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AN ASSESSMENT OF THE ENVIRONMENTAL EMISSIONS FROM A UTILITY BOILER FIRING BENEFICIATED COAL-OIL MIXTURES

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Abstract

A cooperative demonstration project to evaluate the feasibility of burning coal-oil mixtures (COM) in a small utility boiler is described. The project, undertaken by the New Brunswick Electric Power Commission and the Department of Energy Mines and Resources Canada has, as a major objective, an assessment of the environmental impact of COM technology and whether this can be reduced through coal cleaning by spherical agglomeration. It is shown that fly ash emissions can be reduced by as much as 50% and sulphur emissions by 10% using the coal cleaning process. Laboratory tests indicate that this performance can be significantly improved. The paper describes the emissions test program and summarises the emissions of fly ash and sulphur from two years of operation both with and without the agglomeration process.

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Introduction

As the price of crude oil continues to escalate and supply becomes less secure, the direct dependence of the maritime provinces of Canada on imported oil, particularly for electric power generation, has become a matter of national concern. The internal price of oil in Canada is set by the federal government in consultation with the provinces and recent reports indicate that the price of oil will be allowed to rise to near the world level over the next few years. This will certainly encourage the large industrial users to conserve oil and wherever possible convert to coal or natural gas.

As the federal government agency responsible for formulating and implementing energy policy for Canada, the Department of Energy, Mines and Resources has been encouraging the substitution of coal for fuel oil with special emphasis on the four maritime provinces. Coal-oil mixtures are a part of this effort and are being actively supported as a short to medium-term solution to the conversion of oil-fired boilers to partial coal firing where full conversion is not immediately possible. A recent study by the Montreal Engineering Company on behalf of the Canadian Electrical Association (CEA) has shown that five and a quarter million barrels of oil can be saved annually by converting eleven oil-fired utility boilers located in the maritimes to 50% COM (1). These boilers with a total generating capacity of 1865 MW(e) have been identified as having a high enough utilization factor to justify the captial cost of conversion. In western and central Canada there are sufficient alternate means of generation, nuclear, hydro-electric, natural gas or coal fired to ensure that existing oil-fired stations are kept on minimum load and COM's are not as attractive as in the maritimes.

The Canadian COM program falls into two general areas, the demonstration program, and the base R and D support program. At the present time the Canada Centre for Minerals and Energy Technology, CANMET Energy Research Program in collaboration with industry, funds several projects in both these areas, and other projects are indirectly supported by EMR through other funding arrangements. An essential element of the Canadian COM program is the inclusion of coal cleaning during the COM preparation in order to meet environmental objectives when using the high ash and sulphur coals often found in the maritime provinces. It is intended to make the much needed comparisons between the cost of front-end clean-up and the more conventional flue gas cleaning systems such as large dust collectors and flue gas desulphurisation (FGD) devices.

The Chatham COM Project

The major demonstration project for the application of coal oil mixtures to utility boilers has been undertaken by the New Brunswick Electric Power Commission (NBEPC) using a small boiler located at Chatham, New Brunswick.

NBEPC is the largest user of residual fuel oil in the province currently consuming about 8 million barrels of oil a year and as such is interested in the development of methods by which local high sulphur (7%), high ash (20-30%) coals can be used in greater quantities in an environmentally acceptable manner. The combination of coal and oil as a colloidal fuel, represents a promising development combining the major advantages of both fuels. If COM combustion becomes an economically viable means of burning coal in existing oil-fired boilers, improving the coal quality can have a significant influence on the utilization of COM and the environmental impact of the increased use of coal in utility boilers.

The Chatham Thermal Generating Station, Unit No. 1 of 10 MW(e) generating capacity was selected in 1977 for the first phase of this project. Due to its small size and the fact that it is not required to supply to the grid, the unit has the operational flexibility required for the COM study. The boiler is a Foster Wheeler Type "SA" rated at 17.6 kg/s steam flow. It is a dual fired boiler, having the capability for independently firing coal or oil and also of simultaneously burning coal and oil using separate burners.

