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COMBUSTION OF EASTERN CANADIAN COAL IN THIN FIRES ON A SPREADER-FIRED AIR-COOLED OSCILLATING GRATE

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SUMMARY

To strengthen the competitive position of Eastern Canadian coals, an extensive program of research was initiated to improve the combustion performance of the coal. One phase of the program is aimed at improving the design of stokers and grates to better suit the coal. As part of this phase, an investigation was carried out on a Riley spreader-fired air-cooled oscillating grate.

In several carefully controlled and well instrumented experiments, studies were made concerning the influence of burning rate, ash thickness and air distribution on grate temperature and clinkering. An interesting comparison was made of grate temperatures when burning a high ash fusion coal and a low ash fusion eastern Canadian coal known as "Dominion". In addition, the general suitability of the stoker for burning eastern Canadian coal was assessed.

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The oscillating grate proved to be efficient, automatic and satisfactory for burning Dominion coal. Furthermore, it was a useful research apparatus for measuring the behaviour of this coal in thin fires. The results obtained may be safely applied to other stokers offering similar processes of ignition and combustion.

It was found that clinkering and excessive smoke, often considered characteristic of eastern Canadian coals, can be minimized by burning in thin fires. Thin firing overheats the grate, but the investigation left no doubt that overheating can be prevented by controlling the distribution of combustion air and, in this way, the rate of combustion according to the ash thickness. Other advantages are claimed for control of air distribution, and it is reasonable to expect that they apply equally well to most types of stokers.

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INTRODUCTION

Eastern Canadian coals are important industrial fuels which are burned both in suspension as pulverized fuel and on grates as sized coal. In the latter case, problems are encountered for reasons which have been difficult to prove. As a result, Canadian coals have had difficulty in competing against the performance of imported American coals. This is particularly true in central Canada, where the commercial coal market represents a large annual tonnage.

In the past, blame for poor performance of eastern Canadian coals was commonly laid on its unique combination of low ash fusion and highly caking characteristics. This may explain an apathetic attitude, which seems to have existed, toward improving conventional stokers to better suit the coal.

A survey in central Canada of installed combustion equipment revealed it to be wholly of American design, developed primarily to burn American coals. There appeared to be two means of satisfying the apparent need: either change the properties of the coal to suit the equipment, or modify the equipment to suit the coal. While work has been undertaken in both directions, modifications to equipment seemed to offer hopes of immediate results. Accordingly, an extensive program of combustion research was initiated in the year 1956. From this it was hoped would come two results:

the first, simple, inexpensive modifications to most conventional stokers to improve their performance, especially with eastern Canadian coals; and the second, a selection or development of equipment suitable for most Canadian coals.

Early investigations undertaken with large equipment under industrial load conditions demonstrated the design features of stokers which best suit the coal. However, because of their size and configuration, they were inaccessible for instrumentation, and also, expensive to modify and operate at other than demand loads. Therefore, for controlled combustion investigations, to obtain precise and reproducible corroborating data, a small, simple and accessible stoker was needed.

The desired features were found in the spreader-fired air-cooled oscillating grate, manufactured by the Riley Stoker Corporation in the United States, and marketed in Canada by Foster Wheeler Limited. This stoker was thought to offer exceptional promise for boilers in the range of 10,000 to 50,000 lb of steam per hr. To determine its capabilities and to obtain data which could be extrapolated to larger stokers, an investigation was organized and carried out in five parts as described in this report.

THE INVESTIGATION

In June of 1958 it was learned that Foster Wheeler Limited had installed Riley spreader-fired air-cooled oscillating grates under two 10,000 lb per hr steam boilers at the Canadian Steel and Graham Nail Division of the Dominion Steel and Coal Corporation Limited, known as the "Dosco Mill" located at Etobicoke, Ontario. It was then that arrangements were made for the present investigation, through Mr. R.W. Boyd, Sales Engineer of the Foster Wheeler Limited, Toronto office.

The initial experiments of the investigation were intended to establish the suitability and limitations of the oscillating grate for burning eastern Canadian coal. The results were promising and further experiments were performed to collect data concerning the influence of firebed thickness, grate heat release and distribution of combustion air on grate temperature and clinkering. While the tests were run on equipment in industrial operation, and therefore could not be controlled as closely as a laboratory experiment, it was nonetheless possible to maintain any load or furnace condition desired, and the data collected were accurate and reproducible. It was felt that here existed an opportunity to obtain under controlled conditions reliable data which could be applied to the operation and design of spreader-fired travelling grates, spreader-fired dump grates, and other stokers having similar processes of ignition and combustion. The ease with which the oscillating grate could be instrumented with such things as thermocouples in the grate surface made it particularly desirable to extrapolate the data obtained to other equipment, such as travelling grates, where it is extremely difficult to place a thermocouple at the burning surface.

In August of 1958 thermocouples were installed in the grate selected for experimenting and the first two parts of the investigation were carried out. Thereafter, the stoker was operated in a routine manner by the plant staff, and the authors made brief calls during October, November and December to check grate temperatures and to obtain from the operators an up-to-date account of the stoker's behaviour.

Performance during the first series of tests was fairly good, but the data collected indicated that grate temperatures and clinkering could be minimized by controlling the distribution of combustion air under the grate. Accordingly, Foster Wheeler Limited installed zoning dampers under the grate, after which the thermocouples were replaced and the investigation was resumed on January 26, 1959. Combustion and evaporation tests were carried out with both an eastern Canadian and an American coal. The experiments were concluded on January 31, 1959.

TEST COAL

The investigations described in this report are concerned primarily with the burning of a particular eastern Canadian coal mined in Cape Breton by the Dominion Coal Company Limited and normally supplied to the Ontario and Quebec markets under the trade name of "Dominion St. Lawrence Mix", more commonly known as "Dominion". The coal is a mixture of Harbour and Phalen seams, and normally has an ash fusion temperature of 2025°F. It was hoped that representative carload lots could be obtained from a stockpile in the Toronto area, but this was not possible. The St. Lawrence Mix available had a somewhat higher than normal ash fusion temperature, as noted in the following analyses.

The oscillating grate was designed to burn a medium ash fusion coal, but for initial starting up an imported high ash fusion coal, known as "Dundon", was selected. This is a number 5 Block Seam coal mined at Widen, West Virginia. It burned very successfully, and therefore was used as a standard for comparison. Its analysis, as determined from samples taken during the investigation, is given in Table 1.

Also included in this table is an analysis considered typical of the Dominion "St. Lawrence Mix".

TABLE 1

Coal Analyses

Coal Name	Dominion		Dundon		Dominion		Dundon		Dominion		Pittsburgh Champion
Coal Size	1 1/4 in.x 0		1 1/2 in.x 28 mesh		1 1/4 in.x 0		1 1/2 in.x 28 mesh		1 1/4 in.x 0		Slack
Sample Collected	Aug. 12-19/58		Aug. 12-19/58		Jan. 26-28/59		Jan. 26-28/59				Specified for
Sample No.	A796		A797		A877		A879		Typical		boiler and stoker
Laboratory No.	2713-58		2714-58		2085-59		2087-59		Analysis		design.
Moisture Condition	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry	Dry
Proximate Analysis											
Moisture %	1.23	0.00	1.93	0.00	8.92	0.00	6.38	0.00	2.4	0.0	0.0
Ash %	8.19	8.29	9.98	10.18	7.79	8.55	6.72	7.18	8.8	9.0	7.9
Volatile Matter %	36.52	36.97	35.53	36.23	32.92	36.14	34.21	36.54	33.6	34.4	35.6
Fixed Carbon %	54.06	54.74	52.56	53.59	50.37	55.31	52.69	56.28	55.2	56.6	56.5
Ultimate Analysis											
Carbon %					69.31	76.10	74.62	79.70	-	76.6	77.9
Hydrogen %					5.01	5.50	5.44	5.82	-	5.2	5.2
Sulphur %	3.08	3.12	2.41	2.46	2.90	3.18	0.81	0.87	-	2.7	1.2
Nitrogen %					1.20	1.31	1.39	1.48	-	1.5	1.6
Ash %					7.79	8.55	6.72	7.18	-	9.0	7.9
Oxygen %					4.87	5.36	4.64	4.95	-	5.0	6.2
Calorific Value, Btu/lb Gross	13,750	13,930	13,310	13,580	12,560	13,790	13,170	14,070	13,370	13,700	13,500 as fired
Ash Fusibility											
Initial °F	1840		1910		1920		2750+		1925		-
Softening °F	2180		2320		2190		2750+		2025		2450
Fluid °F	2370		2540		2310		2750+		2225		-
ASTM Free Swelling Index	8.5		5.5		8.5		5.5		8.5		-

FACILITIES AND EQUIPMENT

Steam Plant

It was stated, earlier, that the experiments were conducted in the steam plant of the Dosco Mill, Etobicoke, Ontario. This is a new and attractive plant designed by Giffels and Vallet of Canada Ltd., Consulting Engineers, Windsor, Ontario.

Boiler and Furnace

The plant incorporates two Foster Wheeler SA boilers, shown in Figure 1, rated at 10,000 lb of steam per hr continuous and 12,000 lb per hr for a 2 hr peak. A cutaway view of an SA boiler is shown in Figure 2. Each boiler has a furnace volume of 480 cu ft and a total heating surface of 1584.5 sq ft. The boiler operating specifications for a steaming rate of 10,000 lb per hr are given in Table 2.

TABLE 2

Boiler Operating Specifications

Steam Press., psig	150	Furnace Draft, in. water	0.15
Temperatures, °F		Draft Loss, in. water	
Feed Water	220	Boiler	0.31
Ambient Air	80	Flues	0.14
Furnace Exit	1628	Dust Collector	1.75
Boiler Exit	546	Windbox Press., in. water	1.75
CO_2, %	13.67	Fuel Burned, lb/hr	952
Total Air, %	128.6	Furnace Liberation, Btu/cu ft/hr	26,080
Wet Gas, lb/hr	13,290		
Forced Fan, lb/hr	12,050		
HEAT LOSSES, %			
Dry Gas	11.57	Unaccounted	1.50
H_2 and Moist. of Fuel	4.55	Total	21.58
Unburned Carbon	2.16	Expected Efficiency	78.42
Radiation	1.80		

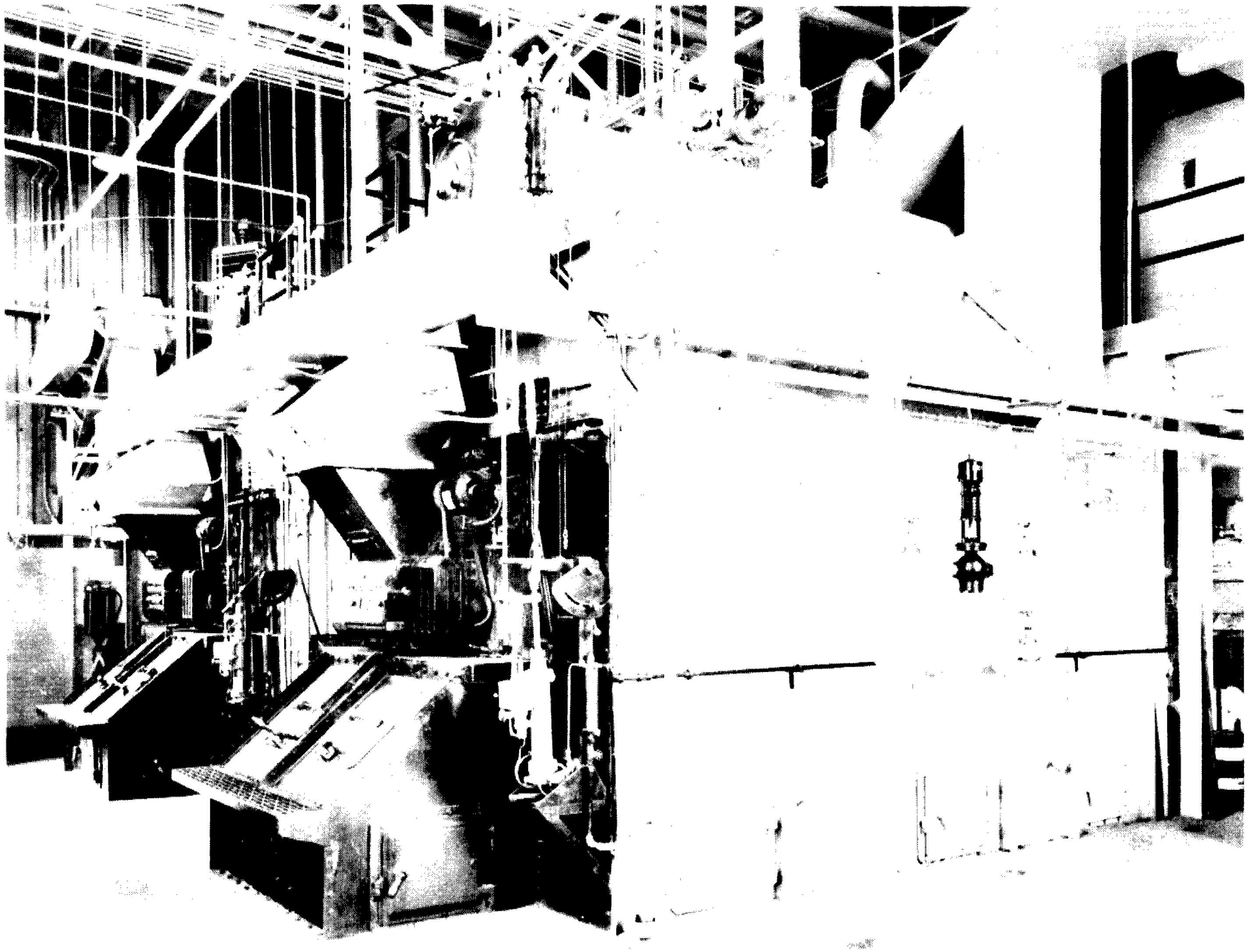


Figure 1   Foster Wheeler boilers with Riley spreader-fired oscillating grates at the Dosco Mill

Included in the ancillaries of each boiler are a Sirocco type D dust collector and an induced draft fan of ample capacity.

Coal and Ash Handling

Although a railway siding is adjacent to the steam plant, coal is normally delivered by truck. It is dumped by truck or by front end loader into a hopper at ground level from which it is elevated by an inclined drag conveyor to a 7 ft diameter silo erected within a few feet of the boiler room wall and in line with the front of the boilers. An enclosed inclined conveyor then transports the coal to a similarly enclosed but horizontal conveyor which fills the hopper of each boiler as shown in Figure 3.

Ash is discharged continuously and automatically off the end of the grate into an enclosed ash pit located at the front of the boiler. A vacuum ash removal system is used, once per shift, to transport the ashes to a storage silo. The entire ash removal system is accessible, clean and effective.

That the coal and ash handling systems contribute much to the automatic operation of the steam plant can be seen from the fact that only one boiler operator is needed per shift. If truck deliveries of coal could be scheduled as required, there would be little or no need for a coal handler. However, practice has been to store truckload lots on the ground in severe weather, making necessary a coal handler with a front end loader to move coal to the receiving hopper.

Figure 1 Foster Wheeler boilers with Riley spreader-fired oscillating grates at the Dosco Mill

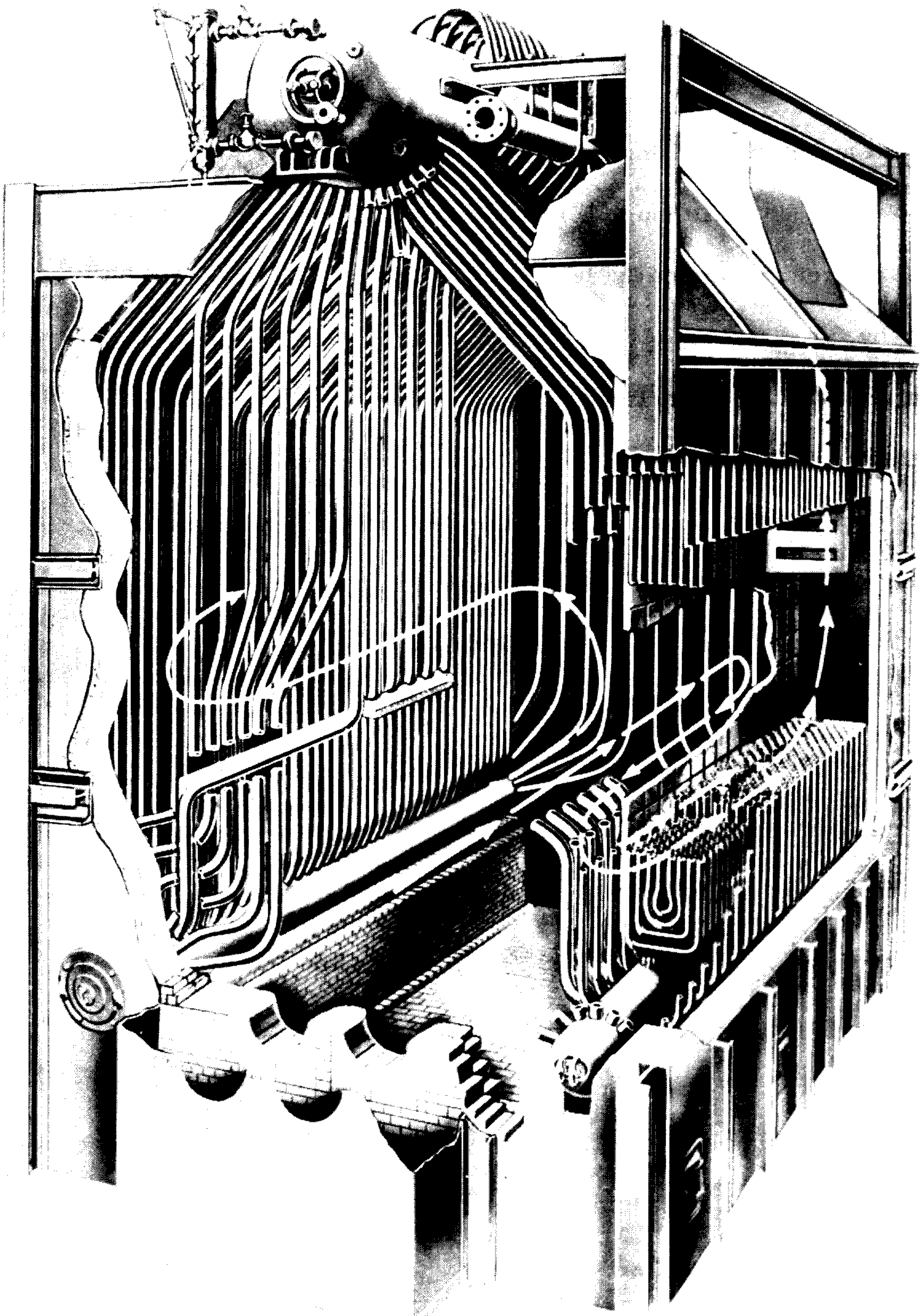


Figure 2 Cutaway view of the Foster Wheeler SA boiler

Overfire Turbulence

Considerable turbulence over the fire is obtained from a total of nine fly ash reinjection nozzles, three of which are located in the bridge wall and three in each furnace side wall as shown in Figure 5. Before combustion tests were started, the reinjection air pressure was measured and found to be 9.5 in. water at the fan discharge.

