Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

CANMET
Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

COMBUSTION EVALUATION OF MIXED MERCOAL IN A PILOT-SCALE UTILITY BOILER

H. Whaley, G.N. Banks, R. Prokopuk and G.K. Lee
Canadian Combustion Research Laboratory

September 1982

[redacted]

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
DIVISION REPORT ERP/ERL 82-17(CF)

Declassification Date:
September 1983

COMBUSTION EVALUATION OF MIXED MERCOAL IN A PILOT-SCALE UTILITY BOILER

by

H. Whaley*, G.N. Banks*, R. Prokopuk** and G.K. Lee***

ABSTRACT

The combustion performance of Mercoal thermal coal was evaluated in a pilot-scale, pulverized-fired research boiler. The mixed coal, which contained about 11% total moisture, handled and flowed readily and burned with good ignition flame stability and carbon burn-out. The coal ash sintered on high temperature refractory-lined boiler surfaces, but deposits on superheater surfaces were light and powdery and did not constitute a fouling problem. The coal's potential for low-temperature corrosion was minimal. Emissions of nitric oxide and sulphur dioxide were less than current allowable North American guidelines.

*Research Scientist, **Quality Assurance Officer, ***Manager, Canadian Combustion Research Laboratory, Energy Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa.

CONTENTS

TABLES

Tables cont'd

FIGURES

INTRODUCTION

Under a cost-shared agreement with Techman Engineering Limited, the Canadian Combustion Research Laboratory (CCRL) carried out a research project to evaluate the combustion performance of coal from the Mercoal deposit located in north-western Alberta.

The coal used for the combustion trials was comprised of an 88% : 12% by weight of the Val d'Or and Silkstone seams respectively, from the Mercoal deposit. The coal mix ranked as a high volatile bituminous by ASTM classification procedures, had not been previously burned in industrial-size equipment. The joint project formed part of the CANMET Energy Research Program and included an analytical investigation of the parent and mixed coals and coal ash properties as well as combustion studies of the coal mix in the CCRL pilot-scale boiler, under conditions representative of those in large boilers.

This report describes the objectives of the project, the analyses of the coals, the facilities used and the operational procedures selected.

RESEARCH OBJECTIVES

The objectives of the combustion trials and related analytical studies were:

1. to determine the comminution and handling characteristics of the mixed coal;
2. to analyze the parent coals and the coal mix;
3. to evaluate the combustion performance at specified feed fineness and excess combustion air levels;
4. to characterize the particulate and gaseous pollutants generated during combustion;
5. to assess the slagging and fouling potential of ash constituents within the furnace and on radiant heat transfer surfaces and superheater tubes respectively;
6. to determine the fly ash resistivity characteristics and ease of fly ash collection by electrostatic precipitation; and
7. to derive coal combustion charts based on heat losses calculated from the ultimate coal analyses.

COAL CHARACTERISTICS

Handling and Preparation

A six tonne sample of Mercoal was delivered to CCRL in sealed plastic-lined drums. The coal shipment consisted of 25 drums of Val d'Or seam and 5 drums of Silkstone seam. Both coal samples were free flowing and no problems were experienced in mixing them or feeding the mix through the pilot-scale coal handling system. Head samples of the individual seams were taken for analytical purposes.

Combustion Reactivity

The screen, proximate, ultimate and ash analyses of the two seams comprising the coal mix are shown in Tables 1 to 4.

Previous research at CCRL has shown that the efficiency of carbon burn-out in turbulent diffusion flames is strongly dependent on the reactivity or combustion characteristics of the coal macerals present. The influence of the main maceral types on combustion, in order of their relative reactivity, is listed in Figure 1. The petrographic data for the component coal seams are shown in Table 5.

With less than 35% inert macerals in both of the component seams, the mixed coal should burn and ignite readily with excellent stability and carbon burn-out. This is endorsed by the high volatile matter content (>30%) the Volatile Matter/Fixed Carbon ratio (>0.6) and the calorific value of about 27 MJ/kg.

The mixed coal and ash analyses are given in Tables 6 and 7. Each analysis was computed by prorating the component seam analyses, except for the ash fusion temperatures, which were measured.

Another comparative index, which can be calculated from the proximate and ultimate analysis is the volatile matter combustion temperature or the adiabatic gas temperature achieved by a stoichiometric mixture of the coal volatile components and air. In this calculation, the coal is considered to be in a dry condition, the combustion air is considered to carry all of the moisture in the coal as fed to the pulverizer, and the combustion of volatile matter is considered to be complete prior to combustion of the fixed carbon. The calculated volatile matter combustion temperature for mixed Mercoal with 11% moisture is 880°C, indicating that ignition and flame stability should be satisfactory. A value above 700°C suggests that the coal should ignite readily and that combustion will be stable.

A mineralogical examination of the coal is also given in Appendix A.

Combustion Charts

Combustion charts, based on the ultimate analyses of the coal, are given in the Appendix B. These charts provide a rapid, graphical means of determining boiler efficiency by the Indirect ASME Heat Loss Method.

HIGH-TEMPERATURE ASH DEPOSITS

Two general types of high-temperature ash deposition can occur on gas-side surfaces of coal-fired boilers:

1. Slagging-fused deposits that form on surfaces exposed predominantly to radiant heat transfer, such as on refractory furnace bottoms.
2. Fouling-high temperature bonded deposits that form on surfaces exposed predominantly to convective heat transfer, such as on superheater or reheater surfaces.

Slagging Indicators

The slagging potential of coal can often be assessed by using indices or composite parameters to describe the nature and severity of the slag deposits (1). Most indices are applied by categorizing the coals as having an "eastern type" or a "western type" ash. The term "western type" ash is defined as an ash having more CaO + Mgo than Fe_2O_3, when the three components are measured as a weight per cent of the coal ash. This criterion is dependent solely on ash analyses and does not have any rank or geographic connotation. On the above basis, the ash from the mixed Mercoal has a CaO + MgO/Fe_2O_3 ratio of 1.46 and can be classified as a "western" coal ash.

Two common indices for determining the slagging potential of the coal ash and furnace deposits are described below:

(1) The Base:Acid Ratio (B/A) is defined as

$$\frac{Fe_2O_3 + CaO + MgO + Na_2O}{SiO_2 + Al_2O_3 + TiO_2}$$, where each oxide

is expressed as a percentage of the total ash. A maximum of 0.5 for the base:acid ratio has been suggested for dry-bottom pulverized-fired units, although this is not a necessary restriction. Values below 0.27 indicate that slagging is unlikely to be a problem at normal furnace operating temperatures.

(2) Potential Slagging Temperature (Tps) is defined:

as $\frac{HT + 4\ IT}{5}$°C, where IT is the minimum temperature at which initial ash deformation occurs (normally in a reducing atmosphere) and HT is the maximum temperature at which hemispherical deformation occurs (normally in an oxidizing atmosphere). Temperature values greater than 1340°C indicate a low slagging potential, whereas values less than 1150°C indicate a severe slagging potential.

Both the base:acid ratio of 0.17 and the potential slagging temperature of 1256°C (see Tables 13 and 14) derived from the ash analyses and the ash fusion data respectively; suggest that the Mercoal mix will have a medium slagging tendency.

Fouling Indicators

There has been general agreement between research and operating practice that one of the dominate factors influencing superheater fouling is the sodium content of the coal ash. The following classification has been proposed:

Fouling Category	% Na_2O in Ash "eastern" coals	"western" coals
Low	0.5	2.0
Medium	0.5 - 1.0	2.0 - 6.0
High	1.0 - 2.5	6.0 - 8.0
Severe	2.5	8.0

The Mercoal ash, classified as a "western type", has an Na_2O content of 0.41% which would indicate that it is in the low fouling category.

PILOT-SCALE RESEARCH BOILER

The CCRL research boiler, illustrated schematically in Figure 2, is a pulverized-coal-fired boiler incorporating two tangentially opposed in-shot burners. The furnace is of membrane-wall construction and operates at pressures of up to 2.5 kPa (10 in. WC). At the full-load firing rate of 2500 MJ/g (0.7 MW), the boiler genertes 730 kg/h of steam at 690 kPa (6.8 atm). The heat is dissipated in an air cooled condenser.

Crushed coal is supplied from a 4500 kg hopper, mounted on an electronic weigh sclae, through a variable-speed worm feeder to a ring-and-roller type of pulverizer, which is normally swept and pressurized by air at any temperature up to 230°C. If necessary, the pulverizer can be swept and pressurized with a mixture of air and flue gas at any temperature up to 490°C. The pulverizer contains a motor-driven classifier for controlling coal fineness and a riffle at the pulverizer outlet proportions the coal to each burner. Secondary air can be supplied to the burner at any temperature up to 260°C.

Combustion gases leave the furnace between 900 - 1100°C and then pass through a transition section, a test-air heater and conventional three-pass air heater before entering a long horizontal sampling duct. A by-pass from the air heater to the stack breecing and additional heat exchanger surface in the sampling duct, permit the gas temperature in the sampling duct to be varied between 150°C and 300°C.

A forced-draft fan supplies air to the air heater at 7 kPa (28 in WC). The air, on leaving the heater, is divided into three systems; primary air to the pulverizer, secondary air to the burners and cooling air to the test-air heater. The last stream, after leaving the test-air heater, can either be exhausted to the atmosphere or blended with the primary-air supply to the pulverizer.

The research boiler is manually controlled, except for electrical interlocks to ensure that safe start-up and shutdown procedures are followed. When burning high-grade coals, it has been possible to operate with as little as 1.0% O and less than 0.1% CO in the flue gases, with a smoke density of less than No. 1 Ringlemann.

EXPERIMENTAL PROCEDURES

Operating Procedure

The operating procedure given below was used for all trials with some minor variations in timing, as necessary.

1. Before starting each test, all boiler and air heater fireside surfaces were thoroughly cleaned by air lancing and the furnace bottom was relined with a refractory blanket. Sufficient coal was bunkered to provide eight hours of continuous operation.

2. At 0800 h, the cold boiler was preheated on No. 2 fuel oil at 16 gph. Excess air was adjusted to provide 5% O_2 in the flue gas and the boiler was allowed to stabilize at full steaming rate and pressure. All continuous monitoring instruments were calibrated and put into service.

3. At 0900 h, pulverized coal was fed to the boiler at a specified classifier speed, mill temperature and excess air level. One oil torch was left in operation.

4. At 0945 h, the oil torch was removed, leaving the boiler operating on pulverized coal only.

5. At 1100 h, scheduled testing was begun. Boiler panel readings were continuously monitored and recorded half-hourly. A specified coal feed rate, coal fineness and excess air level was maintained as closely as possible for the test duration.

6. By 1700 h all measurements were completed and the boiler was shutdown.

7. The furnace was allowed to cool overnight. Then the furnace bottom was removed and the ash remaining in the furnace bottom and duct work was collected, weighed and sampled.

Parameters of Combustion Performance

The following parameters of combustion performance were measured at the sampling stations illustrated in Fig. 2.

1. Coal quality of a composite sample taken from the crushed coal feed at the pulverizer inlet. Station 1.

2. Moisture and sieve analyses of pulverized coal samples taken at the pulverizer outlet. Station 2.

3. CO_2 and CO content of the flue gas measured continuously by infrared monitors. Station 10.

4. O_2 content of the flue gas measured continuously by paramagnetic monitor. Station 10.

5. NO content of the flue gas measured continuously by a chemiluminescent monitor. Station 10.

6. SO_2 content of the flue gas measured continuously by an infrared monitor. Station 10.

7. SO_3 content of the flue gas measured by the modified Shell-Thornton method. Station 15.

8. Fly-ash loading measured by an isokinetic sampling system, two to four samples per test. These samples were analyzed for carbon content, chemical composition and aerodynamic size distribution. Station 16.

9. Fouling of heat-transfer surfaces evaluated by visual examination of ash build-up on a simulated superheater, installed immediately downstream of the screen tubes. Station 20.

10. Slagging propensity by examining the thickness, physical structure, chemical composition and melting characteristics of ash

deposits selected from various parts of the furnace. Station 7-9 and 19.

11. Fly-ash resistivities measured by an in-situ, point-plane resistivity apparatus at flue gas temperatures of about 180°C at Station 17 and about 350°C at Station 15.

COMBUSTION PERFORMANCE

Coal Comminution

The coal was crushed, metered and pulverized to the selected degrees of fineness without difficulty. It was then transported directly to the burners without moisture separation from the carrying air. The CCRL coal drying and grinding system is illustrated in Fig. 3. The grinding performance of the pulverizer, which produced products of 86% and 72% minus 200 mesh, was consistent with the coal's low Hardgrove grindability index of 43. The size distribution of the pulverized coal is shown in Table 8 together with the boiler operating data.

Flame Characteristics

The combustion conditions remained essentially constant throughout each combustion trial and confirmed that the handling characteristics of the mixed coal were excellent. The flame was bright, clean and stable under steady-state conditions; an oil support flame was only required for a few minutes at the start of each trial to establish combustion.

Gaseous Emissions

Carbon monoxide levels at less than 50 ppm did not constitute either an emission problem or a thermal penalty.

The sulphur dioxide emissions from this low-sulphur coal were less than 200 ppm or 0.16 g/MJ, which is well below the U.S. Environmental Protection Agency 1977 guideline of 0.58 g SO_2/MJ for new combustion systems. These emissions were less than total theoretical because of neutralization reactions

occuring between the fuel sulphur and the alkaline ash cations. Only trace quantities of sulphur trioxide were detected. Low-temperature corrosion probes inserted in the utility boiler indicated that sulphuric acid buildup was below the minimum detectable limit.

The nitric oxide emission rate of 0.33 g/MJ was slightly lower than the 1977 EPA guideline of 0.34 g/MJ for new sources.

