VARIABLES AFFECTING THE FUEL-COST FACTOR AT THE VIRGINIA POLYTECHNIC INSTITUTE POWER PLANT

by

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and

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Head of Department

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Dean of Engineering

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Chairman, Graduate Committee

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INTRODUCTION

Before the new steam generator was installed, in 1939 in the power plant of the Virginia Polytechnic Institute, best operating characteristics of the two Casey-Hedges units had been determined by previous thorough boiler tests according to the A.S.M.E. Boiler Code.

With the new unit, however, generating from 20,000 to 35,000 lb. of steam per hour on the average, the demand on the older units decreased even when the increased load was considered. It became necessary, therefore, to establish a new criterion on which to operate economically and efficiently these units.

At present the fuel bed in unit No. 3 is maintained by a four retort underfeed stoker which has secondary rams to assist in moving the bed to the rear. Primary air is supplied through three sets of tuyeres between the retorts, and from each side wall secondary air is supplied. The steam engine drive on the stoker is hand controlled but the air supply is governed by the Hagan combustion control system. If unit No. 4 should need extra air for combustion, due to a sudden increase in load, it is supplied by forced-draft fans controlled by the Hagan system. If at the same time, load on unit No. 3 is decreasing, its air supply is increased as the air supply to both units is delivered from the same air duct. This is one reason why excessive excess air is supplied generally to both furnaces. This matter will be discussed more fully later. This arrangement of air supply obviously make hand control of the stoker important and is mainly the reason for rapid raising or lowering of the fuel bed.

As the coal moves slowly from the ram to the hand operated ash dump it is volatilized, coked and burned. The refuse is left on the dump grates until the combustion is thought complete and its temperature has decreased to the point where loss of heat in the refuse is low.

The fuel bed in unit no. 4 is maintained by two Detroit Roto stokers (left and right) which pitch the fine particles of semi-anthracite culm into the furnace over the fire, where they burn in suspension, if the temperature of the fire is sufficient. Small particles, that do not burn in the air, are thrown to the rear into a pile. Large or wet particles usually fall in the front with average particles falling in the middle. The dump grates occupy the entire rear section of the furnace. The ashes are dumped when they pile up on the ash grates at the rear, the front of the bed is shoved back, spread out and if the remainder of the bed in the boiler is too deep, the back is dumped again and the hot coals are leveled.

It is a known fact that the installation of the new unit has altered operating conditions. It appears, therefore, that a study of present operating practice should be made. It is believed that this information would help to maintain a more constant fuel-cost factor. The planning and performing of the tests reported herein was done with this aim.

The cooperation and advice of Prof. W. T. Ellis, Prof. L. I. Cothern, Prof. J. I. Clower and the superintendent and personnel of the power plant were deeply appreciated by the authors.

C. H. L.

O. N. H.

VARIABLES AFFECTING THE FUEL-COST FACTOR AT THE VIRGINIA POLYTECHNIC INSTITUTE POWER PLANT

INVESTIGATION

1. Purpose:

The purpose of this investigation was to study the regular daily boiler operations in the Virginia Polytechnic Institute power plant. There are five steam generating units in the plant, which are numbered consecutively from one to five. Units Nos. 1 and 2 are only used as standbys and are used so seldom that their operation was not investigated. Units Nos. 3 and 5 burn bituminous coal and No. 4 burns local semi-anthracite culm.

Since the new No. 5, 45,000 lb. per hour unit was installed it has been carrying a fairly constant load, ranging from 20,000 lb. per hour to 35,000 lb. per hour depending upon the seasonal loads. The remainder of the load is distributed between units Nos. 3 and 4. The authors believe the fluctuation of this remaining load between these units accounts for some of the variation of the fuel-cost factor, this being the cost of steam in cents per million B.t.u.

In general, the results obtained at the V. P. I. power plant from tests conducted under conditions specified in codes are far different from those obtained under everyday operations. The loads, generally, do not remain constant, fuel bed levels vary without regard to load, and combustion is neither economically nor theoretically perfect. With high loads on these units, these factors must be controlled to obtain the output desired. With light loads, heavy losses may occur due to sluggish operation. Based on the data derived from this investigation it is believed that a more practical and satisfactory operating procedure can be established.

2. Method:

The plan of investigation was to determine the average operating characteristics for the units Nos. 3 and 4 from twelve hour observation tests run separately on each. No attempt was made to control varying factors as recommended by the A.S.M.E. Boiler Code, nor were operating instructions of any sort given the operating force.

The tests were run from seven A.M. until seven P.M. At the beginning and ending of each test the coal hopper was filled to approximately the same level. Starting at seven o'clock and continuing every twenty minutes thereafter for twelve hours, readings were taken of the lb. coal burned, lb. steam generated, flue gas, superheated steam, combustion air, feedwater and room temperature, barometric, steam, feedwater and draft pressures and Bailey chart values of air and steam flow. The flue gases were analyzed for CO_2, O_2 and CO. No attempt was made to regulate any of these values. An average of the day's operating record was desired.

Samples of the coal and refuse were taken for analyses. (See Analyses of the Coal and Refuse).

Test totals for lb. of coal used and water evaporated were taken. Due to the inconvenience of removing the hot refuse of the semi-anthracite from the pit of unit No. 4, the procedure of determining quantity of refuse as suggested in the Boiler Code was followed.*

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* TEST CODE FOR STATIONARY STEAM GENERATING UNITS (1936). Published by A.S.M.E., New York. Page 13, Item 86.

Method of Coal Analysis:

A one thousand lb. sample of the coal burned during these tests was taken from the hopper of the stoker. This sample was taken to the Fuel Laboratory in the New Minerals Building for analysis. The coal was crushed to one-quarter inch size, coned and quartered to about twenty-five lb. The sample was then run through a roll crusher until it would pass through a twenty mesh screen. It was then riffled to two hundred grams. This sample was ground in the ball mill to 60 mesh. Any of the large particles of coal left were crushed by hand on the surface plate crusher with the crushing hammer. This coal was then ready for analysis. The proximate analysis was run on the coal in accordance with the A.S.T.M. Standards with standard equipment. The per cent fixed carbon, volatile matter, moisture and ash were reported.

Method of Refuse Analysis:

A one thousand lb. representative sample of the refuse was taken from the pit during each test. This was taken to the Fuel Laboratory where it was prepared for analysis similarly to the coal sample. The analysis was run in accordance with the A.S.T.M. code for determining the percentage of combustible in the refuse.

3. Apparatus:

A. Steam Generators:

Both of the steam generators tested in this study were Casey-Hedges, cross-drum, inclined header, water-tube boilers, rated at 354 Hp. at 165 lb. per. sq. in. These two units were manufactured by the Casey-Hedges Company, Chattanooga, Tenn. Each unit has 3,540 sq. ft.

of heating surface in the boiler and 540 sq.ft. of heating surface in the Foster-Wheeler superheater.

B. Stokers:

Unit No. 3 is equipped with a Type U Detroit underfeed stoker having four retorts. There are 68 sq.ft. of grate surface in each boiler.

Unit No. 4 is equipped with a Detroit Roto-Stoker (No. 1049). There are two rotors on this unit with electric drive operated by a Hagan Combustion control. Both of the stokers were made by the Detroit Stoker Company, Monroe, Mich.

C. Fans:

Two No. 2½ FD fans manufactured by the Clarage Fan Company, Kalamazoo, Mich., supplied the forced air for combustion to both of these units. One fan is driven by an electric motor and the other is driven by a steam turbine.

D. Feedwater Heaters:

The feedwater is passed through a 85,000 lb. per hour feedwater heater of the direct contact type, manufactured by the Cochrane Corporation, Philadelphia, Penn.

E. Feedwater Pumps:

The water is pumped into the boilers by either of three pumps. One is an electric, motor driven, centrifugal pump of 55 gallons per minute capacity against a head of 550 ft. The other two pumps are 115 gallons per minute centrifugal pumps, one with an electric drive and the other with a steam turbine drive. All of the pumps were manufactured by the Dayton Dowd Company, Quincy, Ill.

F. Coal and Ash Handling Equipment:

The coal larry, which supplies coal to all of the furnaces, was manufactured by the Jeffrey Manufacturing Company, Columbus, Ohio and is equipped with a Fairbanks weighing beam.

The pneumatic ash handling equipment, which removes the refuse from each of the furnace pits, was manufactured by the United Conveyor Corporation, Chicago, Ill.

G. Coal and Ash Testing Equipment:

The equipment used in the Fuel Engineering Laboratory to analyze the samples of coal and ash was:

Moisture Oven: Burrell Supply Co., Pittsburgh, Penn.

Ash Oven: Hoskins Electric Furnace Co., Detroit, Mich.

5 x 6 Inch Jaw Crusher: Denver Equipment Co., Denver, Colo.

Roll-Crusher: Denver Equipment Co., Denver, Colo.

Jar-Mill: Burrell Supply Co., Pittsburgh, Penn.

Disc Pulverizer: Braun's Co., Los Angeles, Calif.

Screens: W. S. Taylor Company, Cleveland, Ohio.

H. Gas Sampling Apparatus:

The gas sampling apparatus used was designed and installed by the Fuel Engineering fellows of 1932. It is composed of four one-quarter inch wrought iron pipes to take the sample from the second pass to the outside of the boiler walls. These pipes on the intake ends are sawed on a taper, so as to expose a larger opening. They are turned with the long edge to the path of the gases such as to present a baffle to soot and fly ash and prevent their becoming clogged. From the four one-quarter inch pipes, four three-eighths inch wrought iron pipes were run down the outside of the walls to a point about ten feet from the floor line to which they are connected to Mueller streamline one-half inch copper tubing. The joints of this copper tubing are soldered, thereby, giving assurance against air leakage. The pipes from Nos. 3 and 4 units were run the same to the wall in back of the units. Here the four pipes are connected to four, three-way valves, to which four, one-eighth inch copper tubes are connected and extended into a water jar, where the gases are bubbled through water. In each of these copper tubes is a needle valve which enables an adjustment to be made in order to obtain equal flow through each line. The jar is filled approximately one-half full of water, thereby, providing a storage for the gases. The gases are pulled by an ejector which has the suction line in the top of the jar. This enables a rapid change of charges of gases. The charges of gas are then drawn into the Orsat equipment to be analyzed.

I. Flue Gas Analysis Equipment:

The flue gas equipment used in these tests was purchased from the Fisher Scientific Company, Pittsburgh, Penn.

DATA AND RESULTS OF CASEY-HEDGES STEAM GENERATING UNIT TEST

Location	V. P. I. Heating and Power Plant, Blacksburg, Va.
Owner	Commonwealth of Virginia
Make and Type of Boiler	354 Hp., Casey-Hedges, Cross Drum Boiler
Make and Type of Superheater	Type S, Foster Wheeler
Fuel Burning Equipment	Detroit Underfeed Multi-Retort Stoker

Description and Dimensions

Boiler Heating Surface	3540 sq.ft.
Superheater Surface	540 sq.ft.
Total Heating Surface	4080 sq.ft.
Grate Surface	68.3 sq.ft.
Volume of Combustion Space	614.7 cu.ft.
Furnace, center of grate to nearest heating surface	9 ft.
Furnace volume per sq.ft. boiler heating surface	0.174 cu.ft./sq.ft.
Method of Producing Draft	Forced (Clarage Fans)
Fuel Burned	Clintwood Nut and Slack

Analyses of Clintwood Coal, Panther Coal Co., Inc.

* Proximate Analysis (as Rec'd)

Moisture		3.6 %
Volatile Matter		30.9 %
Fixed Carbon		59.8 %
Ash		5.7 %
Heating Value as Fired	B.t.u./lb.	14055
Heating Value Dry	B.t.u./lb.	14580

** Ultimate Analysis

Carbon	81.0 %
Hydrogen	5.0 %
Oxygen	6.0 %
Nitrogen	1.2 %
Sulphur	0.9 %
Ash	5.9 %

* Proximate coal analyses, District #8, National Coal Publication.