In addition to fly ash reinjection there are 4 steam nozzles, 1/8 in. diameter, located under the spreader at the front of the stoker and aimed toward the rear of the furnace. These nozzles are manually operated and used only when necessary. Both the reinjection and steam nozzles are shown in Figure 5.

Instruments

The boilers are equipped with a Kent pneumatic combustion control system and the customary draft and pressure gauges. Figure 3 shows the spreader control drive on the front of the boiler. There is also an electric timer to control the length of time of grate vibration.

For the last series of tests Messrs. Geo. Kent (Canada) Ltd. installed an oxygen recorder as will be noted from the data in Tables 8 to 10. In all tests the flue gases were analyzed with a Fisher unitized gas analyzer of the Orsat type.

Grate surface temperatures of each of the four grate sections were measured by 24-gauge chromel-alumel thermocouples.

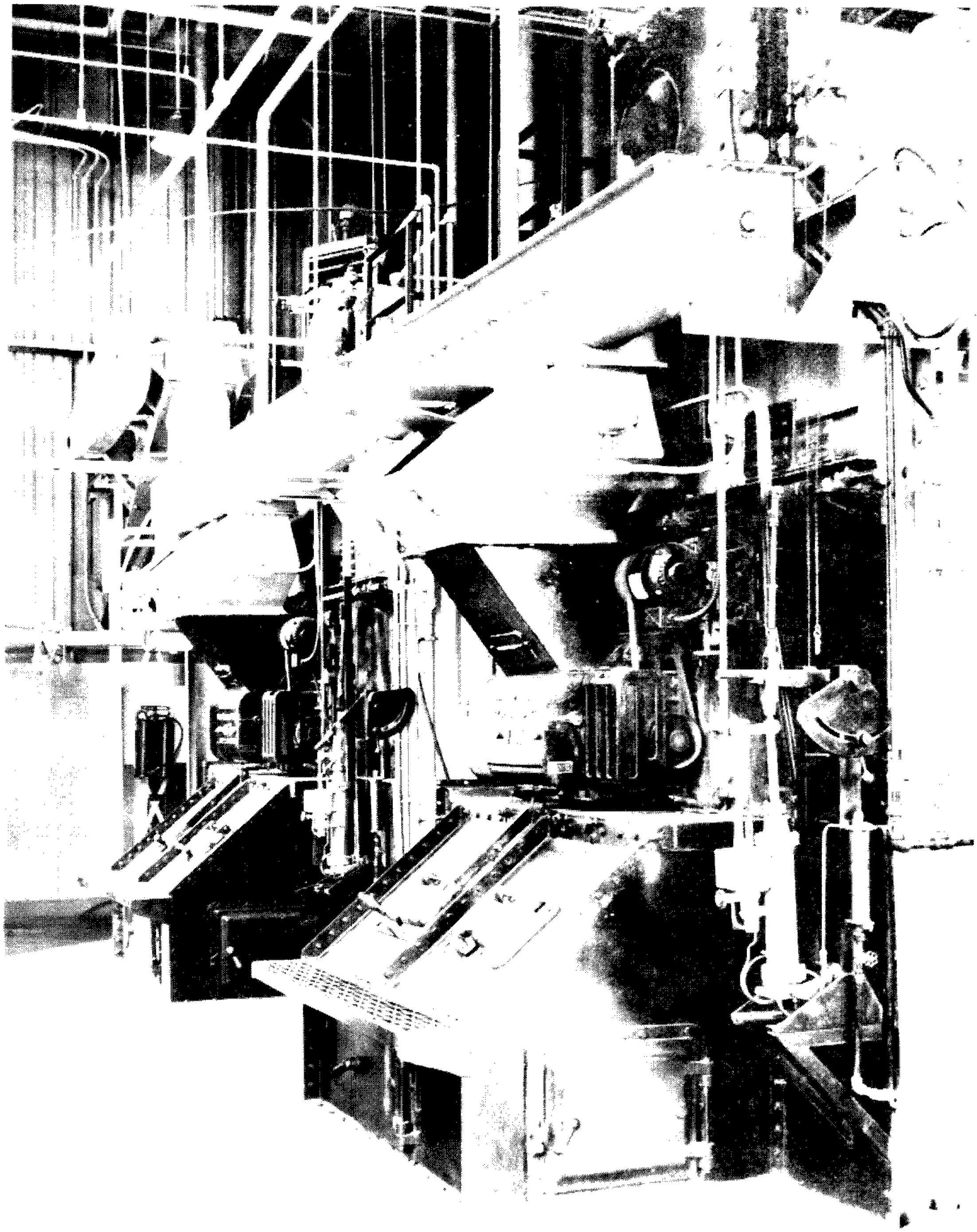


Figure 3 Enclosed coal and ash handling systems provide clean, automatic plant operation

These were installed, as illustrated in Figure 4, at the centre of each section about 6 in. from the centreline of the grate.

This type of installation was adopted after considerable experimenting in the field and in the laboratory. An experiment to compare the accuracy of this installation with a simpler one is described in Appendix I. It should be mentioned that the thermocouples installed for the first series of experiments remained intact for four months before being removed during modification to the stoker. The life expectancy, therefore, barring burning of the grate, would appear to be at least one heating season.

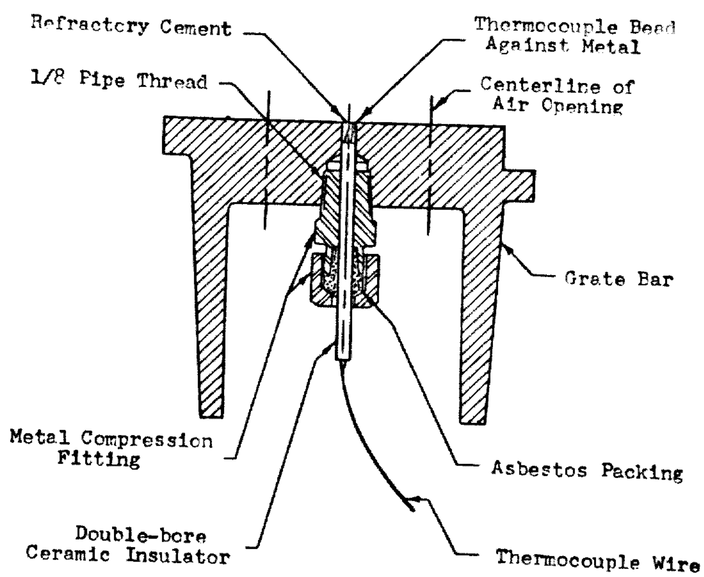


Figure 4 Grate bar thermocouple installation

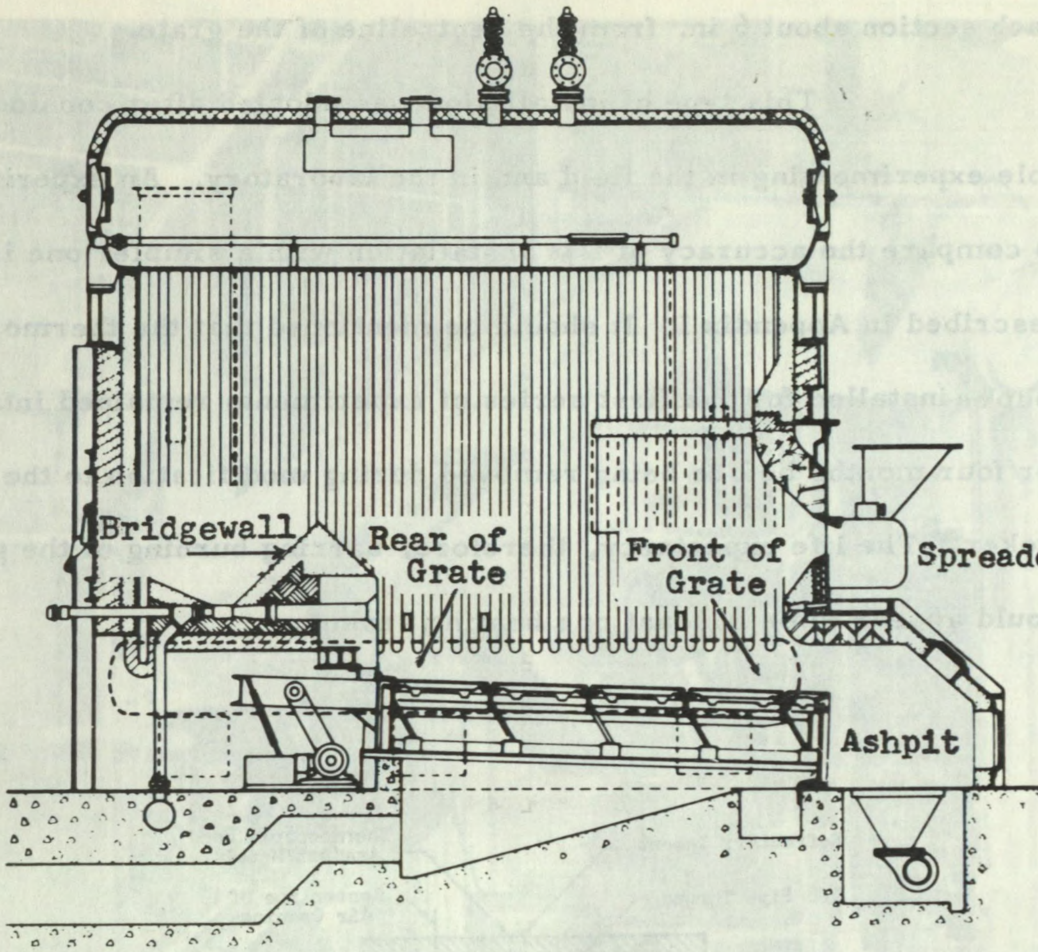


Figure 5 Riley spreader-fired oscillating grate installed at the Dosco Mill

The thickness of the fuel bed was judged, throughout the investigation, from the thickness of ash at the discharge end. This was measured with a long-handled metal probe having a calibrated vertical flange. The fire was judged to be somewhat thicker over part of the grate, but thinner over the rear section.

Furnace temperatures were taken with a portable air-cooled furnace probe developed by the authors. It incorporates a shielded chromel-alumel thermocouple in a 1 in. diameter tube which can be introduced through any accessible boiler opening.

Spreader-fired Oscillating Grate

Each boiler is equipped with the Riley spreader-fired air-cooled oscillating grate shown in Figure 5. The grate surface consists of pinhole-type bars 3 in. wide and 24 in. long, bolted to a rigid steel grid. The grate is the width of 18 bars and the length of 4 rows of bars plus a dead plate. The bars overlap and are bolted at each end, so that each row of bars forms a grate section. The total grate area, including dead plate, is 49 sq ft and the effective grate area is 38 sq ft. The air opening is 2.6% of the effective grate area. The oscillating grate could very readily be made an excellent high resistance grate since the bars are so rigidly fastened that there is little possibility of air leakage due to warping. The rate of coal burning could then be kept to the safe limit by correct sizing of the pinholes.

The grate is inclined slightly downwards to the front, and is supported on steel flexure plates also inclined but at 70° from the horizontal, as shown in Figure 5. The grate drive or oscillating mechanism consists merely of an eccentric shaft mounted on the grid, driven by a fractional horsepower electric motor at the natural frequency of the grate, which is about 1200 rpm. This oscillating motion bounces the ash over the grate surface into the ashpit at the discharge end. The amplitude (usually less than 1/8 in.) and the

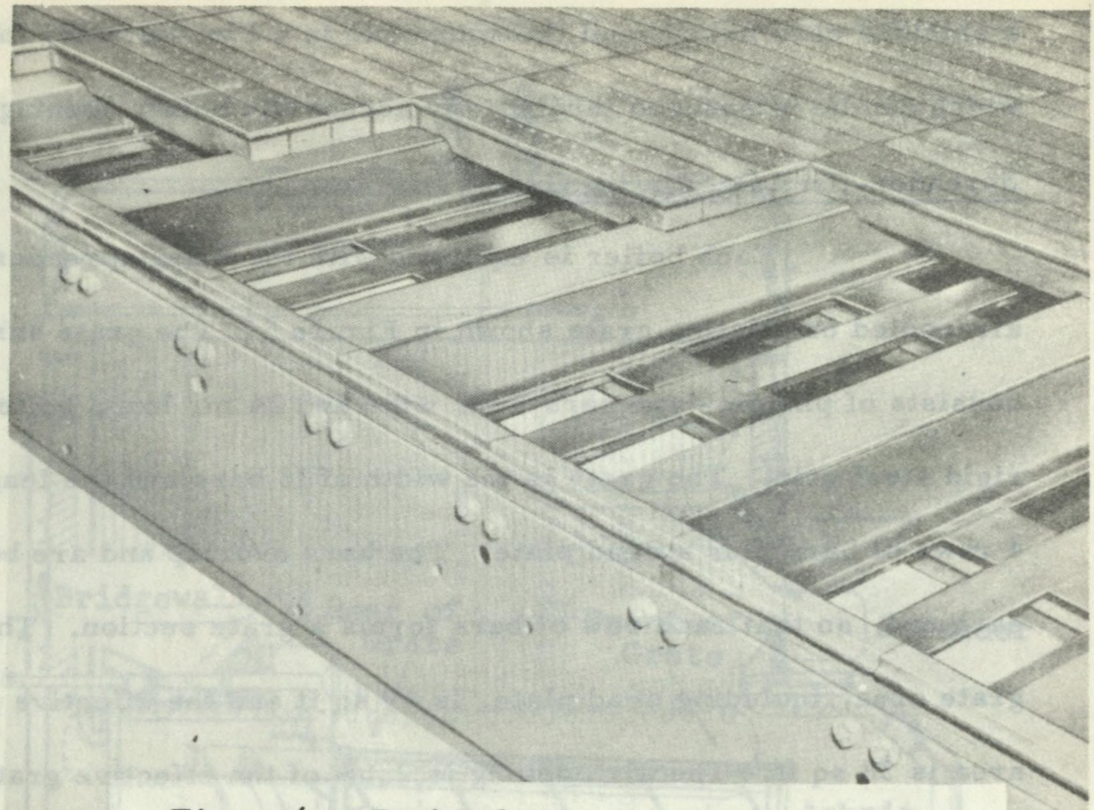


Figure 6 Zoning dampers in open position

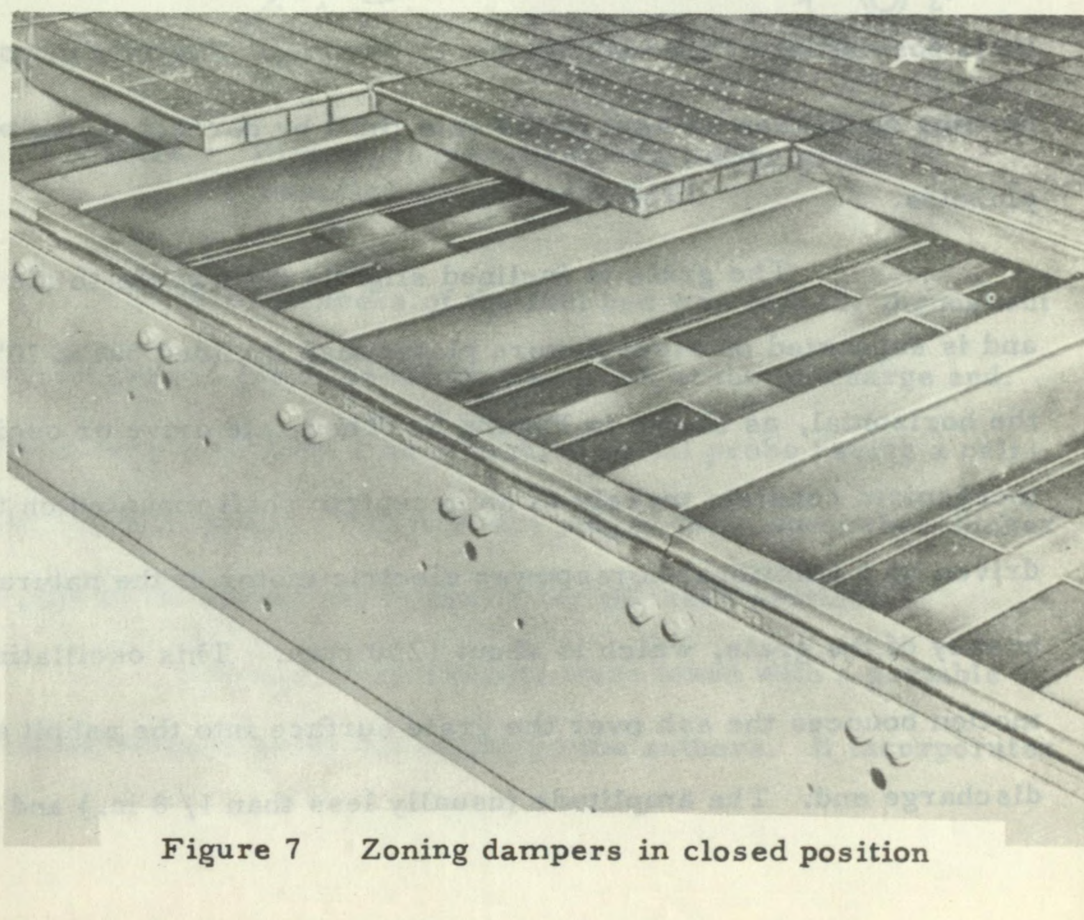


Figure 7 Zoning dampers in closed position

time of oscillation are adjustable to suit the coal. At full boiler load the time of oscillation is only about 5 sec in 20 min.

