



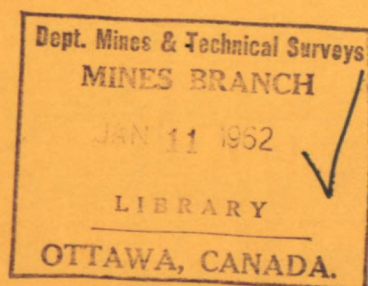
CANADA

# RESEARCH ON THE APPLICATION OF EASTERN CANADIAN COALS TO LARGE STOKERS

PART I: COAL PROPERTIES, COAL SPECIFICATION  
AND COMBUSTION DATA

PART II: RECOMMENDATIONS FOR SELECTION,  
DESIGN AND OPERATION OF LARGE STOKERS

PART III: PRACTICAL RESEARCH ON CONVENTIONAL STOKER



DEPARTMENT OF MINES AND  
TECHNICAL SURVEYS, OTTAWA

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AND G. K. LEE

FUELS AND MINING PRACTICE DIVISION

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## Mines Branch Technical Bulletin TB 14

RESEARCH ON THE APPLICATION  
OF EASTERN CANADIAN COALS  
TO LARGE STOKERS

by

E. R. Mitchell\*, F. D. Friedrich\*\* and G. K. Lee\*\*

## SYNOPSIS

Practical research has been undertaken by the Fuels and Mining Practice Division, Mines Branch, to determine the features necessary to provide efficient, convenient operation with eastern Canadian coal on stokers burning more than 500 lb of coal per hour. The results are summarized in a three-part report.

In Part I the coal properties responsible for combustion difficulties are briefly described, and designers are provided with a coal specification recommended for stoker design, as well as the combustion data for the specified coal. In Part II are enumerated recommendations for the selection and design of new stokers, and for the modification and operation of existing stokers, to successfully burn eastern Canadian coal. Part III gives a description of the application of the aforementioned recommendations to three common stokers as well as to a distinctive combustion system invented by the authors and particularly suited to eastern Canadian coals.

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## Direction des mines

## Bulletin technique TB 14

RECHERCHES RELATIVES À L'UTILISATION DES CHARBONS  
DE L'EST CANADIEN DANS LES GRANDS FOYERS MÉCANIQUES

par

E.R. Mitchell\*, F.D. Friedrich\*\* et G.K. Lee\*\*

## RÉSUMÉ

Des recherches à l'échelle industrielle ont été entreprises à la Division des combustibles et des techniques de l'exploitation minière de la Direction des mines, en vue de déterminer les caractéristiques de rigueur pour assurer un fonctionnement efficace et approprié lorsqu'on utilise du charbon de l'Est canadien dans des foyers mécaniques qui consomment plus de 500 livres de charbon à l'heure. Les résultats sont examinés sommairement dans un rapport en trois parties.

Dans la partie I, on décrit brièvement les propriétés du charbon qui peuvent entraîner des difficultés de combustion, et ceux qui sont chargés du dessin d'un foyer mécanique peuvent y trouver les prescriptions techniques, recommandées à l'égard du charbon de même que les données relatives à la combustion du charbon désigné. La partie II passe en revue les recommandations quant au choix et au dessin de nouveaux foyers mécaniques, ainsi qu'aux modifications et au fonctionnement des foyers mécaniques déjà en service, pour assurer une bonne combustion du charbon de l'Est canadien. La partie III décrit l'application des recommandations susmentionnées à trois foyers mécaniques d'usage courant ainsi qu'à une méthode de combustion mise au point par les auteurs de l'étude et particulièrement bien adaptée aux charbons de l'Est canadien.

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## CONTENTS

	Page
Introduction .....	1
Part I - Coal Properties, Coal Specification and Combustion Data .....	3
1. Influence of Principal Coal Properties on Combustion .....	3
Comparison of Eastern Canadian Coals .....	3
Caking .....	4
Clinkering of Ash .....	4
Volatile Content .....	5
Size Consist .....	6
Sulphur Content .....	6
2. Coal Specification for Stoker Design .....	6
3. Combustion Data for Dominion Slack, 3/4 in. x 0 .....	7
Part II - Recommendations for Selection, Design and Operation of Large Stokers .....	13
General .....	13
Recommendations for Selection of Stokers .....	13
Recommendations for Design of, or Modification to, Stokers and Auxiliaries .....	14
Recommendations for Operation of Stokers .....	19
Conclusion .....	20
Part III - Practical Research on Conventional Stokers .....	21
General .....	21
Conventional Underfeed Stoker .....	21
Spreader-fired Dump Grate .....	27
Smoke Abatement Device .....	33
Smokeless Stoker for Cape Breton Coal .....	35
References .....	38
Appendix - Combustion Calculations, Dominion Slack, 3/4 in. x 0 .....	39

## TABLES

No.		Page
1	Coal Specification Recommended for Stoker Design .....	8
2	Combustion Data for Dominion Slack, 3/4 in. x 0 .....	9

## FIGURES

1	Per cent CO <sub>2</sub> and weight of combustion air and flue gas versus per cent total air for Dominion slack, 3/4 in. x 0 .....	10
2	Volume of combustion air and flue gas versus per cent total air for Dominion slack, 3/4 in. x 0 .....	11
3	Effect of oxygen and fixed carbon on the softening temperature of ash from Dominion coal .....	17
4	Cross-section view of a conventional underfeed stoker .....	22
5	A standard grate bar of a conventional underfeed stoker after a few months of service .....	22
6	FRL-A bars for a conventional underfeed stoker; Canadian patent 609,355, issued 1960 .....	24
7	Experimental grate bar instrumented with 12 thermocouples ....	24
8	Modified FRL-A bar showing heavy tail section and bevelled edges; Canadian patent 609,355, issued 1960 .....	24
9	FRL-C semi-hollow bars for a conventional underfeed stoker, patent applied for .....	27
10	Standard dump grate bars after two months of service with Dominion coal .....	28
11	Temperature patterns of the standard and FRL bars for a spreader-fired dump grate stoker when burning 1 1/2 in. x 1/2 in. Dominion coal .....	28
12	FRL-A bars for a spreader-fired dump grate .....	30
13	Experimental FRL dump grate bars instrumented with thermocouples .....	30

No.		Page
14	Final design of bar for a spreader-fired dump grate, designated FRL-D; patent applied for .....	32
15	Smoke abatement device for small underfeed stokers; patent applied for .....	34
16	Smokeless stoker for Cape Breton coal; Canadian patent 621,375, issued 1961 .....	36

## INTRODUCTION

Since oil and natural gas have replaced coal almost entirely for domestic heating and transportation, there remain only three outlets for coal: the commercial and small industrial market, the large industrial and thermal power plants, and the metallurgical industry. While it can compete in the latter two markets, the Canadian coal industry must, for the present, retain a large share of the former if it is to maintain production at an efficient and prosperous level.

The combustion equipment in the commercial and small industrial market is large enough to burn hundreds of tons of coal annually, and if the nut-slack sizes can be utilized instead of the more expensive double-screened sizes, coal should be able to compete with oil and natural gas. However, technical assistance is urgently required to improve the combustion performance of Canadian coals, particularly those mined in eastern Canada. These have gained a reputation for being difficult to burn on stoker grates, partly because it has been common practice to install stokers of conventional designs developed to burn foreign coals.

To fill the need for suitable stoker equipment a cooperative research program was initiated between the Fuels and Mining Practice Division, Mines Branch and the Dominion Steel and Coal Corporation. One phase of this program comprises a study of the burning of eastern Canadian coal on large stokers, both through laboratory experiments and full-scale combustion experiments on

all types of conventional stokers. The experiments are so numerous and of such a nature that a summary alone might be less interesting, and indeed less effective, than a practical interpretation and application of the results. The present report is accordingly divided into three parts.

In Part I are briefly described the more important combustion properties of eastern Canadian coals, and a coal specification is recommended for the design of new stoker equipment; also given are the appropriate combustion data. In Part II are tabulated recommendations for the selection, design and operation of stoker equipment to successfully burn coal of the quality and size specified in Part I. The results of research on three conventional stokers are summarized in Part III; also described is a stoker design that is specifically suited to burn eastern Canadian coal and incorporates the recommendations given in Part II.

PART I - COAL PROPERTIES, COAL SPECIFICATION  
AND COMBUSTION DATA

1. INFLUENCE OF PRINCIPAL COAL PROPERTIES  
ON COMBUSTION

Comparison of Eastern Canadian Coals

According to the American Society for Testing Materials (ASTM) method of coal classification, nearly all eastern Canadian coals are high volatile "A" bituminous. Two exceptions are the medium-volatile bituminous coal in the Westville Area and the high-volatile "C" bituminous coal in the Inverness Area, both of Nova Scotia.

Uniformity of rank does not suggest uniformity of combustion performance. On the contrary, individual eastern Canadian coals, like all coals, have many physical and chemical properties which combine to influence combustion characteristics. These include quantity of ash, chemical composition and softening temperature of ash, caking properties, plasticity, reactivity, ignitability, volatile and carbon content, surface and inherent moisture content, and finally, of considerable importance, size consist.

The largest coal producing area in eastern Canada is Cape Breton, and though its coals are mined from several seams the Analysis Directory of Canadian Coals and Supplement <sup>(1)</sup>\* show that their properties are fairly uniform, except for the free-swelling index. This property profoundly influences burning on grates. The well known "Dominion" coal mined from the Harbour and Phalen seams is strongly caking, having a free-swelling index of 8 to 9, whereas coals

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\* The references are listed, in order of appearance, on page 38.

such as "Four Star" and "Indian Cove" from the Tracey and Upper Jubilee seams are only moderately caking, having a free-swelling index of 4 to 6. While other eastern Canadian coals vary in ash content and ash-fusion temperature, nearly all have a free-swelling index of less than 7; therefore, Dominion is the most commonly used eastern Canadian coal which has both a high free-swelling index and a low ash-fusion temperature. Consequently, the discussion in this Technical Bulletin will refer particularly to Dominion coal, both because it represents the largest tonnage of coal mined in eastern Canada and because experience has shown that equipment capable of burning Dominion coal will burn other eastern Canadian coals equally well, for the reduced free-swelling index compensates for any decrease in ash-fusion temperature.

### Caking

The strong caking tendency of Dominion coal causes it to swell and agglomerate, on ignition, into plastic masses which later harden into strong, massive cakes as the volatiles are driven off. These cakes sometimes cover most of the grate and, because they resist air penetration, may seriously upset combustion. The coke produced by the caking is very reactive, but difficult to break up. Hence grates may be over-heated by the intense burning at the edges of the cakes while at the same time there is an excessive heat loss due to unburned combustible. The strong caking property, therefore, has the greatest influence on combustion and on the design of suitable equipment.