The program was begun in 1977/78 and employed a cyclone-baghouse combination to separate pulverized coal out of the primary air stream from an existing pulverizer. Afterwards, this coal was mechanically mixed with No. 6 fuel oil in a blender and transported using screw type oil pumps to existing steam-atomized oil burners. Neither the pumps or burners were specifically chosen for handling COM and as a consequence significant wear problems attributable to the abrasive coal ash was encountered. During this phase the COM used was 10 wt % coal.

Modifications were made to the COM preparation system during the 1978/79 second phase of the program to accommodate wet scrubbing and coal-oil agglomeration systems. The purpose of the agglomeration process is to beneficiate the coal by partial ash and sulphur removal with a corresponding reduction in materials erosion and stack fly ash and SO_2 emissions. The wet scrubbing system was used to replace the former cyclone-baghouse combination to facilitate collecting the pulverized coal in water for secondary grinding using a wet mill known as an attritor. This mill produced a coal grind with a mass median diameter of 11 μm which is necessitated by the fine dissemination of the ash impurities throughout the coal used. With this coal fineness the spherical agglomeration process has been shown to be capable of reducing the ash by up to 70% and the sulphur by 50%. A schematic illustration of the COM preparation process employed in Phase II and the ongoing Phase III is shown in figure 1.

During the Phase II tests which are described in this paper, new fuel pumps of the lobe impeller type and two types of burner, a "skew-jet" and a "Y" jet nozzle with replaceable inserts were used.

The coal content of the COM during Phase II operation varied between 10 and 15 wt %. Both of the completed phases of operation at Chatham have been described in more detail elsewhere[2,3].

The Emissions Test Program

The parameters of greatest interest were the suspended particulates and sulphur oxides. In addition to each of these tests the normal flue gas parameters of oxygen, carbon dioxide and carbon monoxide were measured as well as moisture and opacity.

The suspended particulate mass flow and moisture content of the flue gas were determined according to test methods recommended by Environment Canada[4]. Sulphur dioxide emissions were measured using E.P.A. Method 8. For both of these determinations a manual stack sampling train (RAC Model 2343) was used. Continuous oxygen analysis was provided by a Teledyne analyser (Model 320P4) and Orsat analysis provided carbon dioxide and carbon monoxide concentrations. A Lear Siegler portable double pass transmissometer (Model RM 41-P) provided continuous opacity measurement. The measurements of oxygen, carbon dioxide and carbon monoxide concentrations were made at the furnace exit as shown in figure 2. The particulates, sulphur dioxide and opacity measurements were made in the horizontal breeching to the stack as illustrated in figure 3. At this location, the test station was seventeen duct diameters downstream and seven duct diameters upstream of the nearest flow disturbance as required by the Environment Canada test method.

During the emissions tests four combustion modes were utilized and are designated as follows:

Mode 1 - Baseline No. 6 fuel oil, "skew-jet" burner

Mode 2 - Baseline No. 6 fuel oil "Y" jet burner

Mode 3 - COM (about 12 wt %) without fine grinding, "Y" jet burner

Mode 4 - COM (about 12 wt %) with fine grinding, "Y" jet burner

It was not possible to use the "skew-jet" burner on COM because the narrow internal channels of the tip rapidly plugged with coal particles. All tests were conducted at a boiler load of about 10 MW(e) steady state conditions. In practice during Phase II operation the COM composition varied from 10 to 15 wt % coal for the 650 hours of operation on COM but was relatively constant for each emissions monitoring test. In the current Phase III operation 20 to 40 wt % COMs are being evaluated.

The major objectives of the emissions test program were to assess the environmental impact of COM utilization compared to No. 6 fuel oil alone, and to evaluate the potential of the spherical agglomeration process to reduce the environmental emissions of sulphur dioxide and fly ash.