The boiler design provided a longer furnace than the stoker could occupy; therefore, a refractory bridge wall was erected at the end of the stoker, as shown in Figure 5. The influence this had on the burning of Dominion coal is discussed in the test observations.

Zoning Dampers

For reasons explained in the Introduction, Foster Wheeler Limited installed four zoning dampers under each stoker. These zoned the full length of the stoker and are shown open in Figure 6 and closed in Figure 7.

PROCEDURE

General

The investigation was undertaken in five parts, described in detail later. In Parts I and II, combustion tests were conducted with Dundon and Dominion coals before installing zoning dampers. Part III was a combustion test with Dominion after installing zoning dampers. Finally, Parts IV and V were evaporation tests with both Dundon and Dominion.

The evaporation tests presented three problems. First, there was no provision for weighing coal to each boiler; second, the meter which measured the flow of feedwater to the boiler was equipped with a by-pass that leaked; and third, only a small amount of the Dominion test coal was dry -- the remainder had been dumped in individual truck load lots on the ground, where it became saturated with moisture and froze.

The first problem was overcome by erecting an overhead rail and hoist to lift a coal bucket from a weigh scale to the stoker hopper. Unfortunately, there was no solution to the second problem since there was no consistent agreement, in short periods of time, between flows recorded by the feedwater flow meter and the steam flow meter. It was the opinion of plant personnel that the feedwater flow meter was the more accurate, but, with the by-pass leaking as it did, the evaporation tests could only be used for rough comparison. The third problem also had no solution. Most of the dry Dominion was burned in pre-test operation from 8:45 a.m. to 11:45 a.m. on January 28, the data for which are given in Table 9.

Shortly thereafter, the truckload lots of Dominion were broken up, with considerable difficulty, by a front-end loader and placed on the boiler room floor in an extremely wet and frozen condition for transfer to the stoker hopper. There was no way of separating or weighing some of the ice which the coal contained, although the larger pieces were removed by hand.

It was also unfortunate that for a comparative test the coals were not of the same size. In addition to being dry and having a larger top size, the Dundon coal had the advantage of having been double screened to remove minus 28 mesh particles: a 28 mesh sieve will pass 0.59 mm or slightly less than 1/32 in.

It was planned to include a study of the influence of furnace temperature on clinkering and grate temperature. Therefore, furnace temperature measurements were taken early in the series of tests; however, because of liberal furnace dimensions, only moderate temperatures could be obtained.

Part I: Dundon Coal - Before Zoning Dampers

This Part was a study of the normal performance of Dundon coal on the stoker as originally installed without zoning dampers. It consisted of three short combustion tests which were designed to show, primarily, the effect of burning rate and ash thickness on grate temperature when burning a high ash fusion, moderately caking coal. These tests were conducted on August 12, 1958, and the data are given in Table 3.

Part II: Dominion Coal - Before Zoning Dampers

This was similar to Part I, but Dominion was used. It consisted of three combustion tests designed to show the influence of burning rate and ash thickness on clinkering, and the influence of all of these factors on grate temperature. The tests were conducted on August 14, 15 and 19, 1958, and the data are recorded in Tables 4, 5, 6 and 7.

Part III: Dominion Coal - After Zoning Dampers

Following the installation of zoning dampers, exploratory operation determined good combustion conditions and operating techniques. This done, a combustion test was conducted on January 27, 1959, to show the influence of undergrate air distribution on clinkering and grate temperature when burning Dominion at a constant rate and with a constant ash thickness. The data are given in Table 8.

Part IV: Dominion Coal - Evaporation Test

Although this part of the investigation was primarily an evaporation test with Dominion coal, it showed the influence of air distribution on grate temperature at a high burning rate and with a thin layer of ash. This was done on January 28, 1959, and the data are given in Table 9.

Part V: Dundon Coal - Evaporation Test

This was also an evaporation test under normal high load operating conditions, but with Dundon. In addition, it was intended to show the influence of air distribution on grate temperature for a moderately caking, high ash fusion coal. The data are recorded in Table 10.

TEST DATA

Tables 3 to 10 and Figures 8 and 9, which follow, contain the data recorded during the five parts of the investigation.

TABLE 3

Part I - Combustion Data - American Coal (Dundon) 1 1/2 in. x 28 Mesh
Before Installing Zoning Dampers

Boiler No. 2 Time	Steam Flow x 1000	Air Flow x 1000	Flue Gas Analysis % CO_2	O_2	Total Air	Windbox Press., in. water	Draft, in. water Dust Coll. Outlet	Furnace	Uptake	Temp., °F Flue Gas	Feedwater	Steam Press., psig	Ash Thickness, in.	Vibration Time, sec in min	Smoke Density	Grate Temp., °F 1 (rear)	2	3	4 (front)	Remarks
43.6% Boiler Load Aug. 12, 1958																				
11:30	4.5	3.8	6.6	12.7	247	0.30	2.3	0.02	0.29	480	218	150	3	4 in 20		161	91	86	80	
11:45	4.5	3.8	6.2	13.3	266	0.35	2.4	0.03	0.32	475	218	150	3	4 in 20	dark haze	121	84	84	79	
12:00	4.3	0	7.3	12.1	231	0.10	1.6	0.02	0.21	475	218	150	3	4 in 20		105	81	88	80	
12:08	Grate vibrated for 4 seconds.							-	-	-	-	-	-	-		105	81	88	85	
12:15	4.2	0	8.2	11.1	207	0.10	1.4	0.03	0.20	475	218	150	3	4 in 20	dark haze	125	80	84	84	1 - Grate temperature increased after shaking. Air flow recorder temporarily disconnected.
12:30	4.3	0	8.9	10.2	191	0.05	1.1	0.02	0.17	470	218	150	3	4 in 20	dark haze	510	79	79	80	
Avg.	4.36	-	7.4	-	228	0.18	1.8	0.02	0.24	475	218	150	3	-		188	83	85	81	
65.8% Boiler Load Aug. 12, 1958																				
1:45	6.5	3.0	10.1	9.2	176	0.30	2.2	0.02	0.30	500	218	150	3	4 in 20	light haze	390	78	76	78	
2:00	6.5	0	11.6	7.5	154	0.10	1.2	0.03	0.18	490	212	150	3	4 in 20	mod. haze	470	81	76	76	
2:15	6.7	0	13.0	6.0	139	0.10	1.2	0.03	0.19	490	212	150	3	4 in 20	dark haze	930	94	76	76	
2:30	6.7	0	12.4	6.8	147	0.20	1.4	0.02	0.19	485	212	150	3	4 in 20	mod. haze	756	87	76	76	
2:45	6.5	0	11.8	7.4	153	0.15	1.4	0.03	0.19	490	212	150	3	4 in 20	mod. haze	820	85	76	76	
Avg.	6.58	-	11.8	-	154	0.17	1.5	0.03	0.21	491	213	150	3			673	85	76	76	
93.2% Boiler Load Aug. 12, 1958																				
3:30	9.2	7.3	11.6	7.7	157	0.40	3.1	0.07	0.40	540	215	150	4	4 in 20	light haze	635	80	76	76	
3:45	9.2	6.7	10.4	8.9	172	0.40	3.2	0.02	0.40	550	215	150	4	4 in 20	light haze	660	91	76	76	2 - Burning on the dead plates.
4:00	9.0	6.5	9.9	9.3	178	0.50	3.0	0.02	0.40	560	212	150	4	4 in 20	light smoke	685	84	75	75	
4:15	10.2	7.8	11.0	8.3	164	0.55	3.6	0.02	0.47	560	212	150	4	4 in 20	light smoke	914	119	75	75	
4:25	Grate vibrated.				-	-	-	-	-	-	-	-	-		- -	864	140	75	75	3 - Coal and ash samples taken.
4:30	9.0	7.5	10.1	9.2	176	0.50	3.3	0.02	0.41	550	212	150	4	4 in 20	-	1015	150	74	75	
Avg.	9.32	-	10.6	-	169	0.47	3.2	0.03	0.42	552	213	150	4			796	111	75	75	

TABLE 4

Part II - Combustion Data - Dominion Coal 1 1/4 in. x 0
Before Installing Zoning Dampers

Boiler No. 2 Time	Steam Flow x 1000	Air Flow x 1000	Flue Gas Analysis % CO2	O2	Total Air	Windbox Press., in. water	Draft, in. water Dust Coll. Outlet	Furnace	Uptake	Temp., °F Flue Gas	Feedwater	Steam Press., psig	Ash Thickness, in.	Vibration Time, sec in min	Smoke Density	Grate Temp., °F 1 (rear)	2	3	4 (front)	Remarks
106% Boiler Load Aug. 14, 1958																				
9:45	10.0	8.6	9.8	8.8	169	0.50	3.6	0.08	0.52	545	215	150	3	3 in 20	haze	1017	130	80	81	
10:00	10.0	7.8	10.5	8.4	164	0.35	3.3	0.09	0.46	545	215	150	3	3 in 20	haze	1050	136	75	80	
10:15	9.3	6.0	10.1	9.0	173	0.35	3.0	0.08	0.36	535	212	150	3	3 in 20	light haze	990	134	80	83	1 - Clinkers in small patches.
10:30	9.8	5.5	11.5	7.6	155	0.35	2.8	0.08	0.34	525	212	150	3	3 in 20	dark smoke	930	135	80	83	1
10:45	10.3	6.0	11.4	7.7	157	0.35	2.6	0.07	0.36	525	218	150	3	3 in 20	mod. smoke	945	140	80	84	1
11:00	11.0	6.6	11.6	7.3	152	0.45	2.8	0.08	0.40	540	218	150	3	3 in 20	dark smoke	951	365	80	84	1
11:15	11.0	8.5	10.2	9.2	176	0.50	3.6	0.10	0.50	565	218	150	3	3 in 20	light haze	933	905	80	84	2 - Fire thick at rear causing smoke.
11:30	11.3	9.4	10.5	8.7	179	0.70	3.9	0.07	0.55	590	220	150	3	5 in 20	mod. haze	881	1030	84	84	
11:45	11.3	9.5	9.9	9.1	174	0.70	3.9	0.07	0.56	585	220	150	3	5 in 20	mod. haze	872	1210	85	84	
12:00	11.3	8.2	11.4	7.8	158	0.50	3.3	0.09	0.48	580	218	150	3	5 in 20	dark smoke	845	1400	91	85	
12:15	11.4	8.2	11.7	7.5	155	0.60	3.2	0.08	0.46	570	216	150	3	5 in 20	mod. haze	820	1331	132	89	3 - Fire 12 in. thick at rear - stuck to arch.
Avg.	10.6	-	10.8	-	165	0.49	3.3	0.08	0.45	555	217	150	3			930	629	86	84	
43.5% Boiler Load Aug. 14, 1959																				
3:15	5.5	11.6	5.9	13.7	281	0.55	4.7	0.08	0.66	520	216	135	4	7 in 20	haze	740	1021	680	205	4 - Holes in fire from lifting clinker at bridge wall.
3:30	4.1	11.4	6.0	13.5	273	0.50	4.6	0.10	0.62	525	216	150	4	7 in 20	haze	280	785	355	152	
3:45	4.0	5.2	5.9	13.6	276	0.50	2.2	0.08	0.30	490	215	150	4	7 in 20	dark haze	237	759	291	125	
4:00	4.8	6.2	6.9	12.6	245	0.20	2.6	0.06	0.35	480	218	150	4	7 in 20	dark haze	240	636	190	105	
4:15	5.0	6.2	6.6	12.9	254	0.20	2.6	0.07	0.36	490	216	150	4	7 in 20	dark haze	372	596	219	104	
4:30	3.8	5.2	5.1	14.9	339	0.10	2.2	0.07	0.30	480	215	150	4	7 in 20	dark haze	589	398	219	97	
4:45	3.8	5.2	5.4	14.1	296	0.10	2.1	0.07	0.30	480	218	150	4	7 in 20	dark haze	650	335	170	95	
5:00	3.8	5.2	5.4	14.1	296	0.20	2.2	0.07	0.28	475	216	150	4	7 in 20	dark haze	800	325	130	95	
Avg.	4.35	-	5.9	-	283	0.29	2.9	0.07	0.39	493	216	148	4			495	607	281	122	

TABLE 5

Part II - Combustion Data - Dominion Coal 1 1/4 in. x 0
Before Installing Zoning Dampers

Boiler No. 2			Flue Gas Analysis %				Draft, in. water			Temp., °F						Grate Temp., °F				
Time	Steam Flow x 1000	Air Flow x 1000	CO2	O2	Total Air	Windbox Press., in. water	Dust Coll. Outlet	Furnace	Uptake	Flue Gas	Feedwater	Steam Press., psig	Ash Thickness, in.	Vibration Time, sec in min	Smoke Density	1 (rear)	2	3	4 (front)	Remarks
41.5% Boiler Load - Aug. 15, 1958																				
8:45	4.0	6.1	4.7	13.0	249	0.20	2.5	0.06	0.32	470	217	150	2	off	light haze	901	574	217	166	Fire kept thin purposely for entire test to measure influence of ash thickness on grate temperature.
9:00	4.0	6.5	5.6	12.7	242	0.20	2.5	0.06	0.34	465	218	150	2	off	light haze	926	804	200	146	
9:15	3.9	6.2	5.5	13.7	278	0.20	2.5	0.07	0.33	465	218	150	2	off	light haze	907	816	210	118	
9:30	4.8	7.3	6.3	12.9	252	0.30	2.8	0.07	0.38	470	218	150	2	off	clear	985	842	236	110	
9:45	4.7	7.1	6.2	13.0	256	0.25	2.7	0.06	0.36	480	219	150	2	off	clear	1006	812	214	104	
10:00	4.8	7.1	7.0	12.5	242	0.30	2.7	0.07	0.37	485	219	150	2	off	clear	975	943	206	99	
10:15	4.0	6.6	6.4	12.9	253	0.20	2.5	0.08	0.34	485	219	150	2	off	light haze	924	941	177	95	
10:30	4.3	6.5	6.2	13.1	258	0.20	2.5	0.07	0.33	485	220	150	2	off	light haze	863	907	194	102	
10:45	4.0	6.4	5.3	13.9	286	0.15	2.5	0.07	0.33	487	219	150	2	off	light haze	844	797	180	99	
11:00	3.4	5.6	5.0	14.2	298	0.15	2.2	0.08	0.30	480	219	150	2	off	light haze	901	790	337	99	
11:07	Grate vibrated manually.															926	748	342	101	
11:15	3.6	6.2	5.7	13.5	271	0.25	2.5	0.06	0.34	480	220	148	2	off	light haze	956	774	345	102	
11:30	4.2	7.0	5.5	13.7	279	0.30	2.8	0.08	0.36	485	220	149	2	off	light haze	844	840	308	102	
11:45	4.1	6.4	6.1	13.1	258	0.20	2.5	0.07	0.34	490	219	149	2	off	light haze	947	909	308	108	
11:47	Grate vibrated manually.															970	909	294	106	
12:00	4.2	6.8	5.9	13.5	272	0.30	2.6	0.07	0.35	500	219	148	2	off	clear	930	958	263	108	
Avg.	4.15	-	5.8	-	264	0.23	2.6	0.07	0.34	481	219	150	2			925	835	252	110	