### Clinkering of Ash

Because of the intense localized burning described previously, the ash content of the coal and the softening temperature of the ash are the next

important considerations. If the ash-softening temperature is exceeded in the fire-bed, the grate air openings become blocked by the formation of dense clinkers and combustion is stopped or curtailed. Although this condition cools the grate it also reduces boiler steaming capacity.

Experiments have shown that the ash-softening temperature of Cape Breton coal is as much as 400°F higher in an oxidizing atmosphere than in a reducing atmosphere. This has two important implications. First, although the ASTM test procedure may show them to have a lower ash-softening temperature than Dominion coal, coals such as Four Star and Indian Cove may actually be burned with less difficulty because their free-burning nature permits oxidizing conditions to prevail in the fire-bed, thus raising the effective ash-softening temperature. Second, if the caking property of Dominion coal can be reduced the problem of clinkering will be greatly alleviated. It has also been shown that caking can be reduced by oxidizing the coal prior to combustion, and it is proposed to do this in a distinctive stoker described in Part III of this Technical Bulletin.

#### Volatile Content

The tendency of a coal to smoke is proportional to its volatile content; therefore the volatile content influences design of the over-fire turbulence system as well as of the stoker and furnace. A high volatile content also contributes to high ignitability and reactivity. The former refers to the ease with which a coal may be brought to self-supporting combustion, while the latter refers to the rate of reaction between the fuel and oxidizing medium.

### Size Consist

Size consist of coal influences handling as well as combustion, for the amount of free moisture absorbed and retained is proportional to the amount of fine coal present. While this moisture may perform a useful function by increasing porosity of a fire-bed and by reducing burning rate, it causes the fine sizes of coal to pack and block in conveying and feeding devices. One reason double-screened coal is often selected for conventional stokers is that it does not pack so readily when wet. Furthermore, where coal is burned in thick beds, as in underfeed stokers, a double-screened coal provides a more porous fire-bed than a nut-slack coal and the resulting free air penetration minimizes both caking and clinkering.

### Sulphur Content

Finally, because part of the sulphur in the coal is burned to dangerously corrosive  $\text{SO}_2$  and  $\text{SO}_3$ , care must be taken in boiler design and in stoker operation to ensure that flue gases do not cool to the dew-point temperature. However, much of the sulphur may be trapped or fixed in the ash, and this amount can be increased by simple additives.

## 2. COAL SPECIFICATION FOR STOKER DESIGN

Table 1 gives a coal specification which is recommended for the design of stokers burning more than 500 lb of coal per hr. Dominion coal is specified for the reasons given on page 4. The 3/4 in. x 0 slack size is specified because experience has shown that a stoker should be designed to burn the smallest size of coal likely to be continuously available in the area. This ensures that coals of better quality or larger size can be readily burned when they

are available, while coals of poorer quality or smaller size can be tolerated for short periods.

Except for the screen analysis, the values in Table 1 have been drawn from the Analysis Directory of Canadian Coals and Supplement <sup>(1)</sup>, but the table also includes a range of expected values that embraces most eastern Canadian coals. Although the screen analysis limits for slack coal are laid down by the Canadian Government Specifications Board, <sup>(2)</sup> experience has shown that coal of smaller size is often encountered, and the recommended specification has been drawn up to anticipate it.

The recommended specification has already been employed in the design of several large stokers that are now successfully burning Cape Breton coal and are capable of burning any eastern Canadian coal with equal ease.

### 3. COMBUSTION DATA FOR DOMINION SLACK, 3/4 in. x 0

For the convenience of designers of stoker equipment, combustion data for the specified 3/4 in. x 0 coal are summarized in Table 2 and in Figures 1 and 2. In the Appendix, these data are calculated on the "as received" basis with combustion air at 80°F and 60% relative humidity.

Table 1

Coal Specification Recommended for Stoker Design

Dominion Slack, 3/4 in. x 0		As Received	Range to be Expected
<u>Proximate Analysis</u>			
Moisture .....	%	5.5	1.5 to 10.0
Volatile Matter .....	%	30.7	30.7 to 39.3
Fixed Carbon .....	%	53.5	46.1 to 58.8
Ash .....	%	10.3	3.6 to 16.2
Calorific Value,	Btu/lb	12,640	11,120 to 14,290
<u>Ultimate Analysis</u>			
Moisture .....	%	5.5	--
Ash .....	%	10.3	--
Carbon .....	%	71.0	--
Hydrogen .....	%	4.7	--
Nitrogen .....	%	1.3	--
Sulphur .....	%	2.8	--
Oxygen (by diff) .....	%	4.4	--
Ash-softening Temperature, °F		2,065	1,970 to 2,185
Free-swelling Index, ASTM		9.0	8.0 to 9.0
Caking Properties (volatile matter residue, 950°C)		Good	--
<u>Screen Analysis</u>			
Round Hole Size, in.			
plus 3/4 .....	% by wt	0	0 to 1.2
3/4 x 1/2 .....	% by wt	13.3	11.3 to 15.5
1/2 x 3/8 .....	% by wt	9.7	8.8 to 10.1
3/8 x 1/4 .....	% by wt	13.4	12.5 to 14.4
1/4 x 1/8 .....	% by wt	19.3	17.1 to 21.0
1/8 x 1/16 .....	% by wt	15.2	10.5 to 17.2
1/16 x 1/32 .....	% by wt	12.4	11.8 to 12.9
minus 1/32 .....	% by wt	16.7	15.3 to 18.0
minus 1/4 .....	% by wt	63.6	58.8 to 67.4

Table 2

Combustion Data for Dominion Slack, 3/4 in. x 0

Total Combustion Air, %	100	120	140	160	180
CO <sub>2</sub> ..... %	18.05	14.96	12.78	11.15	9.90
Combustion Air,					
lb/lb coal	9.86	11.84	13.81	15.78	17.76
cu ft/lb coal	135.2	162.3	189.4	216.4	243.4
Wet Flue Gas,					
lb/lb coal	10.76	12.74	14.71	16.68	18.66
cu ft/lb coal ..... 300°F	200.4	238.7	277.0	315.2	353.5
cu ft/lb coal ..... 350°F	213.6	254.4	295.2	336.0	376.7
cu ft/lb coal ..... 400°F	226.8	270.1	313.4	356.7	400.0
cu ft/lb coal ..... 450°F	240.0	285.8	331.6	377.4	423.2
cu ft/lb coal ..... 500°F	253.2	301.5	349.8	398.2	446.5
cu ft/lb coal ..... 550°F	266.4	317.2	368.0	418.9	469.8

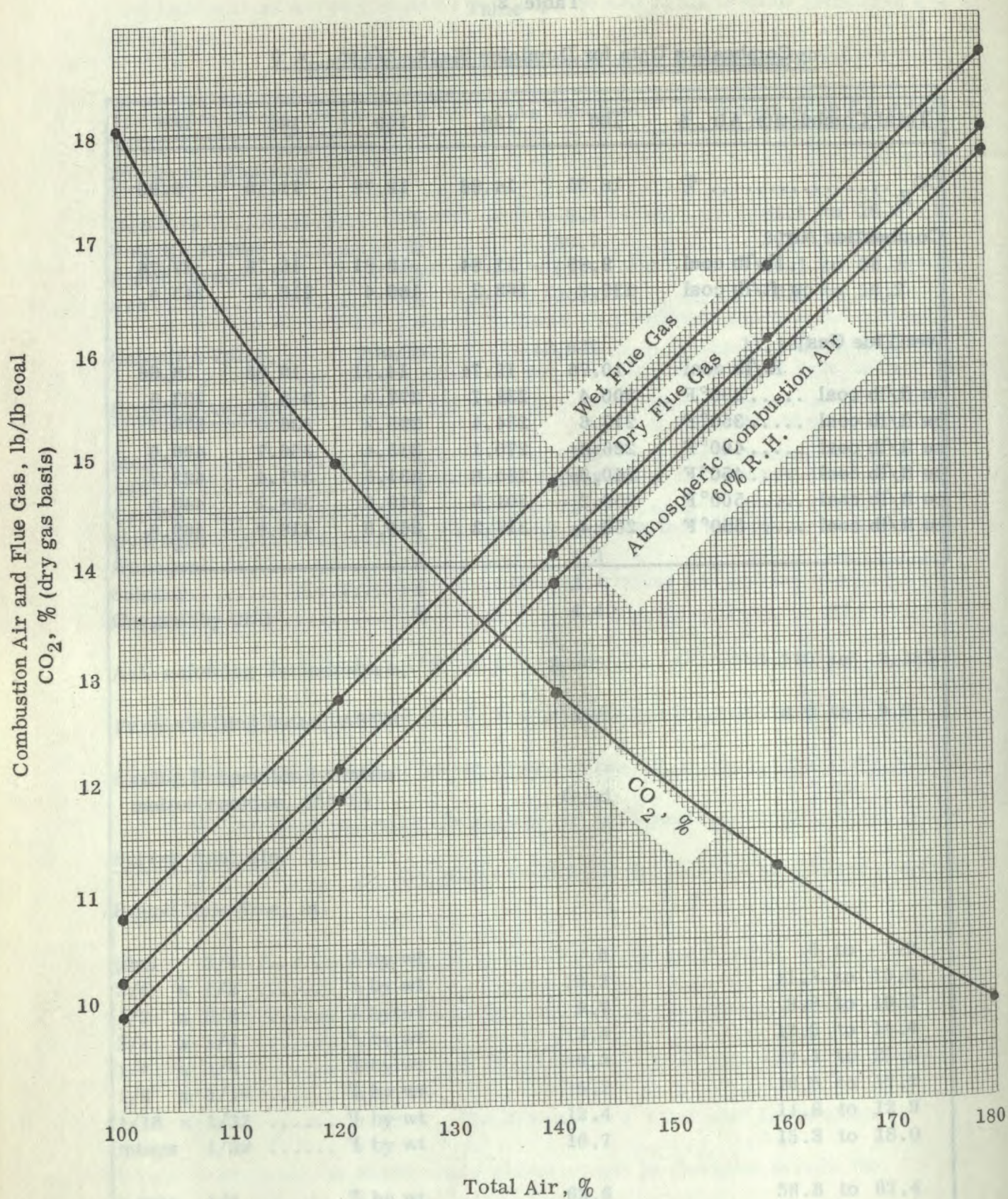


Figure 1 Per cent CO<sub>2</sub> and weight of combustion air and flue gas versus per cent total air for Dominion slack, 3/4 in. x 0.