Fly Ash Characteristics and Coal Burn-Out

The mass loadings, aerodynamic particle size analyses of the fly ash entering the electrostatic precipitator are shown in Table 9. These data show that about 60% by weight of the fly ash particles were less than 10 μm and that the combustion efficiency corresponding to about 2% combustible in the fly ash was greater than 99.9%. It is expected that the combustion efficiency in full-scale furnaces will be as good as or better, because flame quenching is slower and combustion residence times are much longer relative to the pilot-scale system, where burn-out tends to be inhibited by the high surface to volume ratio and the small flame zone of the furnace.

The in-situ resistivities for the Mercoal mix are given in Table 9. In general, high electrical resistivity ($>10^{12}$ ohm-cm) indicates that precipitated fly ash will retain a strong electrical charge and repel any similarly charged particle or generate a back corona within the deposit; precipitation, is therefore difficult. A low resistivity ($<10^{7}$ ohm-cm) indicates fly ash will readily precipitate but will not adhere strongly to the collecting plates and will easily be re-entrained in the flue gas. Low resistivities are usually associated with high carbon losses. Intermediate values of approximately 10^{8} to 10^{11} ohm-cm are considered to yield the highest precipitator efficiencies. The in-situ resistivity of the Mercoal fly ash as shown in Table 9, was close to the maximum of the desirable range of 10^{8} - 10^{11} ohm-cm.

Typically low-sulphur coals yield high-ash resistivity values and require liberally-sized specific collection areas for good precipitator performance.

Chemical analyses of the fly ash, (Table 10) showed very little change in composition of the major elements relative to the parent coal ash. This uniformity in ash composition, which prevailed in ash deposits at different boiler locations, suggests that the physio-chemical properties of the coal ash are not altered during combustion.

Ash Slagging and Fouling

The fusion data for the furnace bottom ash were almost identical to those for the parent coal ash. The ash analyses and fusion temperatures, given in Tables 3, 11 and 12 are normally associated with a low to medium slagging ashes and are consistent with the sintered structure of the bottom ash deposits shown in Figures 3, 4 and 5).

Table 11, which lists the analyses of the bottom ash, shows that preferential volatilization of fluxing components (e.g., Na_2O, K_2O) during combustion was minimal. Therefore, low-melting eutectics which enhance slag build-up are unlikely to form in the bottom ash. This is consistent with the 12 cm porous sinter observed in the furnace bottom after each combustion trial (Fig. 5).

Figure 6 and 7 show photographs of the powdery, loosely adherent superheater deposits, confirm the low-fouling tendency predicted by the analytical and empirical data for the coal ash and the superheater deposits given in Tables 3, 11 and 12. Table 13 shows that the Base:Acid ratio was unaffected by combustion. Measurements of the potential slagging temperature of the coal and related deposits were essentially unchanged by combustion as shown in Table 14. The superheater deposits, due to a slight decrease in potential slagging temperature, move into the high slagging category but this is academic since the deposited ash particles have already left the high temperature boiler zone at this point.

CONCLUSIONS

The Mercoal mix handled and flowed readily with excellent ignition, flame stability and combustion characteristics.

The sulphur content of this fuel is low and a small amount of this sulphur was neutralized by alkali metal ions in the coal ash. The measured emission of less than 200 ppm corresponds to 0.16 g SO_2 per MJ of fuel input, well below the maximum EPA 1977 guideline of 0.58 g SO_2/MJ for new combustion sources.

The nitric oxide emission rate of less than 900 ppm corresponds to 0.33 g NO per MJ of fuel input, which is marginally lower than the maximum EPA 1977 guideline of 0.34 g NO/MJ.

The tendency of the coal ash to produce boiler wall slag deposits or superheater fouling problems is low and routine soot-blowing should be effective in controlling any localized build-up. A porous but liquid sinter about 12 cms thick was formed in the furnace bottom after 8 h operation.

The electrical resistivity of the fly ash, with combustible contents typical of levels found in full-scale units (5%) was about 10^{11} ohm-cm indicating that good precipitator performance will require liberally-sized specific collection areas.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the efforts of the staff of the Canadian Combustion Research Laboratory (CCRL) during the coal evaluation experiments described in this report. In addition, J. Jorgensen and L. Janke of the Energy Research Laboratories who provided invaluable petrographic and analytical support services.

REFERENCE

1. Winegartner, E.C. "Procedures and definitions of fouling and slagging parameters for coal-fired boilers"; Published by the American Society of Mechanical Engineers (ASME) 1972.

Table 1 - Screen analyses of coal seams

Screen Size (mm)	weight % (cumulative)	
	Val d'Or	Silkstone
+25.4	0.1	<0.1
+19.1	5.0	2.8
+12.7	24.9	16.1
+6.4	49.3	40.4
+3.2	70.9	65.6
-3.2	29.1	34.4
Bulk density	833 kg/m^3 at 6% moisture	793 kg/m^3 at 11% moisture

Table 2 - Analyses of coal seams

Analyses	Val d'Or Seam		Silkstone Seam	
Moisture, wt %				
As received	6.0		11.0	
Equilibrium*	8.2		10.8	
Proximate, wt % (dry)				
Ash	13.83		12.41	
Volatile Matter	34.91		32.94	
Fixed Carbon	51.26		54.65	
Ultimate, wt % (dry)				
Carbon	66.35		68.89	
Hydrogen	3.93		3.85	
Sulphur	0.22		0.22	
Nitrogen	0.63		0.77	
Ash	13.83		12.41	
Oxygen (by diff.)	15.04		13.86	
Calorific Value, MJ/kg	26.94		27.54	
Grindability Index, Hardgrove	42		45	
Chlorine in Coal, %	<0.1		<0.1	
Free Swelling Index	non-agglomerating			
Ash Fusibility, °C	Reducing	Oxidizing	Reducing	Oxidizing
Initial	1224	1282	1274	1288
Softening	1304	1321	1388	1393
Hemispherical	1421	1460	>1482	1463
Fluid	1438	1468	>1482	1477

* estimated from Birkley analyses

Table 3 - Analyses of ash from coal seams

Major Elemental Oxides	Weight % of ash	
	Val d'Or	Silkstone
SiO_2	63.37	64.18
Al_2O_3	18.12	20.17
Fe_2O_3	5.08	3.98
TiO_2	0.50	0.64
P_2O_5	0.17	0.11
CaO	6.28	4.41
MgO	1.12	1.50
SO_3	2.13	2.15
Na_2O	0.43	0.22
K_2O	1.62	0.62
BaO	0.50	0.21
SrO	0.03	0.07
L.O.F.	1.26	0.99

Table 4 - Trace elements determined in coal seams

	Val d'Or	Silk stone		Val d'Or	Silk-stone
X-ray Fluorescence Analyses, ppm (dry fuel basis)					
As	1	3	Cd	0.3	0.3
Se	0.4	0.5	Pb	15.9	14.5
Sb	0.3	0.5	Zn	13.2	23.7
Hg	0.1	0.1	Mn	50.9	17.5
Ni	6.4	4.4	Be	0.7	0.6
Cr	8.1	5.3	Cu	7.8	6.5
Co	3.7	2.7	V	13.2	9.8
Neutron Activation Analysis, ppm (dry fuel basis)					
Br	1	2.0	Hf	0.8	0.5
Cl	100	100	Ho	1	1
I	10	10	La	6	7
Dy	0.8	0.8	Lu	0.1	0.1
Eu	0.2	0.2	Mo	5	5
Sm	0.8	1.0	Nd	50	50
U	2.0	1.0	Sc	1	2
Ce	30	30	Th	4	3
Cs	2	2	Rb	100	100

Table 5 - Maceral composition of coal seams

Maceral Form	Volume %	
	Val d'Or	Silkstone
Reactives		
Exinite	2	2
Vitrinite	74	66
Reactive semi-fusinite	-	-
Sub-total	76	68
Inerts		
Fusinite	10	13
Semi-fusinite	6	10
Micrinite	1	2
Mineral matter	8	7
Sub-total	24	32
Mean Reflectance	0.54	0.60

Table 6 - Coal analyses, mixed Mercoal

Analyses (1)	Mixed Coal		Pacific Rim Specifications	
			KECO	JPCD
Moisture, wt %				
As received	<11		<15	<10
Proximate, wt % (dry)				
Ash	13.67		<17	<20
Volatile Matter	34.68		22-36	$\frac{VM}{FC}$ >0.4
Fixed Carbon	51.65		50.60	
Ultimate, wt % (dry)				
Carbon	66.65		-	-
Hydrogen	3.92		-	-
Sulphur	0.22		<1.0	<1.0
Nitrogen	0.65		<2.0	<1.8
Ash	13.67		<17	<20
Oxygen (by diff.)	14.89		-	-
Calorific Value, MJ/kg	27.01		>25.05	>25.05
Grindability Index, Hardgrove	43		>45	>49
Chlorine in Coal, %	<0.1		-	-
Free Swelling Index	non-agglomerating		-	-
<u>Ash Fusibility, °C</u> (2)	<u>Reducing</u>	<u>Oxidizing</u>	<u>Reducing</u>	<u>Oxidizing</u>
Initial	1210	1271	>1250	-
Softening	1285	1313	-	>1200
Hemispherical	1318	1441	-	-
Fluid	1452	1471	-	-

(1) all analyses, except (2), were prorated from the component seams

(2) measured values

Table 7 - Analysis of coal ash from mixed Mercoal

Major Elemental Oxides	weight % (1)
SiO_2	63.47
Al_2O_3	18.36
Fe_2O_3	4.95
TiO_2	0.52
P_2O_5	0.16
CaO	6.06
MgO	1.17
SO_3	2.13
Na_2O	0.41
K_2O	1.50
BaO	0.47
SrO	0.03
L.O.F.	1.23

(1) prorated from component seams

Table 8 - Boiler operating conditions, mixed Mercoal

		Trial 1	Trial 2
Fuel Rate, kg/h		76.3	70.1
Fuel Moisture, wt %		3.1	3.1
Coal Fineness, wt %			
+100 mesh		0.2	0.2
100 x 140 mesh		4.0	1.0
140 x 200 mesh		10.0	27.0
200 x 325 mesh		57.0	38.0
325 x 400 mesh		15.0	16.0
-400 mesh		13.8	17.8
-200 mesh		85.8	71.8
Heat Input, MJ/h		1996	1835
Boiler Exit Temp., °C		912	890
Air Temperature, °C			
Pulverizer in		380	370
Pulverizer out		240	230
Secondary		400	400
Steam Rate, kg/MJ		0.183	0.201
Flue Gas Rate, Nm^3/MJ		0.277	0.312
Flue Gas Analyses,	volume		
CO_2	%	15.8	14.1
2	%	3.0	5.0
CO	ppm	45	30
NO	ppm	870	790
SO_2	ppm	200	160
SO_3	ppm	<1	<1
Emission Rates, g/MJ			
NO		0.322	0.330
SO_2		0.158	0.142

Table 9 - Fly ash characteristics, mixed Mercoal

	Trial 1	Trial 2
Precipitator Inlet Loading,		
g/Nm^3	3.57	2.61
g/MJ	0.99	0.81
Combustible Content, wt %	1-2	1-2
Aerodynamic Particle Size, wt %		
+30 μm	22	28
+10 μm	25	37
+1 μm	76	90
Electrical Resistivity, log (ohm-cm)		
at 143°C	11.4	10.3
at 310°C	10.6	11.5
*Combustion Efficiency, %	>99.9	>99.9

$$\text{*Combustion, \%} = 100 - \frac{14{,}500\ CA}{(100-C)C_v}$$

where C = % Carbon in Ash

A = % Ash in Coal

C_v = Calorific Value of Coal, Btu/lb

Table 10 - Fly ash analyses, mixed Mercoal

Major Elemental Oxides	weight %	
	Trial 1	Trial 2
SiO_2	57.59	58.45
Al_2O_3	20.51	20.32
Fe_2O_3	5.61	5.66
TiO_2	0.79	0.79
P_2O_5	0.23	0.23
CaO	9.50	8.53
MgO	1.65	1.86
SO_3	0.32	0.61
Na_2O	0.38	0.33
K_2O	1.43	1.44
BaO	0.73	0.64
SrO	0.08	0.07
L.O.F.	2.00	2.40

Table 11 - Analyses of furnace bottom and superheater deposits

	Furnace Bottom Deposits		Superheater Deposits	
	Trial 1	Trial 2	Trial 1	Trial 2
Major Elemental Oxides, wt %				
SiO_2	66.75	66.72	60.82	60.35
Al_2O_3	18.08	19.20	19.62	19.37
Fe_2O_3	5.34	5.17	5.73	5.98
TiO_2	0.60	0.57	0.68	0.76
P_2O_5	0.14	0.15	0.19	0.18
CaO	5.60	5.45	8.23	8.00
MgO	0.98	1.43	1.74	1.76
SO_3	0.19	0.28	0.62	0.77
Na_2O	0.42	0.37	0.36	0.35
K_2O	1.50	1.56	1.43	1.47
BaO	0.30	0.51	0.62	0.58
SrO	0.03	0.04	0.06	0.06
L.O.F.	0.80	0.20	1.00	1.70
Ash Fusibility, °C				
Reducing atmosphere				
Initial	1207	1210	1188	1190
Softening	1265	1282	1282	1288
Hemispherical	1390	1363	1382	1302
Fluid	1482	1427	1435	1421
Oxidizing atmosphere				
Initial	1249	1268	1277	1296
Softening	1288	1316	1316	1343
Hemispherical	1393	1416	1365	1385
Fluid	1443	1479	1399	1454

Table 12 - Indices of slagging potential

Slagging propensity	Reference limits	Ash Source				
		Coal	Furnace bottom deposits		Superheater deposits	
			Trial 1	Trial 2	Trial 1	Trial 2
Base/Acid (B/A) Ratio						
Low	<0.15	-	-	-	-	-
Medium	0.15 - 0.30	0.17	0.16	0.16	0.21	0.22
High	0.27 - 0.50	-	-	-	-	-
Severe	>0.5	-	-	-	-	-
Potential Slagging Temp. (Tps, °C)						
Low	>1340	-	-	-	-	-
Medium	1340 - 1230	1256	1244	1251	-	-
High	1230 - 1150	-	-	-	1227	1229
Severe	<1150	-	-	-	-	-

RESINITE	VITRINITE	SEMI-FUSUNITE
EXINITE	TELLINITE	MASSIVE MICRINITE
FINELY-DIVIDED MICRINITE	LOW-REFLECTANCE SEMI-FUSINITE	OXIDIZED VITRINITE
		FUSINITE

——— REACTIVITY DECREASES ———→

←——— IGNITION, FLAME STABILITY AND COMBUSTION EFFICIENCY INCREASES ———

Fig.1 - Influence of coal maceral type on combustion.