TABLE 6

Part II - Combustion Data - Dominion Coal 1 1/4 in. x 0
Before Installing Zoning Dampers

Boiler No. 2 Time	Steam Flow x 1000	Air Flow x 1000	Flue Gas Analysis % CO2	O2	Total Air	Windbox Press., in. water	Draft, in. water Dust Coll. Outlet	Furnace	Uptake	Temp., °F Flue Gas	Feedwater	Steam Press., psig	Ash Thickness, in.	Vibration Time, sec in min	Smoke Density	Grate Temp., °F 1 (rear)	2	3	4 (front)	Remarks
53% Boiler Load Aug. 19, 1958																				
9:15	5.5	7.7	6.7	12.4	238	0.30	3.0	0.08	0.41	485	215	150	3	2 in 20	light haze	793	411	75	74	
9:30	5.5	8.5	6.3	12.8	249	0.50	3.5	0.08	0.43	490	215	150	3	2 in 20		805	344	74	74	1 - Light clinker forma-
9:45	5.5	6.7	6.3	12.8	249	0.25	2.5	0.08	0.36	485	215	150	3	2 in 20		695	497	76	75	tion reduced windbox
10:00	5.2	4.8	7.3	-	-	0.15	1.9	0.08	0.30	480	215	150	3	2 in 20		658	365	80	75	press.
10:15	5.2	4.2	7.6	-	-	0.15	1.8	0.08	0.26	475	215	150	3	2 in 20		782	240	82	78	
10:30	5.2	0	8.3	10.8	202	0.05	1.2	0.07	0.19	470	215	150	3	2 in 20		777	205	82	78	
10:45	5.5	0	9.6	9.5	180	0.10	1.1	0.07	0.19	460	215	150	3	2 in 20		916	160	86	78	2 - Clinker spreading. Air
11:00	5.3	0	9.8	9.3	177	0.08	1.0	0.07	0.12	458	215	150	3	2 in 20		1030	160	87	78	flow recorder temp-
11:15	5.2	0	10.0	9.1	174	0.05	0.9	0.07	0.12	455	215	150	3	2 in 20		1070	160	89	81	orarily disconnected.
11:20	5.2	0	-	-	-	0.40	1.5	0.06	0.20	450	215	150	3	2 in 20		1043	156	89	81	3 - Grate stalled due to
11:30	5.2	0	8.4	10.7	200	0.40	1.5	0.06	0.20	450	215	150	3	2 in 20		1006	136	88	81	expansion.
Avg.	5.3	-	8.0	-	209	0.22	1.8	0.07	0.25	469	215	150	3			870	258	82	78	
74.1% Boiler Load Aug. 19, 1958																				
12:45	7.0	5.0	8.4	10.7	200	0.30	2.0	0.07	0.30	500	215	150	3	5 in 20		1233	710	85	82	
1:00	7.0	2.0	11.3	7.8	158	0.10	1.4	0.07	0.22	500	216	150	3	5 in 20		1217	719	90	84	
1:15	6.7	2.0	10.5	8.6	197	0.10	1.3	0.07	0.20	490	216	150	3	5 in 20		1275	615	100	80	
1:30	7.7	2.0	12.6	6.7	146	0.20	1.5	0.07	0.21	490	216	150	3	off		1240	522	101	85	
1:45	7.8	2.0	13.1	6.2	141	0.20	1.5	0.07	0.21	495	216	150	3	off		1120	390	97	85	
2:00	8.3	3.5	11.3	7.9	159	0.30	1.8	0.07	0.23	500	216	150	3	off		1067	379	98	89	
Avg.	7.41	-	11.2	-	167	0.20	1.6	0.07	0.23	495	216	150	3			1192	556	95	84	

TABLE 7

Part II - Combustion Data - Dominion Coal 1 1/4 in. x 0
Before Installing Zoning Dampers

Boiler No. 2 Time	Steam Flow x 1000	Air Flow x 1000	Flue Gas Analysis % CO2	O2	Total Air	Windbox Press., in. water	Draft in. water Dust Coll. Outlet	Furnace	Uptake	Temp., °F Flue Gas	Feedwater	Steam Press., psig	Ash Thickness, in.	Vibration Time, sec in min	Smoke Density	Grate Temp., °F 1 (rear)	2	3	4 (front)	Remarks
95.8% Boiler Load Aug. 19, 1958																				
2:15	8.8	3.5	13.1	6.1	141	0.40	1.9	0.06	0.24	500	216	150	2	off	dark smoke	1030	295	89	84	
2:30	9.7	8.8	10.5	8.5	166	0.80	3.4	0.07	0.50	545	217	150	2	off	dark haze	837	615	82	82	1
2:45	9.8	9.0	10.3	8.9	172	0.80	3.5	0.07	0.50	560	217	150	2	5 in 20	dark haze	675	254	80	80	
3:00	9.8	9.0	9.4	9.7	183	0.80	4.0	0.06	0.59	580	217	150	2	5 in 20	dark haze	590	230	76	80	
3:15	9.8	9.8	8.9	10.2	191	0.80	3.8	0.06	0.57	575	217	150	3	5 in 20	dark haze	552	219	77	77	1
3:30	10.2	10.5	10.5	8.7	169	0.65	3.9	0.10	0.59	575	217	150	4	5 in 20	light haze	710	1060	85	80	2
3:45	9.0	6.0	9.9	-	-	0.40	2.3	0.08	0.32	555	217	150	4	5 in 20	light haze	475	753	95	85	2
3:50	Broke clinker on rear grate section and reduced boiler load.														light haze	-				3
Avg.	9.58	-	10.4	-	170	0.66	3.3	0.07	0.47	556	217	150				696	489	83	81	
43.5% Boiler Load Aug. 14, 1958 - Measure of Grate Temperature Before and After Vibrating Grate																				
5:15	Constant firing to stabilize grate temperature before and after vibrating grate.															875	765	125	95	
5:30																941	943	107	93	
5:45																907	852	101	89	4
5:50																915	-	-	-	5

Remarks

1 - 6 in. fire at rear spread by slice bar.
2 - Burning fire out.
3 - Increasing thickness of fire decreased temperature of rear grate section and increased temperature of No. 2 section.
4 - Temperature of No. 1 section just prior to grate vibrating. Temperature of No. 2, 3 and 4 sections after grate vibrated.
5 - Temperature of No. 1 section immediately after grate vibrated.

TABLE 8

Part III - Combustion Data - Dominion Coal 1 1/4 in. x 0
After Installing Zoning Dampers

Boiler No. 2 Time	Steam Flow x 1000	Air Flow x 1000	Flue Gas Analysis % CO_2	Flue Gas Analysis % O_2	Flue Gas Analysis % Total Air	Kent O_2 Analyzer, %	Windbox Press., in. water	Dust Coll. Outlet	Draft, in. water Furnace	Draft, in. water Uptake	Temp., °F Flue Gas	Temp., °F Feedwater	Steam Press., psig	Ash Thickness, in.	Vibration Time, sec in min	Smoke Density	Grate Temp., °F 1 (rear)	Grate Temp., °F 2	Grate Temp., °F 3	Grate Temp., °F 4 (front)	Damper position* 1 (rear)	Damper position* 2	Damper position* 3	Damper position* 4 (front)	Remarks
57.6% Boiler Load Jan. 27, 1959																									
11:45	5.4	7.7	7.6	12.8	225	12.6	0.85	2.9	0.05	0.40	470	212	152	2	5 in 15	dark haze	628	99	64	64	1	3	3	1	
12:00	5.4	5.9	9.6	9.8	185	13.6	0.50	2.0	0.04	0.27	470	212	152	2	5 in 15	dark haze	418	117	64	64	1	3	3	1	
12:15	5.2	4.2	9.9	9.3	177	11.2	0.45	1.5	0.01	0.20	470	215	152	2	5 in 15	dark haze	389	319	64	64	1	3	3	1	
1:30	6.5	5.7	9.9	11.0	210	9.2	0.70	2.1	0.01	0.27	480	215	152	2	5 in 15	light haze	323	195	68	64	1	3	3	1	
1:45	6.5	5.5	11.6	8.0	160	11.2	0.65	2.2	0.01	0.30	460	215	151	2	5 in 15	light haze	289	132	71	68	1	3	3	1	
2:00	6.5	5.7	8.5	11.5	197	10.8	0.60	2.2	0.03	0.28	465	215	151	2	5 in 15	light haze	336	117	73	71	1	3	3	1	1
2:15	Dumped ashes.																								
2:30	5.8	7.6	7.5	12.4	215	12.0	0.75	2.7	0.05	0.42	510	218	150	2	5 in 15	light haze	278	91	71	68	1	3	3	1	
2:45	4.8	8.3	7.1	12.9	228	13.8	0.85	3.0	0.04	0.43	520	218	151	2	5 in 15	smoke 30-40	285	143	68	68	1	3	3	1	2
3:00	6.0	5.8	10.4	9.2	176	10.0	0.55	2.0	0.05	0.30	520	218	150	2	5 in 15	light haze	314	444	68	68	1	3	3	1	
3:15	6.0	6.5	10.0	9.4	179	12.0	0.60	2.4	0.04	0.36	510	218	150	2	5 in 10	light haze	305	515	68	68	1	3	3	1	
3:30	4.1	5.1	7.0	12.7	242	13.0	0.45	1.8	0.06	0.28	520	218	150	2	5 in 10	light haze	323	489	68	73	1	1	3	2	
3:45	6.5	5.5	10.2	9.3	178	10.0	0.45	2.0	0.05	0.30	520	218	150	2	5 in 10	light haze	310	460	68	68	1	1	3	2	
4:00	5.5	5.5	9.3	10.5	199	10.2	0.50	1.9	0.05	0.29	530	218	151	2	5 in 10	clear	327	382	68	125	1	1	3	2	
4:15	6.1	5.9	10.0	9.4	179	10.8	0.55	2.4	0.07	0.38	510	218	149	2	5 in 7	clear	346	330	68	147	1	1	3	2	
4:30	5.0	3.9	9.4	10.5	199	10.2	0.35	1.1	0.02	0.14	510	218	152	2	5 in 5	clear	397	300	68	99	1	1	3	2	
5:00	6.5	3.9	8.8	11.1	208	10.8	0.40	1.6	0.03	0.24	495	218	151	2	5 in 5	clear	323	256	73	147	1	1	3	2	
5:15	6.2	5.1	10.2	9.5	182	10.8	0.50	2.3	0.07	0.34	495	218	150	2	5 in 5	clear	354	310	70	101	1	1	3	2	
Avg.	5.76	-	9.2	10.5	196	11.3	0.57	2.1	0.04	0.31	497	217	151	2	5 in 5		350	276	68	84	1				

Remarks

1 - Took simultaneous orsat samples from boiler pass and breeching and found no difference in analyses.
2 - Smoke caused by unbalanced air flow due to ash removal.
* - Damper position: 0 = closed and 3 = open. Damper travel = 3 in.

TABLE 9

Part IV - Evaporation Test - Dominion Coal 1 1/4 in. x 0
After Installing Zoning Dampers

Boiler No. 2 Time	Steam Flow x 1000	Air Flow x 1000	Flue Gas Analysis % CO_2	O_2	Total Air	Kent O_2 Analyzer, %	Windbox Press., in. water	Draft, in. water Dust Coll. Outlet	Furnace	Uptake	Temp., °F Flue Gas	Feedwater	Steam Press., psig	Ash Thickness, in.	Vibration Time, sec in min	Smoke Density	Grate Temp., °F 1 (rear)	2	3	4 (front)	Damper position* 1 (rear)	2	3	4 (front)	Remarks
Pre-evaporation Test Operation - Jan. 28, 1959																									
8:45	5.8	7.6	9.6	11.4	-	-	0.55	3.2	0.15	.55	515	215	145	2	5 in 20	dark haze	278	584	64	64	1	3	3	1	
9:00	Fire unsettled.																								
9:15	Fire unsettled.																								
9:30	5.8	8.7	9.1	10.9	198	12.0	0.55	3.2	0.12	0.50	550	215	150	2	5 in 20	haze	173	305	64	64	1	3	3	1	
9:45	8.2	8.7	12.0	7.5	155	8.2	0.60	2.5	0.03	0.45	545	215	153	2	5 in 20	clear	165	265	68	66	1	2	3	1	1
10:00	6.5	6.7	8.7	11.2	-	10.0	0.50	2.5	0.07	0.38	535	215	150	2	5 in 20	clear	160	296	69	68	1	2	3	1	
10:15	6.7	7.5	8.1	11.9	-	11.2	0.65	3.0	0.05	0.47	530	215	149	2	5 in 20	clear	138	231	69	68	1	2	3	1	2
10:30	4.9	3.5	6.4	13.8	-	13.0	0.25	2.6	0.03	0.40	530	215	150	2	5 in 20	clear	132	314	68	66	1	2	3	3	
10:45	11.3	10.3	14.0	5.2	132	6.0	0.90	3.7	0.05	0.54	585	214	152	2	5 in 20	haze	126	212	68	66	1	2	3	3	
11:00	11.8	10.8	13.5	5.6	135	6.4	0.90	3.8	0.04	0.55	600	215	152	2	5 in 20	smoke	117	580	68	68	1	2	3	3	
11:15	11.3	10.8	12.0	7.5	156	6.0	1.00	3.8	0.02	0.57	600	215	152	2	5 in 20	smoke	121	559	66	66	1	1	3	3	
11:30	9.7	9.6	11.1	8.7	168	7.8	0.80	3.4	0.02	0.48	595	215	152	2	5 in 20	haze	145	584	64	64	1	1	3	3	
Evaporation Test 96.7% Boiler Load																									3
11:45	10.1	8.3	13.2	6.6	145	6.7	0.65	2.9	0.08	0.47	555	215	151	2	5 in 20	-	169	619	61	61	1	0	3	3	
12:00	10.8	10.1	12.2	7.6	156	7.3	0.70	3.6	0.10	0.56	560	215	152	2	5 in 20	dark haze	152	332	60	60	1	0	3	3	
12:15	10.8	10.3	11.8	7.7	157	7.8	0.80	3.7	0.12	0.60	560	215	153	2	5 in 20	smoke	165	288	61	61	1	1	3	3	
12:30	10.5	10.4	11.5	7.9	159	8.0	0.95	3.8	0.09	0.59	565	215	152	1½	5 in 20	smoke	166	239	64	64	1	1	3	3	
12:45	9.5	10.0	11.0	8.4	165	8.6	0.90	3.6	0.10	0.55	560	215	152	1½	5 in 20	smoke	161	217	64	68	1	1	3	3	
1:00	10.0	10.4	11.3	8.1	161	8.5	0.90	3.8	0.12	0.60	555	215	152	1½	5 in 20	haze	161	204	65	65	1	1	3	3	
1:15	10.3	9.9	11.2	8.8	172	8.1	0.80	3.6	0.12	0.58	555	215	152	1¼	5 in 20	haze	160	193	65	65	1	1	3	3	
1:30	9.8	10.3	12.0	7.1	150	8.1	0.80	3.9	0.14	0.63	545	215	151	1¼	5 in 20	haze	167	189	61	65	1	1	3	3	
1:45	9.5	10.0	10.8	8.3	163	8.8	1.10	3.6	0.08	0.54	570	215	152	1¼	5 in 20	haze	163	160	72	72	1	1	3	3	
2:00	9.8	10.8	10.0	9.3	178	8.4	1.10	3.9	0.09	0.56	590	218	152	1¼	5 in 20	light haze	152	134	73	73	1	1	3	3	
2:15	9.6	10.5	10.1	9.4	180	8.9	1.00	3.7	0.10	0.58	580	217	150	1	5 in 20	light haze	156	134	73	73	1	1	3	3	
2:30	10.0	10.6	13.0	6.4	143	7.4	1.15	4.0	0.10	0.63	555	217	150	1	5 in 20	light haze	169	138	81	68	1	1	3	3	
2:45	9.7	11.0	11.4	8.0	160	8.6	1.15	4.0	0.09	0.60	560	216	151	1	5 in 20	light haze	160	132	69	68	1	1	3	3	
3:00	8.9	10.1	11.4	8.0	160	8.5	0.85	3.5	0.11	0.54	555	216	150	1	5 in 20	clear	-	-	-	-	1	1	3	3	
3:15	9.3	10.0	-	-	-	-	1.00	3.9	0.08	0.60	550	216	150	1	5 in 20	clear	-	-	-	-	-	-	-	3	4
3:30	9.7	10.8	9.8	10.0	189	8.8	1.35	3.9	0.08	0.62	555	216	152	1	5 in 20	light haze	145	118	74	74	1	1	3	3	
3:45	8.5	9.1	11.1	8.6	168	9.5	0.80	3.1	0.10	0.48	550	216	150	1½	5 in 20	light haze	166	104	69	69	1	3	3	3	
4:00	9.0	8.5	10.5	9.4	180	9.4	0.75	2.8	0.08	0.40	540	217	152	1	5 in 20	light haze	199	106	71	72	1	3	3	3	
4:15	8.2	7.9	10.0	9.7	184	9.8	0.75	2.7	0.09	0.41	530	218	152	1	5 in 20	light haze	217	104	112	81	1	3	3	3	
4:30	8.5	7.5	12.3	7.2	152	8.5	0.70	2.5	0.09	0.37	520	218	152	1	5 in 20	dark haze	230	105	71	76	1	3	3	3	
4:45	8.6	7.1	12.5	6.9	148	8.6	0.70	2.5	0.09	0.38	515	218	151	1	5 in 20	smoke	245	108	66	73	[illegible]	3	3	3	5
5:00	9.3	8.5	12.5	7.0	149	8.5	1.00	3.3	0.10	0.50	525	218	151	1	5 in 20	smoke	240	106	71	71	1	3	3	3	
5:15	9.5	8.3	11.6	7.8	158	8.1	0.90	3.0	0.10	0.46	530	218	151	1	5 in 20	smoke	230	99	69	73	1	3	3	3	6
5:30	10.5	12.2	11.5	8.0	160	8.8	1.50	4.4	0.10	0.70	560	217	150	1	5 in 20	smoke	223	99	68	73	1	3	3	3	
5:35	11.4	12.2	-	-	-	-	-	-	-	-	560	-	-	-	-	-	-	-	-	-	-	-	-	-	7
Avg.	9.67	-	11.4	8.1	162	8.4	0.93	3.5	0.10	0.54	552	216	151	-	-	-	182	177	70	70	-	-	-	-	

Remarks

1 - Picked up boiler load quickly from bank.
2 - Sharp swing in steaming rate due to plugged feeder.
3 - Began evaporation test. Feedwater integrator reading 14,058,200. Uneven coal feed due to excessive moisture in coal caused more than normal smoke.
4 - Pile-up at rear of grate, raked fire.
5 - Sharp swing in load caused smoke.
6 - Sudden supply of dry coal caused overfeed of coal with resulting smoke and uneven fire. Fire was raked.
7 - End of evaporation test. Feedwater integrator reading 14,111,800.
* - Damper position: 0 - closed and 3 = open. Damper travel = 3 in.