## PART II - RECOMMENDATIONS FOR SELECTION, DESIGN

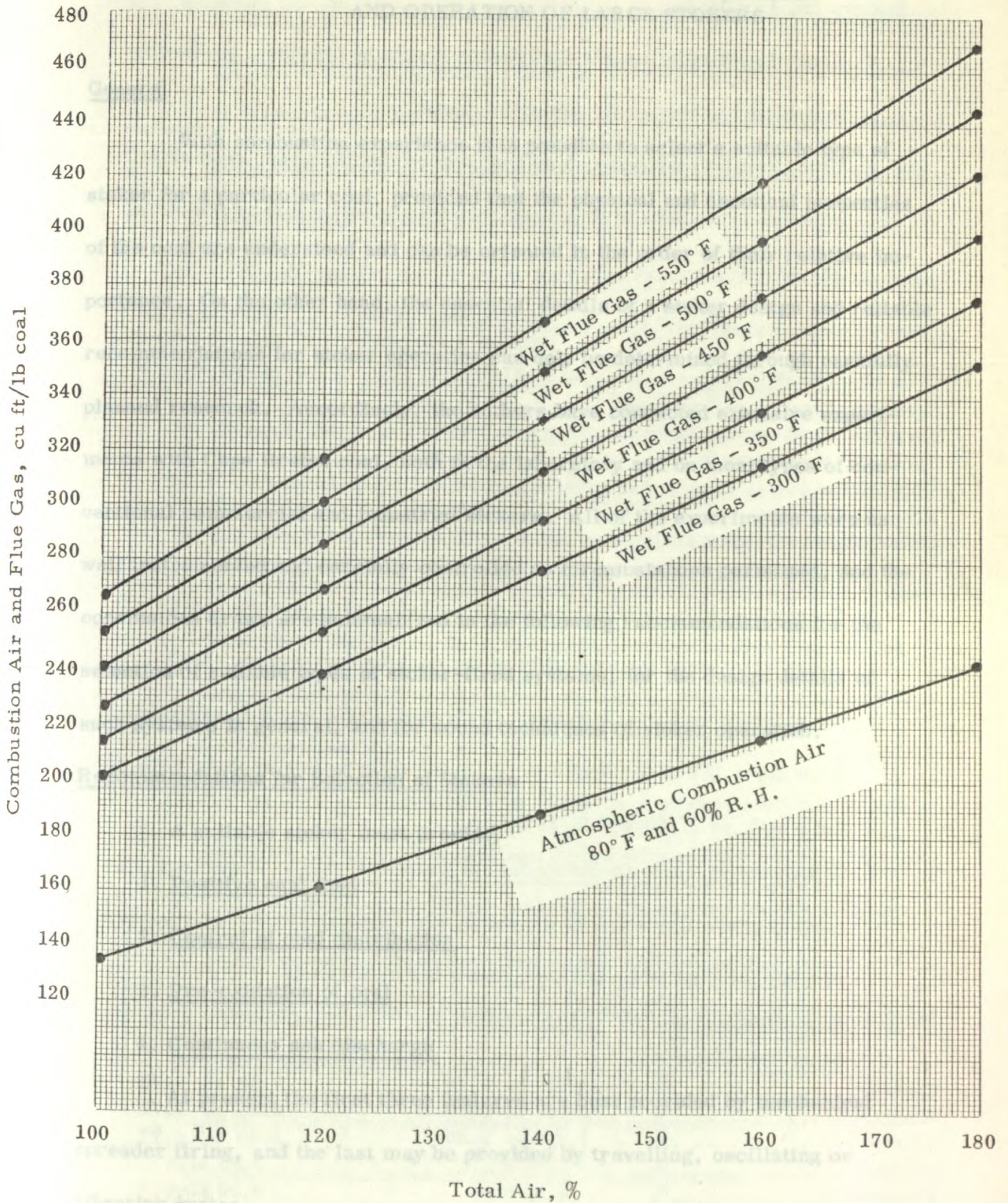


Figure 2 Volume of combustion air and flue gas versus per cent total air for Dominion slack, 3/4 in. x 0.



## PART II - RECOMMENDATIONS FOR SELECTION, DESIGN AND OPERATION OF LARGE STOKERS

### General

With combustion experience it is possible to select a suitable type of stoker for a particular coal, provided that the physical and chemical properties of the coal are understood and can be oriented in the order of their relative importance. On the other hand, the essential details of a stoker design and reliable recommendations for stoker operation can only be determined through carefully-planned research. Accordingly, the authors have conducted extensive experiments with Cape Breton coal, both in the laboratory and on most types of conventional commercial and industrial stokers. All of the experiments were as well instrumented and carefully controlled as circumstances permitted, and the conclusions drawn are summarized in the following recommendations for the selection of suitable types of stoker-fired systems, for the design details of such systems in general, and for sound techniques of stoker operation.

### Recommendations for Selection of Stokers

A suitable stoker must provide:

1. Positive coal feed
2. Control of coal distribution
3. Pre-oxidation of coal
4. Continuous ash discharge

At present the first three features are best provided by mechanical spreader firing, and the last may be provided by travelling, oscillating or vibrating grates.

Recommendations for Design of, or Modifications to,  
Stokers and Auxiliaries

5. Control of combustion air distribution should be provided, preferably  
by zoning dampers under the entire grate.
6. Grate heat release rates should not exceed the following, assuming  
effective grate area to be the instantaneous area through which air is  
introduced:

<u>Type of Stoker</u>	<u>Heat Release Rate, Btu/sq ft effective grate area/hr</u>	<u>Burning Rate,* lb/sq ft effective grate area/hr</u>
Spreader-fired travelling grate	400,000	31.6
Spreader-fired oscillating grate	375,000	29.6
Spreader-fired dump grate	350,000	27.7
Chain grate	350,000	27.7
Underfeed stoker	350,000	27.7
Water cooled vibrating grate	400,000	31.6

(\* Based on coal having a calorific value of 12,640 Btu/lb)

7. Grate dimensions should approach a square design, but the length  
should not exceed the capability of the coal feeding system. With  
spreader-firing and continuous ash discharge, the width should range  
from about 75% of the length for a 10,000 lb/hr boiler to about 125% of  
the length for a 100,000 lb/hr boiler.
8. Grate bars or links should be cast in a suitable alloy. While improve-  
ment in grate alloys can be expected, two compositions already proven  
suitable for both large and small bars are as follows:

<u>Alloy Designation</u>	<u>1% Cr - 1% Ni</u>	<u>1 1/4% Cr - 1/4% Mo</u>
<u>Alloy Specification</u>		
Carbon .....%	3.30 to 3.50	3.30 to 3.50
Manganese .....%	0.50 to 0.70	0.50 to 0.70
Silicon .....%	2.40 to 2.60	2.40 to 2.70
Sulphur .....%	0.15 Max	0.15 Max
Phosphorus .....%	0.30 Max	0.30 Max
Chromium .....%	0.80 to 1.20	1.00 to 1.50
Nickel .....%	0.90 to 1.10	Nil
Molybdenum .....%	Nil	0.15 to 0.35

9. Grate air openings should be slots on the edges of bars or links, and should be self-cleaning, if possible. Air pinholes should not be used in the surface of any grate, with the one exception of a high-resistance grate wherein bars are rigidly bolted together to prevent warping and consequent air leakage between bars.
10. Grate air opening should be no less than 5% of the effective grate area for conventional grates and no less than 3% for high-resistance grates.
11. Grate bars or links should have a massive cross-section to provide adequate heat transfer from the grate surface.
12. A non-segregating type of coal hopper is desirable to ensure that coal of a uniform size consist is fed to the stoker. This applies to slack sizes in particular and sometimes to modified coals -- for example, those which have had the minus 28 mesh size removed. Non-segregating hoppers are usually employed where coal is supplied to large stokers from overhead storage bunkers.
13. An overfire turbulence system should be provided using either high-pressure steam air-inspiring nozzles with sound muffling of the air, or high-pressure air blower jets. Nozzle size and blower pressure depend on conditions of the installation, and design data may be obtained from BCR Aid to Industry 500-300<sup>(3)</sup>. Typical pressures for 1/2 in. nozzles are:  
  
20 in. water gauge air pressure for 5 ft penetration  
  
40 in. water gauge air pressure for 7 ft penetration

14. Overfire air should not exceed 5% of the total combustion air because  
as much air as possible should be introduced through the grate for cooling.
15. Overfire turbulence should cover the entire area producing smoke.  
The nozzles should be located 10 to 12 in. above the fire. Thus, with spreader-fired grates the nozzles should be 13 to 15 in. above the grate and for some underfeed stokers they should be 24 to 26 in. above the grate.
16. Gas temperature leaving the furnace should be at least 160°F below the softening temperature of the ash as determined under conditions exist-  
ing in the furnace; this provides time for the large ash particles to cool to gas-stream temperature. Figure 3 gives the ash-softening temperature under a variety of conditions, from which it can be seen that a safe furnace exit temperature for the recommended stoker operating conditions is about 2175°F.
17. Forced and induced draft fans should be selected for 12.0% CO<sub>2</sub> at the boiler outlet. They should have "Test Block Ratings" (TBR) which are at least 15% higher on volume and 30% higher on pressure than the "Maximum Design Ratings" (MDR) with the specified coal.
18. A high-efficiency dust collector is required. For example, with spreader firing, collection efficiency should not be less than 90% by weight, assuming that 50% of the fly ash produced will pass through a 325-mesh screen, and assuming that the solid material entering the dust collector has the following sizing:

