that there is considerable lag in reduction of steam output even after the fuel supply to the furnace is interrupted. This indicates the extent of the lag which is independent of the combustion system. Where rapid response to changes in rating is desirable, the design should provide for less water-storage capacity and less heat-storage capacity in the furnace and boiler. On the other hand, a large water-storage capacity and large heat-storage capacity in many instances is a desirable characteristic, since the accumulator effect imparts a certain degree of stability to the steam pressure and steam flow with fluctuating loads. Opinion is divided on the degree of responsiveness which should be designed into steam-generating equipment, and as this consideration is dependent upon the nature of the system load and operating practise, there are many conditions where extremely rapid response is not so important.

Concerning Mr. Hettrick's reference to the distribution of work between the two boilers in the twin setting, it has been found that there is no noticeable difference in output with equalizing dampers wide open. In regard to the distribution of coal to the burners, this is controlled by a dividing arrangement for each mill which supplies its three burners. The coal from each mill divides fairly uniformly, and compensating adjustments are made at the secondary air dampers, based on observation of furnace conditions through openings provided for this purpose.

Regarding the question of large drum capacity, water-level fluctuations are less violent with fluctuating loads and afford the attendant more time to attend to his duties than would otherwise be the case.

Replying to Professor Christie's inquiry concerning the slag, the analysis herewith is typical of two of the coals which are used.

The fluxes used were fluorspar and soda ash, the latter appearing to be somewhat more effective. The choice of steam-driven fans was due largely to local conditions and space limitations which somewhat favored the use of steam turbines. Under

ASH ANALYSIS, PER CENT

	Pocahontas	Revloc
Loss on ignition......	2.5	1.5
SiO_2................	49.8	33.8
Fe_2O_3...............	16.8	24.7
Al_2O_3..............	24.7	35.7
CaO................	3.9	2.0
MgO................	2.0	1.2
	99.7	98.9

ordinary conditions motor drives would be expected to show a substantial advantage, unless handicapped by a high-capacity demand charge.

Professor Christie's last question is rather broad, and the author will only attempt to generalize on the subject. In the absence of space or height limitations, it would seem that the heating surface should be somewhat more efficiently utilized than in the conventional type of boiler described in the paper; that is, the unit should be more nearly countercurrent than customary. Where conditions permit the use of a steaming economizer, this may be accomplished with much less boiler surface and with good operating and investment efficiency.

The use of the slag-bottom furnace in many cases appears warranted as a heat accumulator, aside from its benefits to combustion stability. Where very rapid changes in output are demanded, however, the unit should be designed with a minimum of water storage and heat storage to eliminate this source of lag. In the use of direct firing, minor modifications in the arrangement of mills and burners supply may be provided to approximate the characteristics of a bin and feeder system in order to eliminate the lag incidental to the use of direct firing. The superheater and its supporting arrangement is one of the major problems in boiler design, especially with the relatively high-steam temperatures which are now prevalent. Wherever possible, water-cooled supports should be provided, even though this introduces some circulating problems in the water circuit. With higher pressures and the average water supply, some form of steam washing or purification would probably be justified. Some provision for steam-temperature control is essential in order to maintain at all ratings the highest possible steam temperatures permitted by the turbine design.

The type of boiler equipment which might be selected for any condition could only be determined by a careful evaluation, and the foregoing comments merely indicate an opinion of what might be arrived at by such an evaluation under present conditions.