Discussion of Test Results

Boiler conditions were held as steady as possible during the emissions test program. However, it must be noted that comparison between tests is difficult due to:

(1) Variation in fuel composition from 11 to 13 wt % coal COM during the emissions monitoring tests.

(2) Variation in composition of the coal supply during Phase II operation. Coal analyses showed that the sulphur content varied from 6 to 10 wt % and the ash content from 18 to 30 wt %.

Details of the composition and moisture content of the flue gases are summarised in table I. It can be seen that the excess air levels were high corresponding to oxygen levels of between 7.8 and 9.9 vol %. This can be attributed to leakage of air through the boiler casing and around the burners. It should be noted that the unit is quite old and has developed many leaks over the years. The burner ports were originally designed for coal firing and are much larger than those required for oil burners.

The results of the stack emission tests are summarised in table II for three firing modes and for comparative purposes from the 1977/78 Phase I operation when the agglomeration process was not used. It should be noted that although the emitted levels of particulates and sulphur oxides are about the same with and without fine grinding the ash and sulphur input to the system is much higher in the former case.

Particulate Emission Levels

A total of four particulate tests each consisting of three repeat measurements were conducted in the stack breeching (figure 2). These results are shown in tables III and IV. The average particulate emission rates for the No. 6 oil baseline tests were 14 and 20 kg/h for the "skew-jet" and "Y" jet burners respectively. Emissions increased to 69 kg/h when firing COM without fine grinding and to 81 kg/h with fine grinding, however, in the latter case the ash input to the system was almost doubled.

When based on the input ash, the particulate emissions were 48% with fine grinding and 70% without fine grinding. In Phase I when the COM was not beneficiated, the particulate emission rate was 81% of the input ash. In one test shown in table IV the measured emission was slightly higher than the ash input. During this test, combustion conditions and flame stability was poor due to progressive erosion of the burner tip, and the increase was due to unburnt carbon in the fly ash. The opacity readings were higher for COM firing, 24 to 35%, compared to 8 to 15% on baseline No. 6 oil. In New Brunswick the opacity standard is 20% which indicates that COM utilization may require particulate collection equipment.

Sulphur Oxide Emission Levels

A total of five sulphur oxide tests, each consisting of duplicate runs, were conducted at the location in the stack breeching shown in figure 2. The results are shown in table V. The concentration of sulphur trioxide did not vary significantly ranging between 17.4 and 22.2 ppm for both COM and baseline No. 6 oil firing. This was expected since excess air levels remained relatively constant during the sampling periods. However, the concentration of sulphur dioxide was higher for COM firing than for baseline No. 6 oil, due to the higher sulphur content of the fuel even after spherical agglomeration. The emission rates of sulphur oxides on the various firing modes are given in table VI. When firing baseline No. 6 oil the average emission rate was 190 kg/h. On COM firing without the fine grinding the emission rate was 225 kg/h and with fine grinding, 284 kg/h. However, in the latter case the input sulphur had been increased by about one third. As mentioned earlier it is difficult to compare between tests due to variable coal content and composition; however it is clear that the spherical agglomeration process resulted in a modest reduction in SO_2 emission levels when compared on a sulphur input basis, and particularly when compared to the earlier Phase I operation.

As shown in table VI, the total sulphur dioxide emissions were reduced by 10.4% and 5.7%, with and without fine grinding respectively. In the earlier Phase I operation without beneficiated COM, the reduction was only 2.7%. Laboratory tests have indicated that the spherical agglomeration process is capable of removing about half of the input sulphur with this particular coal[5].

Conclusions

The operation of a 10 MW(e) utility boiler on a 10 to 15 wt % COM has shown that:

(1) An in-line oil-agglomeration coal beneficiation process has been shown to be feasible to produce COM for direct supply to the oil burners and to reduce the environmental impact of increased coal utilization using this technology.

(2) It has been shown that coal beneficiation during the formation of COM fuel can reduce fly ash emissions by 50% and sulphur oxide emissions by about 10%. The current phase of operation and laboratory tests have indicated that this performance can be significantly improved, particularly if the coal can be economically reduced in size to less than a mass median diameter of 10 μm.