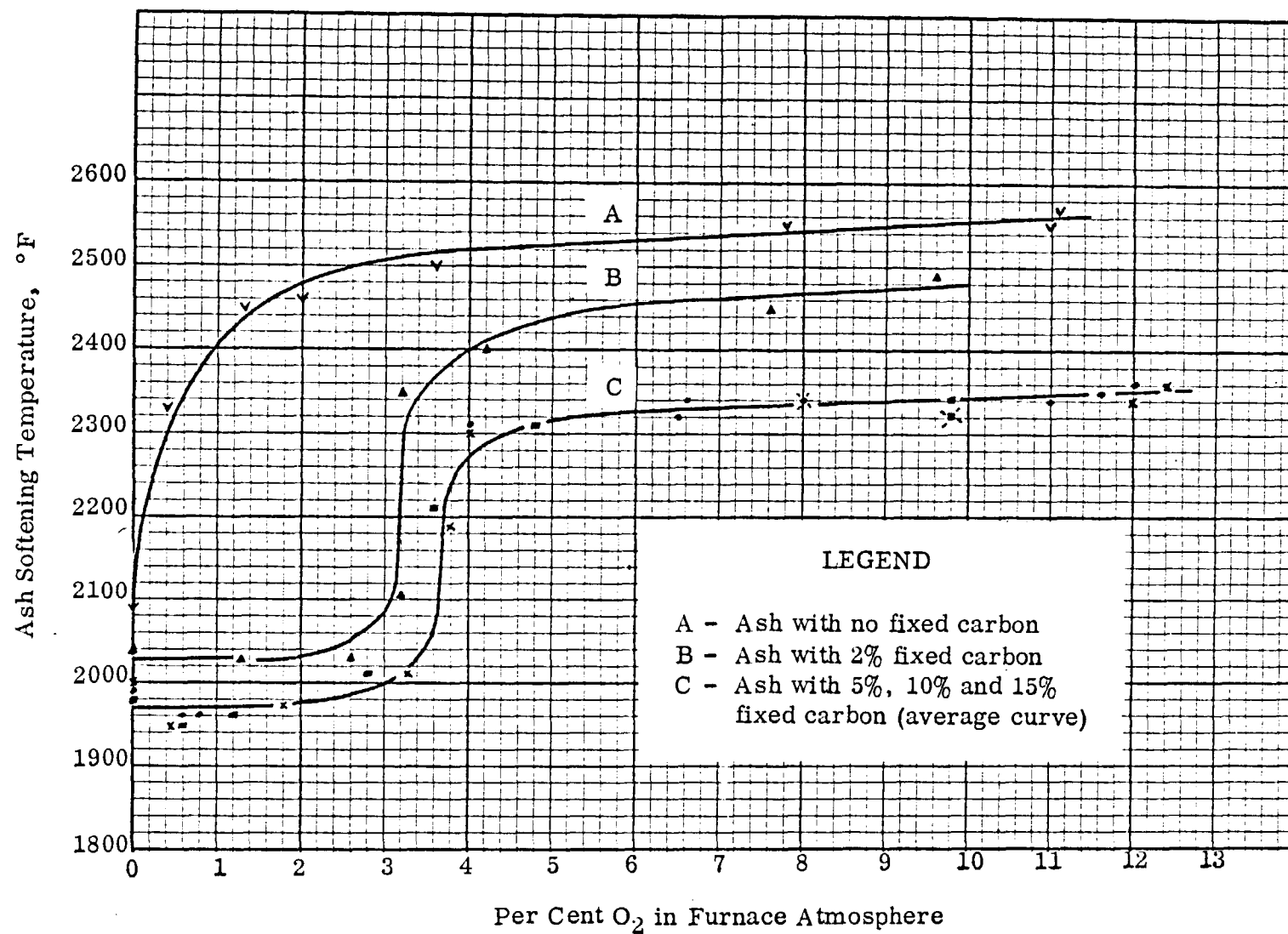


Figure 3 Effect of oxygen and fixed carbon on the softening temperature of ash from Dominion coal.

Particle Size, microns (0.001 mm)		Average Size, microns (0.001 mm)	% by wt in Gas Stream
	+60	60	41
-60	+40	50	11
-40	+30	35	8
-30	+20	25	10
-20	+15	17.5	7
-15	+10	12.5	6
-10	+7.5	8.75	5
-7.5		3.75	12

19. If a cinder recovery system is selected it should collect cinders only from the boiler hoppers and air heater or economizer hoppers and should reinject them gently onto a quiet zone of the grate in order to minimize dust loading of combustion gases. Cinders from the dust collector hoppers should be discharged to waste.
20. Automatic coal-handling and ash-handling systems are essential for efficient operation of a steam plant. Both should be dust-proof and the coal-handling system should be capable of feeding slack coal containing up to 10% moisture.
21. The automatic combustion control system should regulate forced and induced draft fan dampers according to steam pressure, furnace draft, and steam flow to air flow ratio. It should also provide remote manual control and hand-automatic transfer of total boiler load, coal feed, and forced and induced draft fan dampers. The forced draft fan damper should have a minimum stop to ensure that windbox pressure is never less than 0.2 in. water gauge, to prevent overheating of the grate. If steam is used to provide overfire turbulence its flow should be controlled according to smoke density.

Recommendations for Operation of Stokers

22. Cape Breton coal should be burned in thin fires. With spreader-fired continuous ash discharge grates, fire-beds should be 2 in. to 3 in. thick. On all other stokers they should be as thin as possible to ensure oxidizing conditions in the fire-bed and thereby reduce both caking of the coal and clinkering of the ash.
23. CO<sub>2</sub> leaving the boiler should normally not exceed 12.0%. This represents about 150% total combustion air.
24. The fire on any grate should not be disturbed. Pokers and slice bars should not be used, except to gently pack cake formations as required to fill holes in a fire.
25. Undergrate air should never be shut off completely with a hot fire on a grate. The control drive on the forced draft fan dampers or louvres should be equipped with a minimum stop to provide at least 0.2 in. water gauge pressure under the grate, as mentioned in Recommendation 21.
26. "On-off" operation of a stoker should be avoided as much as possible, to prevent smoke. This applies mostly to small underfeed stokers. At the time of writing an inexpensive control system was under development by the authors which, it is hoped, will minimize smoke emission resulting from "on-off" operation. It is described in Part III of this Technical Bulletin.

### Conclusion

The foregoing recommendations are based on the best information available at the time of writing, and they have already been applied in the design of several stoker-fired systems successfully burning eastern Canadian coal. Research is continuing, and as new information comes to light it will be incorporated into the recommendations.

It has been found advisable to draft the specifications for a boiler and its combustion system in such a manner as to give designers the greatest possible latitude. If this is done, the consumer should get the most economical and workable plant commensurate with the quality range of coal to be burned.

### PART III - PRACTICAL RESEARCH ON CONVENTIONAL STOKERS

#### General

Few of the conventional stokers in existence possess the features recommended in Part II, and how some of these features can be incorporated is not always obvious. Therefore, practical research was undertaken on some of the more common stokers to provide improved performance with Cape Breton coal. During the past three years extensive field experiments have been carried out in which various designs of equipment were tested using systematic operational procedures and specialized measuring techniques. Suitable equipment designs were evolved from the information gained, and three successful and gratifying cases are described herein. Since some features appeared to be novel, patent applications were made to protect the designs for use by Canadian industry. The grate designs referred to as "conventional" or "standard" are those of the stoker manufacturers, while "FRL" designs are those of the authors.

Also described is a distinctive design of stoker for eastern Canadian coal, developed by the authors, which incorporates the recommended design features. A Canadian patent has been granted.

#### Conventional Underfeed Stoker

Figure 4 shows a cross-section of a stoker widely used throughout Canada. A ram feeds coal into the central retort, from whence it spills over onto the grate bars, which are hollow. Since alternate bars reciprocate, the ash is carried progressively down to the dump trays as the coal burns.

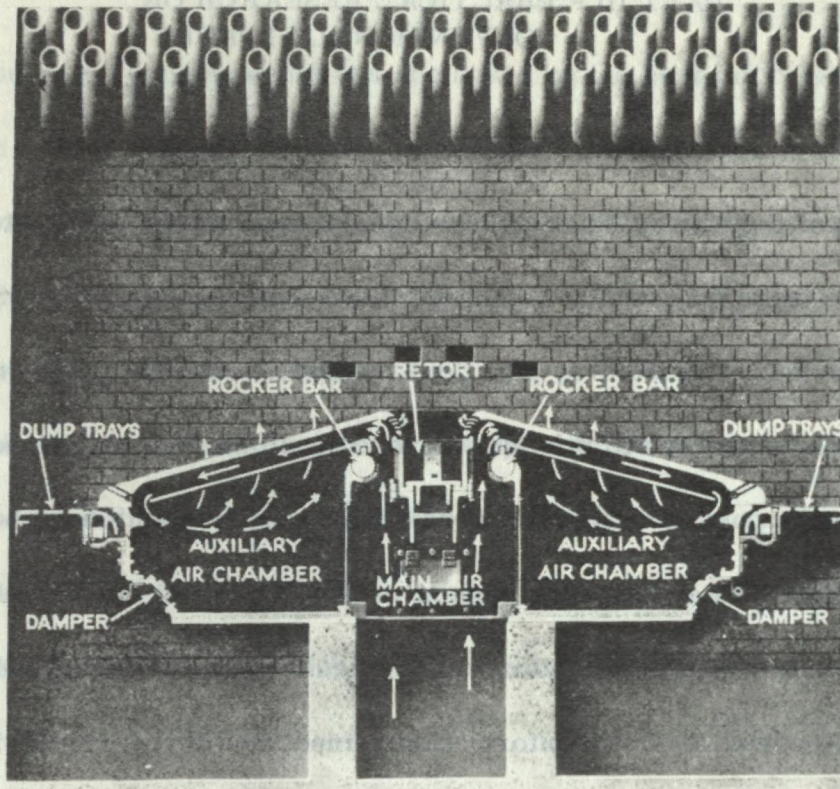


Figure 4 Cross-section view of a conventional underfeed stoker.

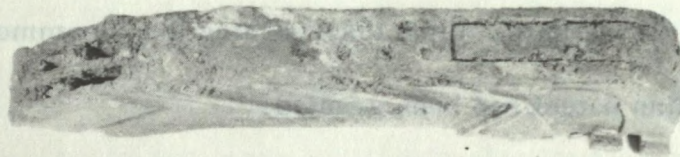


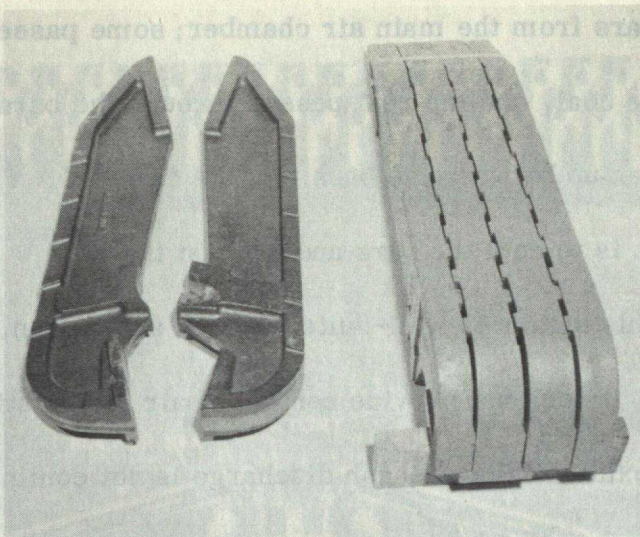
Figure 5 A standard grate bar of a conventional underfeed stoker after a few months of service.