** Calculated from Table XXX, page 325, Vol. II, Heat-Power Engineering, Barnard, Ellenwood and Hirshfeld.

Time Test #1 Boiler #3	Flue Gas Analysis CO_2	O_2	CO	N_2	Boiler Press.	Steam (Feed-water) Press.	Wind-box Rear	Wind-box Front	Fire Draft	Stack Draft	Front Bed Depth	Rear Bed Depth	Air Rate	Steam Rate	Flue Gas Temp.	Super-heat Temp.	Feed-water Temp.	Comb. Air Temp.
	% by Vol.				#/sq.in. gage			in. of water			in.		in. H_2O	%	°F			
7:00	10.0	10.2	0.2	79.6	168	2	1.2	2.8	-0.05	-0.30	6	Medium	3.5	115	540	480	219	72
7:20	9.5	9.5	0.0	81.0	175	3	1.7	3.5	-0.04	-0.30	8	High	3.6	150	540	475	220	74
7:40	10.0	10.0	0.0	80.0	173	2½	1.7	3.3	-0.02	-0.30	8	High	3.8	150	560	475	220	76
8:00	8.0	11.0	0.0	81.0	170	2¼	1.7	3.5	0.00	-0.30	6	High	3.8	150	555	480	220	70
8:20	9.0	11.0	0.0	80.0	170	3	1.7	3.5	-0.01	-0.30	6	Medium	3.5	150	555	480	220	68
8:40	10.5	8.9	0.0	80.6	165	2½	1.5	3.2	0.00	-0.25	6	Medium	3.8	150	560	480	220	72
9:00	9.0	11.0	0.0	80.0	165	2½	1.5	3.5	-0.02	-0.25	8	Medium	3.8	150	560	480	220	72
9:20	10.4	9.0	0.4	80.2	168	2½	1.5	3.4	-0.02	-0.25	8	Medium	3.9	155	560	485	220	74
9:40	9.2	10.6	0.2	80.2	170	2½	1.5	3.3	-0.05	-0.25	6	Medium	3.9	150	555	485	220	74
10:00	8.4	11.8	0.0	79.8	170	3	1.5	3.4	-0.05	-0.25	8	Medium	4.0	160	555	480	220	76
10:20	9.2	9.6	0.0	81.2	165	2¾	1.5	3.4	0.05	-0.25	8	Medium	4.0	160	560	485	220	76
10:40	8.4	11.8	0.0	79.8	170	3	1.5	3.4	0.05	-0.25	8	Low	3.8	150	570	485	219	78
11:00	9.0	10.4	0.0	80.6	173	2¾	1.5	3.3	0.05	-0.25	8	Low	3.8	150	570	490	219	78
11:20	9.5	11.1	0.0	79.4	175	2¾	1.5	3.2	0.05	-0.25	6	Low	3.9	145	570	495	219	78
11:40	11.0	8.4	0.0	80.6	170	2½	1.5	3.3	0.05	-0.25	6	Low	4.0	150	570	490	219	78
12:00	7.0	13.0	0.0	80.0	180	2½	1.4	3.0	0.03	-0.25	1	Low	3.8	135	570	495	219	80
12:20	7.0	13.2	0.4	79.4	173	2¼	1.5	3.3	0.05	-0.25	1	Low	3.9	160	580	490	219	80
12:40	8.5	12.7	0.0	78.8	180	2½	0.9	2.0	-0.08	-0.30	1	Low	3.2	100	560	505	219	80
1:00	9.8	10.4	0.0	79.8	175	2½	1.2	2.8	-0.03	-0.30	1	Low	3.5	130	540	485	219	80
1:20	8.2	11.8	0.8	79.2	166	2	1.6	3.6	0.05	-0.15	6	Low	3.4	170	530	475	218	85
1:40	8.2	12.0	0.0	79.8	168	2	1.5	3.6	0.05	-0.15	8	Low	3.5	165	545	475	217	83
2:00	7.0	13.0	0.0	80.0	171	2	1.8	4.2	0.15	-0.10	8	Low	3.6	175	565	480	217	84
2:20	7.2	12.8	0.0	80.0	175	2	1.6	3.6	0.09	-0.10	6	Low	3.7	185	575	480	213	86
2:40	7.4	13.6	0.3	78.7	166	2	1.6	3.8	0.08	-0.15	4	Low	3.7	160	570	485	214	84
3:00	9.5	10.7	0.0	79.8	170	2	1.6	3.6	1.01	-0.10	4	Low	3.8	135	560	485	215	86
3:20	8.0	12.0	0.1	79.9	175	2	1.7	3.8	1.00	-0.10	1	Low	3.7	155	570	485	215	84
3:40	8.2	11.4	0.1	80.3	176	2	1.8	3.6	0.06	-0.15	1	Low	3.8	175	560	485	217	86
4:00	7.9	12.3	0.1	79.7	185	2	1.9	3.8	0.08	-0.10	1	Low	3.5	135	560	475	218	86
4:20	14.0	5.2	0.4	80.4	180	2	1.4	2.8	-0.01	-0.20	2	Low	3.0	140	550	480	212	86
4:40	9.2	11.9	0.0	78.9	170	2	1.9	3.9	0.06	-0.15	4	Low	3.4	155	560	485	217	86
5:00	9.0	10.8	0.0	80.2	170	2¼	1.8	3.7	0.07	-0.15	8	Medium	3.5	175	560	485	218	88
5:20	12.5	7.7	0.2	80.1	173	2¼	1.9	3.8	0.05	-0.10	8	Low	3.4	165	555	480	218	90
5:40	11.5	7.5	0.0	81.0	178	2½	1.9	3.7	0.07	-0.10	6	Low	3.5	160	560	480	219	91
6:00	11.0	9.0	0.0	80.0	180	2½	1.7	3.7	0.15	-0.10	1	Low	3.5	125	560	485	220	90
6:20	11.2	8.7	0.1	80.0	170	2½	1.8	3.6	0.00	-0.25	1	Low	4.0	125	560	480	219	90
6:40	12.8	7.0	0.0	80.2	175	2	1.5	3.5	-0.05	-0.20	2	Low	3.8	125	560	490	215	90
Avg.	9.3	10.6	0.1	80.0	172	2½	1.6	3.4	0.12	-0.21	5	Medium	3.7	150	559	484	218	81

Front Bed Depth (11:20 through 5:00): Above front observation door

Time Test #2 Boiler #3	Flue Gas Analysis CO_2	O_2	CO	N_2	Boiler Press.	Steam (Feed-water) Press.	Wind-box Rear	Wind-box Front	Fire Draft	Stack Draft	Front Bed Depth	Rear Bed Depth	Air Rate	Steam Rate	Flue Gas Temp.	Super-heat Temp.	Feed-water Temp.	Comb. Air Temp.
	% by Vol.				#/sq.in. gage			in. of water			in.		in. H_2O	%	°F			
7:00	8.2	11.8	0.3	79.7	173	2½	1.8	3.7	0.07	-0.10	3	Medium	3.4	150	550	480	217	81
7:20	13.8	6.2	0.0	80.0	169	2¼	2.0	4.0	0.15	-0.05	6	Medium	3.6	155	560	480	219	80
7:40	9.8	9.9	0.1	80.2	171	2	1.7	3.3	0.06	-0.10	6	Medium	3.3	140	550	480	216	82
8:00	10.0	9.9	0.2	79.9	174	2	1.6	3.2	0.05	-0.15	7	Medium	3.4	135	555	480	214	79
8:20	9.4	10.6	0.0	80.0	170	2	1.6	3.1	0.06	-0.10	6	Medium	3.4	145	555	485	219	76
8:40	10.6	8.8	0.0	79.6	168	2¾	1.5	3.1	0.12	-0.05	4	Low	3.5	145	550	485	220	78
9:00	8.5	11.6	0.0	79.9	173	2¾	1.4	3.1	0.09	-0.10	3	Low	3.4	145	550	485	219	76
9:20	10.0	10.0	0.0	80.0	175	2½	1.4	3.1	0.05	-0.15	4	Low	3.3	140	550	485	218	78
9:40	7.5	12.8	0.1	79.7	174	2¼	1.5	3.0	0.05	-0.15	4	Low	3.3	130	545	480	219	79
10:00	10.2	8.8	0.0	81.0	175	2½	1.3	2.9	0.05	-0.15	5	Medium	3.3	140	545	485	219	82
10:20	9.2	10.1	0.1	80.6	182	2	1.3	2.7	0.01	-0.15	6	Medium	3.1	100	535	495	220	83
10:40	9.8	10.0	0.0	80.2	175	2¼	1.3	3.0	0.02	-0.15	7	Medium	3.3	165	555	475	218	85
11:00	10.8	8.8	0.0	80.4	174	2¼	1.5	2.9	0.04	-0.15	6	Medium	3.2	160	560	480	218	85
11:20	8.8	11.0	0.4	79.8	179	2	1.5	2.9	0.04	-0.15	2	High	3.4	115	560	485	218	84
11:40	11.8	7.0	0.0	81.2	174	2	1.6	2.8	0.04	-0.15	2	Medium	3.2	140	550	480	217	85
12:00	12.0	7.2	0.0	80.8	175	2	1.8	2.9	0.04	-0.15	2	High	3.1	155	550	475	217	86
12:20	10.0	9.5	0.0	80.5	182	2¼	1.5	3.0	0.04	-0.15	3	Medium	3.1	140	550	485	218	86
12:40	10.2	9.8	0.1	79.7	175	1½	1.5	3.0	0.05	-0.15	6	High	3.3	145	550	475	213	85
1:00	10.6	8.4	0.0	81.0	179	1	1.3	2.5	0.02	-0.15	8	Medium	3.1	150	550	480	215	86
1:20	10.5	9.5	0.0	80.0	167	1½	1.8	3.5	0.12	-0.10	8	Medium	3.4	150	560	475	218	89
1:40	9.0	11.0	0.0	80.0	166	2	1.6	3.3	0.10	-0.10	8	Low	3.5	175	540	475	220	89
2:00	8.6	11.4	0.2	79.8	170	2¼	1.5	2.9	0.10	-0.10	8	Low	3.4	160	550	480	220	88
2:20	8.4	11.6	0.0	80.0	170	2	1.2	2.7	0.05	-0.15	6	Low	3.4	140	540	485	218	86
2:40	9.2	10.8	0.0	80.0	170	2	1.3	2.8	0.06	-0.15	6	Low	3.4	130	540	485	219	86
3:00	11.2	8.8	0.0	80.0	167	2	1.2	2.9	0.06	-0.15	6	Low	3.4	135	540	480	219	88
3:20	11.4	8.6	0.2	80.0	165	2	1.4	3.1	0.08	-0.15	8	Low	3.4	150	550	480	220	86
3:40	8.0	12.6	0.0	79.4	172	2	1.4	3.2	0.06	-0.15	6	Medium	3.4	145	550	485	217	86
4:00	7.8	12.2	0.2	79.8	170	2¼	1.4	3.2	0.05	-0.15	6	Medium	3.4	140	540	480	220	86
4:20	11.0	9.2	0.0	79.8	168	2	1.5	3.4	0.04	-0.15	6	Medium	3.4	140	550	480	218	85
4:40	10.0	10.0	0.0	80.0	173	2	1.7	3.4	0.04	-0.15	6	Medium	3.4	150	550	490	219	86
5:00	8.8	11.6	0.0	79.6	170	2	1.5	3.3	0.05	-0.20	8	Low	3.4	135	550	485	220	86
5:20	10.0	10.0	0.0	80.0	172	2	1.6	3.3	0.05	-0.15	8	Low	3.4	140	550	485	220	85
5:40	10.2	8.8	0.4	80.6	175	2	1.5	3.3	0.04	-0.20	4	Medium	3.4	160	550	480	220	86
6:00	11.4	9.0	0.0	79.6	175	2	1.4	3.1	0.02	-0.20	6	Low	3.3	135	540	485	217	85
6:20	8.5	11.9	0.6	79.0	170	2	1.5	3.4	0.04	-0.20	8	Low	3.4	145	540	480	216	85
6:40	9.2	10.8	0.0	80.0	175	2	1.4	3.0	0.00	-0.20	8	Low	3.4	150	540	485	216	85
Avg.	9.9	9.9	0.1	80.1	173	2	1.5	3.1	0.06	-0.14	6	Medium	3.3	144	549	482	218	84