References

1. Montreal Engineering Company, "Coal-in-oil combustion study", Final report CEA 77-56 prepared for the Canadian Electrical Association; (1977).

2. P. J. Whalen and F. W. Davies, "Coal-oil slurry firing of a utility boiler". Report prepared for Energy, Mines and Resources Canada under Supply and Services Canada, Contract No. 18SQ.23440-7-9033; June (1978).

3. P. J. Whalen, F. W. Davies, L. K. Lee and K. A. Mitchell, "A study of coal agglomeration and coal-oil mixture combustion on a utility boiler". Report prepared for Energy, Mines and Resources Canada under Supply and Services Canada, Contract No. 18SQ.23440-7-9055IV; September (1979).

4. Environment Canada, "Measurement of emissions of particulates from stationary sources". EPS report 1-AP-74-1; (1974).

5. C. E. Capes, private communication; (1980).

List of Figure Captions

Figure 1 Schematic illustration of coal-oil agglomeration process.

Figure 2 Schematic illustration of breeching from Chatham unit 1.

Figure 3 Schematic illustration of air heater on Chatham unit 1.

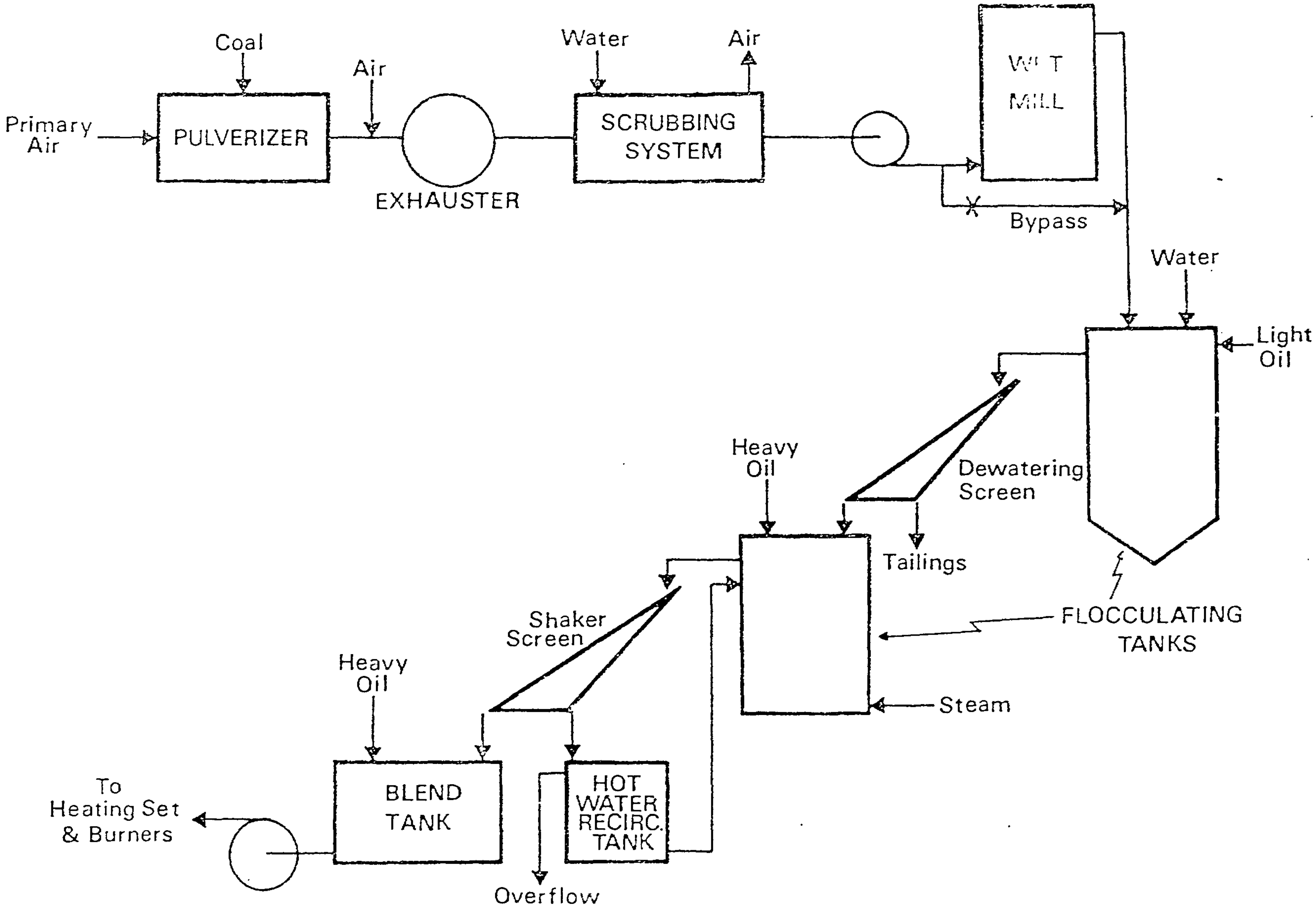

FIGURE 1. Schematic illustration of coal-oil agglomeration process.