Air enters the bars from the main air chamber; some passes through tuyeres in the bars to the coal, and the rest passes through the bars into the auxiliary air chamber, then up between the bars into the fire-bed. The purpose of this complicated path is to cool the bars and preheat the air.

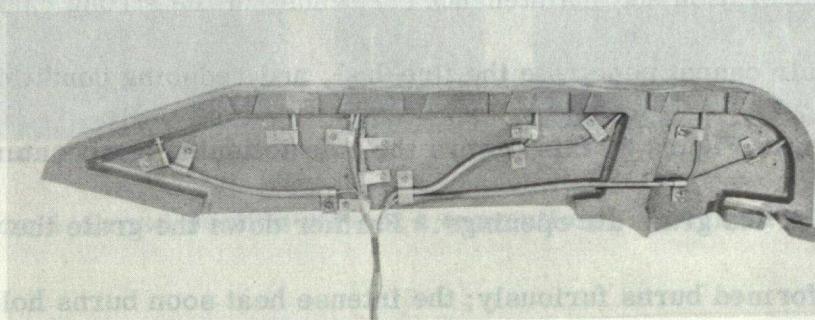
While this stoker is well-suited to high ash-fusion, free-burning bituminous coal, it does not provide control of air distribution, it does not effectively pre-oxidize the coal, ash discharge is not continuous, and often grate heat release rates are high. Accordingly, with highly-caking, low ash-fusion coals such as those mined in Cape Breton, there are usually serious problems in operation and maintenance. Because of the strong caking tendency of the coal, air cannot penetrate the fire-bed, and reducing conditions result. As was shown in Figure 3, this lowers the ash-softening temperature, permitting slag to fill the grate air openings. Farther down the grate the very reactive coke that is formed burns furiously; the intense heat soon burns holes through the tails of the bars, upsetting air distribution completely; and thereafter operation is poor and the grate deteriorates at an accelerated rate. It is common for a grate to be burned out in a heating season. Figure 5 shows a standard bar for this particular stoker after a few months of service.

It was felt that to improve conditions the bars must be designed to do two things:

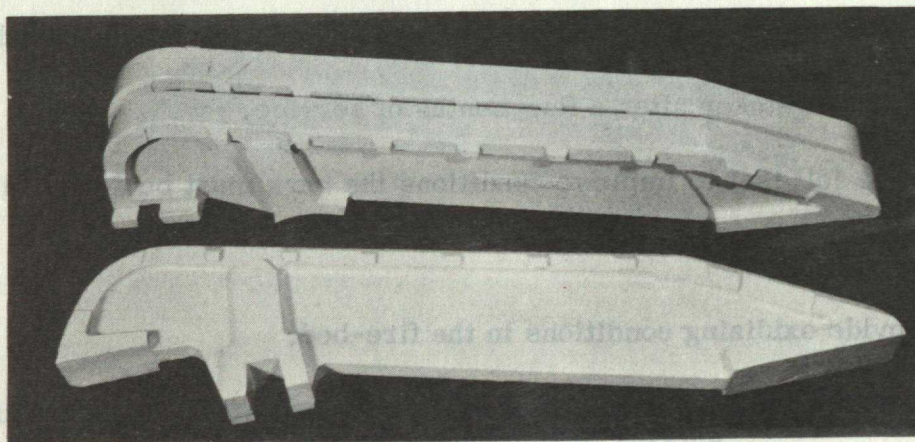
1. Provide oxidizing conditions in the fire-bed.
2. Provide good heat transfer from the burning surface to the cooling surfaces below.



**Figure 6 FRL-A bars for a conventional underfeed stoker;  
Canadian patent 609,355, issued 1960.**



**Figure 7 Experimental grate bar instrumented with  
12 thermocouples.**



**Figure 8 Modified FRL-A bar showing heavy tail  
section and bevelled edges; Canadian  
patent 609,355, issued 1960.**

To obtain these features, the experimental bars shown in Figure 6 were designed. The hollow-bar principle was abandoned for a simple Tee shape with the air passing directly up between the bars. The total air opening was increased to about 3.5 to 5% of the grate surface and pinhole air openings were replaced by slots along the edges because the better heat transfer makes them less susceptible to clogging by slag. The slots were made to interlock, allowing the reciprocating bars to remove ash from the air openings. Furthermore, the amount of air opening was made proportionately greater at the front end of the bar, and a crossweb was placed to direct a strong blast of air into the raw coal in the retort, to minimize caking. Thick flange and web sections were used to provide rapid heat transfer from the burning surface to the cooler air and metal below. Finally, the bars were cast in a 1% chromium - 1% nickel alloy for increased oxidation resistance. However, because coring was eliminated, a set of these alloy bars cost less than a set of standard grey iron bars, despite the increased weight and alloy composition.

During the 1959-60 heating season, three stokers were operated with these experimental bars and extensive tests were run in which grate surface temperature and temperature gradients were measured by means of bars instrumented with thermocouples, such as the one shown in Figure 7. In general, the experimental bars were found to run about 300° F cooler than the standard bars. In all cases there was a definite improvement in operation because clinkering was less severe, and the air openings never became blocked although some slag settled in them. Some bars burned at the tail end, but not as severely as the standard bars.

As a result of the winter's experience, the design was modified by making the tail section considerably heavier and providing an extra passage for cooling air to minimize burning in this area. It was also found that air openings could be kept free of slag by simply bevelling the upper corners of the bars. Slag then freezes to the bevelled surface before it reaches the air openings. The features of the modified design are illustrated in Figure 8.

Several stokers were operated with the modified bars during the 1960-61 heating season, with very satisfactory results. In one case, dampers were installed between the primary and secondary windboxes to provide a certain amount of control over air distribution, and a series of experiments was carried out in which temperatures were measured on both the original FRL and revised FRL designs. Peak temperatures of  $1400^{\circ}\text{F}$  were recorded, but only for a few minutes. The revised design was usually cooler than the original design.

It was found that the best operating conditions were obtained with the dampers wide open, providing uniform air distribution along the length of the bars. The average temperature at the tail was then only about  $490^{\circ}\text{F}$  and the maximum temperature was  $920^{\circ}\text{F}$ ; under such conditions the grate would suffer little deterioration.

To reduce overheating at the tail ends of the bars, where, by nature of the equipment, burning is most intense, another design was developed. It is illustrated in Figure 9, and is designated as the FRL-C semi-hollow grate bar. Like the FRL-A bar, it has bevelled edges and self-cleaning air openings, but flanges along the lower edges that meet when the bars are assembled form cavities into which air can only enter through openings at the tail ends. Thus, all the combustion air cools the tail ends of the bars before passing into the fire-bed.

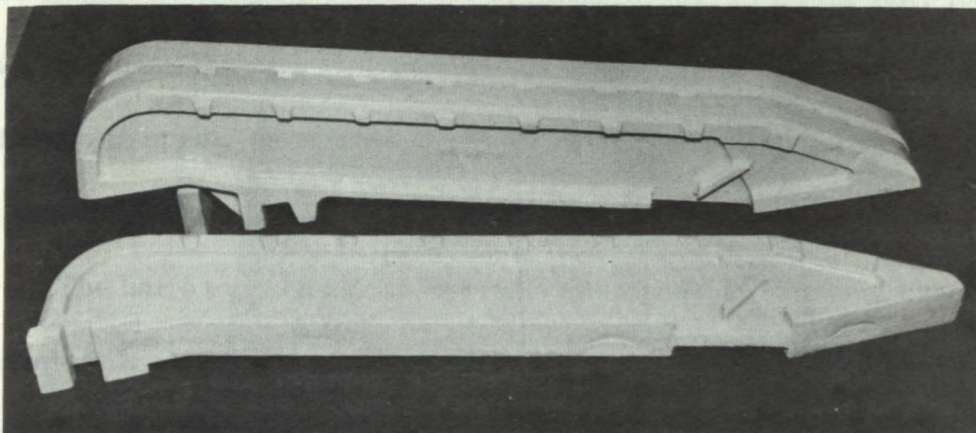
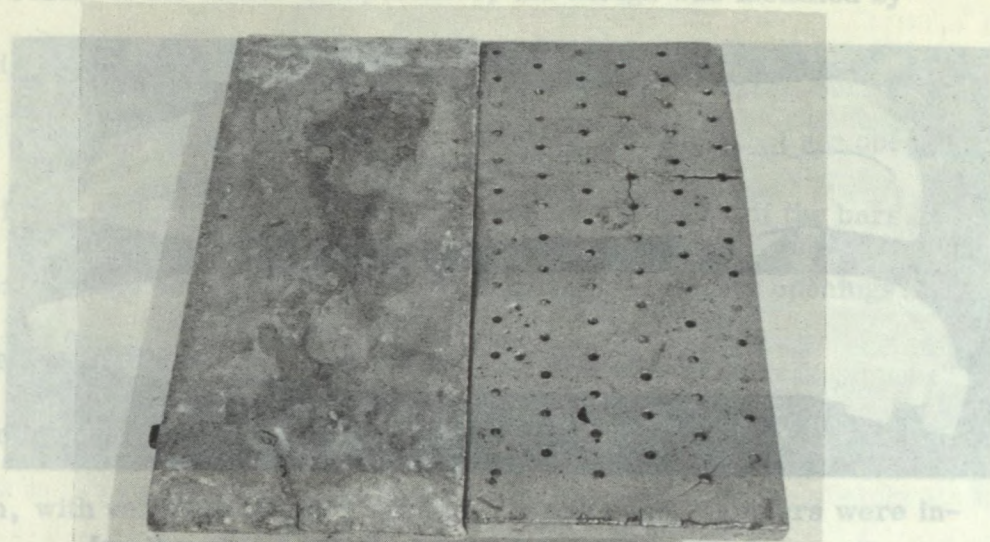


Figure 9 FRL-C semi-hollow bars for a conventional underfeed stoker; patent applied for.