Above front observation door

Time Test #3 Boiler #3	Flue Gas Analysis CO_2	O_2	CO	N_2	Boiler Press.	Steam Feed-water Press.	Wind-box Rear	Wind-box Front	Fire Draft	Stack Draft	Front Bed Depth	Rear Bed Depth	Air Rate	Steam Rate	Flue Gas Temp.	Super-heat Temp.	Feed-water Temp.	Comb. Air Temp.
	% by Vol.				#/sq.in. gage			in. of water			in. (Above front observation door)		in. H_2O	%		°F		
7:00	9.7	11.6	0.2	78.5	174	3¼	1.4	2.9	-0.04	-0.30	3	Medium	3.4	130	530	475	221	74
7:20	9.8	10.7	0.3	79.2	175	3	1.7	3.3	0.04	-0.15	4	Medium	3.4	155	540	475	221	75
7:40	10.8	9.1	0.0	80.1	175	2	1.4	2.9	0.00	-0.15	6	Medium	3.5	155	550	485	216	74
8:00	11.2	8.3	0.0	80.5	174	2	1.5	3.1	0.03	-0.20	6	Medium	3.5	150	545	485	215	74
8:20	10.0	10.0	0.0	80.0	170	2¾	1.6	3.3	0.05	-0.15	8	Medium	3.5	130	550	485	220	76
8:40	8.8	12.0	0.0	79.2	170	2½	1.6	3.2	0.04	-0.20	8	High	3.5	125	540	485	220	78
9:00	9.9	9.9	0.2	80.0	175	2¼	1.5	3.0	0.03	-0.20	8	High	3.6	140	550	490	219	78
9:20	10.8	10.0	0.2	79.0	170	2¾	1.3	3.1	0.09	-0.10	8	Low	3.3	145	545	485	220	79
9:40	11.2	8.2	0.0	80.6	175	2¼	1.7	3.9	0.15	-0.05	9	Low	3.9	155	570	490	217	78
10:00	11.0	9.0	0.0	80.0	175	2¼	1.6	3.8	0.15	-0.10	9	Low	3.8	160	570	490	217	81
10:20	9.5	10.3	0.0	80.2	177	2	1.5	3.4	0.10	-0.15	6	Low	3.8	125	565	500	215	83
10:40	9.2	10.6	0.3	79.9	170	2	1.4	2.6	0.08	-0.15	5	Low	3.5	140	540	485	215	86
11:00	10.2	10.4	0.0	79.2	172	2½	1.3	2.5	0.00	-0.20	5	Low	3.4	145	540	485	219	84
11:20	9.3	10.5	0.0	80.2	170	2½	1.6	3.0	0.03	-0.15	5	Medium	3.5	155	555	475	220	84
11:40	10.0	9.9	0.1	80.0	173	2¾	1.7	3.2	0.02	-0.20	4	Medium	3.4	160	550	480	220	87
12:00	10.2	9.3	0.0	80.5	170	2¾	1.8	3.3	0.01	-0.20	3	Medium	3.4	150	550	480	220	86
12:20	8.5	11.2	0.3	80.0	170	2	1.7	3.1	0.02	-0.20	6	Medium	3.4	140	545	485	217	88
12:40	8.2	11.3	0.0	80.5	175	2	1.8	3.2	0.02	-0.20	8	Medium	3.5	140	545	480	215	88
1:00	8.3	12.6	0.3	78.8	174	2¼	1.7	3.2	0.03	-0.15	8	Medium	3.4	145	535	485	217	88
1:20	5.5	14.5	0.0	80.0	170	2½	1.8	3.1	0.06	-0.15	8	Medium	3.4	150	540	480	220	88
1:40	7.8	12.4	0.2	79.6	172	2½	1.7	3.3	0.08	-0.15	8	Medium	3.4	165	550	485	220	88
2:00	10.0	10.8	0.0	79.2	165	2	1.8	3.4	0.07	-0.15	8	Medium	3.4	145	550	485	214	86
2:20	9.8	11.2	0.0	79.0	174	2	1.8	3.5	0.08	-0.15	8	Low	3.6	140	550	485	214	86
2:40	6.2	12.8	0.4	80.6	174	2½	1.7	3.2	0.08	-0.15	8	Low	3.4	180	560	480	220	85
3:00	8.2	10.6	0.4	80.8	175	2½	1.8	3.5	0.10	-0.10	6	Medium	3.6	160	560	485	220	85
3:20	7.6	13.0	0.2	79.2	170	2½	1.8	3.4	0.10	-0.10	8	High	3.4	165	560	480	220	84
3:40	7.0	13.0	0.8	79.2	175	2½	2.0	3.6	0.12	-0.10	6	High	3.6	180	565	485	220	84
4:00	8.0	12.0	0.4	79.6	174	2½	2.0	3.6	0.12	-0.10	6	High	3.6	190	570	485	220	86
4:20	9.8	10.0	0.2	80.0	170	2½	1.8	3.4	0.12	-0.10	6	High	3.5	180	560	480	220	84
4:40	12.0	8.2	0.8	79.0	173	2¼	1.7	3.3	0.10	-0.10	6	High	3.4	180	560	490	220	85
5:00	10.2	9.8	0.0	80.0	175	2¼	1.8	3.4	0.10	-0.10	6	High	3.4	150	550	485	220	85
5:20	7.9	11.7	0.2	80.2	173	2¼	1.9	3.6	0.12	-0.10	8	High	3.5	175	570	480	220	85
5:40	10.2	9.8	0.0	80.0	173	2¼	1.7	3.3	0.10	-0.10	8	High	3.4	170	560	485	220	85
6:00	10.0	9.8	0.2	80.0	172	2¼	1.6	3.3	0.08	-0.10	10	High	3.4	160	550	485	220	84
6:20	9.2	10.0	0.0	80.8	170	2¼	1.6	3.3	0.08	-0.10	10	High	3.4	160	550	480	220	84
6:40	9.0	12.0	0.4	78.6	170	2½	1.6	3.2	0.07	-0.10	10	High	3.4	155	550	480	220	85
Avg.	9.3	10.7	0.2	79.8	172	2¼	1.7	3.3	0.07	-0.14	7	High	3.5	154	552	484	218	83

Time Test #4 Boiler #3	Flue Gas Analysis CO_2	O_2	CO	N_2	Boiler Press.	Steam (Feed-water) Press.	Wind-box Rear	Wind-box Front	Fire Draft	Stack Draft	Front Bed Depth	Rear Bed Depth	Air Rate	Steam Rate	Flue Gas Temp.	Super-heat Temp.	Feed-water Temp.	Comb. Air Temp.
	% by Vol.				#/sq.in. gage			in. of water			in.		in. H_2O	%		°F		
7:00	5.0	15.0	0.4	79.6	165	3	0.0	0.0	-0.45	-0.40	10	Medium	1.2	60	440	440	222	88
7:20	6.0	14.6	0.0	79.4	165	3	0.0	0.0	-0.45	-0.40	10	Medium	1.4	55	440	440	222	88
7:40	7.0	13.6	0.0	79.4	165	3	0.0	0.0	-0.44	-0.35	12	Medium	1.3	55	430	440	222	86
8:00	6.0	13.8	0.0	80.2	170	3	0.5	1.2	-0.18	-0.25	12	Medium	1.6	70	460	450	222	85
8:20	6.4	13.8	0.0	79.8	167	3	0.7	1.5	-0.10	-0.20	12	Medium	1.6	70	460	450	222	88
8:40	6.0	14.2	0.6	79.2	165	3	1.0	2.1	-0.02	-0.10	14	Medium	1.6	75	460	450	221	88
9:00	7.8	13.2	0.0	79.0	173	2¾	1.0	2.0	0.00	-0.10	14	High	1.7	100	500	460	220	88
9:20	6.4	13.2	0.4	80.0	170	2¾	0.4	1.0	-0.17	-0.25	14	High	1.7	80	490	465	220	88
9:40	6.2	14.8	0.0	79.0	175	2¾	0.9	1.8	0.12	0.00	14	High	1.9	110	520	475	220	88
10:00	6.0	14.2	0.0	79.8	173	2¾	0.7	1.5	0.10	0.00	14	High	1.9	100	520	475	220	88
10:20	6.0	14.0	0.0	80.0	173	2¾	0.8	1.7	0.10	0.00	14	High	1.9	90	520	480	220	90
10:40	6.0	14.0	0.0	80.0	170	2¾	0.6	1.4	0.05	-0.10	12	Medium	2.4	90	520	485	220	90
11:00	7.0	13.6	0.4	79.0	175	2½	0.5	1.3	0.06	-0.10	10	Medium	2.5	70	520	490	220	92
11:20	6.4	14.0	0.2	79.4	170	2½	0.6	1.3	0.07	-0.05	10	Medium	2.6	70	515	490	220	92
11:40	7.2	13.2	0.0	79.6	177	2¼	0.5	1.0	0.05	-0.10	8	Medium	2.5	75	520	495	219	94
12:00	7.0	14.0	0.0	79.0	180	2¼	0.2	0.9	-0.13	-0.20	6	Medium	2.2	90	525	495	219	94
12:20	6.4	13.6	0.0	80.0	178	2¼	0.2	0.9	-0.15	-0.20	2	Medium	1.8	70	500	475	219	92
12:40	7.0	13.4	0.2	79.4	176	2¼	0.2	0.9	-0.16	-0.25	1	Medium	1.7	70	480	465	219	92
1:00	6.8	13.2	0.0	80.0	170	2¼	0.0	0.4	-0.30	-0.30	1	Medium	1.6	65	450	455	219	92
1:20	5.2	15.4	0.2	79.2	174	2¼	0.3	1.0	-0.11	-0.15	1	Medium	1.8	70	485	455	219	95
1:40	5.0	15.7	0.0	79.3	170	2¼	0.4	0.9	-0.12	-0.15	1	Medium	1.8	70	480	460	218	96
2:00	7.2	13.2	0.0	79.6	165	2¼	0.5	0.9	-0.11	-0.15	4	Low	1.9	75	485	465	219	96
2:20	7.3	13.2	0.0	79.5	170	2¼	0.6	0.9	-0.10	-0.15	6	Low	1.8	75	480	465	218	96
2:40	6.4	13.0	0.2	80.4	174	2¼	0.5	0.9	-0.12	-0.15	6	Medium	1.7	70	475	460	219	97
3:00	7.5	13.0	0.4	79.1	175	2¼	0.5	0.9	-0.14	-0.15	6	Low	1.7	70	470	460	219	97
3:20	7.5	13.5	0.0	79.0	170	2¼	0.8	1.8	-0.07	-0.15	7	Low	2.0	70	485	460	218	97
3:40	5.2	13.8	0.1	80.9	168	2¼	0.6	1.7	-0.05	-0.15	9	Medium	2.0	75	500	465	218	96
4:00	8.5	12.5	0.2	78.8	170	2¼	0.9	2.0	0.01	-0.05	10	Low	2.2	100	515	470	218	96
4:20	8.5	12.3	0.3	78.9	175	2¼	0.7	1.6	-0.04	-0.10	14	Low	2.2	96	520	475	218	96
4:40	6.5	13.5	0.2	78.8	170	2½	0.7	1.7	-0.05	-0.15	14	Medium	2.2	80	500	475	218	96
5:00	5.8	15.2	0.2	78.8	170	2½	0.8	1.8	-0.03	-0.10	14	Low	2.2	90	510	465	219	94
5:20	6.2	13.7	0.0	80.1	180	2¾	0.5	1.2	-0.19	-0.15	14	Medium	2.2	90	520	475	219	92
5:40	7.8	12.8	0.2	79.2	175	2¼	0.5	1.2	-0.01	-0.15	14	Medium	2.0	90	500	465	218	92
6:00	5.3	14.5	0.4	79.8	180	2½	0.0	0.8	-0.40	-0.25	14	Medium	2.0	90	495	460	218	92
6:20	4.0	17.0	0.0	79.0	165	2½	0.2	0.6	-0.13	-0.20	14	Medium	1.7	60	480	460	219	92
6:40	4.0	16.2	0.6	79.2	165	2½	0.1	0.5	-0.13	-0.20	14	Medium	1.8	70	470	460	219	90
Avg.	6.4	13.9	0.1	79.6	171	2½	0.5	1.1	-0.10	-0.17	10	Medium	1.9	78	495	466	219	92