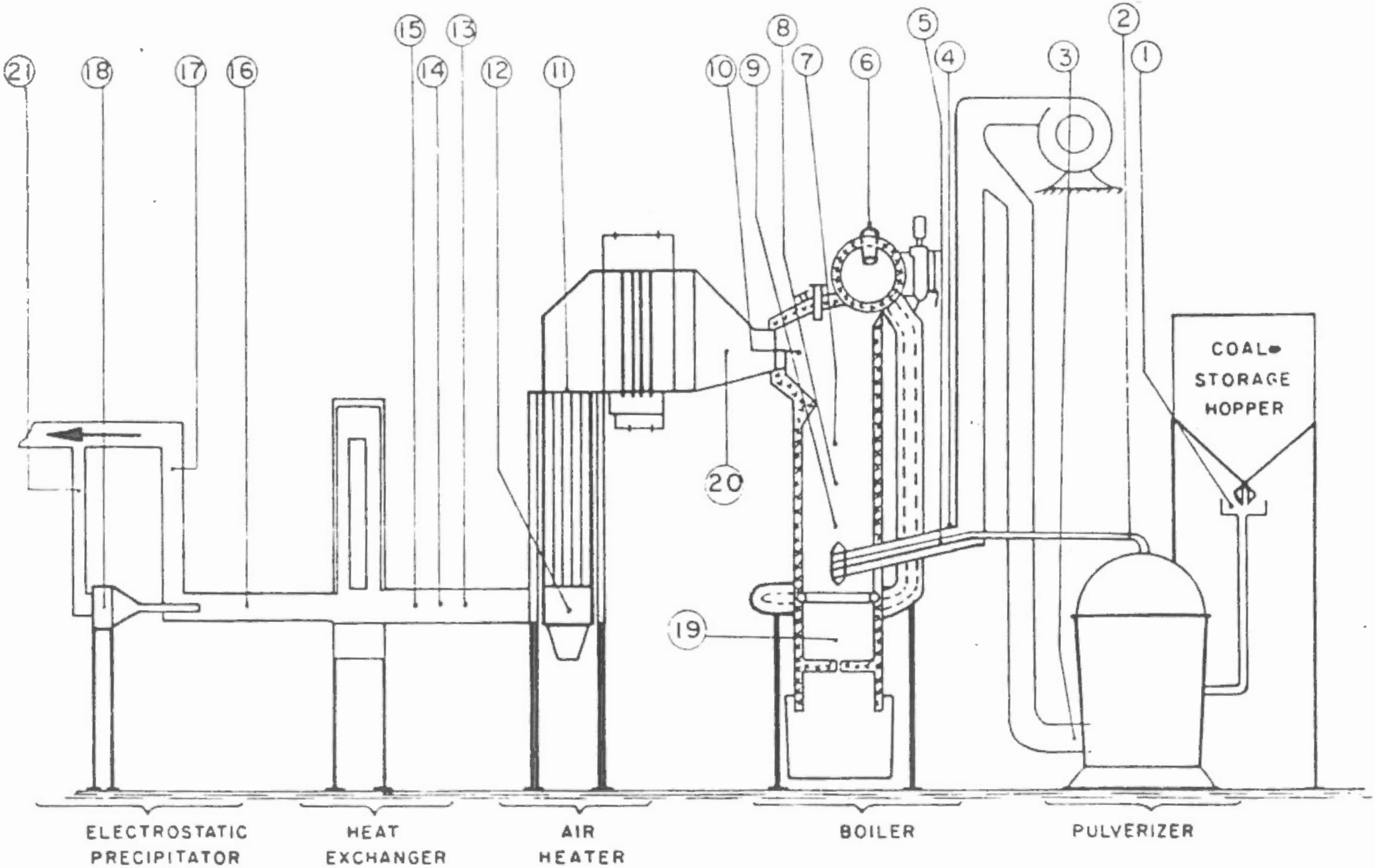


Fig. 2 - Schematic illustration of the pilot-scale boiler showing the sampling stations

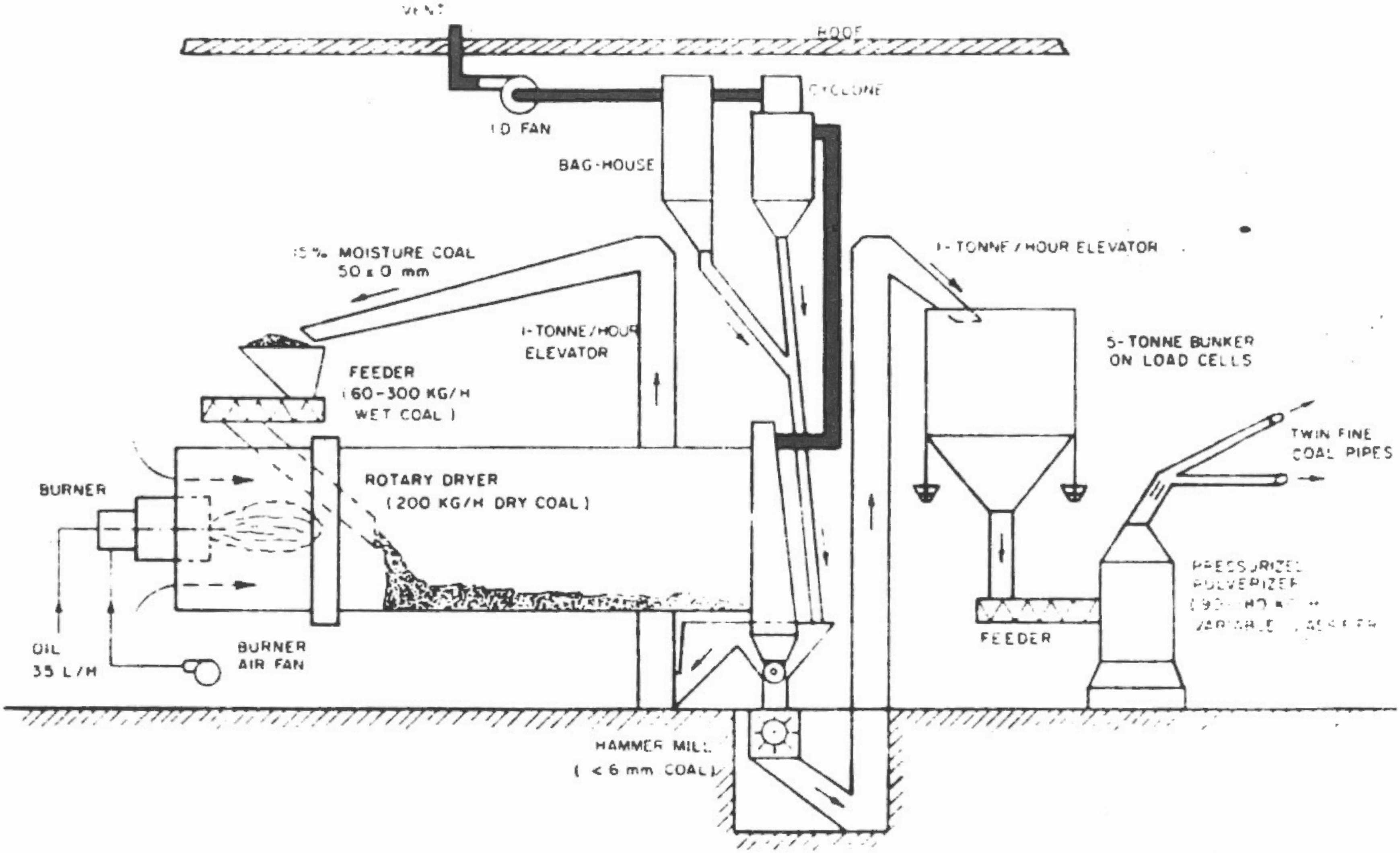
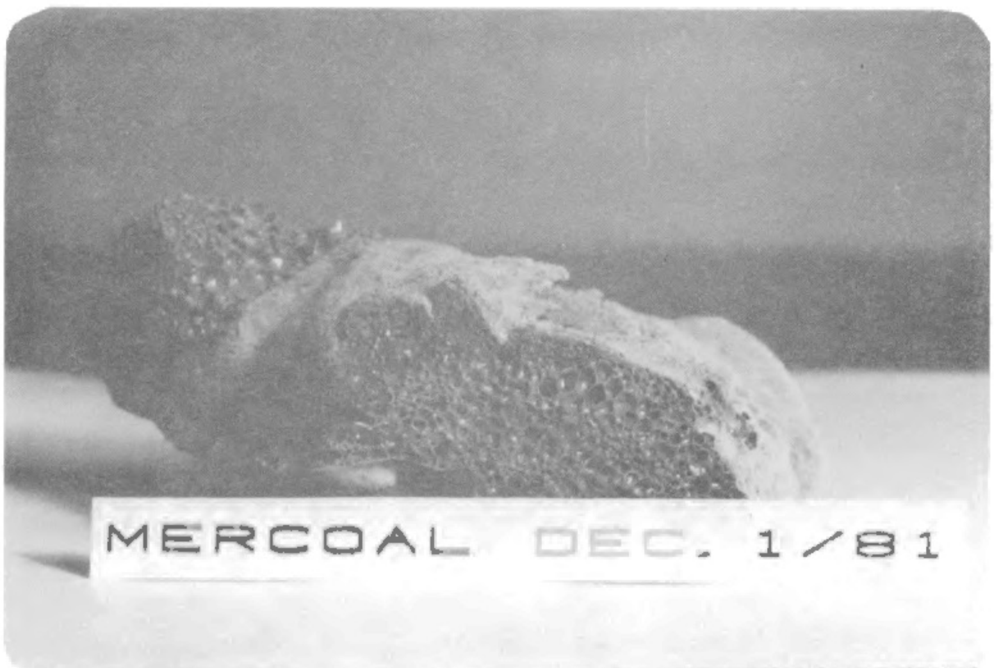


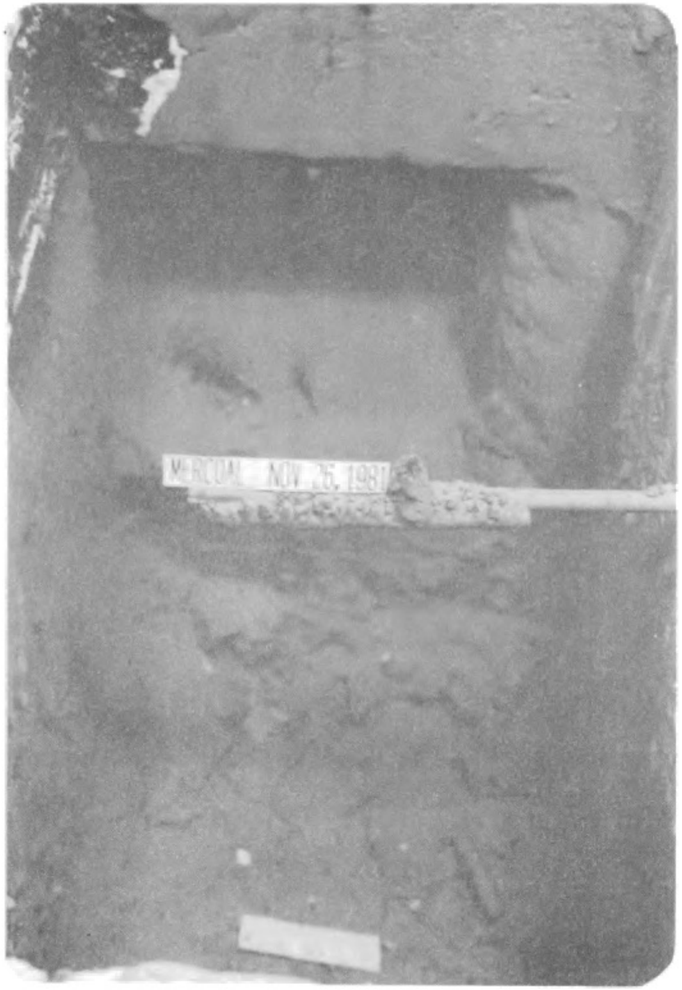
Fig. 3 - Schematic illustration of solid fuel drying and grinding system

Trial 1

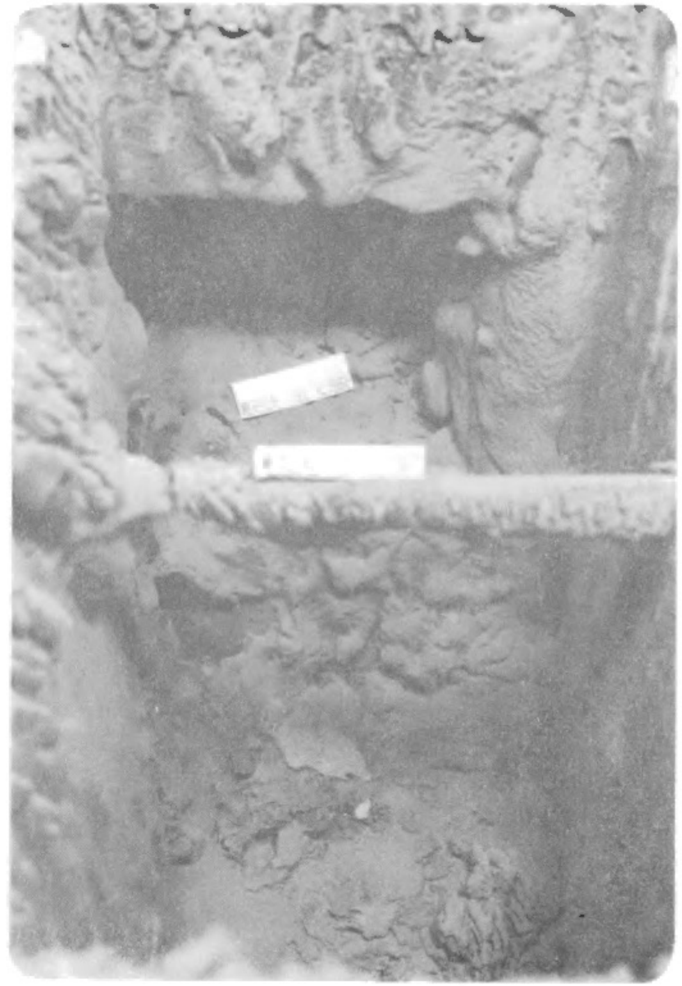


Trial 2

Fig. 4 - Photographs of furnace bottom deposits



Trial 1



Trial 2

Fig. 5 - Deposits in furnace bottoms

Trial 1 Trial 2

Fig. 6 - Deposits on superheater tubes

APPENDIX A

MINERAL ANALYSIS OF MERCOAL

COMPANY Energy, Mines & Resources Canada FILE 7002-82-9

Introduction

Eight (8) samples of coal were submitted by CANMET/ Energy Research Labs., for mineral content determination by X-Ray Diffraction.