TABLE 10

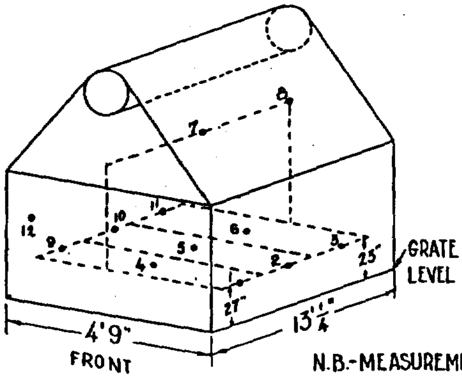
Part V - Evaporation Test - Dundon Coal 1 1/2 in. x 28 Mesh After Installing Zoning Dampers

Boiler No. 2 Time	Steam Flow x 1000	Air Flow x 1000	Flue Gas Analysis % CO_2	O_2	Total Air	Kent O_2 Analyzer, %	Windbox Press., in. water	Dust Coll. Outlet	Draft, in. water Furnace	Uptake	Flue Gas	Temp., °F Feedwater	Steam Press., psig	Ash Thickness, in.	Vibration Time, sec in min	Smoke Density	Grate Temp., °F 1 (rear)	2	3	4 (front)	Damper position* 1 (rear)	2	3	4 (front)	Remarks
84.6% Boiler Load Jan. 29, 1959																									
11:25	9.7	9.5	11.7	8.2	163	8.1	0.75	3.4	0.04	0.48	550	214	152	-	off	clear	81	68	65	65	3	3	3	3	1
12:00	9.0	9.5	10.5	9.4	180	8.8	0.70	3.3	0.04	0.47	550	214	152	2	5 in 20	clear	110	64	62	64	3	3	3	3	
12:30	8.9	8.9	10.8	9.8	188	8.6	0.60	3.0	0.06	0.40	540	215	152	3	5 in 20	light haze	431	62	64	64	3	3	3	3	
1:05	8.5	8.5	10.8	8.7	169	8.6	0.55	2.9	0.05	0.40	535	215	152	3	off	clear	471	90	68	68	3	3	3	3	
1:30	8.5	8.5	10.0	9.7	184	8.9	0.60	2.9	0.04	0.41	530	216	152	2	5 in 20	clear	156	77	66	68	3	3	3	3	
2:00	8.2	8.5	10.5	9.0	174	8.8	0.60	2.9	0.03	0.40	525	216	152	2	5 in 20	clear	382	68	68	71	3	3	3	3	
2:30	7.8	8.2	10.3	9.1	174	9.0	0.60	2.9	0.05	0.42	515	217	151	2	5 in 20	light haze	391	67	67	68	3	3	3	3	
3:00	8.0	7.2	10.7	8.9	172	8.8	0.50	2.4	0.04	0.34	510	217	152	2	5 in 20	light haze	413	68	68	67	3	3	3	3	
3:30	8.5	8.0	10.4	9.2	176	8.9	0.60	2.8	0.03	0.38	505	216	151	2	5 in 20	light haze	614	67	67	68	3	3	3	3	
4:00	8.5	7.7	10.0	9.7	184	8.0	0.55	2.5	0.02	0.31	505	216	152	3	5 in 20	light haze	493	68	68	68	3	3	3	3	
4:30	7.1	7.1	9.9	9.8	186	9.8	0.50	2.4	0.03	0.32	485	217	151	3	5 in 20	light haze	395	69	68	68	3	3	3	3	
5:00	8.5	7.3	11.1	8.6	168	8.2	0.50	2.5	0.03	0.33	500	217	152	3	5 in 20	haze	454	68	67	67	3	3	3	3	
5:35	8.8	8.2	10.6	9.1	176	8.4	0.75	2.9	0.04	0.40	510	216	151	3	5 in 20	haze	448	71	68	69	3	3	3	3	2
Avg.	8.46		10.6	9.2	176	8.7	0.60	2.8	0.04	0.39	520	216	152				372	70	67	67					

Remarks

1 - Began Evaporation Test. Feedwater integrator reading 14,259,920. Steam integrator reading 2,449,705.
2 - End of Evaporation Test. Feedwater integrator reading 14,310,700. Steam integrator reading 2,455,005.
* - Damper Position: 0 = Closed and 3 = Open - Damper travel = 3 in.

1	RIGHT SIDE
2	RIGHT SIDE
3	RIGHT SIDE
4	CENTRE
5	CENTRE
6	CENTRE



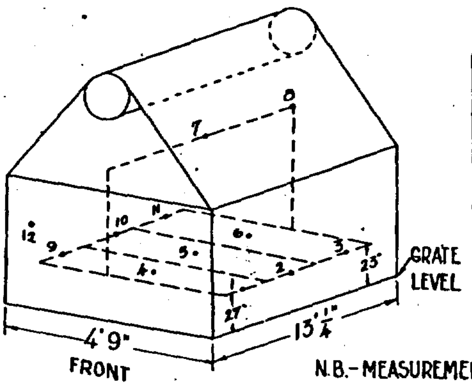
7	TOP CENTRE
8	TOP REAR
9	LEFT SIDE
10	LEFT SIDE
11	LEFT SIDE
12	FURNACE EXIT

N.B.-MEASUREMENTS RECORDED 6" FROM WALLS.

DATE	TIME	LOAD	1	2	3	4	5	6	7	8	9	10	11	12
AUG.14,1958	12:20 P.M	106%	835	945	590	1030	990	950	850	—	—	—	860	750
AUG.14,1958	5:10 P.M.	43.5%	595	550	375	840	830	530	600	540	600	630	540	530
AUG.19,1958	2:55 P.M.	74.1%	700	940	810	1040	1010	850	820	710	625	940	930	685

Figure 8 Furnace temperature with Dominion coal before installing zoning dampers

1	RIGHT SIDE
2	RIGHT SIDE
3	RIGHT SIDE
4	CENTRE
5	CENTRE
6	CENTRE



7	TOP CENTRE
8	TOP REAR
9	LEFT SIDE
10	LEFT SIDE
11	LEFT SIDE
12	FURNACE EXIT

N.B.-MEASUREMENTS RECORDED 6" FROM WALLS.

DATE	TIME	LOAD	1	2	3	4	5	6	7	8	9	10	11	12
AUG.12,1958.	12:40 P.M.	43.6%	470	500	540	690	710	670	720	730	540	600	630	590
AUG.12,1958.	2:50 P.M.	65.8%	620	720	750	790	890	890	810	770	720	799	770	575
AUG.12,1958.	4:35 P.M.	93.2%	740	750	550	980	980	830	900	750	730	780	680	720

Figure 9 Furnace temperature with Dundon coal before installing zoning dampers

OBSERVATIONS

General

The data contained in Tables 3 to 10 and Figures 8 and 9 are self-explanatory. Nevertheless, attention will be drawn in the following paragraphs to the more significant aspects of the tests.

With heavy caking coals the influence of spreader-firing onto the oscillating grate is profound in that the coal is pre-oxidized in its travel and is ignited in thin fires. This reduces caking of the coal and correspondingly reduces clinkering.

It is accepted that uniform coal feed is essential for good combustion, and that excessive moisture, more than any other factor, will often cause disruptions. Although moisture varied considerably during the investigation, adjustments to the stoker and spreader were adequate to maintain uniform distribution.

Because the flexure plates are inclined, the grate rises slightly in an arc as it oscillates. This is illustrated in Figure 10, which exaggerates the amplitude of the flexure plates to show them in both a high forward position and a low rear position. Consequently, the ash and burning coal are violently shaken, and this is responsible for much of the success of the stoker operation, for the shaking action breaks up brittle formations of clinker and coke, and consolidates the fuel and ash into a uniform bed. Thus are eliminated the coke islands and holes in the fuel bed which so often cause difficulty when burning Dominion.

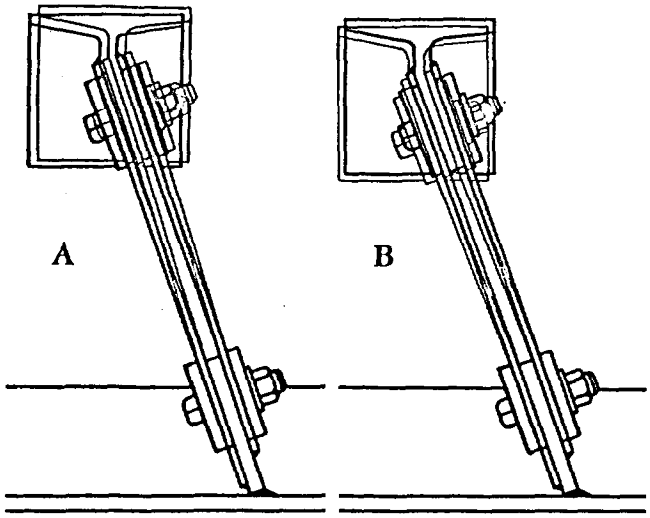


Figure 10 Grate flexure plates in extreme positions

The operation of the oscillating grate has often been compared with that of the travelling grate, but these tests showed little similarity. Although in both cases the ash is discharged continuously into the ash pit, on the travelling grate the fuel bed is carried quiescent and undisturbed, while on the oscillating grate it is bounced over the surface to the discharge end.

Because of its liberal volume the furnace could not be brought to high temperatures at any load. Consequently, a study of the influence of furnace temperature on clinkering was abandoned. Figures 8 and 9 give temperatures measured before the installation of zoning dampers and a comparison shows that, with Dominion, they were higher at full load and lower at part load than with Dundon.

Observations on Part I

These tests were run on automatic control under conditions typical of normal operation with Dundon. The fires were good at all times but smoke was excessive at low load. From Table 3 it will be seen that at 44% boiler load the total combustion air averaged 228%. Undoubtedly, this excess of air created much of the smoke by cooling the furnace and reducing flame temperatures. At this low load it was difficult to maintain a fire over the whole grate without raising the boiler pressure; therefore, some means of reducing the effective grate area seemed necessary.

Grate temperatures were low at all boiler loads or burning rates and increased only slightly after the grate shook in its routine cycle. For full boiler output it was only necessary for the grate to shake 4 sec in 20 min.

The ash was mostly dry and dusty, but small patches of clinker were observed at full boiler load.

The automatic controls maintained constant furnace draft, with the result that at low load the uptake draft was higher than at 66% of full load. This was attributed to the adjustment of the controller.

Observations on Part II

For similar boiler loads when burning Dundon and Dominion, it is interesting to compare the resistance to air flow of the respective fuel beds as indicated by the furnace draft in relation to uptake draft and windbox pressure (see Table 11).

TABLE 11

Average Pressure Drop Across Grate Without Zoning Dampers

Coal	Boiler Load, %	Windbox Pressure, in. water	Draft, in. water Uptake	Draft, in. water Furnace	Ash Thickness, in.
A. Approximately Full Load					
Dundon	93.2	+0.47	-0.42	-0.03	4
Dominion	95.8	+0.66	-0.47	-0.07	2 to 4
Dominion	106.0	+0.49	-0.45	-0.08	3
B. Approximately 3/4 Load					
Dundon	65.8	+0.17	-0.21	-0.03	3
Dominion	74.1	+0.20	-0.23	-0.07	3
C. Approximately 1/2 Load					
Dundon	43.6	+0.18	-0.24	-0.02	3
Dominion	43.5	+0.29	-0.39	-0.07	4
Dominion	53.0	+0.22	-0.25	-0.07	3

Tables 4, 5, 6 and 7 show that grate temperatures were excessive at high loads when burning Dominion without control of combustion air distribution. There was intense burning over the rear section of the grate which overheated the refractory bridge wall and caused clinkering over the rear section, particularly against the bridge wall. When this happened the burning rate increased on the next forward section and it, too, overheated, causing the longitudinal tee rails to expand. This pre-stressed the flexure plates in opposite directions, thereby forming a rigid frame, and the stoker stalled. As the grate cooled, the stresses were relieved and it vibrated as before. Thus the stalling proved to be an effective and automatic safety device to prevent overheating of the grate, though at the expense of steam production.

The influence of fuel bed thickness on grate temperature when burning Dominion is well illustrated in Table 7, which also shows the small increase in grate temperature following shaking.

The Dominion, when reasonably dry, produced less smoke than the Dundon, especially at low loads and with the thinner fires found necessary to minimize caking.

Observations on Part III

It was not possible to equip each compartment with a separate air-pressure indicator after zoning dampers were installed. However, the increased windbox pressure attributed to these dampers is evident in Table 12 which compares Tables 8 and 10 with Table 11.

It is interesting to compare the windbox pressures when burning Dundon with the dampers wide open, with those when burning Dominion in thinner fires with one or two dampers partly closed. Although the dampers appeared to increase resistance to air flow, they were obviously effective in reducing and controlling grate temperatures in the rear zones where there normally is

TABLE 12

Average Pressure Drop Across Grate
With and Without Zoning Dampers

	Boiler Load, %	Windbox Pressure, in. water	Draft, in. water Uptake	Draft, in. water Furnace	Ash Thickness, in.
A. Dominion Coal					
No Dampers	53.0	+0.22	-0.25	-0.07	3
Dampers	57.6	+0.57	-0.31	-0.04	2
B. Dundon Coal					
No Dampers	93.2	+0.47	-0.42	-0.03	4
Dampers	84.6	+0.60	-0.39	-0.04	2 to 3

little protective ash. This clearly is the result of being able to control the burning rate on any section, to suit the fuel bed thickness.

Observations on Part IV

The evaporation test with Dominion was run at 96.7% boiler load and the data are recorded in Table 9. It should be observed that a thin layer of ash was maintained purposely, but with control of undergrate air distribution it was nonetheless possible to keep grate temperature low.

Unfortunately, for the greater part of the evaporation test the coal was extremely wet and contained some ice. Difficulty in spreading resulted and caused intermittent smoke. With coal as dry as the Dundon used in the next test it is probable that thicker, more efficient fires could have been maintained quite easily. The observed overall thermal efficiency when burning Dominion under the existing conditions is summarized in Table 13.

TABLE 13

Summary of Evaporation Test,
Dominion Coal

Coal	Dominion 1 1/4 in. x 0
Date of Evaporation Test	January 28, 1959
Average Boiler Steaming Rate	9,670 lb/hr
Evaporation Rate, Observed (Corrected for an observed 4.2% error between steam integrator and feedwater meter readings)	9.74 lb steam/lb coal
Average Boiler Steam Pressure	166 psia
Average Feedwater Temp.	216.3°F
Calorific Value, as Fired	12,560 Btu/lb
Observed Thermal Efficiency =	$\frac{1195.1-(216.3-32)}{12,560} \times 9.74$
	= 78.4%

The above efficiency figure is modified later by a calculated heat balance.

Observations on Part V

From the data contained in Table X it can be seen that the zoning dampers contributed little to the performance of Dundon at high boiler loads. However, in preliminary operation at low loads it was possible to improve combustion conditions and reduce smoke, by closing dampers to reduce the effective grate area. The improvement, although small, was noticeable. Again, a relatively high excess air was used to burn the coal completely and without smoke, and this reflects in a calculated heat balance, discussed later.

The observed overall thermal efficiency when burning Dundon is summarized in Table 14.