Front bed depths from 11:40 to 5:00: Above front observation door

LOG OF RESULTS FOR TESTS ON BOILER #3

Test No.		1	2	3	4
Date of Test		4/9/41	4/10/41	4/11/41	4/19/41
Gases:					
1. Carbon Dioxide	%	9.3	9.9	9.3	6.4
2. Oxygen	%	10.6	9.9	10.7	13.9
3. Carbon Monoxide	%	0.1	0.1	0.2	0.1
4. Nitrogen	%	80.0	80.1	79.8	79.6
5. Dry gas per lb. dry fuel	lb.	20.9	20.0	21.2	29.9
6. Air required per lb. dry fuel	lb.	10.6	10.7	10.8	10.6
7. Air supplied per lb. dry fuel	lb.	20.5	19.5	20.7	29.4
8. Excess Air	%	93.3	82.2	91.7	177.4
Pressures and Drafts:					
9. Barometric pressure	in. of Hg.	28.01	28.04	28.16	28.04
10. Steam pressure	lb./sq.in. gage	172	173	172	171
11. Air pressure in front windbox	in. of water	3.4	3.1	3.3	1.1
12. Air pressure in rear windbox	in. of water	1.6	1.5	1.7	0.5
13. Fire draft	in. of water	0.12	0.06	0.07	- 0.10
14. Stack draft	in. of water	- 0.21	- 0.14	- 0.14	- 0.17
15. Pressure in feedwater heater	lb./sq.in. gage	$2\frac{1}{2}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$
Temperatures:					
16. Steam temperature at superheater outlet	°F	484	482	484	466
17. Superheat of steam	°F	108	109	108	90
18. Temperature of air surrounding boiler	°F	78	79	79	92
19. Temperature of air for combustion	°F	81	84	83	92
20. Temperature of gases leaving boiler	°F	559	549	555	495
21. Temperature of feedwater entering boiler	°F	218	218	218	219

LOG OF RESULTS FOR TESTS ON BOILER #3 (Continued)

Test No.	1	2	3	4
Date of Test	4/9/41	4/10/41	4/11/41	4/19/41
Hourly Quantities:				
22. Duration of Tests .... hr.	12	12	12	12
23. Fuel per hour as fired .... lb.	1658	1675	1633	825
24. Fuel per hour dry .... lb.	1598	1615	1574	795
25. Dry fuel per sq.ft. of grate area .... lb.	23.4	23.6	23.0	11.6
26. Refuse per hour .... lb.	126	106	98	59
27. Actual water per hour .... lb.	16000	16083	17083	8583
Unit Quantities:				
28. Heat absorbed by steam generating unit ..... B.t.u./lb.	1076	1075	1076	1064
Refuse:				
29. Refuse, per cent of dry fuel .... %	7.9	6.6	6.2	7.4
30. Percentage of combustible in refuse .... %	25.4	9.8	5.3	21.1
31. Carbon burned per lb. dry fuel .... lb.	0.79	0.80	0.81	0.79
Evaporation:				
32. Rate of heat absorption per lb. fuel as fired .... B.t.u./lb.	10384	10322	11256	11069
33. Rate of heat absorption per lb. dry fuel ... B.t.u./lb.	10773	10705	11678	11487
34. Rate of heat absorption per sq.ft. of heating surface per hour .... B.t.u./sq.ft.	4219	4238	4505	2238
Efficiency:				
35. Efficiency of steam generating unit .... %	73.9	73.4	80.1	78.8

DATA AND RESULTS OF CASEY-HEDGES STEAM GENERATING UNIT TEST

Location	V. P. I. Heating and Power Plant, Blacksburg, Va.
Owner	Commonwealth of Virginia
Make and Type of Boiler	354 Hp., Casey-Hedges, Cross Drum Boiler
Make and Type of Superheater	Type S, Foster Wheeler
Fuel Burning Equipment	Detroit Roto Stoker

Description and Dimensions

Boiler Heating Surface	3540 sq.ft.
Superheater Surface	540 sq.ft.
Total Heating Surface	4080 sq.ft.
Grate Surface	68.3 sq.ft.
Volume of Combustion Space	614.7 cu.ft.
Furnace, center of grate to nearest heating surface	9 ft.
Furnace volume per sq.ft. boiler heating surface	0.174 cu.ft./sq.ft.
Fuel Burning Equipment	Detroit Roto Stoker
Method of Producing Draft	Forced (Clarage Fans)
Fuel Burned	Brush Mountain Culm

Analyses of M. C. Slusser's Brush Mountain Semi-Anthracite Coal

* Proximate Analysis

Moisture		4.1 %
Volatile Matter		12.5 %
Fixed Carbon		67.8 %
Ash		15.6 %
Heating Value as Fired	B.t.u./lb.	12420
Heating Value Dry	B.t.u./lb.	12950

* Ultimate Analysis

Carbon	76.6 %
Hydrogen	3.6 %
Oxygen	2.1 %
Nitrogen	0.9 %
Sulphur	0.5 %
Ash	16.3 %

* Analyses taken from Virginia Geodetic Survey on Valley Coals published in 1925 - page 109.

Time Test #5 Boiler #4	Flue Gas Analysis CO_2	O_2	CO	N_2	Boiler Press.	(Steam Feed-water) Press.	Wind-box Right	Wind-box Left	Fire Draft	Stack Draft	Front Bed Depth	Rear Bed Depth	Air Rate	Steam Rate	Flue Gas Temp.	Super-heat Temp.	Feed-water Temp.	Comb. Air Temp.
	% by Vol.				#/sq.in. gage			in. of water			in.		in. H_2O	%	°F			
7:00	5.8	14.2	0.6	79.4	160	3¾	0.1	0.1	-0.17	-0.25	2	Medium	1.5	50	455	465	223	73
7:20	6.3	13.7	0.3	79.7	165	3¾	0.3	0.1	-0.18	-0.30	2	Medium	1.7	60	466	460	223	74
7:40	7.0	13.1	0.2	79.7	165	3½	0.3	0.2	-0.18	-0.30	2	Medium	1.9	80	465	460	223	73
8:00	6.8	13.3	0.0	79.9	175	3½	0.4	0.3	-0.20	-0.30	2	High	1.7	70	475	465	222	73
8:20	7.2	13.0	0.0	79.8	160	3½	0.4	0.4	-0.28	-0.40	2	High	2.0	100	470	465	223	74
8:40	8.0	12.2	0.0	79.8	155	2¼	0.5	0.5	-0.28	-0.40	2	High	2.0	95	470	460	218	74
9:00	8.2	11.3	0.0	80.5	180	2½	0.5	0.5	-0.28	-0.40	1	Low	2.0	95	475	475	219	74
9:20	7.8	11.4	1.0	79.8	175	2¾	0.2	0.4	-0.22	-0.30	1	Low	2.6	110	480	465	220	74
9:40	8.5	11.5	0.0	80.0	175	1	0.4	0.4	-0.10	-0.15	1	Medium	1.8	80	485	485	215	75
10:00	9.0	11.6	0.2	79.2	160	3	0.4	0.4	-0.15	-0.40	1	High	2.3	105	490	475	221	75
10:20	8.8	11.2	0.3	79.7	165	3	0.4	0.4	-0.27	-0.45	2	High	2.2	70	470	475	221	76
10:40	7.8	12.4	0.0	79.8	155	3	0.3	0.3	-0.28	-0.45	2	High	2.4	90	470	460	221	76
11:00	10.0	9.2	0.0	80.8	185	3	0.6	0.5	-0.17	-0.30	2	High	2.6	130	470	470	221	74
11:20	7.0	12.9	0.9	79.2	168	2½	0.7	0.7	-0.17	-0.25	3	High	1.9	60	460	460	220	75
11:40	5.5	14.5	0.1	79.9	165	2½	0.7	0.7	-0.17	-0.25	3	High	1.9	60	460	465	220	76
12:00	6.8	14.0	0.4	78.8	175	2½	0.8	0.7	-0.10	-0.25	1	Low	1.6	85	465	460	220	76
12:20	5.5	14.6	0.1	79.8	168	2½	0.3	0.4	0.00	-0.20	1	Low	2.2	65	480	455	219	80
12:40	6.3	14.3	0.0	79.4	162	2½	0.3	0.4	-0.08	-0.25	1	Low	2.2	50	475	480	219	80
1:00	5.8	14.1	0.0	80.1	162	2	0.5	0.5	-0.07	-0.20	1	Low	2.0	65	480	480	215	80
1:20	7.5	13.5	0.0	79.0	162	2½	0.4	0.5	-0.10	-0.25	3	Low	2.0	80	470	480	220	80
1:40	6.6	14.4	0.0	79.0	153	2½	0.4	0.4	-0.20	-0.30	3	Medium	1.9	75	470	470	220	80
2:00	9.2	10.8	0.0	80.0	160	2¼	0.8	0.8	-0.05	-0.20	4	High	1.9	90	470	465	220	80
2:20	8.0	11.6	0.0	80.4	162	2¼	1.0	0.9	-0.08	-0.20	4	High	1.6	85	470	460	220	80
2:40	8.0	12.0	0.6	79.4	155	2¼	0.3	0.4	-0.15	-0.30	2	Low	2.0	100	480	460	220	80
3:00	9.8	10.8	0.0	79.4	170	2¼	0.2	0.3	-0.12	-0.25	2	Medium	1.2	50	480	480	220	80
3:20	9.0	11.8	0.0	79.2	170	2½	0.3	0.5	-0.10	-0.20	3	Medium	2.0	50	470	470	220	80
3:40	7.0	12.0	0.2	80.8	167	2¼	0.5	0.5	-0.08	-0.20	4	High	1.6	70	480	475	220	80
4:00	7.2	12.2	0.2	80.4	169	2¼	0.5	0.5	-0.10	-0.20	4	High	1.6	75	480	475	220	80
4:20	8.5	11.9	0.2	79.4	170	2¼	0.9	0.9	-0.05	-0.25	4	High	2.4	105	490	470	220	82
4:40	8.8	11.8	0.0	79.4	170	2¼	0.3	0.4	0.00	-0.20	2	Low	1.6	100	490	470	220	82
5:00	7.8	12.6	0.0	79.6	167	2¼	0.6	0.5	0.08	-0.20	2	Low	2.2	90	490	475	220	82
5:20	7.0	12.6	0.2	80.2	163	2¼	0.8	0.7	-0.07	-0.30	4	Low	3.0	100	500	480	220	80
5:40	7.0	12.8	0.0	80.2	165	2¼	0.8	0.7	-0.02	-0.25	4	Low	2.8	110	500	485	220	80
6:00	7.0	13.2	0.0	79.8	165	2½	1.0	0.9	0.04	-0.20	5	Medium	1.7	100	500	485	220	80
6:20	5.5	13.5	0.0	81.0	168	2½	1.0	0.8	0.00	-0.20	4	Medium	1.9	70	490	485	220	80
6:40	8.0	11.8	0.4	79.8	172	2½	0.8	0.7	-0.07	-0.20	4	Medium	1.8	90	490	485	220	80
Avg.	7.5	12.6	0.1	79.8	166	2½	0.5	0.5	-0.12	-0.27	2	Medium	2.0	82	477	471	220	78