Sample Treatment

X-Ray Diffraction Analysis: A sample representing the interval indicated is disaggregated and subjected to a five step analysis: bulk (greater than 5 microns), clay size fraction (less than 5 microns), at room humidity, clay size fraction glycolated, clay size fraction heat treated and, where necessary, clay size fraction acidized. The clay fraction is prepared by dispersion in sodium hexametaphosphate solution and flocculation in magnesium chloride solution. This also stabilizes the ionic state of some clays. The glycolation treatment is used to identify swelling clays such as smectites and vermiculites. These clays expand on glycolation to different degrees when the available cation sites are magnesium saturated. The heat treatment aids in identification of chlorite type and also differentiates between some chlorites and kaolinite. Where further identification of clay type in a chlorite-kaolinite mix is necessary, the sample is treated with warm dilute hydrochloric acid, which decomposes the chlorite.

CORE LABORATORIES - CANADA LTD.

CALGARY, ALBERTA

COMPANY	Energy, Mines & Resources Canada	PAGE	1 of 8
WELL		FILE	[illegible]
LOCATION		DATE	[illegible]
FIELD			

Sample Number: A751 Mercoal Blend

CLAY SEPARATION BY FLOTATION

Material Less than 5 Microns	20.0 %
Material Greater than 5 Microns	79.1 %

X-RAY DIFFRACTION ANALYSIS

	Material Less than 5 Microns	Material Greater than 5 Microns	Calculated Bulk Composition
Quartz	23	73	62
Feldspar	nil	trace	trace
Calcite	nil	nil	nil
Dolomite	nil	nil	nil
Siderite	nil	trace	trace
Pyrite	nil	nil	nil
Kaolinite	30	27	28
Illite	7	nil	2
Chlorite	nil	nil	nil
Smectite	40	nil	8
Mixed Layer Clays (Swelling)	present	nil	present
Clay Minerals	NA	NA	NA