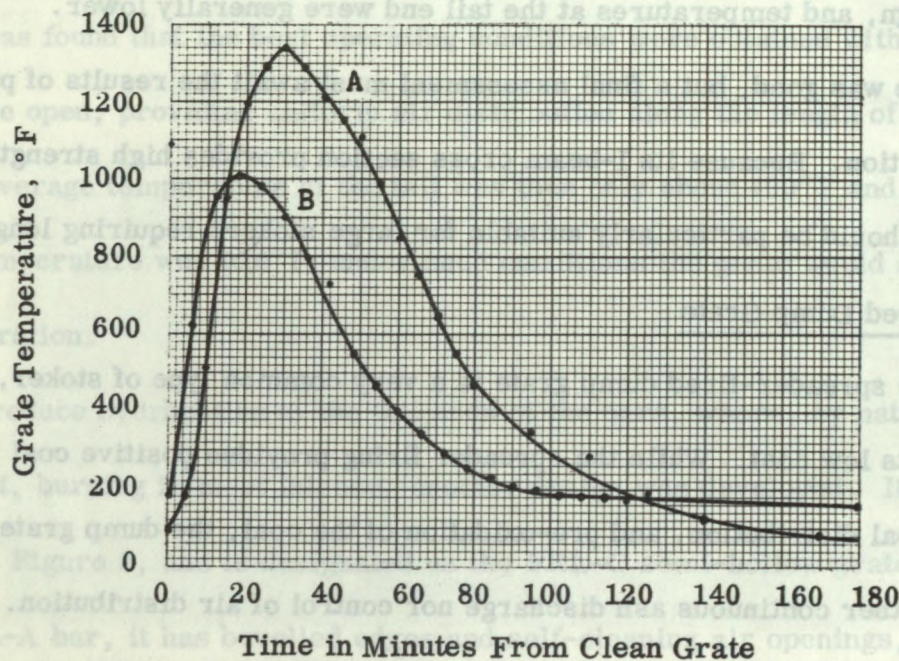
In February, 1961, a set of the semi-hollow bars was put into service, and tests were run using an automatic recorder to monitor grate temperatures. These were found to be more uniform along the length of the bar than with the FRL-A design, and temperatures at the tail end were generally lower. Performance was good, but a final assessment must await the results of prolonged operation. Because its I-beam cross section provides high strength, this design should be particularly suitable for large stokers requiring long bars.

#### Spreader-fired Dump Grate

The spreader-fired dump grate is a very common type of stoker, partly because of its low cost. While the spreader firing provides positive coal feed, control of coal distribution, and pre-oxidation of the coal, the dump grate provides neither continuous ash discharge nor control of air distribution. Furthermore, the grate air openings usually consist of pinholes, and the total air opening is normally only about 2.5% of the grate surface. With Cape Breton coal, maintenance is high, smoke is excessive, and operation is difficult.



**Figure 10** Standard dump grate bars after two months of service with Dominion Coal. The one on the right has been sandblasted to show the thermal cracks.



**Figure 11** Temperature patterns of the standard and FRL bars for a spreader-fired dump grate stoker when burning 1 1/2 in. x 1/2 in. Dominion coal. Curve A represents the standard bar; curve B represents the FRL bar.

While nothing could be done to provide continuous ash discharge or control. Figure 10 shows two standard dump grate bars that had been in service for two months. Of the 80 pinhole air openings in the bar on the left, less than a dozen are open; the rest have been plugged by slag. When this happens, air distribution is upset, the fire smokes continuously, and the bars deteriorate from over-heating.

The bar on the right was sandblasted to show the thermal cracks that had developed. A thermocouple recording the surface temperature of a similar bar gave curve A shown in Figure 11, which shows that each time the grate is dumped, and is exposed to the radiant heat of the furnace, its surface temperature rises sharply up to about 1350°F. Then, as the ash builds up, the grate cools back down to room temperature. This temperature cycling every two or three hours causes the thermal cracks, and in conjunction with oxidation growth it can destroy a grey-iron grate in three or four months.

With Cape Breton coal, fires must be kept thin to prevent severe clinkering. This means that at high burning rates, corresponding to grate heat release rates of 350,000 to 400,000 Btu/sq ft/hr, the fire must be cleaned about every two hours, resulting in dust from dumping and smoke from rekindling the green coal. Even so, the air openings quickly become plugged with slag. In one case, it became established practice to shut the boiler down every twelve to fourteen days, and remove the slag from the air openings with hammers and punches. Otherwise, smoke was continuous, grate bars broke from thermal stress, and it became difficult to maintain steam load.

Figure 10 shows two standard dump grate bars that had been in service

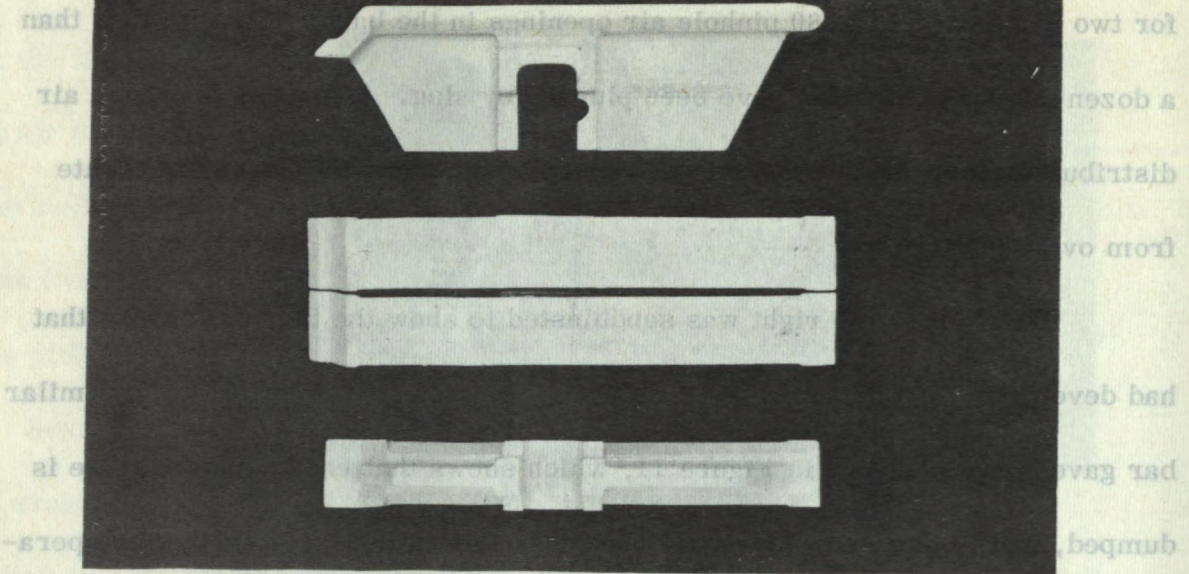


Figure 12 FRL-A bars for a spreader-fired dump grate.

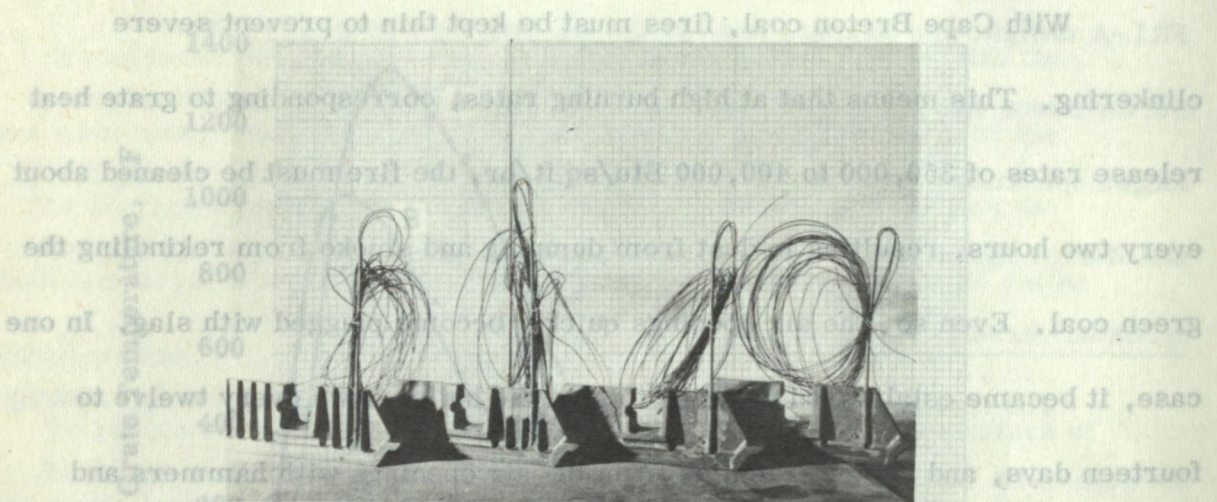


Figure 13 Experimental FRL dump grate bars instrumented with thermocouples.

Figure 11 Temperature patterns of the standard and FRL bars for a spreader-fired dump grate stoker when burning 1 1/8 in. x 1/2 in. Dominion coal. Curve A represents the standard bar; curve B represents the FRL bar.

While nothing could be done to provide continuous ash discharge or control of air distribution, it was felt that a grate bar could be designed to provide better combustion and better heat transfer. Accordingly, the bar shown in Figure 12 was developed.

This bar was designed keeping in mind the recommendations tabulated in Part II, to wit:

Air openings should be slots, rather than pinholes.

There should be at least 5% air opening.

There should be good heat transfer from the burning surface to the substructure.

To obtain these features, the standard 6 in. bar was replaced by three 2 in. bars, and the pinhole air openings were replaced by a simple slot between the bars, providing about 5.5% air opening. To provide rapid heat transfer, the web was made thick, with the flanges projecting only  $3/4$  in. from it. To provide extra cooling surface the web was enlarged, and to provide resistance to oxidation growth the 1% chromium - 1% nickel alloy was specified.

In February of 1960 a set of these bars was put into service and an extensive series of tests was run in which peak temperatures and temperature gradients in the bars were measured continuously.

Peak temperatures over two weeks of operation were averaged, and that at the burning surface was found to be  $1008^{\circ}\text{F}$  -- nearly  $350^{\circ}\text{F}$  cooler than the standard 6 in. bar and well under the safe temperature limit of  $1200^{\circ}\text{F}$  for the alloy used. Curve B in Figure 11 is a typical temperature pattern for the FRL-A-bar.

Operation was also much improved, because the increased air opening maintained oxidizing conditions in the fire-bed, thereby eliminating clinkering. Accordingly, the air openings remained free, ash fell easily from the grate on dumping, fresh fires were quickly re-established, and smoke emission was reduced.