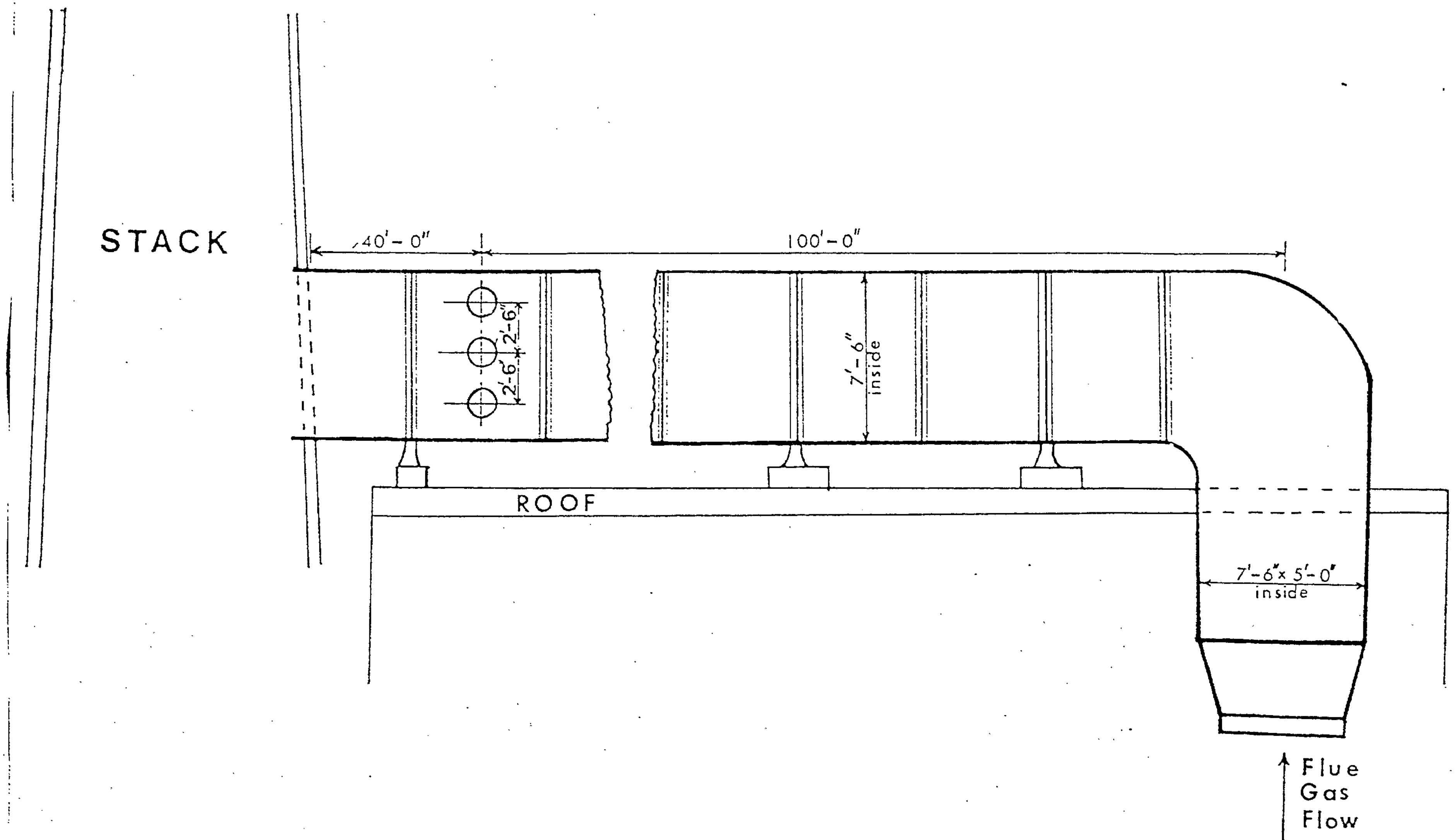

FIGURE 2. Schematic illustration of breeching from Chatham unit 1.