Above front observation door

Time Test #6 Boiler #4	Flue Gas Analysis CO_2	O_2	CO	N_2	Boiler Press.	Steam (Feed-water) Press.	Wind-box Right	Wind-box Left	Fire Draft	Stack Draft	Front Bed Depth	Rear Bed Depth	Air Rate	Steam Rate	Flue Gas Temp.	Super-heat Temp.	Feed-water Temp.	Comb. Air Temp.
	% by Vol.				#/sq.in. gage			in. of water			in. (Above front observation door)		in. H_2O	%		°F		
7:00	9.8	10.2	0.0	80.0	155	3¼	0.4	0.4	-0.07	-0.20	1	Low	1.6	80	470	470	222	67
7:20	9.6	10.6	0.1	79.7	165	3	0.3	0.3	-0.05	-0.20	1	Low	1.7	70	470	475	222	68
7:40	10.0	11.8	0.0	78.2	165	3	0.4	0.4	-0.05	-0.15	1	Low	1.7	70	475	475	222	70
8:00	9.0	11.2	0.0	79.8	170	3½	0.8	0.6	0.00	-0.25	1	Low	1.9	70	480	475	222	70
8:20	8.0	11.9	0.1	80.0	180	2½	0.7	0.6	0.05	-0.05	1	Low	2.1	80	485	475	220	70
8:40	8.0	12.4	0.0	79.6	165	3	1.0	1.0	1.00	0.00	1	Low	2.7	105	480	465	222	69
9:00	10.0	10.0	0.0	80.0	162	3	0.9	0.8	1.00	0.00	1	Medium	2.1	75	485	485	222	68
9:20	10.2	9.8	0.5	79.5	160	3	0.9	0.8	0.70	0.05	1	Medium	2.2	90	480	480	221	68
9:40	9.2	7.6	0.0	79.2	162	3	1.0	1.0	1.00	0.00	1	Medium	2.3	90	470	450	221	70
10:00	11.2	9.6	0.0	79.2	180	2½	0.9	0.9	0.80	-0.10	2	High	1.9	70	485	485	219	70
10:20	8.0	10.8	0.0	81.2	172	3	1.0	0.9	-0.12	-0.25	2	High	2.3	75	480	475	220	71
10:40	10.2	10.6	0.0	79.2	169	2½	0.9	0.8	0.02	-0.15	2	High	1.7	80	480	475	220	72
11:00	8.0	12.0	0.0	80.0	180	3	0.5	0.5	-0.17	-0.25	2	High	2.1	120	480	455	220	73
11:20	9.8	10.2	0.0	80.0	175	2½	1.0	1.0	0.08	-0.20	1	Low	2.4	100	485	470	220	73
11:40	9.2	11.2	0.0	79.6	170	2½	0.8	0.6	0.00	-0.25	1	Low	2.2	85	485	470	220	74
12:00	10.0	9.7	0.1	80.2	165	2¼	0.6	0.6	0.00	-0.15	2	High	2.3	75	490	490	221	74
12:20	10.1	10.1	0.0	79.8	160	2½	0.0	0.3	-0.25	-0.25	2	High	1.0	65	485	490	218	76
12:40	10.0	9.6	0.0	80.4	170	2¼	0.5	0.5	-0.05	-0.15	3	High	1.6	80	475	470	212	76
1:00	9.0	11.0	0.3	79.7	170	2¼	0.8	0.8	0.00	-0.10	4	High	2.4	95	470	460	213	76
1:20	9.5	10.5	0.0	80.0	160	2	0.7	0.8	0.00	-0.20	6	High	1.9	80	460	460	217	78
1:40	9.0	11.4	0.0	79.6	165	2	0.4	0.6	-0.15	-0.25	7	High	1.2	70	460	460	219	78
2:00	8.2	11.8	0.0	80.0	165	2	1.2	1.2	0.00	-0.20	8	High	2.9	90	460	460	220	78
2:20	8.0	11.0	0.0	81.0	158	2½	0.0	0.3	-0.20	-0.25	1	Low	1.4	90	450	445	220	78
2:40	10.0	11.2	0.0	78.8	163	2½	0.5	0.5	-0.05	-0.25	2	Low	2.0	80	460	455	220	76
3:00	10.0	10.5	0.0	79.5	150	2½	0.3	0.3	-0.05	-0.25	2	Medium	1.4	70	450	450	220	76
3:20	9.2	11.2	0.0	79.6	165	2½	0.5	0.6	-0.05	-0.25	3	Medium	1.6	70	470	470	220	76
3:40	8.5	11.3	0.0	80.2	175	2½	1.0	1.0	0.08	-0.20	3	Low	1.7	70	470	475	220	76
4:00	9.0	11.2	0.0	79.8	170	2½	0.8	0.8	-0.05	-0.25	3	Low	1.7	70	480	475	220	76
4:20	10.0	10.0	0.4	79.6	168	2½	0.7	0.7	0.02	-0.20	3	Medium	1.7	70	480	480	220	76
4:40	9.6	10.0	0.0	80.4	163	2½	0.4	0.4	-0.15	-0.25	3	Medium	2.2	100	480	470	220	78
5:00	9.0	10.0	0.2	80.8	163	2½	0.8	0.8	0.05	-0.20	3	Medium	2.4	85	480	470	220	78
5:20	10.5	9.7	0.0	79.8	163	2½	0.8	1.0	0.05	-0.20	4	High	2.3	80	480	475	220	78
5:40	10.6	9.4	0.0	80.0	168	2½	0.8	1.0	0.02	-0.20	4	High	2.3	85	480	480	220	78
6:00	10.8	10.0	0.0	79.2	175	2½	1.0	1.0	0.00	-0.20	5	High	2.4	90	490	480	220	78
6:20	10.8	9.4	0.0	79.8	180	2½	0.7	0.7	0.05	-0.15	1	Low	2.0	80	490	490	220	76
6:40	10.0	10.0	0.2	79.8	175	2½	0.7	0.8	0.00	-0.20	1	Low	2.2	80	490	490	220	76
Avg.	9.5	10.6	0.1	79.8	167	2½	0.7	0.7	0.08	-0.18	2	Medium	2.0	82	476	472	220	74

Time Test #7 Boiler #4	Flue Gas Analysis CO_2	O_2	CO	N_2	Boiler Press.	Steam (Feed-water) Press.	Wind-box Right	Wind-box Left	Fire Draft	Stack Draft	Front Bed Depth (Above front observation door)	Rear Bed Depth	Air Rate	Steam Rate	Flue Gas Temp.	Super-heat Temp.	Feed-water Temp.	Comb. Air Temp.
	% by Vol.				#/sq.in. gage			in. of water			in.		in. H_2O	%		°F		
7:00	6.8	11.0	0.6	81.6	163	2½	0.5	0.5	-0.10	-0.25	1	High	1.8	65	470	470	219	70
7:20	7.0	10.0	0.0	83.0	163	3	0.9	0.8	-0.03	-0.20	1	High	2.0	65	475	475	221	68
7:40	7.5	10.5	0.8	81.2	160	3	1.2	1.1	0.00	-0.15	1	High	2.1	70	475	475	221	68
8:00	9.0	9.2	0.3	81.5	170	2	0.2	0.2	-0.20	-0.30	1	High	2.0	85	485	490	216	69
8:20	9.0	10.0	0.4	80.6	170	3	0.8	0.8	-0.50	-0.20	2	High	1.7	90	485	465	221	69
8:40	8.0	9.0	0.2	82.8	170	3	0.9	0.9	-0.50	-0.20	2	High	2.0	80	485	475	221	69
9:00	8.6	9.6	0.0	81.8	165	3	1.0	1.0	-0.50	-0.20	2	High	2.0	85	480	475	221	68
9:20	9.2	9.8	0.0	81.0	170	2½	0.0	0.4	-0.15	-0.25	1	Low	2.0	105	480	465	221	69
9:40	9.0	9.4	0.0	81.6	170	3	0.5	0.5	-0.02	-0.20	2	Medium	1.9	105	485	460	221	71
10:00	9.6	8.9	0.0	81.5	170	2½	0.0	0.3	-0.24	-0.30	2	Medium	2.6	105	495	480	217	81
10:20	9.4	9.4	0.0	81.2	150	2	1.0	1.0	0.05	-0.15	1	High	1.9	110	490	460	215	82
10:40	12.0	6.4	0.2	81.4	165	2	0.9	0.9	0.00	-0.20	2	High	2.0	100	490	490	215	82
11:00	12.0	7.0	0.0	81.0	173	3	0.2	0.4	-0.14	-0.25	1	Low	1.7	75	490	480	215	84
11:20	9.4	9.4	0.2	81.0	165	2	0.6	0.7	-0.03	-0.20	2	Low	1.8	110	485	462	215	85
11:40	10.0	8.0	0.2	81.8	160	2	0.5	0.6	-0.05	-0.20	2	Medium	2.1	110	490	480	215	85
12:00	10.7	7.3	0.0	82.0	180	2	0.0	0.4	-0.28	-0.35	2	High	2.6	125	500	480	215	84
12:20	10.8	8.2	0.2	80.0	173	2	0.6	0.7	-0.07	-0.15	3	High	1.3	70	460	470	215	86
12:40	9.8	9.0	0.2	81.0	160	2	0.6	0.7	-0.87	-0.15	3	High	1.1	60	455	460	215	86
1:00	9.8	8.4	0.0	81.8	155	2	1.1	1.4	-0.02	-0.10	2	High	1.1	60	450	460	214	86
1:20	10.8	8.8	0.0	80.4	162	2	1.0	1.2	-0.05	-0.15	6	High	2.2	80	460	460	215	86
1:40	11.2	9.0	0.2	79.6	165	2	1.2	1.3	-0.05	-0.20	7	High	2.1	100	460	450	214	86
2:00	11.2	9.0	0.2	79.6	158	2	0.5	0.4	-0.02	-0.20	1	Low	2.0	100	470	445	215	86
2:20	9.4	8.6	0.2	81.8	165	2	0.8	0.7	0.10	-0.10	2	Low	2.2	70	480	465	214	88
2:40	12.0	7.0	0.0	81.0	162	3	0.3	0.3	-0.10	-0.25	3	Medium	1.6	70	480	475	221	88
3:00	10.8	8.2	0.2	80.8	165	3	1.0	1.0	-0.08	-0.25	4	Medium	2.4	40	450	475	221	88
3:20	9.0	9.0	0.0	82.0	155	3	1.0	1.0	0.08	-0.25	5	Medium	2.0	60	450	460	222	88
3:40	10.0	9.2	0.2	80.6	175	2½	1.0	0.9	0.08	-0.20	5	Medium	2.6	50	470	480	220	88
4:00	9.4	8.8	0.2	81.6	162	2½	1.1	1.0	0.06	-0.15	7	Medium	2.4	50	450	460	220	72
4:20	10.0	8.2	0.2	81.6	173	2	0.0	0.4	-0.20	-0.25	1	Low	2.4	40	450	465	216	72
4:40	9.0	9.0	0.2	81.8	163	2	1.0	0.8	0.10	-0.10	1	Low	2.4	70	470	465	217	72
5:00	10.0	8.0	0.0	82.0	170	2	0.8	0.7	0.05	-0.15	2	Medium	2.4	70	460	475	218	72
5:20	10.0	8.0	0.0	82.0	168	2¼	0.9	0.7	0.05	-0.15	3	Medium	2.5	70	470	475	220	72
5:40	9.6	9.4	0.0	81.0	170	2	0.7	0.7	-0.04	-0.20	3	Medium	2.2	70	480	480	216	72
6:00	9.8	7.2	0.2	82.8	170	2¼	0.5	0.5	-0.13	-0.25	5	Medium	2.0	80	480	475	219	72
6:20	9.0	9.0	0.0	82.0	170	2	0.5	0.5	0.00	-0.20	1	Low	2.0	80	470	465	217	72
6:40	9.5	8.0	0.0	82.5	178	2½	0.0	0.4	-0.30	-0.30	2	Medium	1.0	50	450	470	220	72
Avg.	9.7	8.7	0.1	81.5	166	2½	0.6	0.7	-0.07	-0.20	3	High	2.0	79	473	470	218	78