Tests were continued during the 1960-61 heating season with bars having thinner webs, both with and without cooling fins, in an attempt to find the lightest shape which would still provide adequate cooling. As before, thermocouples were installed, and grate temperatures were continuously recorded for a week. The various bars that were instrumented and installed for these tests are shown in Figure 13. It was found that fins were effective enough in dissipating heat to permit a reduction in the depth of the bar. Accordingly, a final version designated as FRL-D was designed, and is illustrated in Figure 14. It is expected to have a temperature cycle similar to curve B in Figure 11.

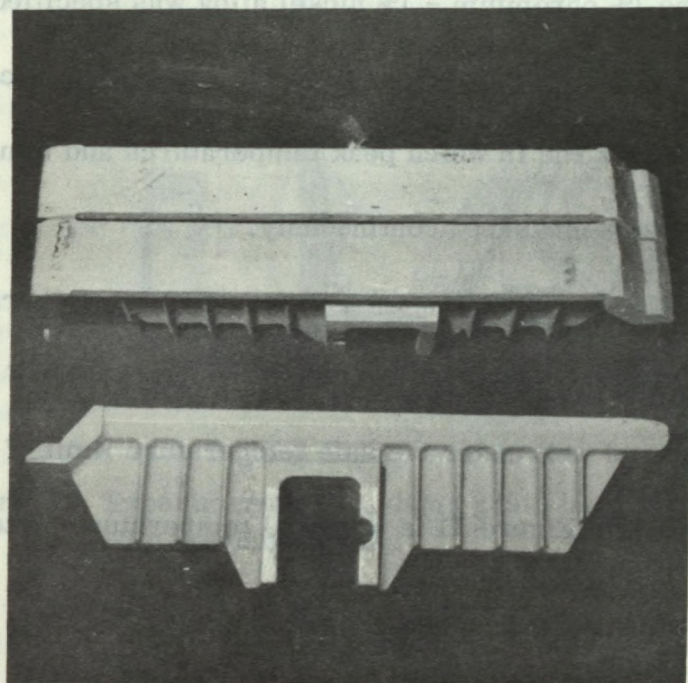


Figure 14 Final design of bar for a spreader-fired dump grate, designated FRL-D; patent applied for.

At the time of this writing, the first FRL grate to be installed was in service for 1 1/2 heating seasons, and appeared capable of lasting at least five years. The air openings did not require cleaning, while those in the standard grate in a duplicate boiler had to be manually cleaned every two weeks until that grate was also converted to the FRL bars.

#### Smoke Abatement Device

Small underfeed stokers such as those used in fire-box boilers usually have the stoker and fan coupled to the same motor, and operate on an on-off cycle, rather than having modulating controls. This type of firing is not well suited to high-volatile bituminous coal, because when the stoker is off there is no air to burn the volatiles that are driven off by the residual heat of the fire, and smoke forms. Also, the fire-bed gradually loses much of its ignition. Then, when the stoker comes on again, raw coal is fed into the retort, and cold air is blasted into the half-ignited fire-bed. Heavy black smoke results until good ignition is re-established which may take ten or fifteen minutes. A highly-caking coal aggravates the situation.

While it is best to adjust stoker speed to steam load, thus achieving continuous operation, this is not always possible and for such cases a smoke abatement device has been devised.

As shown in Figure 15, it consists of

- (a) a high-pressure air blower which runs continuously;
- (b) two ducts, one leading to a row of overfire nozzles, the other to the windbox; and
- (c) a pair of motor-controlled dampers.

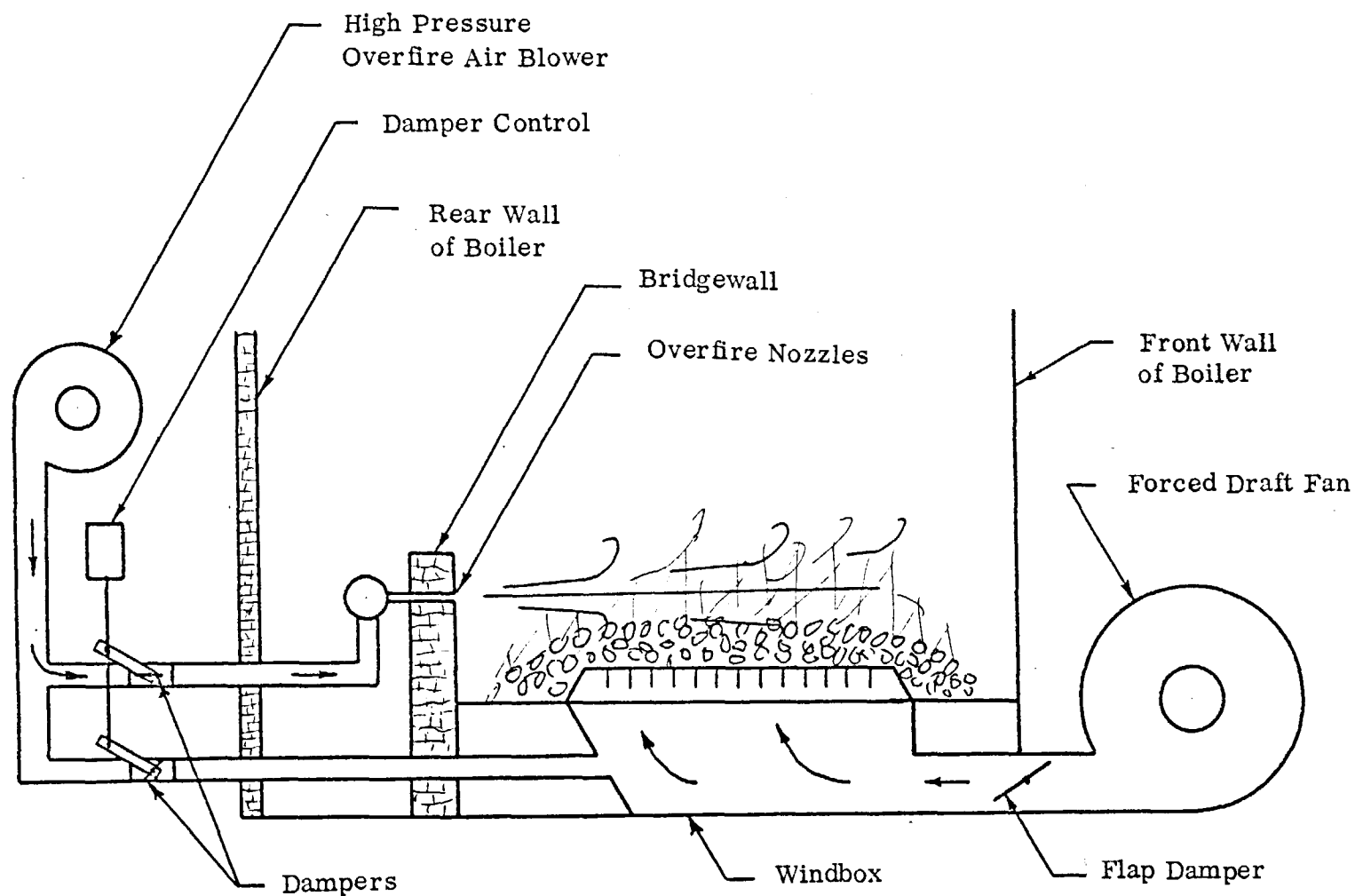


Figure 15 Smoke abatement device for small underfeed stokers;  
patent applied for .

When the stoker is on, the dampers are automatically adjusted so that air from the blower provides overfire turbulence which reduces smoke from normal burning.

When the stoker shuts off, automatic controls adjust the dampers so that the overfire air is shut off and directed instead into the windbox where it comes up through the fire-bed. Since the blower is sized to have only 5 to 10% of the capacity of the stoker fan, the air from it is not enough to raise steam pressure, but consumes the volatiles being driven off, and maintains good ignition in the fire-bed, thus avoiding the smoky rekindling period when the stoker comes back on.

One experimental installation was made in July 1960, and brief tests indicated that it effectively reduced smoke emission. Consequently, further installations are planned.

#### Smokeless Stoker for Cape Breton Coal

The conclusions drawn from the research program concerning the features necessary in equipment to burn low ash-fusion, highly-caking coal satisfactorily have already been stated. It seems a logical step to apply them to the design of a distinctive stoker particularly suited to Cape Breton coal and a proposal incorporating all the features found desirable is shown in Figure 16.

In this design, positive coal feed and control of coal distribution are provided by a plate feeder extending the full width of the grate. Control of combustion air distribution is provided by zoning dampers under the entire grate and continuous ash discharge is provided by vibrating the grate. The grate may be flat or inclined and can be water-cooled if necessary.