TABLE 14

Summary of Evaporation Test, Dundon Coal

Coal	Dundon 1 1/ 2 in. x 28 mesh
Date of Evaporation Test	January 29, 1959
Average Boiler Steaming Rate	8,460 lb/ hr
Evaporation Rate, Observed (Corrected for an observed 4.2% error between steam integrator and feedwater meter readings)	10.93 lb steam/ lb coal
Average Boiler Steam Pressure	166.4 psia
Average Feedwater Temp.	215.8°F
Calorific Value, as Fired	13,170 Btu/ lb
Observed Thermal Efficiency =	$\frac{1195.1-(215.8-32)}{13,170} \times 10.93$ = 83.9%

The above efficiency figure is also modified later by a calculated heat balance.

DISCUSSION OF RESULTS

Coal Burn Out and Ash Analyses

The boiler efficiency as determined by a weight balance was so susceptible to inaccuracies that it was necessary to calculate a heat balance based on thermal losses. The data required are available from the evaporation tests, except for ash analyses and, of course, the coal analyses which appear in an earlier section of this report.

Composite ash samples were taken during the entire series of combustion tests and were submitted to a thorough chemical analysis in order to identify the principal constituents. The results are shown in Table 15.

As stated previously, for smokeless, troublefree operation, Dundon required more excess combustion air than did Dominion. From Table 15 it may also be seen that with Dundon there was considerably more combustible in the ash. Furthermore, Dundon contained more ash than did Dominion: 8.66% as compared with 8.04%, both determined on the dry coal basis.

It is apparent from this that heat losses due to dry flue gas and unburned carbon are likely to be higher for Dundon, and this is shown later.

An explanation for the higher losses with Dundon may be that because a thicker fire bed is required to suit its dry

TABLE 15

Ash Analyses

Coal Name	Dominion		Dundon	
Time Ash Collected	Aug/ 58	Jan/ 59	Aug/ 58	Jan/ 59
Sample No.	A800	A878	A799	A880
Laboratory No.	2717-58	2086-59	2716-58	2088-59
Moisture .... %	0.18	0.10	0.25	0.13
Ash .... %	94.77	93.83	87.98	90.87
Combustible .... %	5.05	6.07	11.77	9.00
Chemical Analysis				
SiO_2......... %	43.32	49.93	47.68	37.57
Al_2O_3 .... %	34.97	23.81	34.80	41.34
Fe_2O_3....... %	13.88	34.69	13.44	5.39
CaO......... %	1.12	3.46	2.54	0.23
MgO......... %	0.59	1.00	0.82	0.72
K_2O ....%	2.08	1.51	1.48	1.00
Na_2O ....%	0.33	0.39	0.47	0.15
SO_3 .... %	1.14	0.67	0.91	0.17

and dusty ash, some fine coal may land on cool ash and be shaken into it, so that ignition is lost and the coal goes into the ashpit unburned. This loss would be most severe near the front end, where the ash is thickest and where much of the fine coal lands. Ash of

Dominion, on the other hand, was heavier and clinkered at times in thin layers which were both brittle and porous and hence no obstacle to good operation. However, the tendency to clinker did prohibit the spreading of coal against the bridge wall because of overheating when burning coal piled up in front of it.

Calculated Heat Balances

Heat balances were computed by a nomograph method* based on the foregoing data and are given in Table 16.

TABLE 16

Calculated Heat Balances

	Dominion Coal		Dundon Coal	
	Btu/ lb	%	Btu/ lb	%
Input	12,560		13,170	
1. Output	9,461	75.30	9,925	75.35
2. Dry Flue Gas Loss	1,900	15.10	2,000	15.20
3. Loss Due to Hydrogen	600	4.80	630	4.80
4. Loss Due to Moisture in Fuel	110	0.90	80	0.60
5. Loss Due to Carbon in Ash	75	0.60	100	0.75
6. Loss Due to Radiation	226	1.80 (specs)	237	1.80 (specs)
7. Unaccounted For, Including Moisture in Air	188	1.50 (specs)	188	1.50 (specs)
		100.00		100.00
Efficiencies:				
Based on Calculated Heat Balance	75.30%		75.35%	
Based on Weight Balance During Test	78.40%		83.90%	

* Johnson and Auth, Fuels and Combustion Handbook, pp 388-413, McGraw Hill Book Company Inc.

Coal Burning Rate, Ash Thickness and Air Distribution vs Grate Temperature

A. General

From the preceding data it was possible to calculate the coal burning and grate heat release rates for the several combustion tests. These are summarized in Table 17, together with the respective ash thicknesses and corresponding grate temperatures.

B. Effect of Burning Rate on Grate Temperature

The effect of coal burning rate, measured in pounds per square foot of effective grate area per hour, on grate temperature for both Dominion and Dundon is best analyzed from the data collected before the installation of zoning dampers.

1. Dominion Coal

It was observed that when burning Dominion at low rates, grate temperatures increased with burning rate. However, there appeared to be a critical burning rate above which grate temperatures decreased as shown in Figure 11. This is probably caused by clinker beginning to form and locally reducing burning rate by obstructing air flow through the fuel bed. This would be an advantage, except that the clinker might obstruct ash discharge if it were allowed to build up.

For all three rates of burning given in Figure 11, grate temperatures in the rear zone are above 800°F, the safe limit for continuous operation with grey iron.

TABLE 17

Summary - Coal Burning Rate vs Grate Temperature

A. Before Installing Zoning Dampers

Steam Load, %	Coal Type	Coal Calorific Value	Calculated Coal Burning Rate, lb/sq ft/hr	Calculated Grate Heat Release, Btu/sq ft/hr	Ash Thickness, in.	Grate Temperature, °F (Rear) 1	2	3	(Front) 4
41.5	Dominion	13,750	10.8	148,500	2	925	835	252	110
43.5	Dominion	13,750	11.2	154,000	4	495	607	281	122
43.6	Dundon	13,310	11.6	154,000	3	188	83	85	81
53.0	Dominion	13,750	13.7	188,000	3	870	258	82	78
65.8	Dundon	13,310	17.2	230,000	3	673	85	76	76
74.1	Dominion	13,750	19.2	264,000	3	1192	556	95	84
93.2	Dundon	13,310	24.6	328,000	4	796	111	75	75
106.0	Dominion	13,750	27.4	376,000	3	930	629	86	84
B. After Installing Zoning Dampers									
57.6	Dominion	12,560	16.3	204,000	2	350	276	68	84
84.6	Dundon	13,170	22.8	300,000	3 to 2	372	70	67	67
96.7	Dominion	12,560	27.2	342,000	2 to 1	182	177	70	70

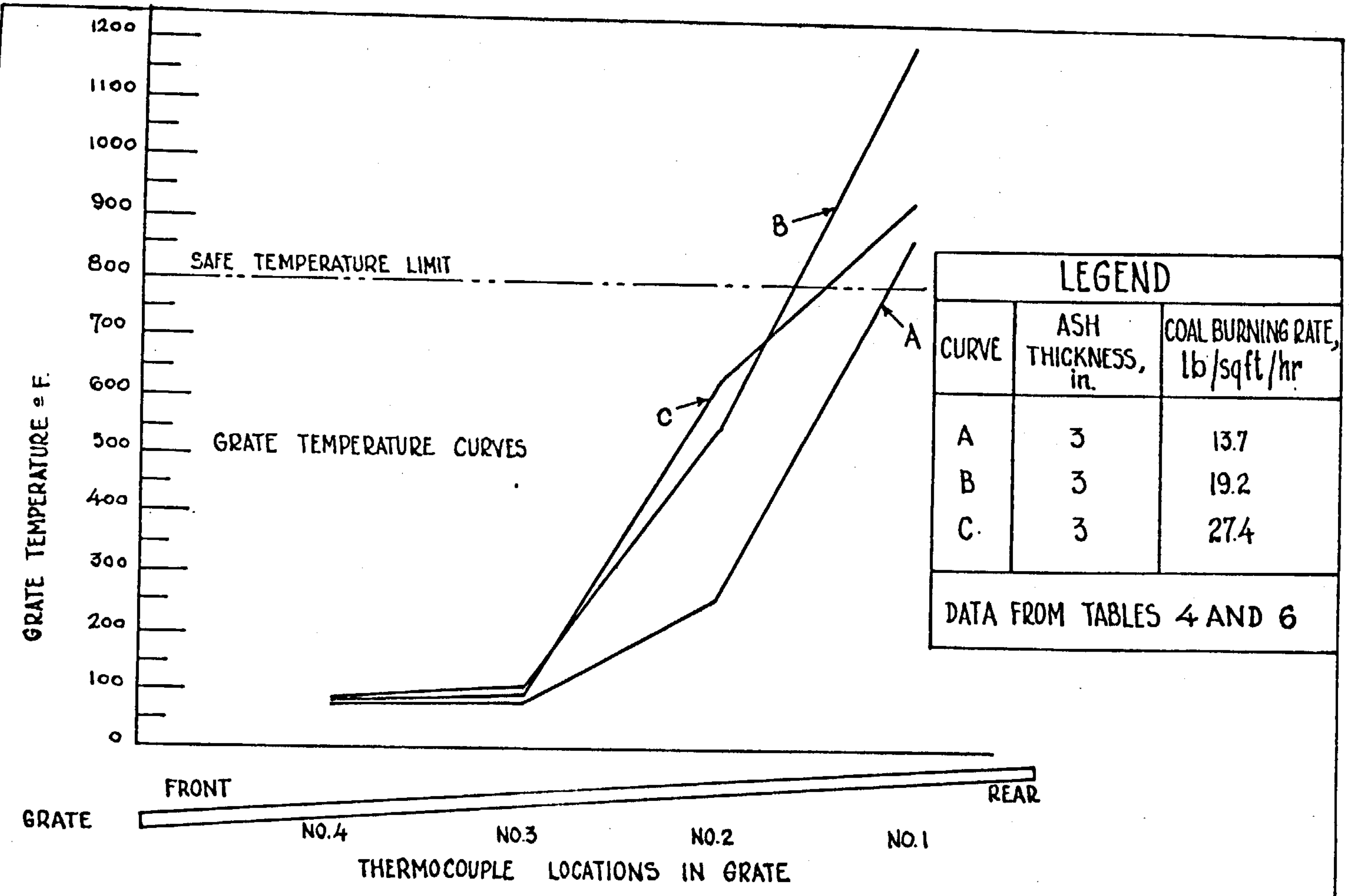


Figure 11 Effect of burning rate on grate temperature with Dominion coal before installing zoning dampers

2. Dundon Coal

From the data in Table 3, summarized in Figure 12, it can be seen that the grate temperature increases within safe limits as the coal burning rate increases.

C. Ash Thickness vs Grate Temperature

1. Dominion Coal

It is reasonable to expect, and experience has shown, that a thick layer of ash better protects a grate from overheating than a thin one. This was confirmed when burning Dominion under non-clinkering conditions as shown in Tables 4, 5 and 6, summarized in Figure 13. Table 7 also shows the cooling influence of increased thickness at a constant high boiler load. But in this case clinkering occurred and raised the temperature in zone 2.

There is, of course, little if any ash over the rear section of the grate, and so a partly ignited layer of coal must be relied upon for insulation from the radiant heat of the furnace. The increased air flow resulting from the low resistance of the thin fuel bed causes excessive local burning rate and clinkering. To prevent this, manual control of air distribution is necessary.

2. Dundon Coal

When burning Dundon it was again observed that increased ash thickness reduced grate temperature, but unlike Dominion, no clinkering occurred.

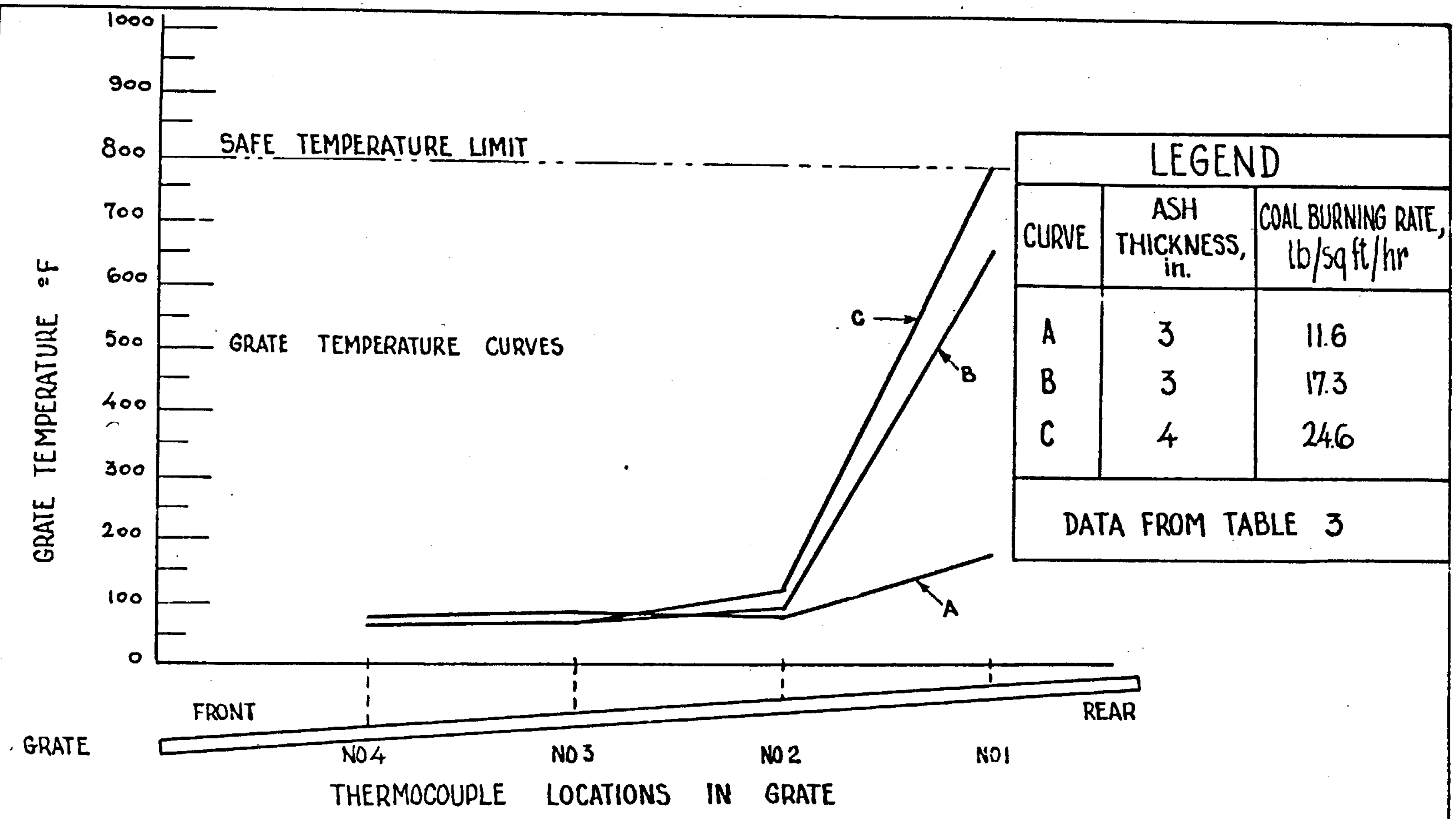


Figure 12 Effect of burning rate on grate temperature with Dundon coal before installing zoning dampers

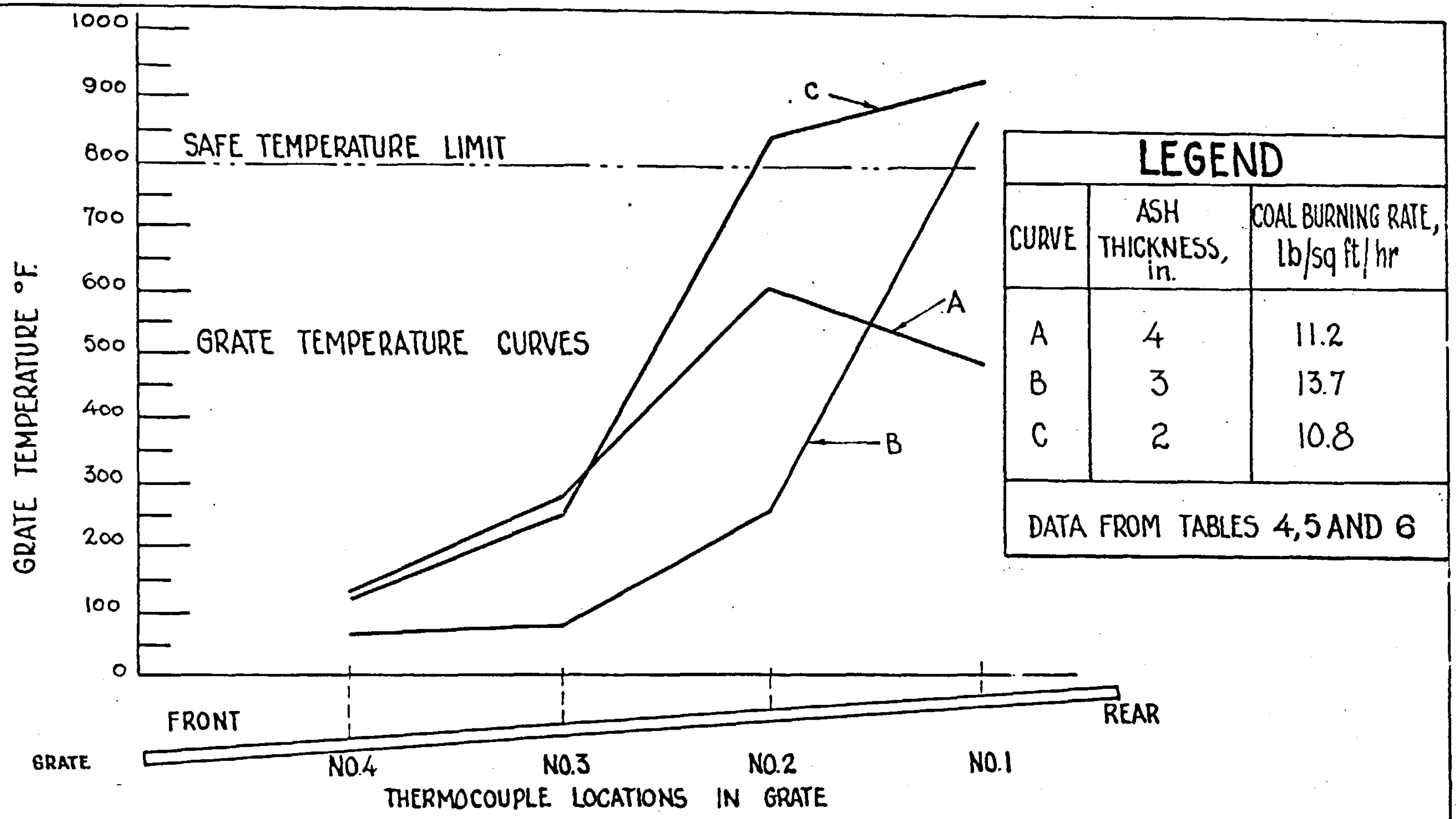


Figure 13 Influence of ash thickness on grate temperature with Dominion coal before installing zoning dampers

D. Grate Temperature - Dominion vs Dundon Coal

The comparison of grate temperatures shown in Figure 14 is made from data in Tables 3 and 4, taken before installing zoning dampers. It illustrates the increase in grate temperature when burning Dominion. This seems to be quite typical of operation with that coal and it should be possible to extrapolate the trend to other stokers not so easily instrumented as the oscillating grate.