APPENDIX B

MERCOAL COMBUSTION CHARTS

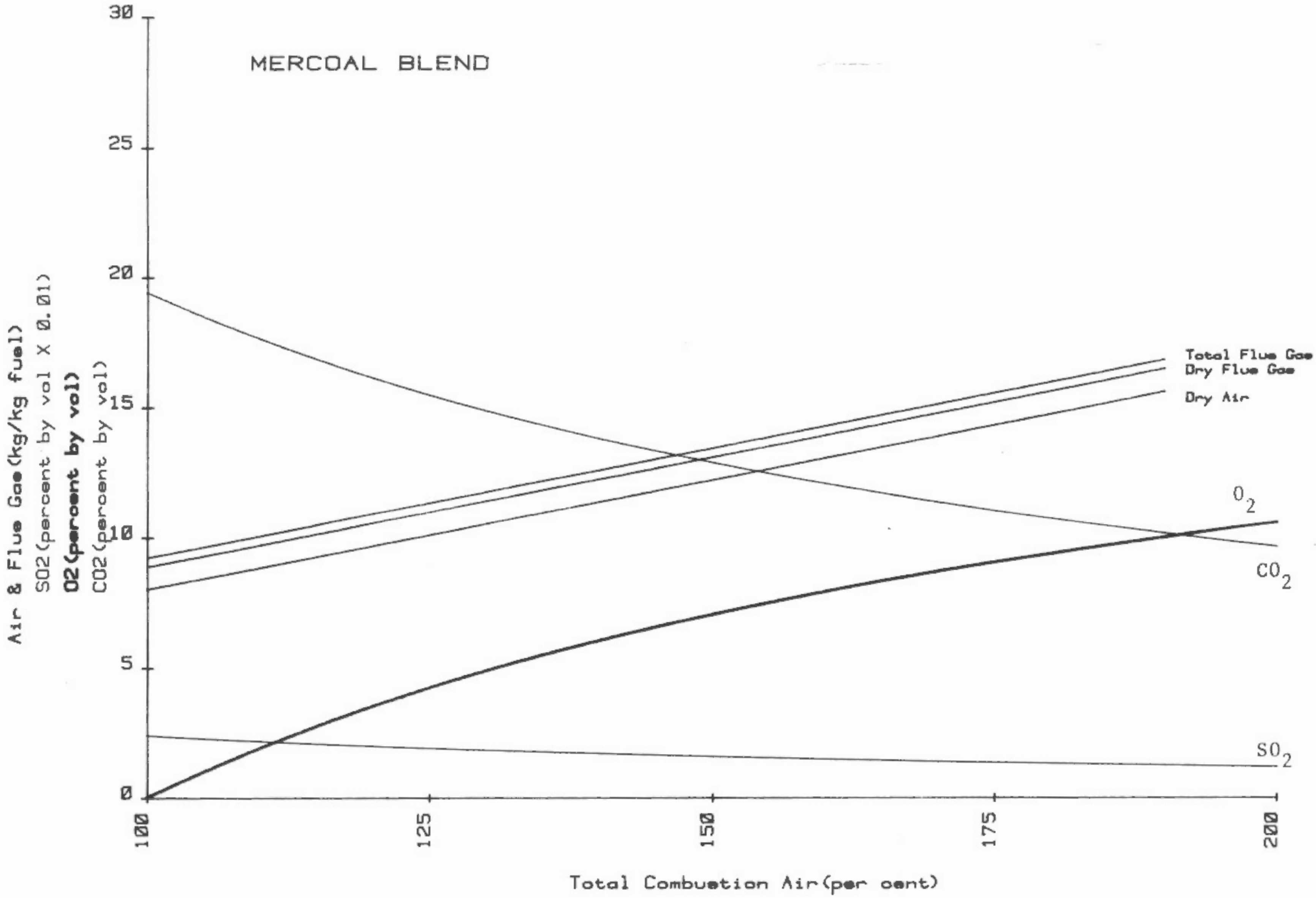


Fig. 1A - Combustion data, eight basis

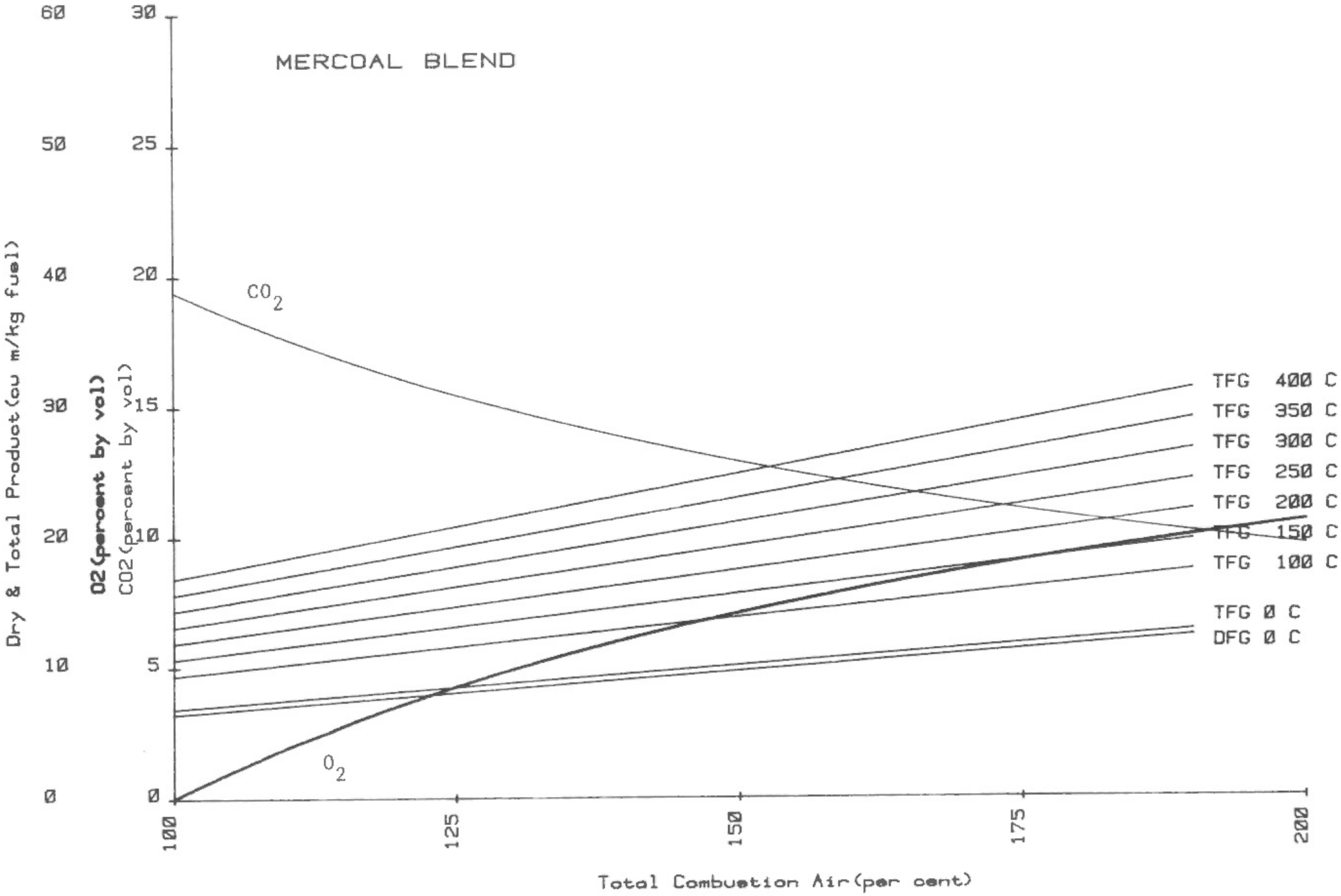


Fig. 2A - Combustion data, volume basis

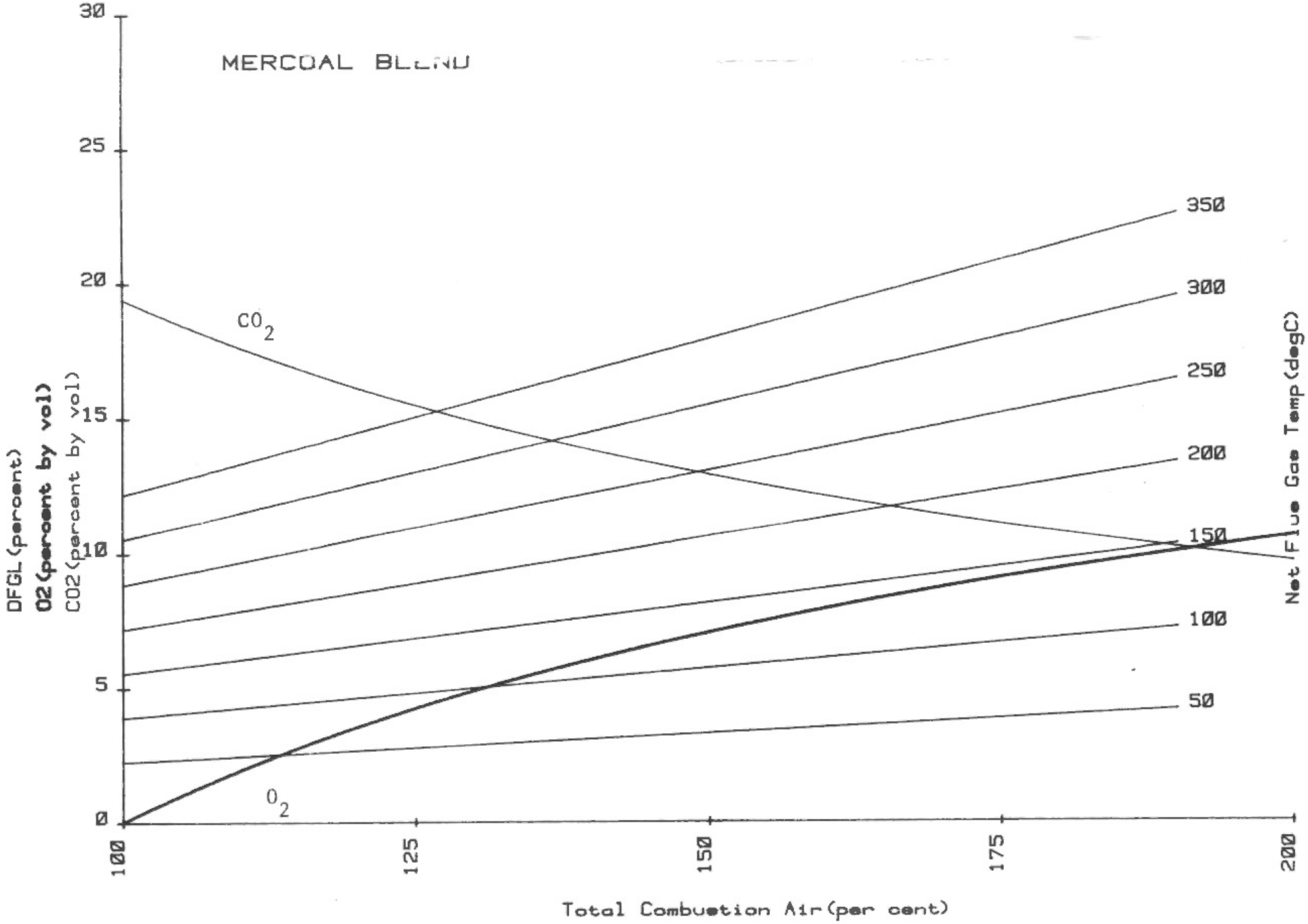


Fig. 3A - Dry flue gas loss for a range of temperature differentials