Time Test #8 Boiler #4	Flue Gas Analysis CO_2	O_2	CO	N_2	Boiler Press.	Steam (Feed-water) Press.	Wind-box Right	Wind-box Left	Fire Draft	Stack Draft	Front Bed Depth	Rear Bed Depth	Air Rate	Steam Rate	Flue Gas Temp.	Super-heat Temp.	Feed-water Temp.	Comb. Air Temp.
	% by Vol.				#/sq.in. gage			in. of water			in.		in. H_2O	%	°F			
7:00	8.2	11.8	0.0	80.2	160	1½	0.6	0.6	-0.10	-0.35	1	Low	3.4	95	505	480	214	86
7:20	8.6	11.2	0.4	79.8	170	1½	0.9	0.9	-0.08	-0.30	2	Medium	3.3	115	505	500	217	86
7:40	8.2	11.4	0.7	79.7	155	1½	0.5	0.5	-0.15	-0.35	3	High	3.1	110	500	470	217	86
8:00	7.7	12.1	0.4	79.8	168	1½	0.6	0.6	-0.17	-0.40	3	High	3.1	105	500	480	217	86
8:20	8.2	11.4	0.7	79.7	170	1½	0.7	0.8	-0.10	-0.25	3	High	3.1	110	500	470	217	86
8:40	8.6	11.2	0.4	79.8	172	1½	0.7	0.8	-0.10	-0.25	4	High	3.0	110	500	470	217	86
9:00	9.8	10.2	0.5	79.5	175	1½	0.4	0.5	-0.31	-0.45	6	High	3.0	120	500	470	216	86
9:20	7.3	12.4	0.0	80.3	174	1½	0.8	0.8	-0.18	-0.45	6	High	3.2	90	490	485	216	86
9:40	8.6	10.6	0.0	80.8	168	1½	0.3	0.3	-0.15	-0.25	9	High	1.2	85	460	450	216	87
10:00	11.0	9.0	0.0	80.0	170	1½	0.3	0.3	-0.15	-0.25	1	Low	1.8	80	470	440	216	86
10:20	10.0	10.0	0.0	80.0	170	1½	0.4	0.5	-0.05	-0.20	2	Low	2.0	75	480	475	215	86
10:40	9.2	10.9	0.6	79.3	168	1½	0.5	0.5	0.02	-0.10	2	Low	2.1	85	490	470	215	88
11:00	8.0	11.7	0.0	80.3	165	1½	0.6	0.6	0.04	-0.15	2	Medium	2.1	110	490	470	215	88
11:20	7.3	12.4	0.0	80.3	165	0	0.7	0.8	-0.10	-0.25	3	Medium	2.3	100	490	470	215	88
11:40	6.8	13.2	0.8	79.2	165	0	0.7	0.8	-0.10	-0.25	3	Medium	2.3	100	490	465	214	88
12:00	5.5	13.5	0.8	80.2	165	0	0.0	0.3	-0.30	-0.35	2	Medium	1.5	105	490	465	214	88
12:20	6.8	13.2	0.8	79.2	163	0	0.5	0.5	-0.14	-0.30	5	Medium	2.5	95	485	465	214	90
12:40	6.0	13.0	0.0	81.0	160	0	0.6	0.6	-0.10	-0.25	5	Medium	2.3	85	485	475	214	90
1:00	7.5	13.0	0.0	79.5	165	0	0.9	0.8	0.00	-0.20	5	Low	2.2	90	480	470	213	90
1:20	9.0	12.0	0.0	79.0	165	0	0.5	0.5	-0.15	-0.25	5	Low	2.0	90	480	470	213	90
1:40	7.0	13.4	0.2	79.4	165	0	0.5	0.5	-0.20	-0.25	6	Low	1.6	80	480	470	214	90
2:00	9.8	11.2	0.0	79.0	165	0	1.0	0.9	-0.10	-0.25	2	Low	1.8	80	480	475	214	90
2:20	9.0	12.0	0.0	79.0	162	0	0.6	0.3	0.00	-0.25	3	Low	2.0	80	480	465	214	90
2:40	9.2	11.4	0.0	79.4	165	0	0.8	0.8	-0.10	-0.25	1	Low	2.2	90	480	470	214	90
3:00	8.6	12.4	0.0	79.0	165	0	0.3	0.3	-0.10	-0.25	2	Low	2.2	100	490	470	214	90
3:20	8.2	12.8	0.0	79.0	165	0	0.4	0.3	-0.08	-0.25	2	Low	2.2	90	485	475	214	90
3:40	9.0	11.6	0.2	79.2	163	0	0.4	0.4	-0.08	-0.25	2	Low	2.2	80	490	475	214	92
4:00	8.8	12.0	0.0	79.2	165	0	0.3	0.4	-0.09	-0.25	3	Low	2.2	90	490	475	214	92
4:20	9.0	11.5	0.3	79.2	165	0	0.6	0.6	-0.04	-0.20	4	Low	2.2	95	490	470	213	92
4:40	11.0	9.8	0.0	79.2	165	0	0.4	0.6	-0.10	-0.25	5	Low	2.4	110	500	475	213	92
5:00	11.0	9.5	0.0	79.5	165	0	0.5	0.5	-0.05	-0.25	2	Low	2.2	110	490	465	215	95
5:20	11.0	9.8	0.2	79.0	162	0	0.6	0.6	-0.05	-0.20	2	Low	2.4	110	490	475	215	94
5:40	9.8	11.2	0.0	79.0	165	0	0.5	0.4	-0.05	-0.25	3	Low	2.2	110	490	465	214	94
6:00	9.5	11.5	0.0	79.0	165	0	0.5	0.5	-0.10	-0.25	4	Low	2.0	100	490	475	214	94
6:20	8.0	12.5	0.0	79.5	165	0	0.7	0.7	-0.05	-0.25	7	Medium	2.2	100	490	470	214	94
6:40	9.0	12.0	0.0	79.0	165	0	0.7	0.8	-0.10	-0.25	3	Medium	2.0	110	490	465	214	94
Avg.	8.7	11.7	0.2	79.4	166	½	0.5	0.6	-0.10	-0.26	3	Medium	2.3	100	489	471	215	89

Front Bed Depth: Above front observation door

LOG OF RESULTS FOR TESTS ON BOILER #4

Test No.		5	6	7	8
Date of Test		4/22/41	4/23/41	4/24/41	4/26/41
Gases:					
1. Carbon Dioxide	%	7.5	9.5	9.7	8.7
2. Oxygen	%	12.6	10.6	8.7	11.7
3. Carbon Monoxide	%	0.1	0.1	0.1	0.2
4. Nitrogen	%	79.8	79.8	81.5	79.4
5. Dry gas per lb. dry fuel	lb.	15.3	10.9	15.2	21.0
6. Air required per lb. dry fuel	lb.	6.6	6.0	7.1	9.3
7. Air supplied per lb. dry fuel	lb.	15.0	10.6	15.2	20.3
8. Excess Air	%	127.0	69.7	114.1	118.2
Pressures and Drafts:					
9. Barometric pressure	in. of Hg.	28.27	28.23	28.12	28.19
10. Steam pressure	lb./sq.in. gage	166	167	166	166
11. Air pressure in left windbox	in. of water	0.5	0.7	0.7	0.8
12. Air pressure in right windbox	in. of water	0.5	0.7	0.6	0.7
13. Fire draft	in. of water	- 0.12	0.08	- 0.07	- 0.1
14. Stack draft	in. of water	- 0.27	- 0.18	- 0.20	- 0.25
15. Pressure in feedwater heater	lb./sq.in. gage	$2\frac{1}{2}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{2}$
Temperatures:					
16. Steam temperature at superheater outlet	°F	471	472	470	471
17. Superheat of steam	°F	98	98	97	98
18. Temperature of air surrounding boiler	°F	81	83	81	82
19. Temperature of air for combustion	°F	78	74	78	89
20. Temperature of gases leaving boiler	°F	477	476	473	489
21. Temperature of feedwater entering boiler	°F	220	220	218	215

LOG OF RESULTS FOR TESTS ON BOILER #4 (Continued)

Test No.	5	6	7	8
Date of Test	4/22/41	4/23/41	4/24/41	4/26/41
Hourly Quantities:				
22. Duration of Tests .... hr.	12	12	12	12
23. Fuel per hour as fired .... lb.	1375	1275	1350	1267
24. Fuel per hour dry .... lb.	1319	1223	1295	1215
25. Dry fuel per sq.ft. of grate area .... lb.	19.3	17.9	19.0	17.8
26. Refuse per hour .... lb.	621	645	437	207
27. Actual water per hour .... lb.	8417	8417	8333	10416
Unit Quantities:				
28. Heat absorbed by steam generating unit ..... B.t.u./lb.	1067	1066	1072	1069
Refuse:				
29. Refuse, per cent of dry fuel .... %	45.2	50.6	32.4	16.3
30. Percentage of combustible in refuse .... %	65.4	69.1	51.7	21.3
31. Carbon burned per lb. dry fuel .... lb.	0.47	0.42	0.60	0.75
Evaporation:				
32. Rate of heat absorption per lb. fuel as fired .... B.t.u./lb.	6532	7037	6617	8788
33. Rate of heat absorption per lb. dry fuel ... B.t.u./lb.	6809	7336	6898	9164
34. Rate of heat absorption per sq.ft. of heating surface per hour .... B.t.u./sq.ft.	2201	2199	2189	2729
Efficiency:				
35. Efficiency of steam generating unit .... %	52.6	56.6	53.3	69.0

TOTALS FOR TESTS ON BOILER #3

Test No.	Weight of Coal Fired	Weight of Steam Generated	Weight of Refuse	Per Cent Refuse	Per Cent Combustible in Refuse
1	19,900 lb.	192,000 lb.	1512 lb.	7.9	25.4
2	20,100 lb.	193,000 lb.	1272 lb.	6.6	9.8
3	19,600 lb.	205,000 lb.	1176 lb.	6.2	5.3
4	9,900 lb.	103,000 lb.	708 lb.	7.4	21.1

TOTALS FOR TESTS ON BOILER #4

Test No.	Weight of Coal Fired	Weight of Steam Generated	Weight of Refuse	Per Cent Refuse	Per Cent Combustible in Refuse
5	16,500 lb.	101,000 lb.	7452 lb.	45.2	65.4
6	15,300 lb.	101,000 lb.	7740 lb.	50.6	69.1
7	16,200 lb.	100,000 lb.	5244 lb.	32.4	51.7
8	15,200 lb.	125,000 lb.	2484 lb.	16.3	21.3

HEAT BALANCE FOR TEST #1 BOILER #3

		B.t.u.	Per Cent
36.	Heat absorbed by water and steam in boiler	10773	73.9
37.	Heat loss due to moisture in coal	47	0.3
38.	Heat loss due to water from combustion of hydrogen	565	3.9
39.	Heat loss due to dry chimney gases	2398	16.5
40.	Heat loss due to unburned gaseous combustible	85	0.6
41.	Heat loss due to combustible in refuse	283	1.9
42.	Heat loss due to unconsumed hydrogen, hydrocarbons, moisture in air, radiation, and unaccounted for	429	2.9
43.	Heating value of fuel	14580	100.0

HEAT BALANCE FOR TEST #2 BOILER #3

		B.t.u.	Per Cent
36.	Heat absorbed by water and steam in boiler	10705	73.4
37.	Heat loss due to moisture in coal	47	0.3
38.	Heat loss due to water from combustion of hydrogen	562	3.9
39.	Heat loss due to dry chimney gases	2232	15.3
40.	Heat loss due to unburned gaseous combustible	81	0.6
41.	Heat loss due to combustible in refuse	99	0.7
42.	Heat loss due to unconsumed hydrogen, hydrocarbons, moisture in air, radiation, and unaccounted for	854	5.8
43.	Heating value of fuel	14580	100.0