E. Effect of Air Distribution on Grate Temperature

1. Dominion Coal

One of the most striking disclosures of the several combustion tests is the effectiveness of air distribution in controlling grate temperature. Data from Tables 4, 5, 8 and 9, summarized in Figure 15, show this clearly. Furthermore, the more zoning dampers installed the greater the control. Additional benefits are reduced smoke, especially at low load, and increased operating flexibility. The latter was particularly valuable when moisture in the coal varied to upset uniform spreading.

2. Dundon Coal

Control of air distribution by zoning dampers was not necessary to limit grate temperature when burning Dundon. This is evident from data in Tables 3 and 10. Actually, when a coal fire produces a dry unclinkered ash at high boiler loads the fuel bed may be whatever thickness is required to provide the air distribution which best suits the particular coal.

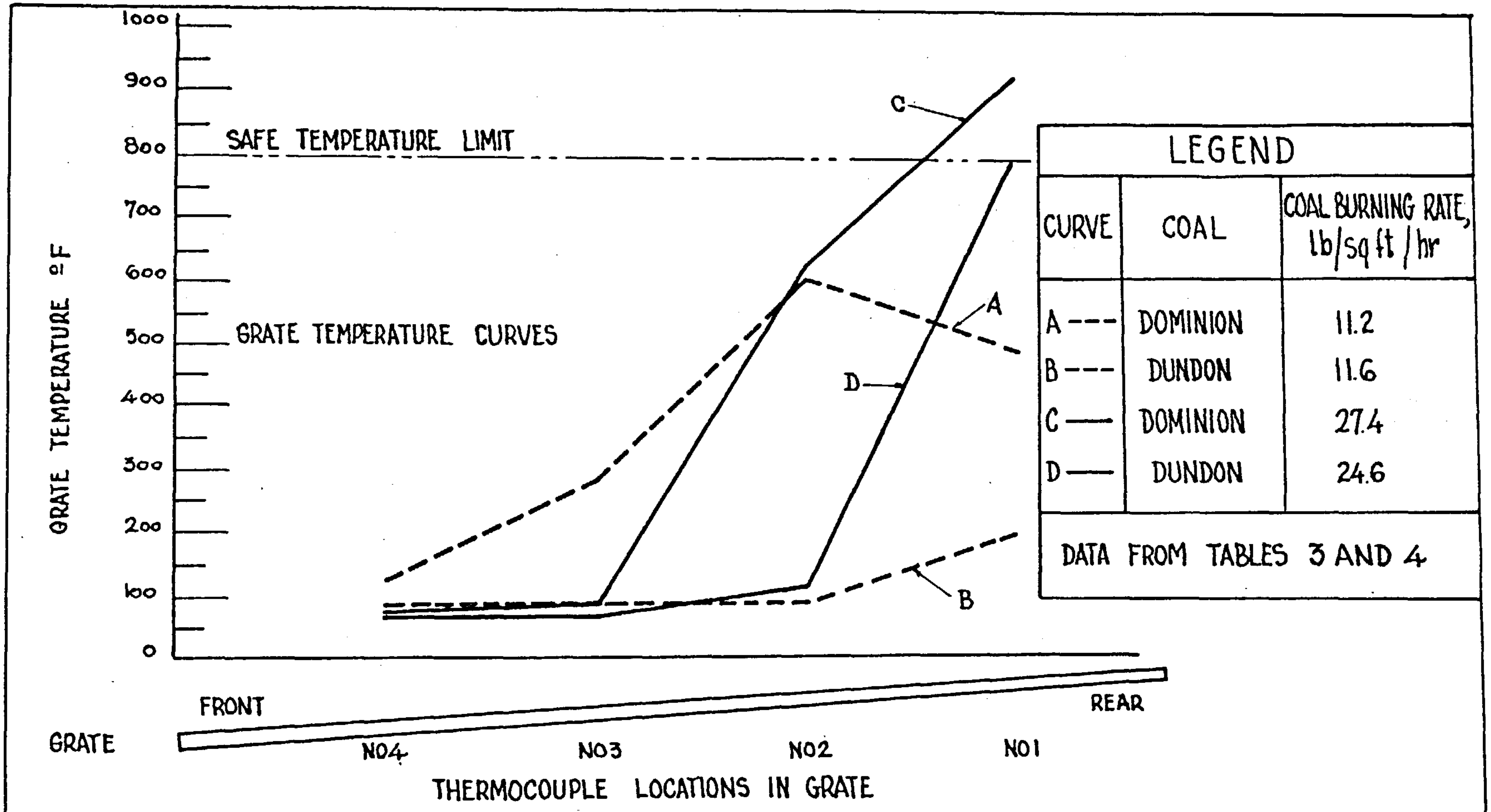


Figure 14 Grate temperatures - Dominion vs Dundon coal before installing zoning dampers

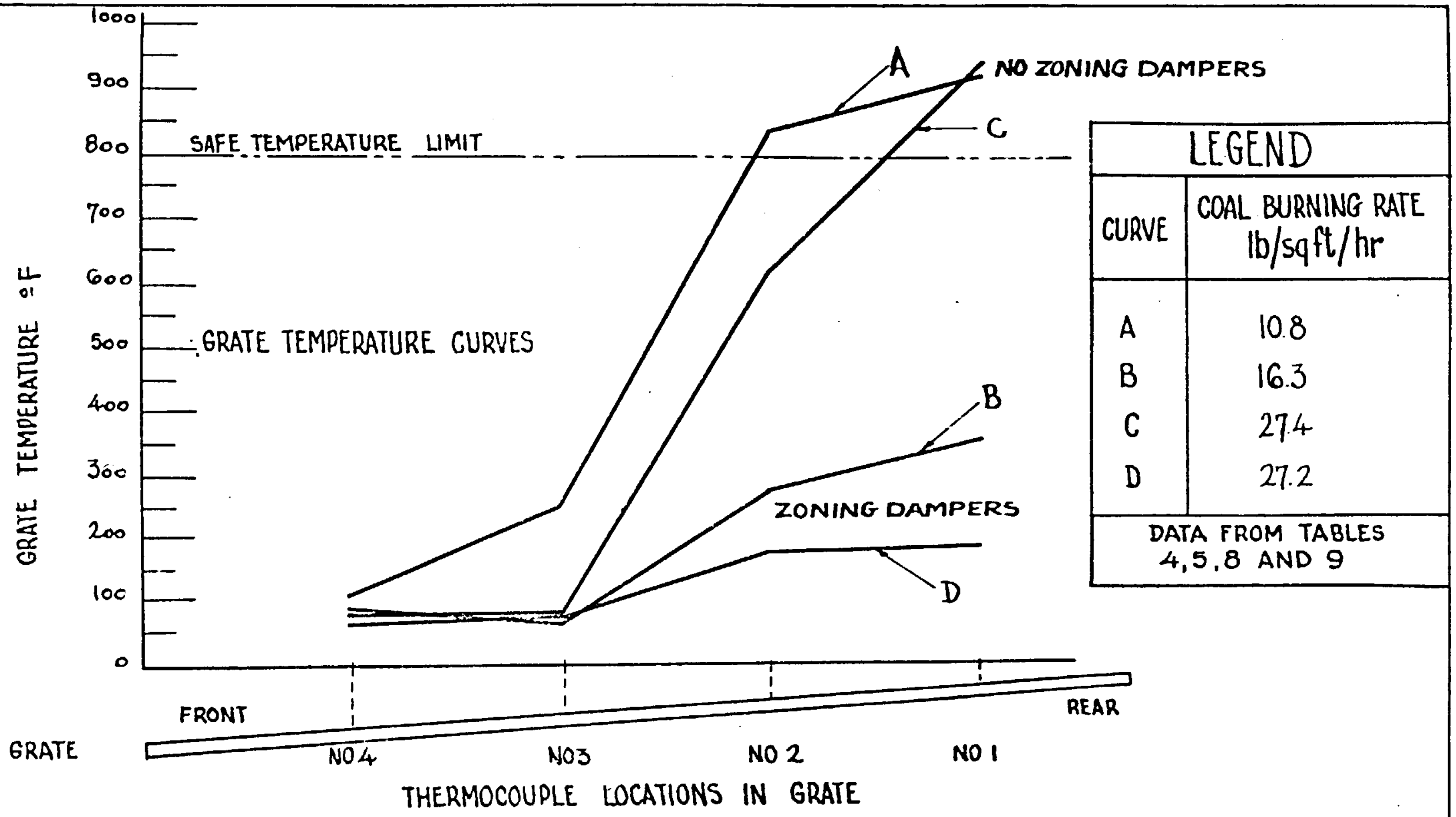


Figure 15 Effect of air distribution on grate temperature with Dominion coal

For high ash fusion coals like Dundon there is one important advantage to be gained from zoning dampers; that is, during low load operation the effective grate area may be reduced, permitting thicker fires and reduced smoke without exceeding a given steam pressure.

F. Comparison of Grate Heat Release vs Grate Temperature

Comparative curves are given in Figure 16 of grate temperatures at various grate heat release rates for both Dominion and Dundon before and after installing zoning dampers. This is another interesting and valuable result of the tests for it establishes reliably that clinkering of Dominion just commences at a heat release of 300,000 Btu per sq ft of grate area per hr. This is evident from the declining grate temperature which means that the formation of clinker has started to impede air flow. When the rate increases to 350,000 Btu per sq ft per hr small patches of clinker form which the violent shaking of the grate is able to move. But, at 375,000 Btu per sq ft per hr some of the clinker does not move and in 2 or 3 days it grows sufficiently large to require manual lifting with a slice bar.

Influence of Ash Thickness on Clinkering of Dominion Coal

It should not be concluded, from the foregoing, that with Dominion the grate temperature may be controlled at all burning rates by merely increasing the thickness of ash. On the contrary,

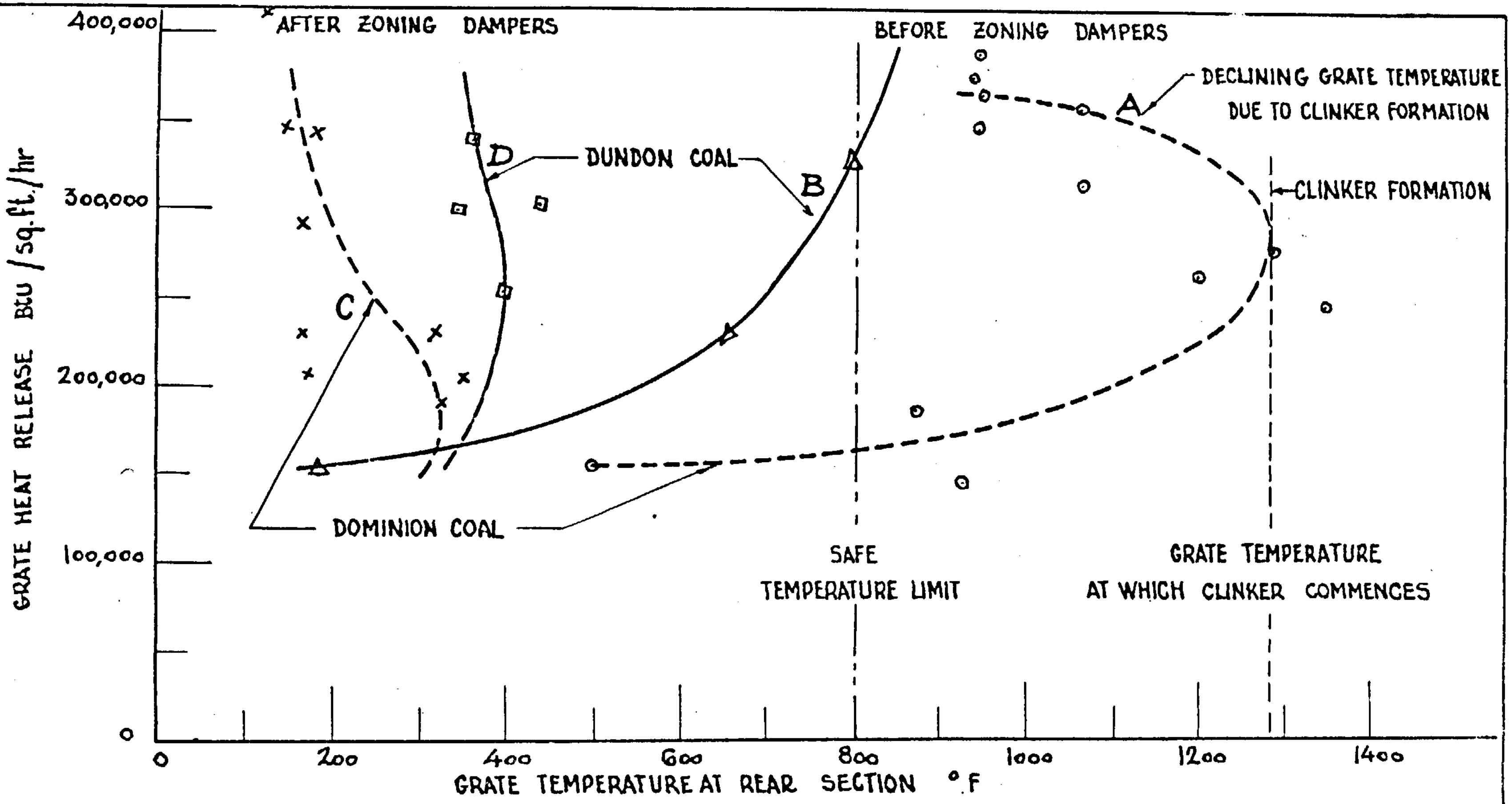


Figure 16 Grate heat release vs grate temperature before and after installing zoning dampers

it is essential that thin fires be maintained to take advantage of the higher ash softening temperature which an oxidizing atmosphere provides. Sometimes the fire must be thin enough to pass sufficient excess air to dilute the flames and cool the ash.

Before installing the zoning dampers, it was observed that the best fires for moderate boiler loads left a layer of 2 in. of ash while for full loads they left less than 4 in. of ash. When the ash thickness was maintained at 4 in. for several hours, excessive clinkering resulted. However, after installing zoning dampers it was possible to burn Dominion with a 1 in. layer of ash without forming clinker. Control of air distribution is important, therefore, in that it makes thin fires possible without overheating the grate, but the reduced clinkering in the thin fire is due to uniform oxidizing conditions.

This does not apply when burning a high ash fusion coal such as Dundon, for clinkering is not a problem. Factors limiting fuel bed thickness with such coals are smoke and carbon in the ash.

LOG OF ROUTINE OPERATION

The steam plant personnel maintain a convenient and valuable daily log in which are recorded any operating difficulties or equipment failures. A review of this log for the period from December 1958 to January 1959, when Dominion was burned in routine operation without zoning dampers, showed that no serious difficulties were encountered with the coal. It was reported that clinker at the rear of the stoker had to be lifted every two or three days, but the operators gave assurance that this was not difficult to do.

A record was also kept of cumulative steam production, feedwater flow, and weight of coal delivered, as shown in Table 18.