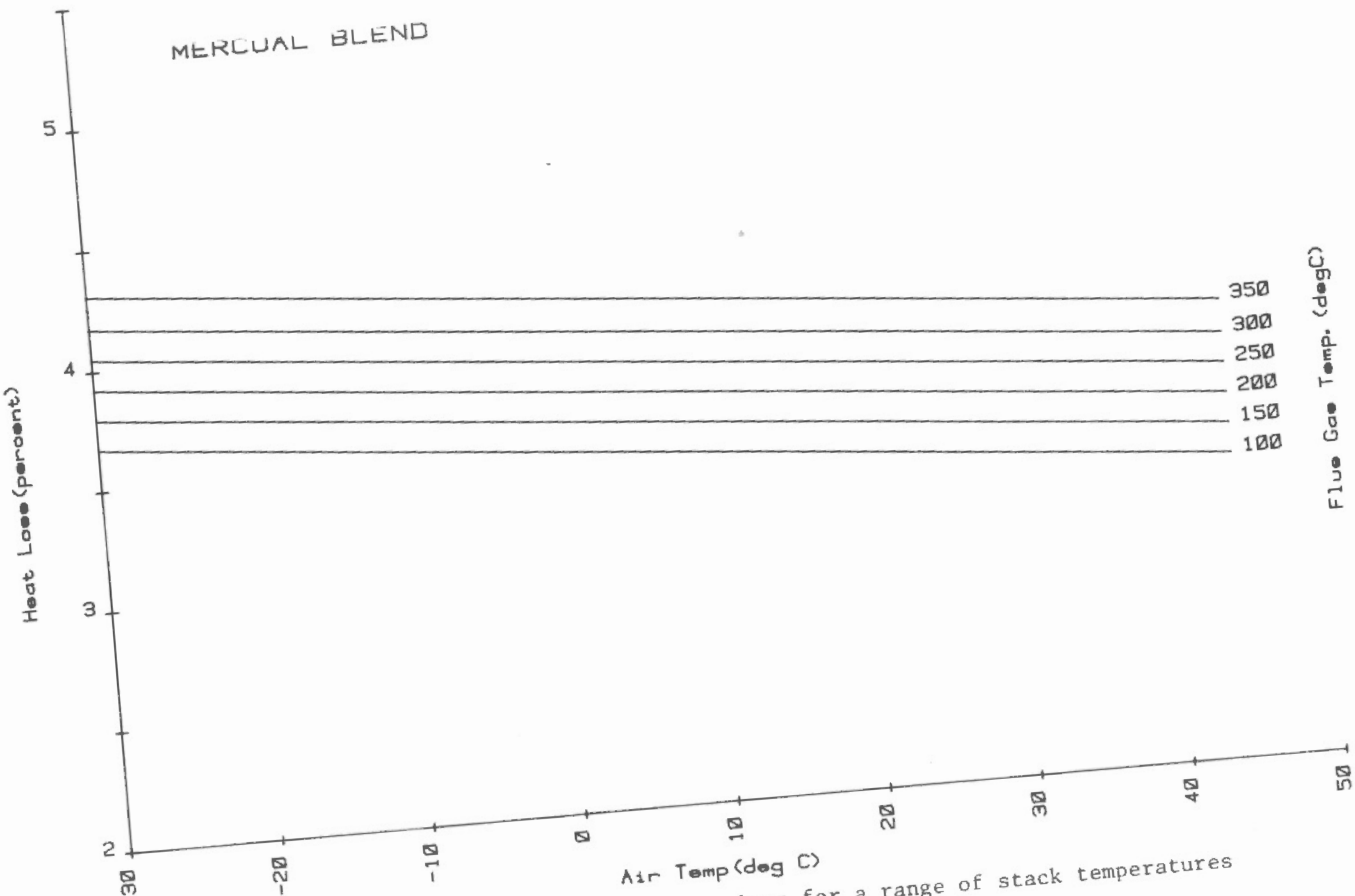


Fig. 4A - Hydrogen loss for a range of stack temperatures

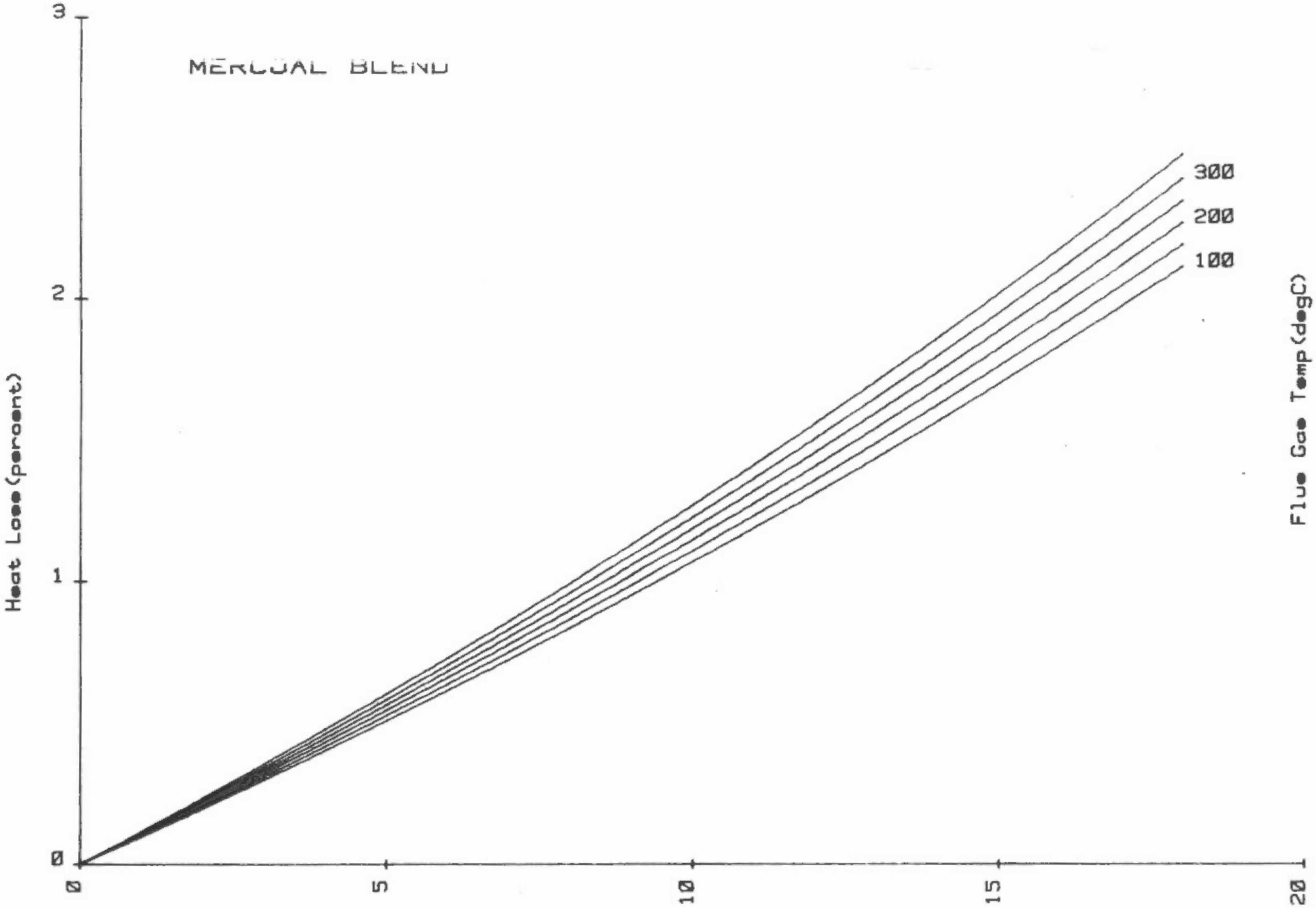


Fig. 5A - Heat loss due to moisture in coal at 20°C.

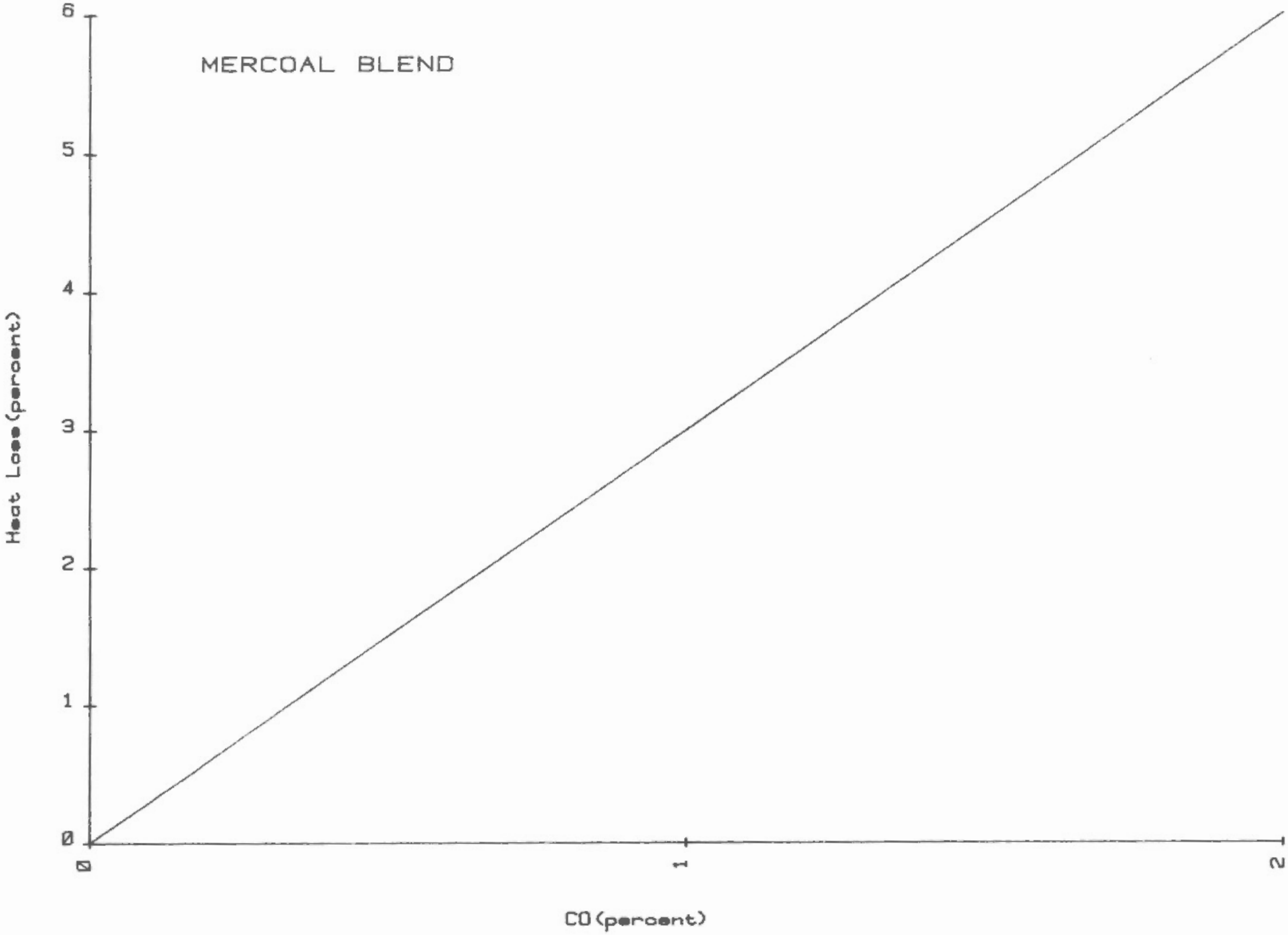


Fig. 6A - Heat loss for a range of CO concentrations, assuming neglible excess air.