HEAT BALANCE FOR TEST #3 BOILER #3

		B.t.u.	Per Cent
36.	Heat absorbed by water and steam in boiler	11678	80.1
37.	Heat loss due to moisture in coal	47	0.3
38.	Heat loss due to water from combustion of hydrogen	563	3.9
39.	Heat loss due to dry chimney gases	2402	16.5
40.	Heat loss due to unburned gaseous combustible	174	1.2
41.	Heat loss due to combustible in refuse	43	0.3
42.	Heat loss due to unconsumed hydrogen, hydrocarbons, moisture in air, radiation, and unaccounted for	- 327	- 2.3
43.	Heating value of fuel	14580	100.0

HEAT BALANCE FOR TEST #4 BOILER #3

		B.t.u.	Per Cent
36.	Heat absorbed by water and steam in boiler	11487	78.8
37.	Heat loss due to moisture in coal	46	0.3
38.	Heat loss due to water from combustion of hydrogen	547	3.8
39.	Heat loss due to dry chimney gases	2892	19.8
40.	Heat loss due to unburned gaseous combustible	123	0.8
41.	Heat loss due to combustible in refuse	212	1.5
42.	Heat loss due to unconsumed hydrogen, hydrocarbons, moisture in air, radiation, and unaccounted for	- 727	- 5.0
43.	Heating value of fuel	14580	100.0

HEAT BALANCE FOR TEST #5 BOILER #4

		B.t.u.	Per Cent
36.	Heat absorbed by water and steam in boiler	6809	52.6
37.	Heat loss due to moisture in coal	53	0.4
38.	Heat loss due to water from combustion of hydrogen	399	3.1
39.	Heat loss due to dry chimney gases	1470	11.4
40.	Heat loss due to unburned gaseous combustible	63	0.5
41.	Heat loss due to combustible in refuse	4089	31.6
42.	Heat loss due to unconsumed hydrogen, hydrocarbons, moisture in air, radiation, and unaccounted for	67	0.5
43.	Heating value of fuel	12950	100.0

HEAT BALANCE FOR TEST #6 BOILER #4

		B.t.u.	Per Cent
36.	Heat absorbed by water and steam in boiler	7336	56.6
37.	Heat loss due to moisture in coal	53	0.4
38.	Heat loss due to water from combustion of hydrogen	400	3.1
39.	Heat loss due to dry chimney gases	1053	8.1
40.	Heat loss due to unburned gaseous combustible	44	0.3
41.	Heat loss due to combustible in refuse	4853	37.5
42.	Heat loss due to unconsumed hydrogen, hydrocarbons, moisture in air, radiation, and unaccounted for	- 789	- 6.0
43.	Heating value of fuel	12950	100.0

HEAT BALANCE FOR TEST #7 BOILER #4

		B.t.u.	Per Cent
36.	Heat absorbed by water and steam in boiler	6898	53.3
37.	Heat loss due to moisture in coal	176	1.4
38.	Heat loss due to water from combustion of hydrogen	398	3.1
39.	Heat loss due to dry chimney gases	1441	11.1
40.	Heat loss due to unburned gaseous combustible	62	0.5
41.	Heat loss due to combustible in refuse	2278	17.5
42.	Heat loss due to unconsumed hydrogen, hydrocarbons, moisture in air, radiation, and unaccounted for	1696	13.1
43.	Heating value of fuel	12950	100.0

HEAT BALANCE FOR TEST #8 BOILER #4

		B.t.u.	Per Cent
36.	Heat absorbed by water and steam in boiler	9164	69.0
37.	Heat loss due to moisture in coal	175	1.3
38.	Heat loss due to water from combustion of hydrogen	397	3.0
39.	Heat loss due to dry chimney gases	893	6.7
40.	Heat loss due to unburned gaseous combustible	171	1.3
41.	Heat loss due to combustible in refuse	509	3.8
42.	Heat loss due to unconsumed hydrogen, hydrocarbons, moisture in air, radiation, and unaccounted for	1975	14.9
43.	Heating value of fuel (Mixed)	13284	100.0

CALCULATIONS USED IN DETERMINING THE HEAT BALANCE

Items 1 to 4 inclusive are the averages for a 12 hour test taken from the log sheets of the flue gas analyses.

Item 5: Dry flue gas per lb. of dry fuel.

$$W_g = \frac{11CO_2 + 8O_2 + 7(CO + N_2)}{3(CO_2 + CO)} \times C_b \qquad \text{(By Volume)}$$

where W_g = lb. of dry flue gas per lb. dry fuel

C_b = lb. of carbon burned per lb. dry fuel

Item 6: Air required per lb. of dry fuel.

$$W_a = 11.5\ C_b + 34.5(H - \frac{O}{8}) + 4.32\ S \qquad \text{(By Weight)}$$

Item 7: Air supplied per lb. of dry fuel.

$$W_A = \frac{3.04\ N_2}{(CO_2 + CO)} \times C_b \qquad \text{(By Volume)}$$

Item 8: Excess air.

$$\%\ \text{excess air} = \frac{W_A - W_a}{W_a} \times 100$$

Item 9 to 15 inclusive are obtained from the log sheets.

Item 16 to 21 inclusive (except Item 17) are obtained from the log sheets.

Item 17: The superheat is the difference in temperature of the steam at the boiler superheater outlet at the absolute boiler pressure and the saturation temperature at that pressure. All of the values of steam characteristics were taken from the 1936 edition of THERMODYNAMIC PROPERTIES OF STEAM by J. H. Keenan and F. G. Keyes.

Item 22: Self-explanatory.

Item 23: Fuel per hour (as fired).

$$\text{Fuel per hour} = \frac{\text{Total fuel consumed during test}}{\text{Length of test}}$$

Item 24: Fuel per hour dry.

$$\text{Fuel per hour} = \frac{\text{Total fuel consumed during test} \times (100-\%\ \text{moisture})}{\text{Length of test}}$$

Item 25: Dry fuel per sq.ft. of grate area.

$$\text{Dry fuel/sq.ft./hr.} = \frac{\text{Dry fuel per hour}}{\text{Sq.ft. of grate area}}$$

Item 26: Refuse per hour.

$$\text{Refuse per hour} = \frac{\%\ \text{ash} \times \text{dry fuel per hour}}{(100 - \%\ \text{combustible in refuse})}$$

Item 27: Actual water per hour.

$$\text{Water/hr.} = \frac{\text{Total water evaporated during test}}{\text{Length of test}}$$

Item 28: Heat absorbed by the steam generating unit.

$$H = h_1 - h_2$$

where h_1 is the enthalpy of the steam at superheater outlet.

h_2 is the enthalpy of the steam at feedwater heater.

Item 29: Refuse, per cent of dry fuel.

$$\% \text{ refuse} = \frac{\text{lb. of refuse per hour}}{\text{lb. of dry fuel per hour}}$$

Item 30: Percentage of combustible in the refuse.

Reported on the log sheet of test totals.

Item 31: Carbon burned per lb. of dry fuel.

$$C_b = \% C - (\% \text{ refuse} \times \% \text{ combustible in refuse})$$

Item 32: Rate of heat absorption per lb. of fuel as fired.

$$= \frac{\text{Heat absorbed by steam generating unit} \times \text{lb. steam per hour}}{\text{lb. of fuel per hour as fired}}$$

Item 33: Rate of heat absorption per lb. of dry fuel.

$$= \frac{\text{Heat absorbed by steam generating unit} \times \text{lb. steam per hour}}{\text{lb. of dry fuel per hour}}$$

Item 34: Rate of heat absorption per sq.ft. of heating surface per hour.

$$= \frac{\text{Heat absorbed by steam generating unit} \times \text{lb. steam per hour}}{\text{sq.ft. of heating surface}}$$

Item 35: Efficiency of the steam generating unit.

$$= \frac{\text{Rate of heat absorption per lb. dry fuel}}{\text{Heating value of the dry fuel}}$$

Item 36: Same as Item 33.

Item 37: Heat loss due to moisture in the coal.

$$= \frac{\%\ \text{moisture}}{100 - \%\ \text{moisture}} \times (1089 + 0.46\ t_g - t_c)$$

Item 38: Heat loss from combustion of hydrogen.

$$= \frac{9\ H_2}{100} \times (1089 + 0.46\ t_g - t_c)$$

Item 39: Heat loss due to dry flue gases.

$$= W_g\ c_p\ (t_g - t_c)$$

where c_p is the specific heat at constant pressure.

Item 40: Heat loss to CO in flue gases.

$$= \frac{CO \times C_b}{CO_2 + CO} \times 10,\ 160$$

Item 41: Heat loss due to combustible in refuse.

$$= \frac{\%\ \text{refuse} - \%\ \text{ash}}{100} \times 14{,}150$$

Item 42: Heat loss due to unconsumed hydrogen, hydrocarbons, moisture in air, radiation and unaccounted for.

= Heating value of fuel - (sum of Items from 36 to 41 inclusive)

A TABLE COMPARING FUEL-COST FACTOR

Test No.	1	2	3	4	5	6	7	8
Unit No. 3								
Fuel/hr.	1525	1625	1550	925	660	1000	1225	1050
Steam/hr.	15625	16125	17125	8500	6375	8875	10400	9875
lb. Steam/ lb. Fuel	10.2	9.9	11.0	9.2	9.7	8.9	8.5	9.4
% Rating	141	145	154	76	57	80	94	89
% Total load	32.7	34.9	37.3	22.6	14.4	19.9	19.3	17.7
Fuel-cost factor	17.3	17.8	16.0	19.4	18.2	19.4	20.0	18.7
Unit No. 4								
Fuel/hr.	1690	1825	1613	775	1310	1125	1490	1110
Steam/hr.	10250	11375	11500	5250	8250	8500	10600	10625
lb. Steam/ lb. Fuel	6.1	6.2	7.1	6.7	6.3	7.6	7.1	9.6
% Rating	92	102	103	47	74	76	95	96
% Total load	21.5	24.7	25.1	14.0	18.6	19.8	19.6	19.1
Fuel-cost factor	8.2	8.0	7.0	7.5	7.9	6.5	7.0	9.7
Unit No. 5								
Fuel/hr.	--	--	--	2360	2860	2340	3300	3400
Steam/hr.	--	--	--	23800	29500	25600	33000	35250
lb. Steam/ lb. Fuel	--	--	--	10.1	10.3	10.9	10.0	10.4
% Total load	--	--	--	63.4	66.9	59.6	61.1	63.2
Fuel-cost factor	--	--	--	17.2	16.8	15.9	17.3	16.7