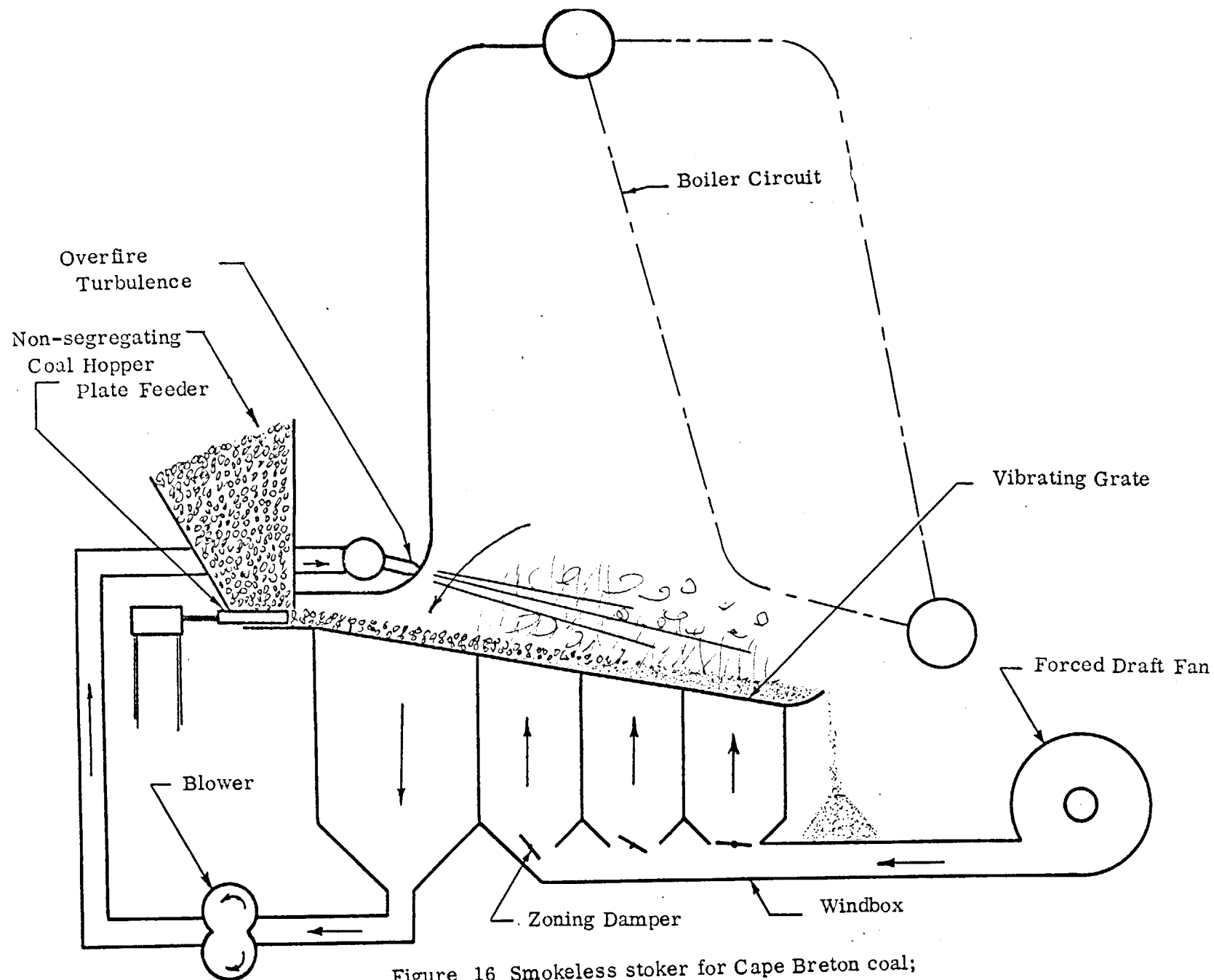


Figure 16 Smokeless stoker for Cape Breton coal;  
Canadian patent 621,375, issued 1961.

The most novel feature of the design is the means used to obtain pre-oxidation of the coal. To accomplish this the first zone under the grate is shut off from the rest of the windbox and to it is applied a suction. This draws hot gases from the furnace down through the bed of raw coal to heat it, thus distilling off some of the volatiles and thereby destroying the caking property of the coal. The free-burning, partially devolatilized coal that remains moves on down the grate and burns in the regular manner, while the furnace gases and combustibles drawn from the coal are re-injected into the furnace either through the grate or through nozzles to provide overfire turbulence.

This system had not been tested at the time of writing but details of design and construction were finalized so that development could proceed. Furthermore, crucible-scale experiments are being carried out to establish the optimum coal bed-temperature. It is planned to build a small working model in the laboratory, and experiments will be carried out on it to determine the most suitable shape of furnace, the amount and temperature of furnace gas that must be drawn through the coal to destroy its caking tendency, the permissible grate heat release rates, and other pertinent information which can be extrapolated to full-scale units.

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2. Canadian Government Specifications Board Specification for Coal, 18-GP-1A, 18 August 1950, National Research Council, Ottawa.
3. "Application of Overfire Jets to Prevent Smoke From Stationary Plants". BCR Aids to Industry. Report 500-300 (revision of BCR Technical Report 7), Bituminous Coal Research, Inc., Pittsburgh, Pa., 1951.

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ERM:FDF:GKL:(PES)AC:MEC

## APPENDIX

COMBUSTION CALCULATIONS,  
DOMINION SLACK, 3/4 in. x 0Ultimate Analysis, lb/lb

Moisture .....	0.055
Ash .....	0.103
Carbon .....	0.710
Hydrogen .....	0.047
Nitrogen .....	0.013
Sulphur.....	0.028
Oxygen (by diff) ..	<u>0.044</u>
Total .....	1.000 lb

Assume air at 80° F, 60% relative humidity, and 14.696 psia.

1. Stoichiometric air required

<u>Combustible</u>	<u>O<sub>2</sub> from air, lb</u>
C = 2.667 x 0.710	= 1.894 (CO <sub>2</sub> )
H <sub>2</sub> = 8 x 0.047	= 0.376 (H <sub>2</sub> O)
S = 1 x 0.028	= 0.028 (SO <sub>2</sub> )
Total .....	= <u>2.298</u>
Less O <sub>2</sub> in coal	= <u>0.044</u>
O <sub>2</sub> from air, lb/lb coal	= <u><u>2.254</u></u>
Associated N <sub>2</sub> = $\frac{76.85}{23.15} \times 2.254$	= <u>7.483</u>
Dry air, lb/lb coal	= <u>9.737</u>
Moisture in air = 9.737 x 0.0132	= <u>0.128</u>
Atmospheric air, lb/lb coal	= <u><u>9.865</u></u>

2. Stoichiometric products of combustion

<u>Dry</u>	<u>lb</u>
C = 0.710 + 1.894	= 2.604 (CO <sub>2</sub> )
N <sub>2</sub> = 0.013 + 7.483	= 7.496 (N <sub>2</sub> )
S = 0.028 + 0.028	= 0.056 (SO <sub>2</sub> )
Dry flue gas, lb/lb coal	= <u>10.156</u>

<u>Wet</u>	
H <sub>2</sub> O = 0.047 + 0.376	= 0.423 (H <sub>2</sub> O)
Moisture in coal	= 0.055
Moisture in air	= <u>0.128</u>
Wet flue gas, lb/lb coal	= <u>10.762</u>

3. Combustion air for a range of total air

Specific volume of air = 13.89 cu ft/lb dry air.

Total air, %	100	120	140	160	180
Dry air, lb/lb coal	9.737	11.684	13.632	15.579	17.527
Atm air, lb/lb coal	9.865	11.838	13.811	15.784	17.757
Atm air, cu ft/lb coal	135.25	162.30	189.35	216.40	243.45

4. Products of combustion for a range of total air and temperature

## (a) At stoichiometric

<u>Dry products</u>		<u>lb/lb coal</u>		<u>Mol wt</u>		<u>Mols</u>		<u>cu ft at 32° F</u>
CO <sub>2</sub>	=	2.604	÷	44	=	0.05918 x 359	=	21.24
N <sub>2</sub> from coal	=	0.013	÷	28	=	0.00046 x 359	=	0.16
N <sub>2</sub> from air	=	7.483	÷	28	=	0.26725 x 359	=	95.94
SO <sub>2</sub>	=	<u>0.056</u>	÷	64	=	<u>0.00088</u> x 359	=	<u>0.32</u>
Dry flue gas	=	<u>10.156</u>				<u>0.32777</u>		<u>117.66</u>
<u>Wet products</u>								
H <sub>2</sub> O from coal and H <sub>2</sub>	=	0.478	÷	18	=	0.02656 x 359	=	9.54
H <sub>2</sub> O from air	=	<u>0.128</u>	÷	18	=	0.00711 x 359	=	<u>2.55</u>
Wet flue gas	=	<u>10.762</u>						<u>129.75</u>

## (b) For 20% excess air

Additional O <sub>2</sub> , 0.2 x 2.254	=	0.451	÷	32	=	0.01409 x 359	=	5.06
Additional N <sub>2</sub> , 0.2 x 7.483	=	<u>1.497</u>	÷	28	=	0.05346 x 359	=	<u>19.19</u>
Additional dry products	=	<u>1.948</u>						<u>24.25</u>
Additional H <sub>2</sub> O, 0.2 x 0.128	=	<u>0.026</u>	÷	18	=	0.00144 x 359	=	<u>0.52</u>
Total	=	<u>1.974</u>						<u>24.77</u>

Total air, %	100	120	140	160	180
Dry flue gas, lb/lb coal	10.156	12.104	14.052	16.000	17.948
Dry flue gas cu ft at 32° F/lb coal	117.66	141.91	166.16	190.41	214.66
Wet flue gas, lb/lb coal	10.762	12.736	14.710	16.684	18.658
Wet flue gas, cu ft at 32° F/lb coal	129.75	154.52	179.29	204.06	228.83

$$\text{Wet gas correction for } 300^{\circ}\text{ F} = \frac{460 + 300}{460 + 32} = 1.54472$$

$$\text{" " " " } 350^{\circ}\text{ F} = \frac{460 + 350}{492} = 1.64634$$

$$\text{" " " " } 400^{\circ}\text{ F} = \frac{460 + 400}{492} = 1.74797$$

$$\text{" " " " } 450^{\circ}\text{ F} = \frac{460 + 450}{492} = 1.84959$$

$$\text{" " " " } 500^{\circ}\text{ F} = \frac{460 + 500}{492} = 1.95122$$

$$\text{" " " " } 550^{\circ}\text{ F} = \frac{460 + 550}{492} = 2.05284$$

Total air, %	Wet flue gas, cu ft/lb coal						
%	32° F	300° F	350° F	400° F	450° F	500° F	550° F
100	129.75	200.43	213.61	226.80	239.98	253.17	266.36
120	154.52	238.69	254.39	270.10	285.80	301.50	317.20
140	179.29	276.95	295.17	313.39	331.61	349.83	368.05
160	204.06	315.22	335.95	356.69	377.43	398.17	418.90
180	228.83	353.48	376.73	399.99	423.24	446.50	469.75

5. Per cent CO<sub>2</sub> for a range of total air (dry gas basis)

CO<sub>2</sub>, cu ft at 32° F/lb coal = 21.24

Total Air, %	100	120	140	160	180
Dry flue gas, cu ft at 32° F/lb coal	117.66	141.94	166.16	190.41	214.66
CO <sub>2</sub> , %	18.05	14.96	12.78	11.15	9.90

6. Total air corresponding to round figures of per cent CO<sub>2</sub>(dry gas basis)

CO <sub>2</sub> , %	Total Mols (1)	Mols excess air (2)	Excess air, lb (3)	Total air, % (4)
18.00	0.32878	0.00101	0.029	100.30
17.00	0.34812	0.02035	0.589	106.05
16.00	0.36988	0.04211	1.218	112.51
15.00	0.39453	0.06676	1.931	119.83
14.00	0.42271	0.09494	2.747	128.21
13.00	0.45523	0.12746	3.687	137.87
12.00	0.49317	0.16540	4.785	149.14
11.00	0.53800	0.21023	6.082	162.46
10.00	0.59180	0.26403	7.638	178.44

(1)  $\frac{0.05918 \times 100}{\% \text{ CO}_2}$

(2) Total Mols - 0.32777

(3) Mols excess air x 28.93

(4)  $100 + \frac{\text{wt excess air} \times 100}{9.737}$

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