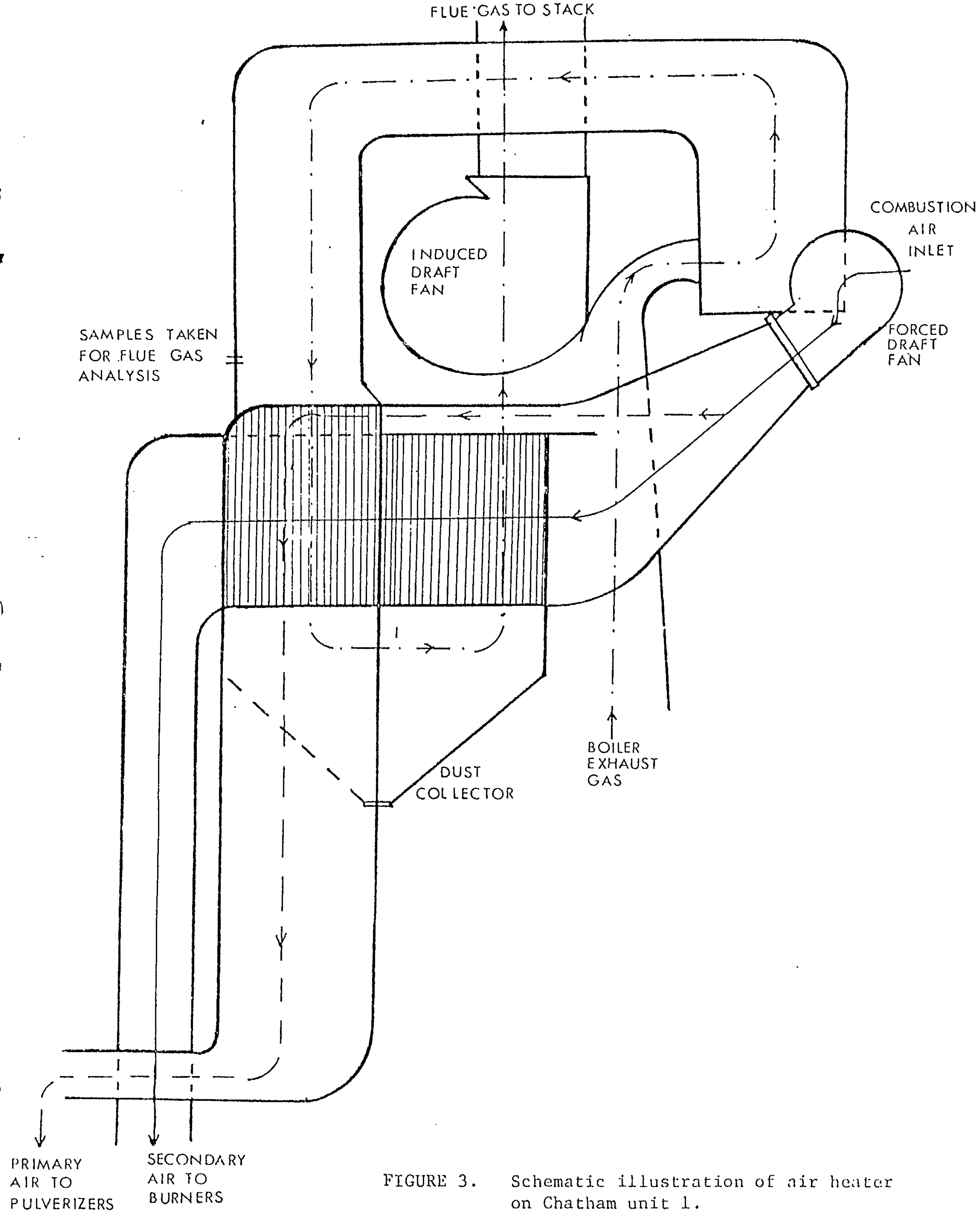

FIGURE 3. Schematic illustration of air heater on Chatham unit 1.

TABLE I. FLUE-GAS AND MOISTURE ANALYSES, PHASE II C.O.M. EMISSIONS TESTS

Firing Mode	Test	Date	Time	O_2 vol%	CO_2 vol%	CO vol%	N_2 vol%	Moisture %
1	1	79/1/31	1900-2015	8.1	10.1	<0.1	81.8	7.5
	2	79/1/31	2050-2205	8.2	10.9	<0.1	80.9	7.2
	3	79/2/1	1050-1205	8.5	9.4	<0.1	82.1	5.6
2	1	79/3/14	1955-2110	7.8	15.6	<0.1	76.6	8.0
	2	79/1/15	1000-1115	7.9	15.5	<0.1	76.6	7.2
	3	79/3/15	1330-1445	9.9	13.4	<0.1	76.7	7.0
3	1	79/3/26	1505-1620	9.0	10.4	<0.1	80.6	7.6
	2	79/3/27	1000-1115	9.0	10.4	<0.1	80.6	7.1
	3	79/3/27	1335-1450	9.0	10.4	<0.1	80.6	6.6
4	1	79/4/11	0130-0245	8.1	11.3	<0.1	80.6	7.6
	2	79/4/11	1400-1515	8.1	11.2	<0.1	80.2	7.0
	3	79/4/11	1615-1730	8.6	11.2	<0.1	80.2	7.1

FIRING MODES - 1: Oil Alone, "Skew-Jet" Burner
2: Oil Alone, "Y" jet Burner