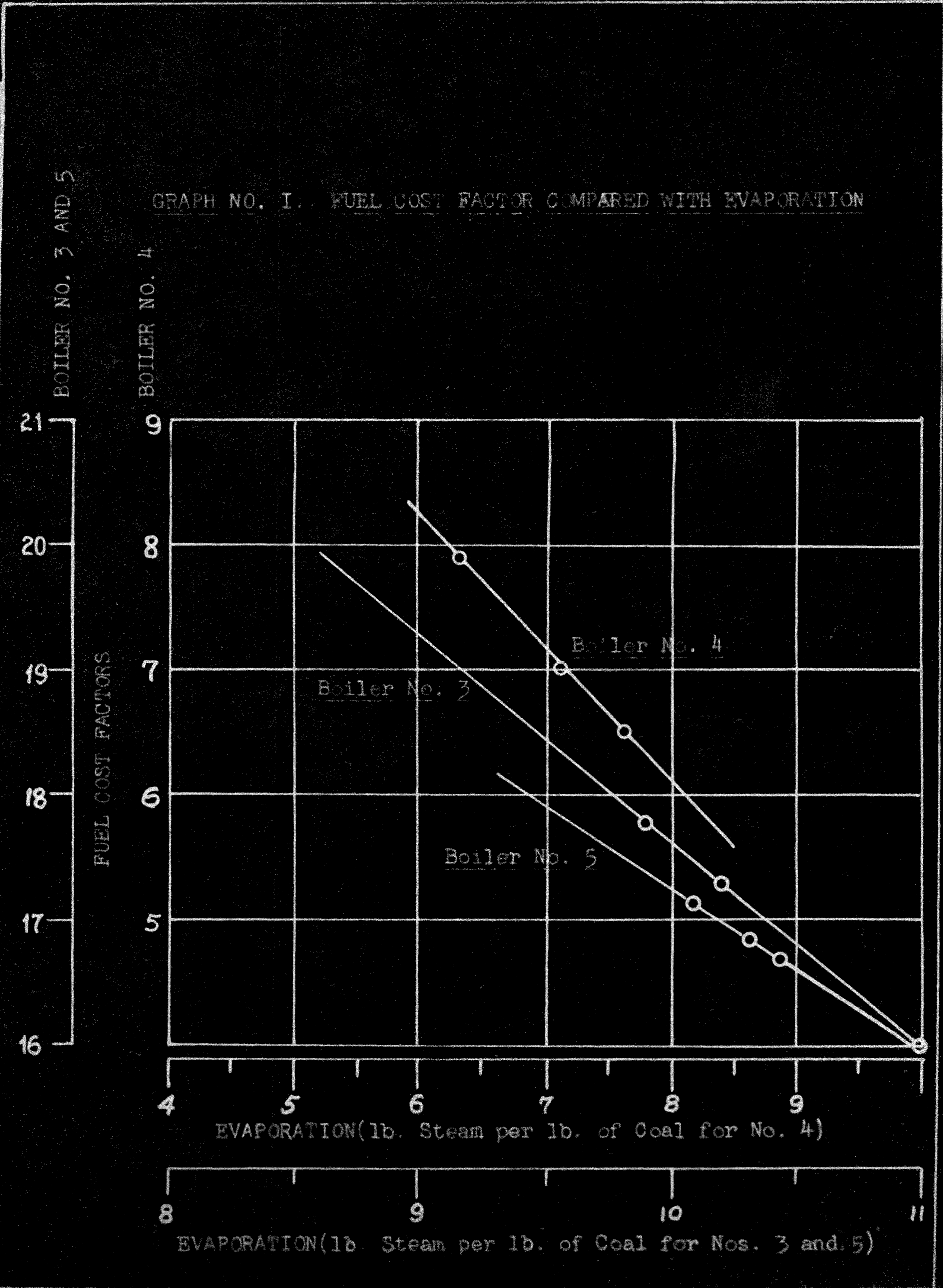
Explanation of Graph:

The table of comparisons of fuel-cost factors for the three units was calculated from the daily power plant logs for the days when the observation tests were conducted. The values of steam and coal are in lb. per hour figured from the shift totals. The evaporation is found by dividing the weight of steam generated by the weight of coal burned. The fuel-cost factor is calculated according to the procedure on page 40.

Graph No. 1, on the following page, shows the rapid rate of variation in the fuel-cost factor with slight changes in evaporation.

The heat absorbed per lb. of steam in unit No. 5 is on an average 35 B.t.u. higher than in unit No. 3 due to the higher temperature and pressure. If all other conditions were constant, this would make the evaporation in unit No. 5 lower than that in unit No. 3. The higher evaporation in unit No. 5 tends to prove that operating conditions in this unit are better controlled than are those of unit No. 3 as the same coal is used in both.

The fuel-cost factor is the cost in cents per million B.t.u. absorbed by the steam per ton of coal and varies directly as the cost of the coal and inversely as the evaporation.


GRAPH NO. I. FUEL COST FACTOR COMPARED WITH EVAPORATION
BOILER NO. 3 AND 5
BOILER NO. 4
FUEL COST FACTORS
21
20
19
18
17
16
9
8
7
6
5
Boiler No. 4
Boiler No. 3
Boiler No. 5
4
5
6
7
8
9
EVAPORATION(lb. Steam per lb. of Coal for No. 4)
8
9
10
11
EVAPORATION(lb. Steam per lb. of Coal for Nos. 3 and 5)

CALCULATION OF FUEL-COST FACTOR

H_a = total heat of steam at superheater outlet minus the total heat of the feedwater entering the boiler.

Evaporation = lb. of steam generated divided by the lb. of coal used.

Cost of coal = $3.79 per ton for bituminous coal used in this test.

= $1.05 per ton for semi-anthracite coal used in this test.

Fuel-cost factor for bituminous coal:

$$= \frac{379}{2,000} \times \frac{1,000,000}{H_a \times \text{evaporation}}$$

Fuel-cost factor for semi-anthracite coal:

$$= \frac{105}{2,000} \times \frac{1,000,000}{H_a \times \text{evaporation}}$$

DISCUSSION OF RESULTS

During the first three of these eight observation boiler studies, unit No. 5 was off of the line for repairs to the superheater. The total plant load was carried by the four, 165 lb. boilers. The portion of the load considered in this study was that on unit Nos. 3 and 4. Due to the fact that none of the variables were controlled, it was practically impossible to correlate a relationship between boiler characteristics, such as, efficiency vs. load, or CO_2 vs. load for given fuel bed depths, but this study was not made to establish these relations.

From the results on the soft coal stoker, it was found that in Test No. 1, the bed decreased from six to two inches above the front observation door. In Test No. 2, the bed increased from three to eight inches above the front observation door. In Test No. 3, the bed increased from three to ten inches above the front observation door. The excess air increased as the average depth of the fuel bed increased with the lowest CO_2 being recorded on Test No. 4 where the excess air was the highest and the load was the lightest. The CO_2 ran fairly constant for the first three tests when the beds were more nearly constant and the steam and air pens of the boilermeter were on an average close together or as close as could be expected under ordinary operations. If the fire lanes were broken and rough or cool ashes left on the dump grate, the CO_2 dropped appreciably. It was observed that conditions of refuse and periods of dumping varied with different operators.

During the first three of these four tests, unit No. 3 carried from 145 to 155 per cent rating on an average from which good evaporation and smaller losses could be expected. In Test No. 4, the unit averaged a load of 77 per cent and ran at a very good efficiency of 78 per cent.

The heat added to each lb. of steam was constant at 1076 B.t.u. per lb. for the heavy ratings, but dropped sharply to 1064 B.t.u. per lb. in Test No. 4 when running at a low rating. This was a definite reason for a variation in the fuel-cost factor. The weight of carbon burned per lb. dry fuel was fairly constant for these tests and averaged around 0.80 lb. per lb. dry coal for a coal that had only 0.81 lb. carbon per lb. of dry coal.

The temperature of the air for combustion varied much depending upon the method of ventilation to the fan room. When the General Electric turbine was on the line, the generator air was blown directly into the fan room where it was used for combustion purposes. When this was not the case, the air for combustion was drawn from the boiler room or from the outside atmosphere, depending upon whether or not the windows in the fan room were open or closed. This variation in temperature was from 10 to 20°F.

Unit No. 5 carried an average of 60 per cent of the load each day a test was run on unit No. 4. The first three tests on unit No. 4 were run using local culm. For these tests, it was found that the excess air was lowest when the best evaporation and CO_2 were obtained. The air flow on this unit was much more difficult to adjust since the bed varied, from time of cleaning the fire to time of dumping the back again, as much as four inches in the front and 18 inches in the rear.

The combustion control system took care of this to some extent but the hand controlled dampers on the unit also required adjustment to control the excess air even more. High values of excess air in three of these tests on unit No. 4 show that this item needs consideration.

The heat absorbed by the steam in this boiler also varied considerable affecting the fuel-cost factor and efficiency to an appreciable degree. Because of the high percentage of combustible in the refuse, approximately 30 per cent of the heating value of the coal was lost.

The best efficiency was obtained when the excess air was the lowest and the rating about 80 per cent.

The last test on unit No. 4 was conducted using a mixture of hard and soft coals. This was done due to the fact that the hard coal contained 12.4 per cent moisture (as Rec'd.) and would not feed through the stoker alone. The ratio of the mixture was approximately two of the hard to one of the soft. This mixing of coals gave a distinct change in results from the preceding tests. The per cent refuse of the fuel decreased from an average of 40 per cent to about 16 per cent with a 40 per cent decrease in the percentage combustible in the refuse. The carbon content of the fuel was increased which resulted in an increase of one-quarter lb. more carbon burned per lb. of dry fuel. The efficiency increased from an average of 54 to 69 per cent, which could probably be raised considerably more with closer control of excess air and fuel bed thickness. All of the calculations for this test were computed considering the ratios of the two coals mixed.

CONCLUSIONS

It cannot be definitely stated as a result of these observation tests that any one of the boiler variables varied directly or inversely as any one of the other variables was held constant, increased or decreased. It can be stated that the variations in the fuel-cost factor are dependent on certain items that can be controlled to some extent.

The fuel-cost factor can vary with the cost of the coal and the heat added to the steam in the unit due to the heat absorbed from the coal. For unit Nos. 3 and 5, the cost per ton was the same and for unit No. 4, the cost was approximately one-third of this amount. The cost of the coal remains fairly constant and even though it should vary, it would not affect the fuel-cost factor from day to day. It would raise or lower it depending upon the cost perhaps from month to month. As this was a variable over which there was no control, either by the personnel or operation of the equipment, it will not be considered further.

The heat added to the steam can easily be controlled by maintaining the pressure at a maximum without pop-off loss and keeping the feedwater temperature and pressure as high as possible and remain a liquid.

The evaporation, expressed as lb. of steam, generated per lb. of fuel as fired, offers a varying factor which is the real cause of variation in the fuel-cost. Keeping this evaporation constant for either boiler is quite a problem. Even during the tests the evaporation varied. The values of evaporation obtained for the eight hour shifts on the days the various tests were run varied as much as one lb. from the test evaporation. There are many things affecting this fluctuation and some of them cannot be controlled. The amount of coal in the hopper at the beginning and ending of the test, the level of the fuel bed, the combustible in the refuse, quantity of ash on the dump grate and the level of the water in the drum---these are items which can be controlled by careful vigilance. To provide the desired smoothness of daily operations, this would be necessary. One of the possible variables, which was not studies during this test, is the accuracy of the steam flowmeters. These meters may be more accurate at high loads and at 165 lb. per sq.in. than at light loads and at 150 lb. per sq.in. In February the Bailey meters were checked but it is considered good practice to calibrate these meters periodically.

It is the practice in the plant at present to operate the soot-blowers on the day shift. It was observed during their operation that the boiler room became enveloped in a cloud of dust, which indicates that there are holes of some nature in the top of the boilers. This in itself may account for some of the high percentage of excess air due to infiltration.

It is shown by the last test on unit No. 4 that its efficiency can be increased considerably by mixing the two coals. To what extent this can be done would have to be determined by further study on this subject. It is known, however, from experience that the soft coal burns with a longer flame and clinkers are more readily formed in this boiler. If too high a percentage of soft coal is used, the chances of overheating the refractory walls and causing them to flow is increased.

It was found that the combustion of the fuel in the furnaces had little to do with the fluctuation of the fuel-cost factor. The variation is due mainly to physical conditions of operation. If smooth daily operating data are desired, then stated loads, levels of beds, conditions of beds on dump grates, quantity of coal left and received in the hoppers must be set and rigidly followed.

These tests show that unit No. 3 operates best with 125 to 175 per cent rating and No. 4 operates best at 80 to 125 per cent rating under present conditions. Because of the great difference in cost per million B.t.u., the loss due to light loads on No. 3 can be absorbed by the saving when operating No. 4 at ratings as stated above.

RECOMMENDATIONS

1. The plant personnel should agree on a definite set of conditions by which the units in operation will be rendered and received at the beginning of each shift. Such items as fuel bed depth, quantity of coal in the hoppers, condition of the beds on the dump grate section of the units, and exact time of readings for the various meters should be specified and posted for the operators use. Incoming operators should not accept the responsibility under any other conditions.
2. The leaks in the settings of both unit Nos. 3 and 4 should be repaired to decrease and if possible eliminate air infiltration.
3. The combustion air for unit No. 4 should be regulated for varying depths of the fuel bed.
4. Unit No. 5 should carry enough of the plant load to generate between 25,000 and 35,000 lb. steam per hour.
5. Unit No. 4 should carry a load between the limits of 8,800 and 13,750 lb. of steam per hour at all times.
6. The remainder of the load should be carried on No. 3 when it is needed.