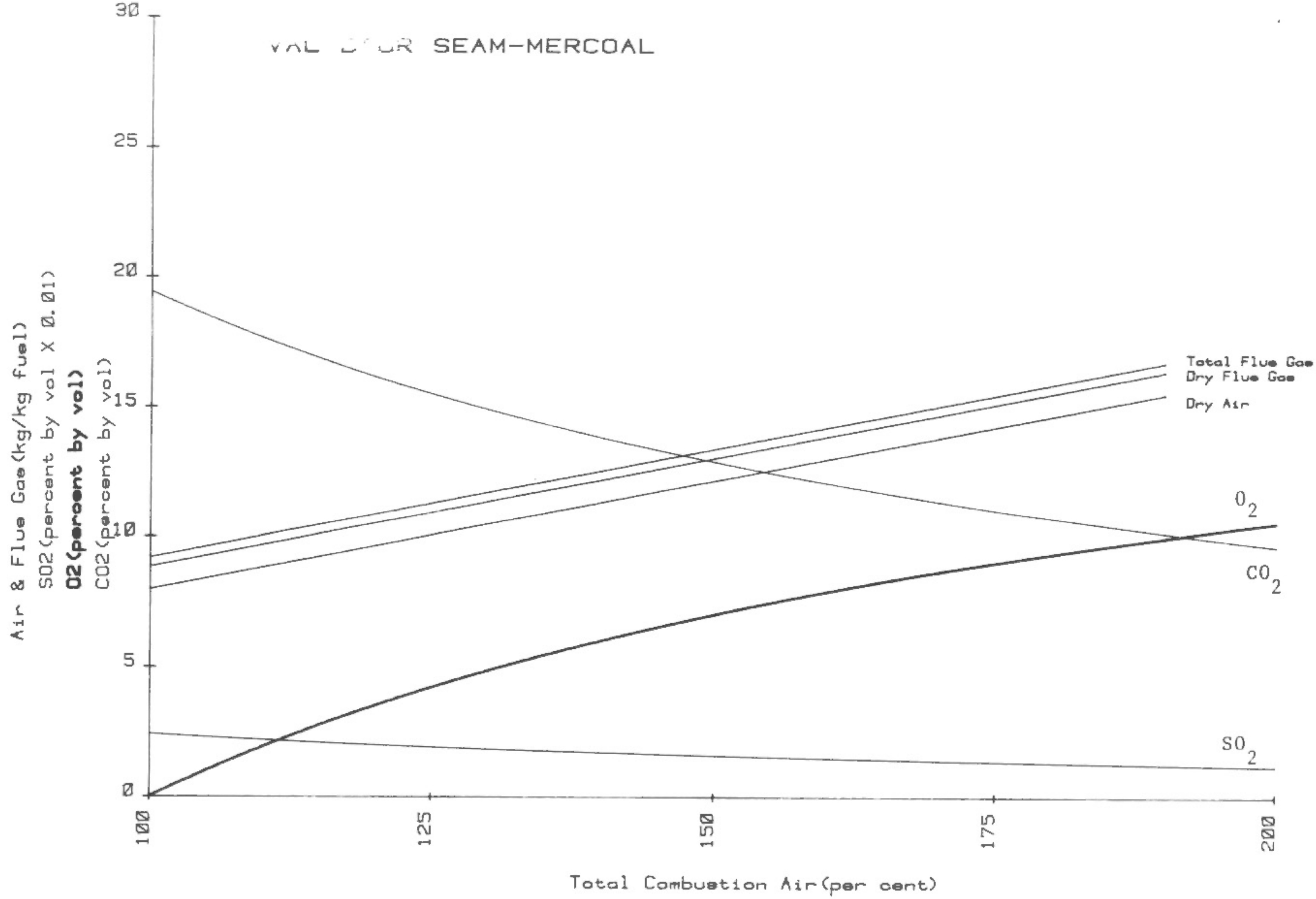


Fig. 7A - Combustion data, eight basis

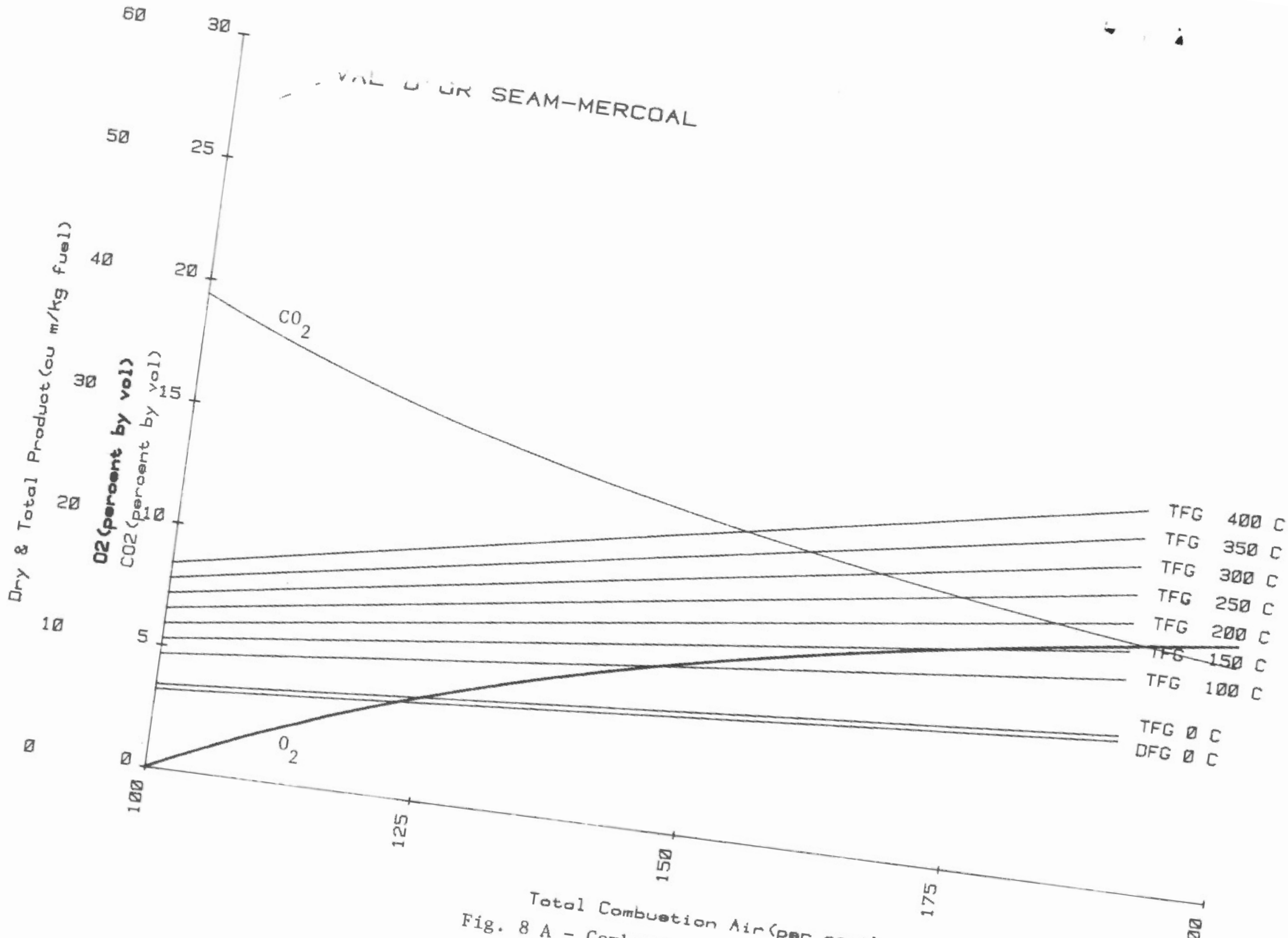


Fig. 8 A - Combustion data, volume basis

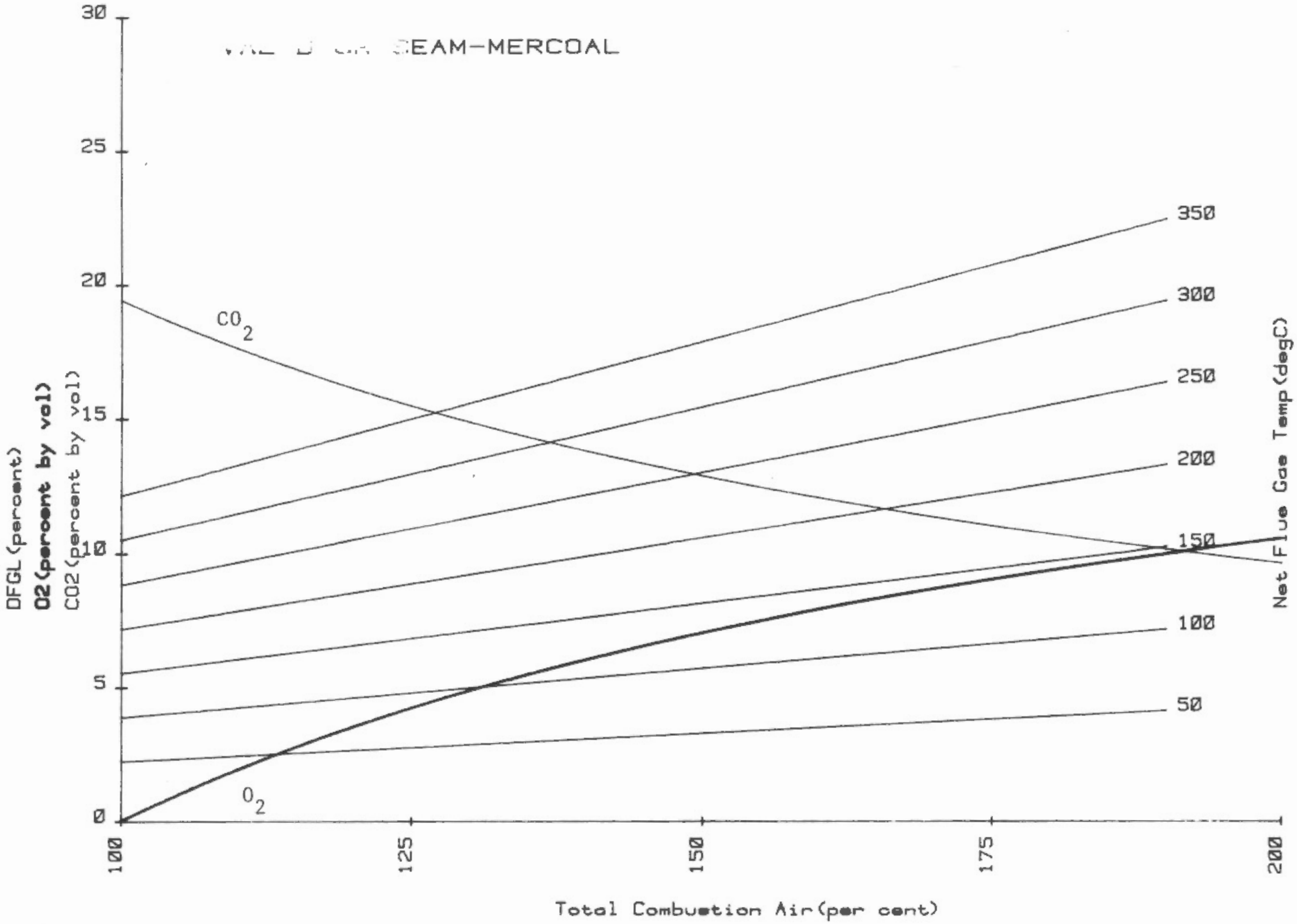


Fig. 9A - Dry flue gas loss for a range of temperature differentials

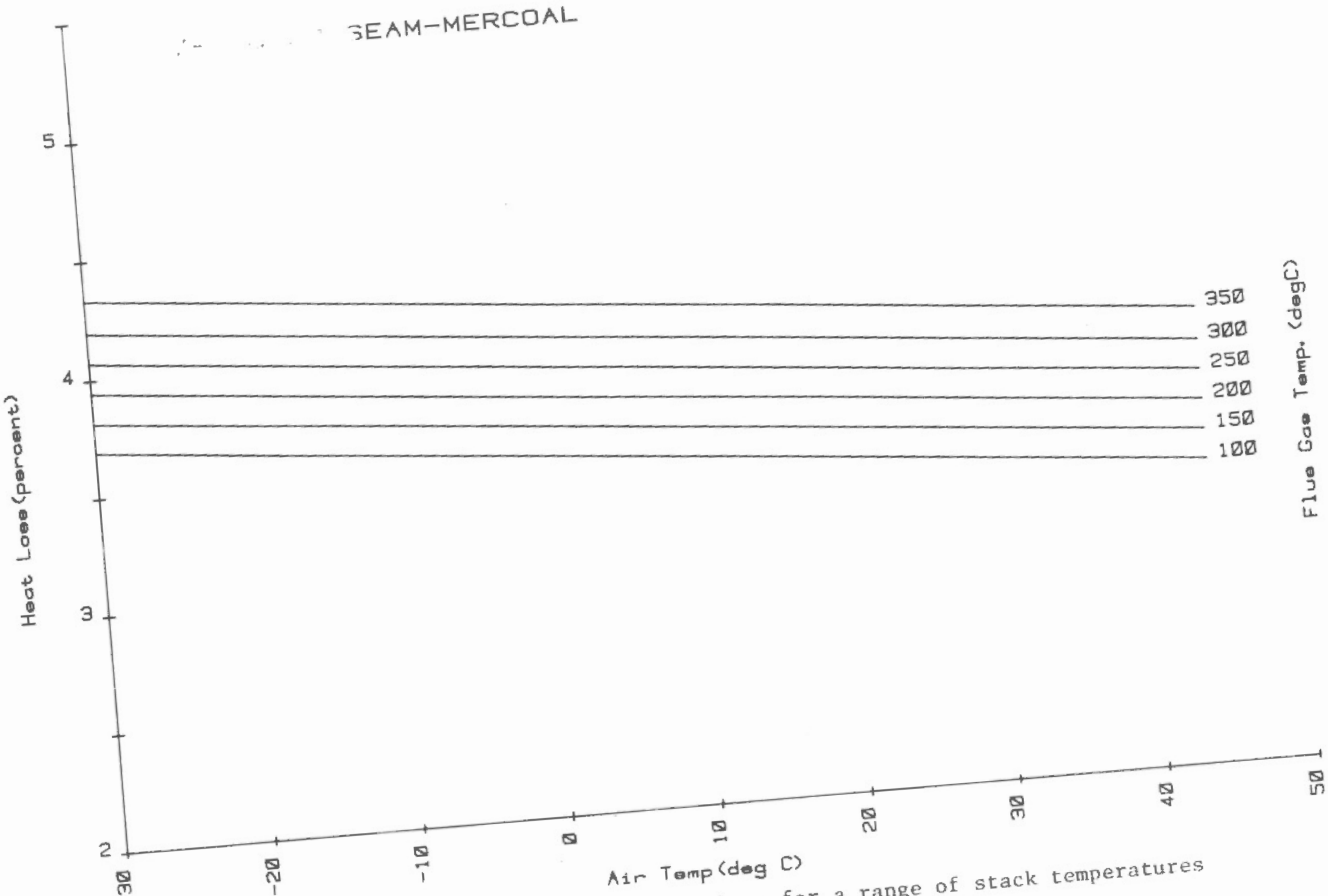


Fig. 10A - Hydrogen loss for a range of stack temperatures

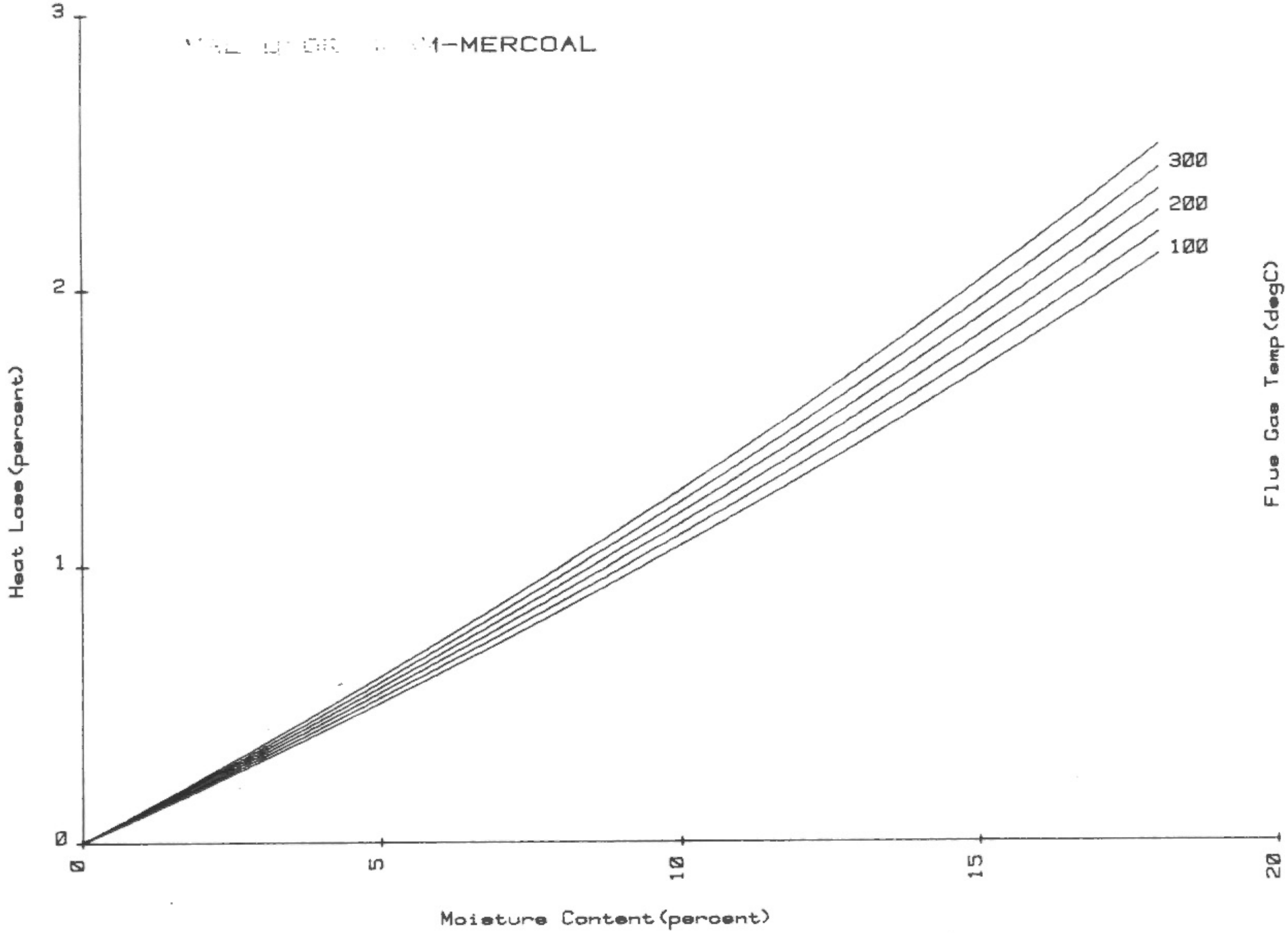


Fig. 11A - Heat loss due to moisture in coal at 20^{o}C.

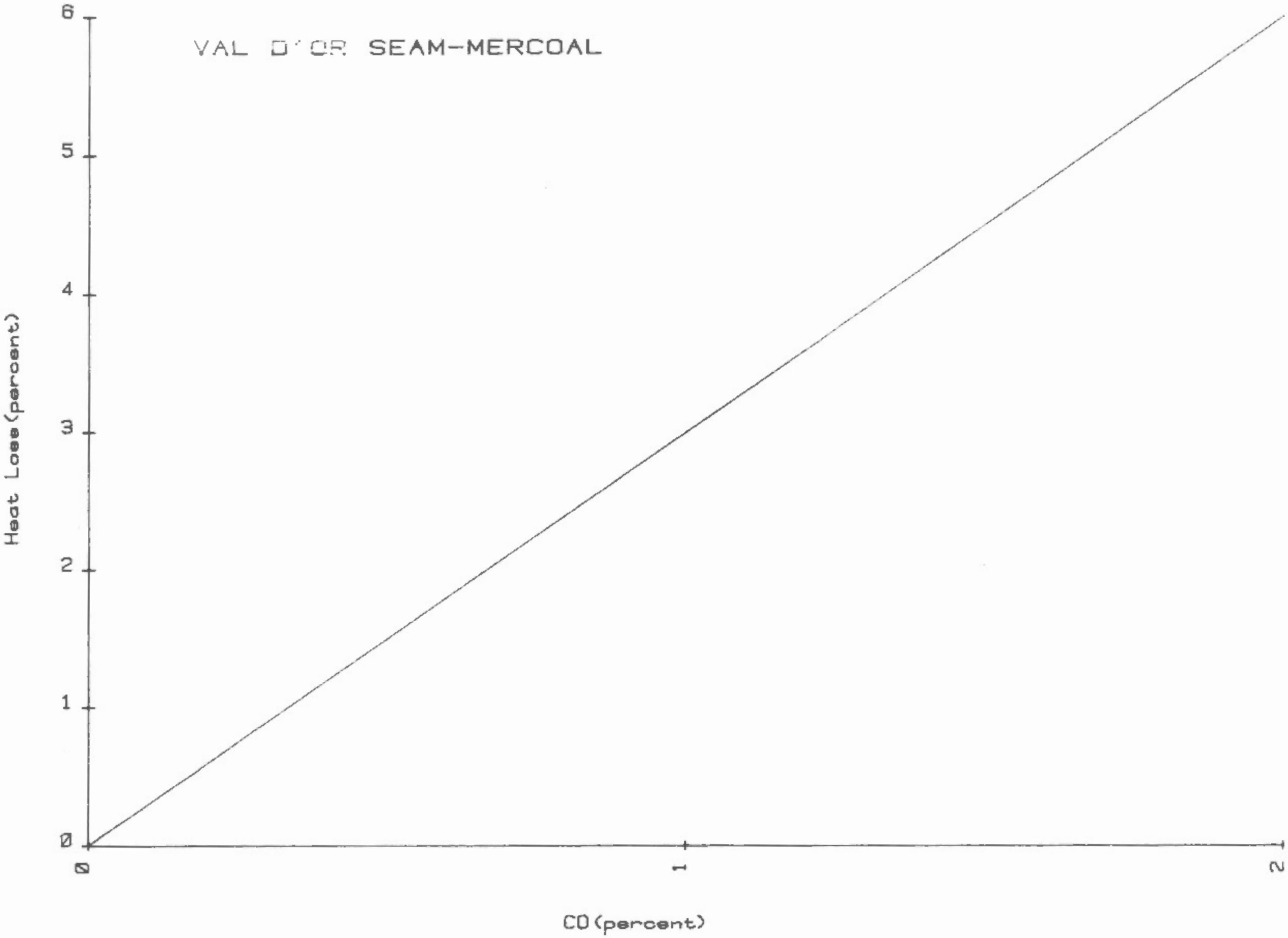


Fig. 12A - Heat loss for a range CO concentrations,
assuming neglible excess air.