3: Agglomeration Without Attritor, "Y" Jet Burner
4: Agglomeration with Attritor, "Y" Jet Burner.

All values reported on "dry basis".

TABLE II. STACK EMISSIONS DATA SUMMARY, PHASES I AND II

Parameter	Oil Alone Mode 2	COM Firing Mode 3	COM Firing Mode 4	COM Firing Phase I
Excess O_2 (%)	8.3	9.0	8.3	6.0
Excess Air (%) To System (kg/h)	62	73	168	86
Particulate Loading* (g/m^3)	0.20	0.81	0.94	1.0
Total Ash Input To System (kg/h)	NIL	85	168	106
Particulate Emission Rate (kg/h)	19.7	69.3	81	86
kg/gJ	0.12	0.44	0.52	0.54
Total Sulphur Input To System (kg/h)	104	120	159	128
SO_2 Concentration (ppm)	815	960	1200	1100
SO_2 Emission Rate (kg/h)	186	225	284	249
kg/gJ	1.15	1.42	1.80	1.62
SO_3 Concentration (ppm)	22	18	19	3.3
SO_3 Emission (kg/h)	6.4	5.0	5.4	0.9
g/gJ	38.7	34.4	34.4	4.3
Moisture (%)	7.4	7.1	7.2	6.6
Opacity (%)	5-20	20-30	25-35	35-70
Combustible In Fly Ash (%)	82.3	21.3	19.1	12.7