CONCLUSIONS

The Riley spreader-fired air-cooled oscillating grate proved to be an efficient and automatic stoker. Through its particular combination of spreader firing and grate action, it provides the uniform and compact fuel bed needed for successful burning of highly caking, low ash fusion coals like those mined in eastern Canada. Adequate overfire turbulence is provided and is an essential feature for eliminating smoke. Improvement in performance is considered possible by water-cooling the bridgewall so that it may be used as a target against which large coal particles may strike without sticking and building up to a large coke or clinker mass.

It was generally concluded that, for maximum performance, coals like Dominion must be burned in thin fires. With spreader firing and continuous ash discharge the optimum fuel bed thickness is 2 in. to 3 in. Thin fires normally overheat the grate but zoning dampers are effective in limiting this tendency.

TABLE 18

Log of Routine Operation

Week 1958-59	Total Steam Produced, lb	Total Feedwater, lb	Total Coal Delivered, lb
Dec. 2-8	1,389,400	1,362,000	157,590
Dec. 9-15	1,398,500	1,372,100	158,020
Dec. 16-22	1,449,800	1,556,300	135,750
Dec. 23-29	1,048,700	1,203,600	137,600
Dec. 30-Jan. 5	1,185,400	1,114,500	123,300
Jan. 6-12	1,578,200	1,604,700	164,480
Jan. 13-19	1,283,900	1,416,300	147,170
Jan. 20-26	1,366,500	1,459,600	161,380
	10,700,400	11,089,100	1,185,290

Feedwater Meter Reading - Jan. 26	-	13,548,000
" " " - Dec. 2	-	2,808,000
Total Feedwater		10,740,000 lb

Actual Evaporation

1. Based on feedwater meter readings - 9.06 lb/ lb coal
2. Based on log record of feedwater - 9.36 lb/ lb coal
3. Based on log record of steam production - 9.02 lb/ lb coal

When burning Dominion coal in thin fires without zoning dampers, clinkering can be expected to commence at a grate heat release rate of 300,000 Btu per sq ft per hr. With zoning dampers to control air distribution the grate heat release rate can be increased without clinkering, but the limits have not been conclusively established.

Zoning dampers were neither intended nor needed to compensate for uneven coal distribution. Nevertheless, they are considered essential for burning highly caking, low ash fusion coals in that they reduce grate temperature, control clinkering, and increase permissible overall burning rate. Furthermore, with both high ash fusion and low ash fusion coals they permit smoke-free low load operation by reducing effective grate area.

ACKNOWLEDGMENTS

Without the generous cooperation of Foster Wheeler Limited and the Dominion Steel and Coal Corporation Limited, this investigation would not have been possible. Special credit is due Mr. J. West, of Foster Wheeler Limited, for his skill in operating and adjusting the stoker.

The steam plant personnel of the Dosco Mill were always cooperative and their assistance ensured the success of the investigation.

APPENDIX I. - TWO GRATE BAR THERMOCOUPLE INSTALLATIONS

Introduction

In stoker investigations it is often desirable to measure the temperature of the grate to determine to what extent scaling and oxidation growth are likely to occur for given combustion conditions. The critical temperature is that at the burning surface of the grate, and thermocouples must be installed to measure this temperature accurately. However, it is often necessary to compromise between accuracy and ease of installation; for the sake of the latter, the authots prefer beaded to peened thermocouples.

When using beaded thermocouples it is sometimes difficult to be sure that they are measuring the actual surface temperature. It seems reasonable to assume that a thermocouple bead located in a small hole in the grate, flush with the surface and in contact with the metal, should be quite accurate. It is often simpler to place the bead in an air opening in the grate and hold it in place with refractory cement. However, such an installation may be inaccurate because of the difference between the thermal conductivities of the refractory material and the grey iron of the grate.

To determine the accuracy of a thermocouple installed in an air opening as just described, in comparison with one in contact with the metal at the grate surface, experiments were run under temperature conditions similar to those in a furnace as hereinafter described.

Procedure

Two thermocouples of 24 gauge chromel-alumel wire were installed in a grate bar as shown in Figure 17. One was located in an air opening of the bar, and was surrounded on all sides by refractory cement which held it in place so that the bead was 1/8 in. from the metal. The other thermocouple was placed in a 1/8 in. hole drilled through the bar, with the bead bent over tightly against the metal; refractory cement was used to seal the hole and hold the bead in position. Both beads were flush with the burning surface and protected from the radiation of the fire.

The thermocouples were connected to a potentiometer through a selector switch, and the burning surface of the grate bar was heated in a gas flame large enough to subject both beads to the same heat input. This minimized heat flow across the surface, and the temperature registered by a thermocouple depended on the heat transfer away from the surface to the parts of the bar not exposed to the flame. Thus it was possible to compare the heat transfer, and hence the accuracy, of the two installations.

Two runs were made: one in which the temperature of the bar was slowly raised by increasing the heating rate in small irregular increments, and one in which the bar was rapidly heated

(Appendix I, concluded) -

in the full flame of the burner. In both cases a temperature of about 1300°F was reached, and readings were taken at suitable intervals while the bar was heating and cooling.

Observations

The readings obtained from the two runs are plotted in Figures 18 and 19. These show that at both slow and fast heating rates the thermocouple in refractory cement heated more rapidly and reached an ultimate temperature 30°F higher than that of the thermocouple in contact with metal. When the heat was removed, the thermocouple in refractory cement cooled somewhat more rapidly.

Conclusions

The above results seem to show that in heating, the refractory cement, because of its insulating properties, impedes heat flow from the thermocouple to the cooler parts of the bar, and this thermocouple is accordingly at a higher temperature than the burning surface. In cooling, the opposite happens: heat flows from the rest of the bar to the burning surface so that it cools more slowly than the thermocouple.

Therefore, to measure accurately the temperature of the burning surface it seems necessary to have the thermocouple bead in firm contact with the metal at the surface of the grate.

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ERM:FDF:GAG:(PES)/DL

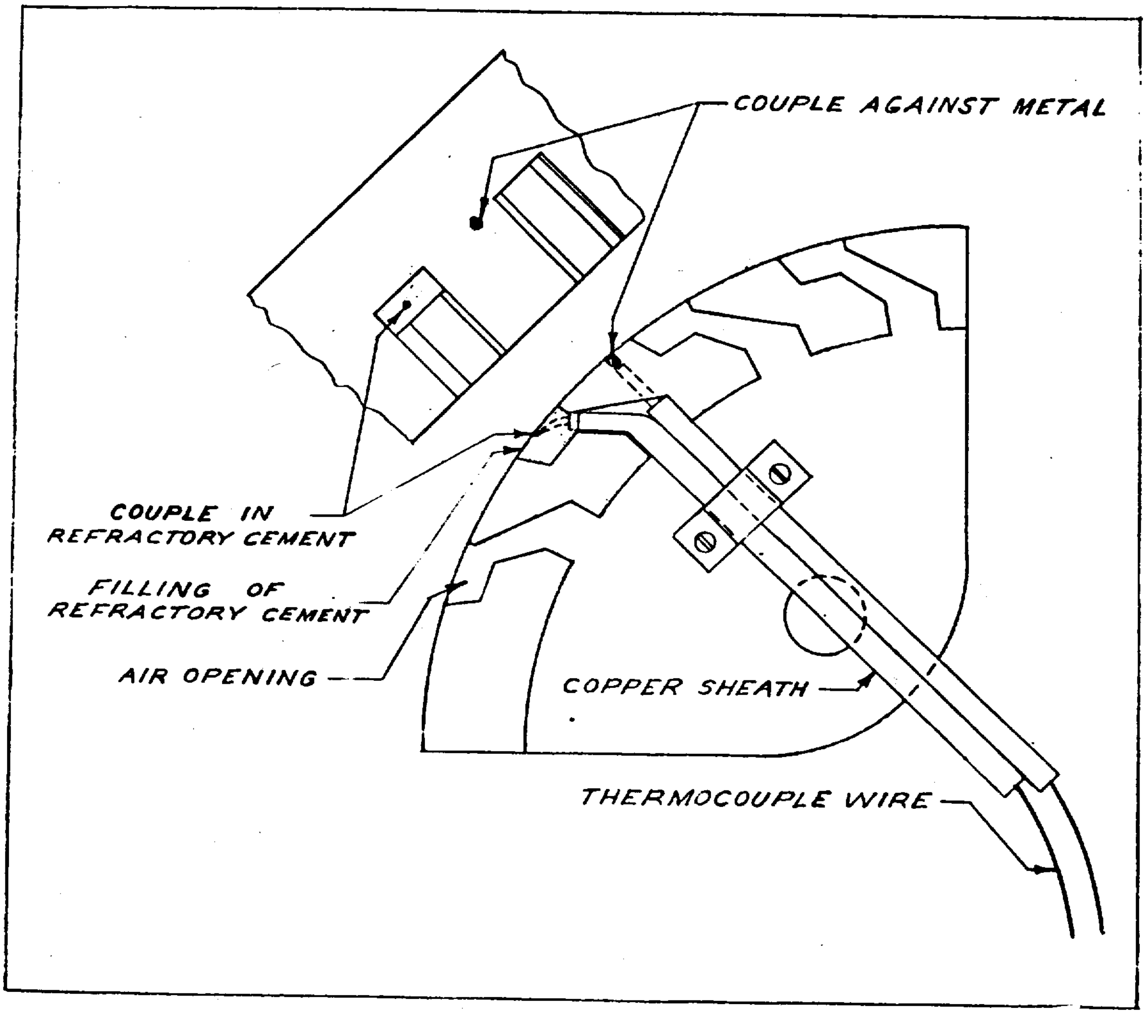
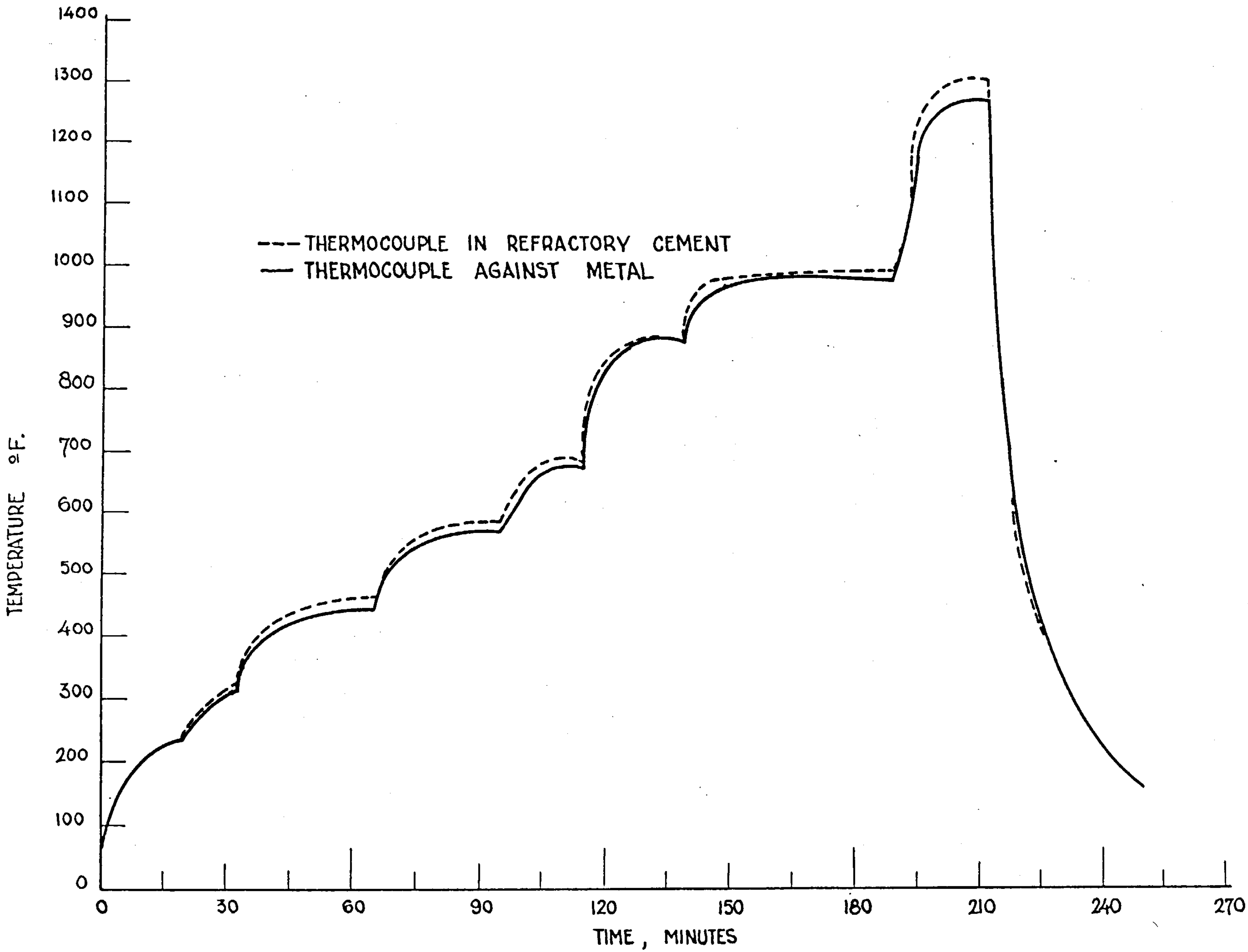


Figure 17   Experimental thermocouples in grate bar



<u>Figure 18</u> Temperatures of experimental thermocouples during slow heating of grate bar

1300

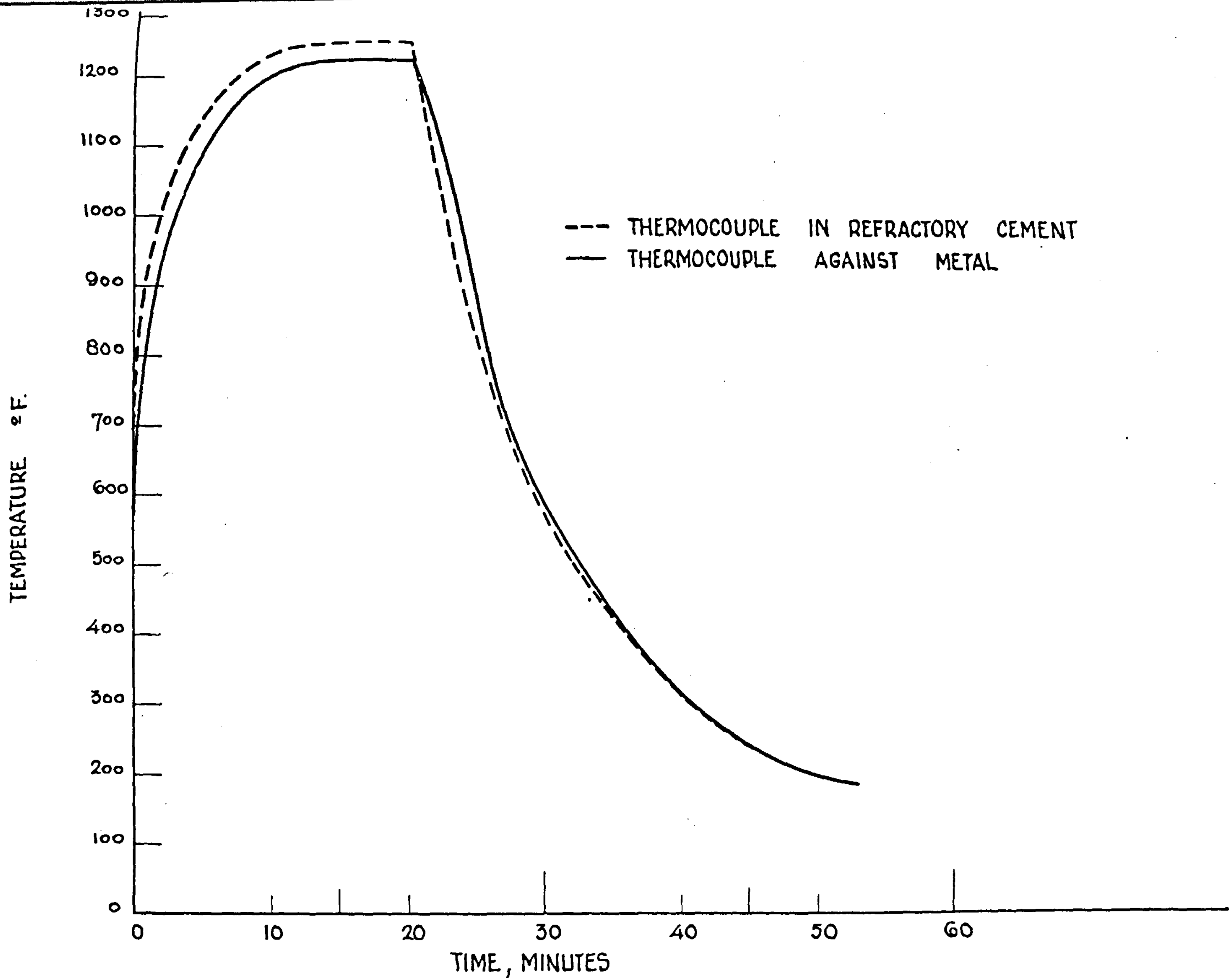


Figure 19 Temperatures of experimental thermocouples during rapid heating of grate bar