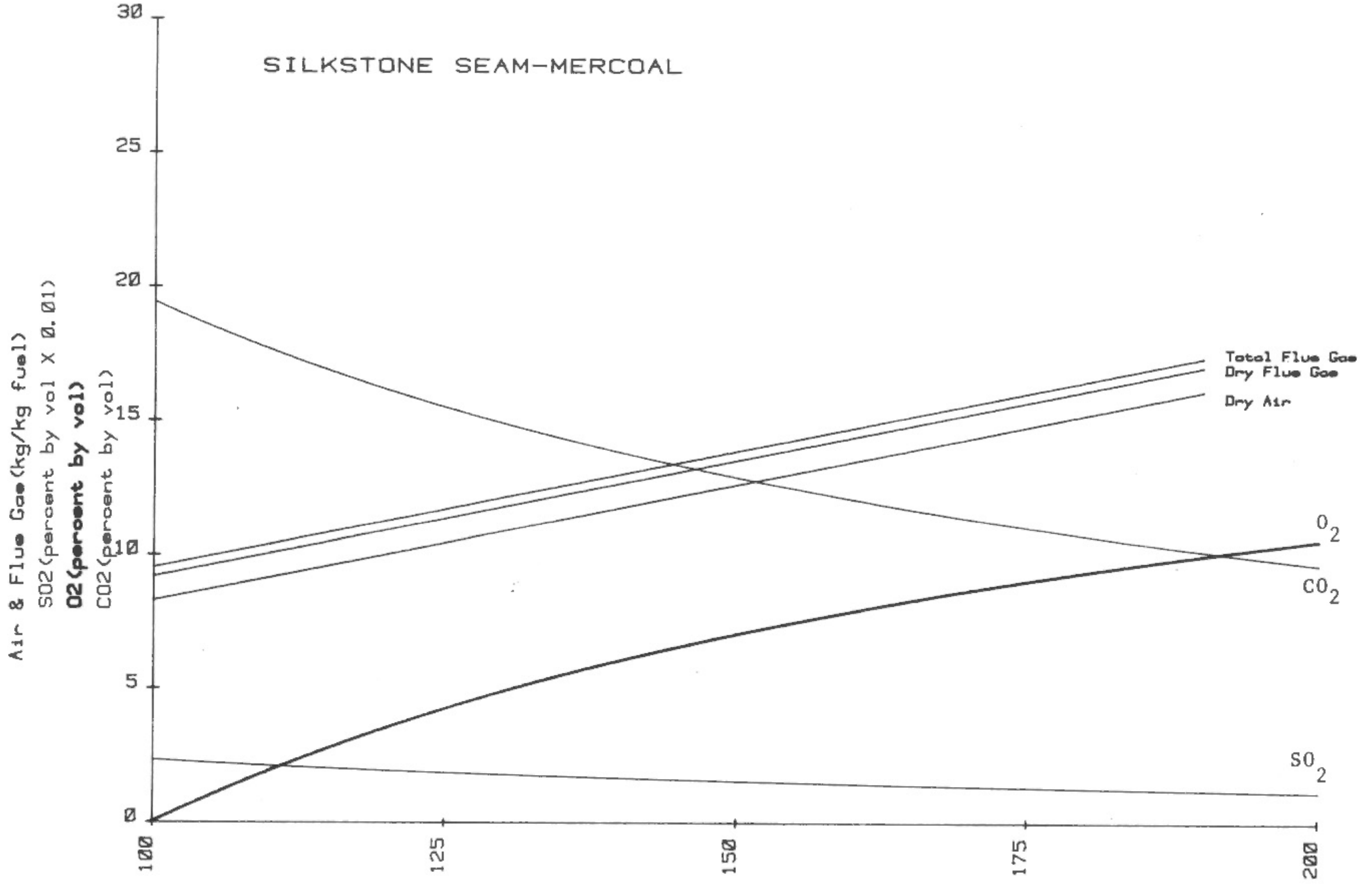


Fig. 13A - Combustion data, eight basis

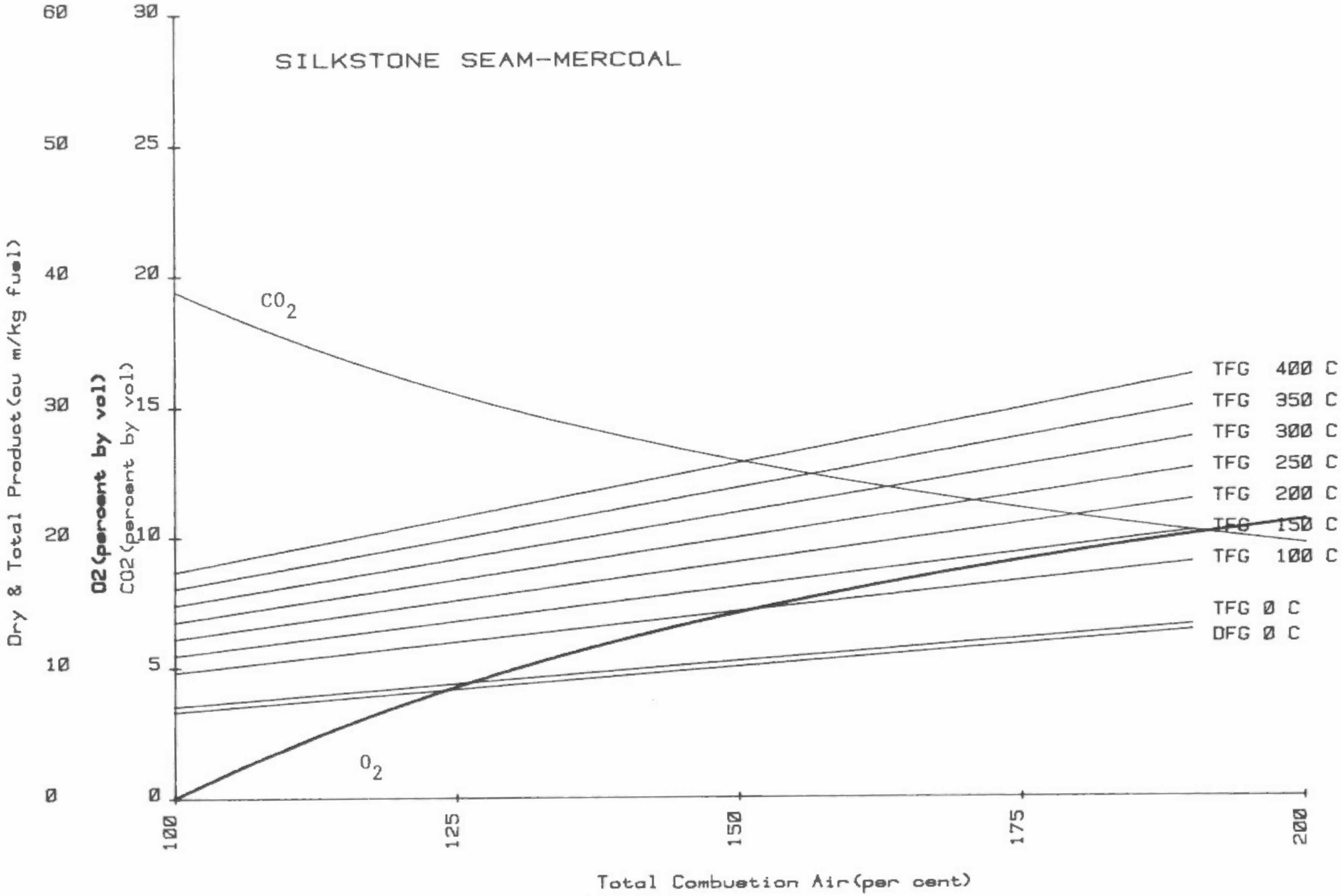


Fig. 14A - Combustion data, volume basis

Fig. 15A - Dry flue gas loss for a range of temperature differentials

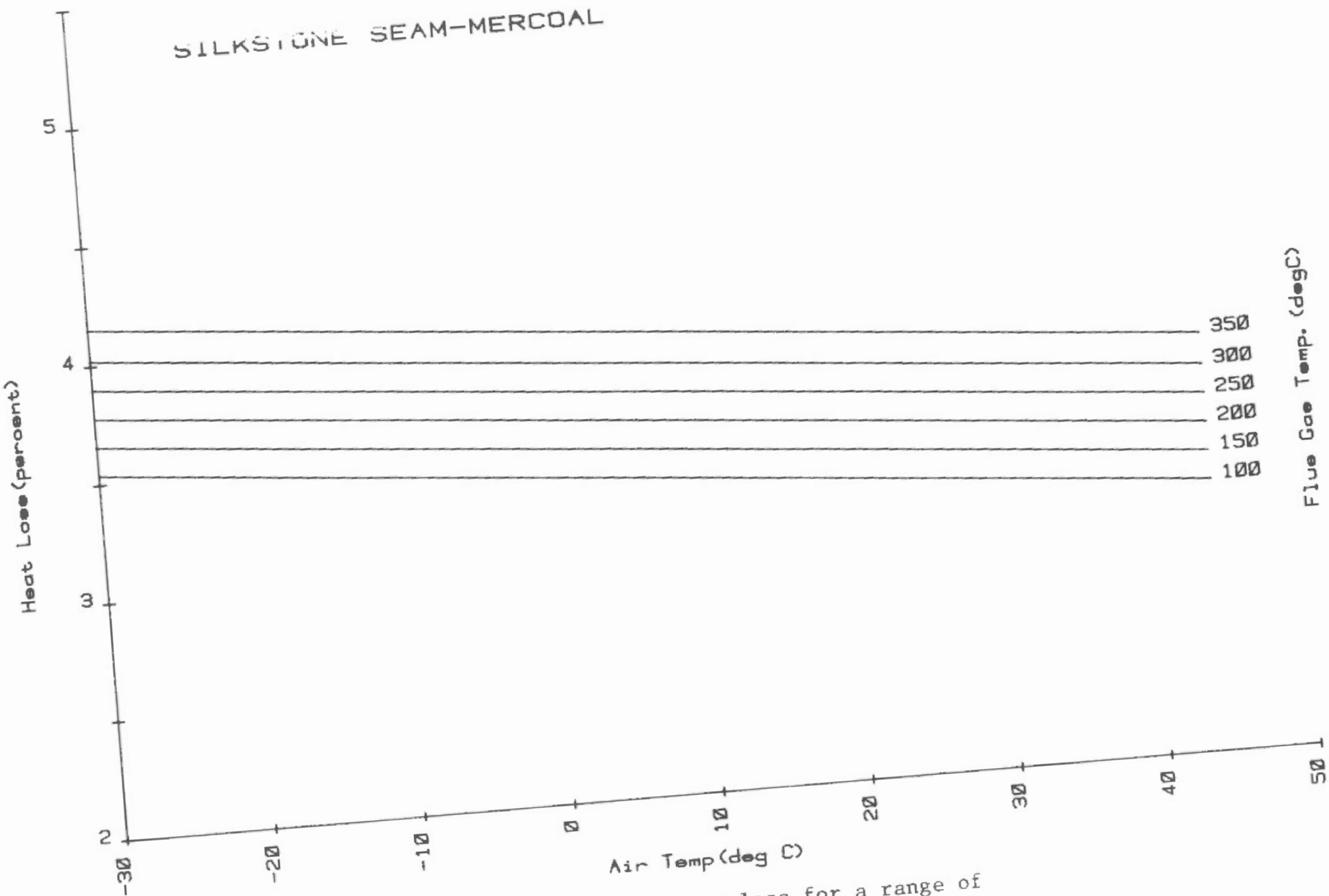


Fig. 16A - Hydrogen loss for a range of stack temperatures

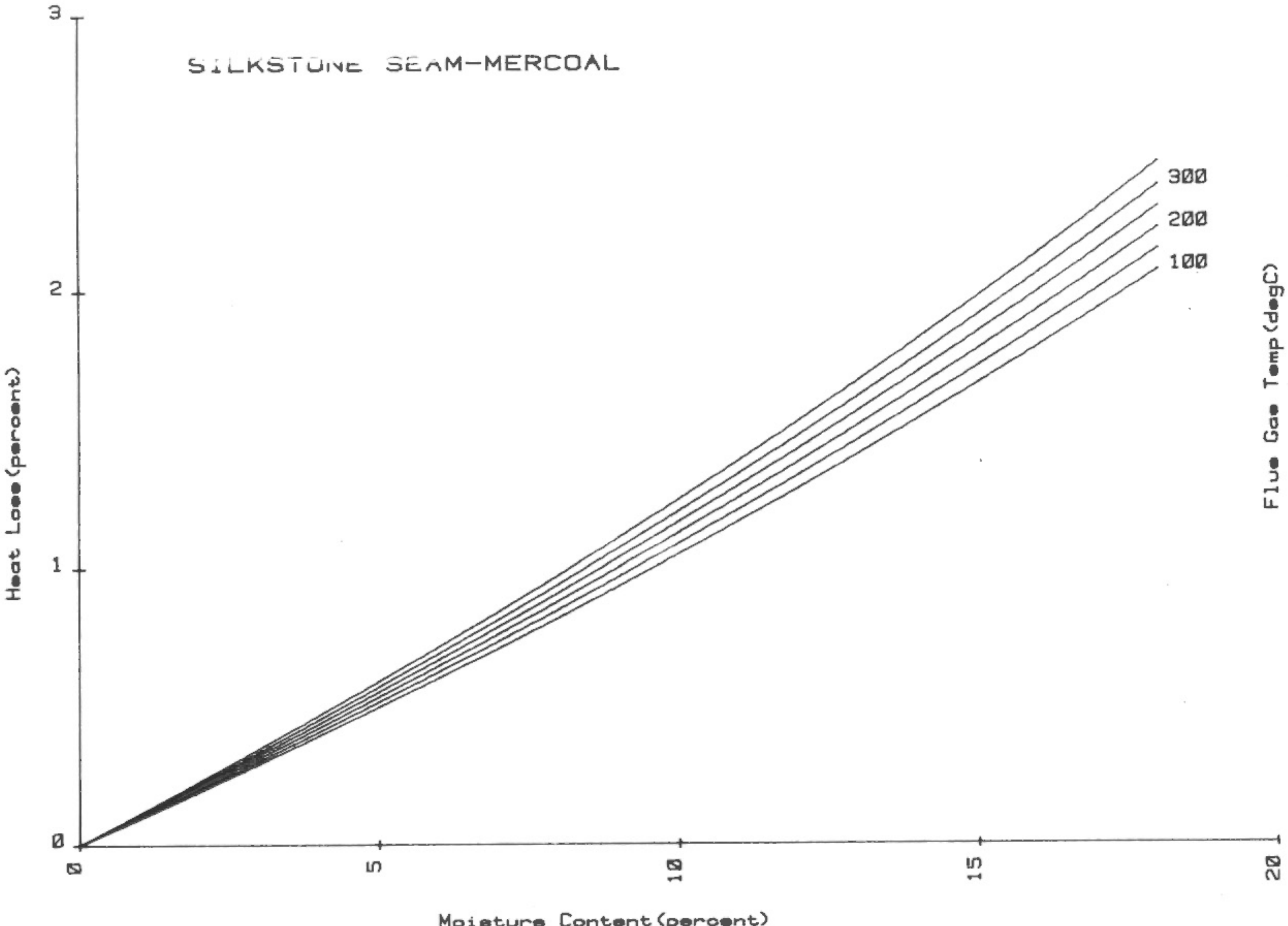


Fig. 17A - Heat loss due to moisture in coal at $20^{o}C$.

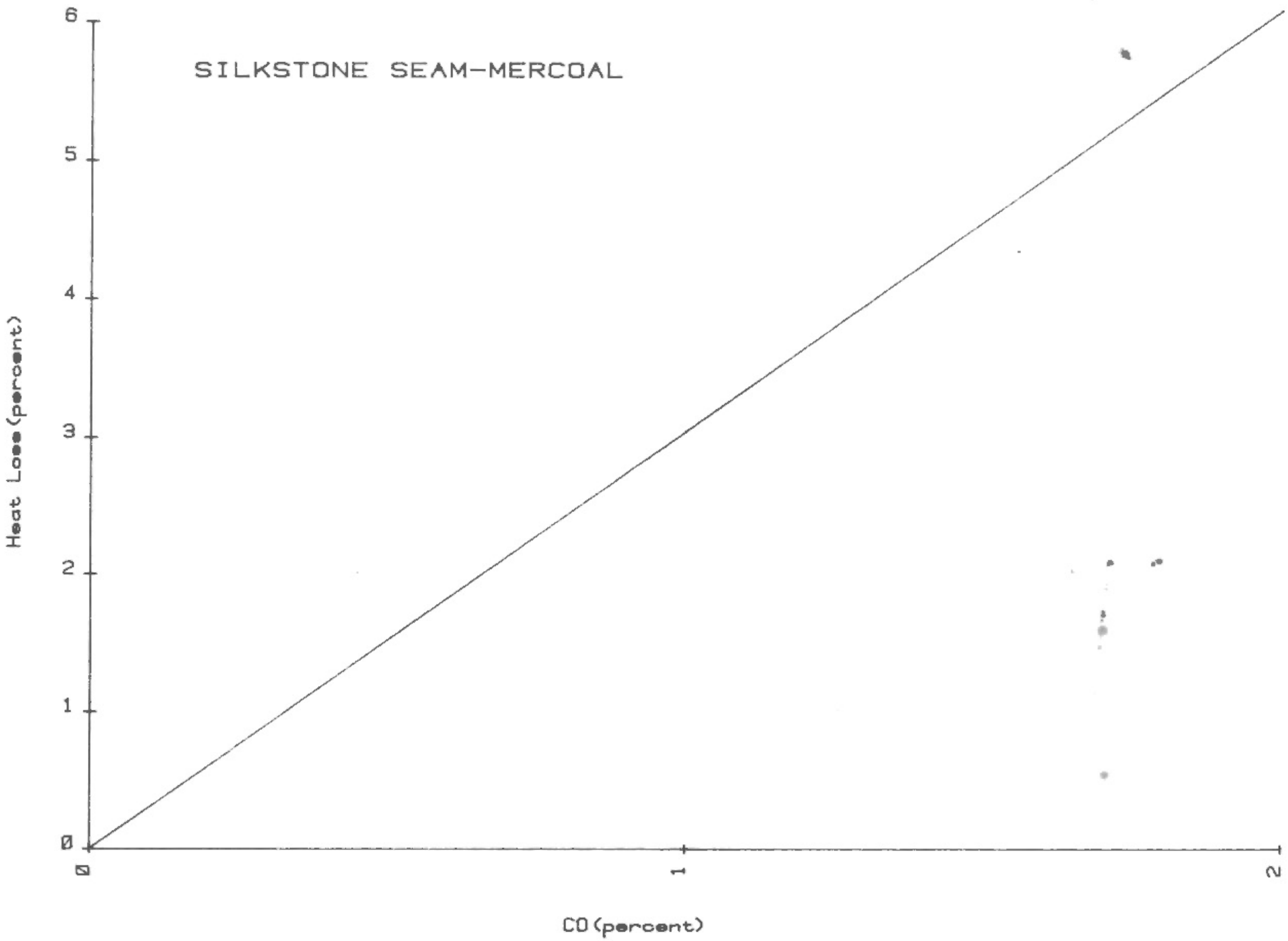


Fig. 18A - Heat loss for a range of CO concentrations, assuming neglible excess air.