*Particulate loadings are at 21.0°C and 101.3 kPa

TABLE III. SUMMARY OF PARTICULATE TEST RESULTS, PHASE II

Mode No.	Test No.	Fuel Temp (°C)	FLUE GAS PARAMETERS: Average Temp (°C)	Average (m^3/s)	Flowrate* (kg/s)	PARTICULATE: Concentration* (g/m^3)	Emission Rate (kg/h)	Average Opacity (%)
1	1	112	163	23.1	30.0	0.016	14	24
	2	112	163	22.5	29.1	0.150	13	24
	3	112	163	23.8	30.9	0.160	14	26
2	1	106	168	21.5	28.0	0.256	21	7
	2	103	168	22.5	29.2	0.217	19	4
	3	103	168	22.5	29.2	0.221	19	3
3	1	79	168	22.6	29.4	0.630	54	28
	2	79	168	22.7	29.5	1.02	88	30
	3	77	166	23.1	30.0	0.755	66	24
4	1	92	169	22.8	30.2	0.836	72	32
	2	91	166	23.1	30.0	0.869	76	30
	3	89	168	22.9	29.7	1.11	96	35

*Values are reported at 21.0°C 101.3 kPa

TABLE IV. COMPARISON OF PARTICULATE EMISSION RATE FOR C.O.M. FIRING, PHASE II

Test No.	Date	Total Ash Input to System* (kg/h)	Measured Emission Rate (kg/h)	% Emitted
	PHASE I	106	86	81
Without fine grinding Mode 3 (80%<75 μm).				
1	79/3/26	83	54	65
2	79/3/27	86	88	–
3	79/3/27	86	66	77.2
With fine grinding Mode 4 (80%<20 μm)				
1	79/4/11	168	72	42.3
2	79/4/11	168	76	44.7
3	79/4/11	168	96	56.4

* Before agglomeration

TABLE V. SUMMARY OF SULPHUR OXIDE CONCENTRATIONS IN FLUE GAS, PHASE II

Firing Mode	Test No.	Date	Average Gas Flowrate (m^3/s)	SULPHUR OXIDES CONCENTRATION			
				SO_2 (g/m^3)	SO_3 (mg/m^3)	SO_2 (ppm)	SO_3 (ppm)
1	1	79/2/1	23.1	2.37	-	821	-
1	2	79/2/1		2.31	-	808	-
2	1	79/3/14	22.2	2.27	76.6	796	21.4
2	2	79/3/14		2.47	79.4	862	22.2
2	3	79/4/3		2.29	-	801	-
2	4	79/4/3		2.29	-	799	-
3	1	79/3/27	22.8	2.71	62.1	948	17.4
3	2	79/3/27		2.77	63.8	965	17.8
4	1	79/4/10	22.9	3.43	61.5	1199	17.2
4	2	79/4/10		3.44	72.2	1205	20.2

Gas volume is calculated at 21.0°C and 101.3 kPa

TABLE VI. COMPARISON OF SULPHUR OXIDE EMISSIONS FOR No. 6 OIL AND C.O.M. FIRING, PHASE II

Firing Mode	Total Sulphur Input to System (kg/h)	Measured SO_2 Emission Rate (kg/h)	Sulphur Emitted as SO_2 (%)
1	99	194	98.4
2	105	186	89.1
3	120	225	94.3
4	159	284	89.6
PHASE I	128	249	97.3

$$\%\ \text{Sulphur emitted} = \left(\frac{SO_2\ \text{Emission rate}}{2 \times \text{Input S}}\right) \times 100$$