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THE UTILIZATION OF CRUDE BITUMEN AS A BOILER FUEL

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MAY 1984

For presentation to and publication by the Engineering Foundation Conference on "Combustion of Tomorrows Fuels II, Davos Switzerland, October 21-26, 1984

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
DIVISION REPORT ERP/ERL 84-40(OPJ)

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ABSTRACT

The handling, combustion, heat transfer and emission characteristics of a crude bitumen were studied in a flame research furnace. The bitumen, which was recovered from an underground reservoir by steam injection, was contaminated with water and fine solids. It was found that bitumen, containing up to 26% water and 4.3% ash, could be successfully burned using commercial equipment designed for No. 6 fuel oil. In addition, the axial heat flux distribution and the flue gas emissions generated by the crude bitumen were comparable to No. 6 oil.

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UTILISATION DU BITUME BRUT POUR ALIMENTER LES CHAUDIÈRES

par

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

RÉSUMÉ

On a étudié la manutention, la combustion, le transfert de chaleur et les caractéristiques d'émission des gaz du bitume brut au moyen d'un four à combustion expérimental. Le bitume récupéré d'un réservoir souterrain par injection de vapeur d'eau était souillé par l'eau et des matières fines. On a découvert que l'on pouvait réussir à brûler du bitume contenant jusqu'à 26% d'eau et 4,3% de cendre en utilisant une installation commerciale conçue pour la combustion de l'huile n° 6. En outre, les résultats concernant la distribution axiale du débit de chaleur et les émissions de gaz de combustion produites par le bitume étaient comparables aux résultats obtenus avec de l'huile n° 6.

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INTRODUCTION

The supply of boiler fuel to field installations for in situ recovery of heavy oil or bitumen by down-hole steam injection often poses severe logistic problems, particularly in remote areas. It was for this reason that a combustion research project was undertaken to assess the technical feasibility of using recovered, contaminated, crude bitumen as a fuel for a pilot-scale in situ extraction plant at a location in Western Canada that could not be readily serviced with conventional fuel.

This paper describes the facilities and procedures used, and gives an evaluation of the experimental results.

EXPERIMENTAL OBJECTIVES

The objectives of the research project were:

1. to demonstrate whether the "as recovered" bitumen contaminated with water, sand, carbonates and other impurities, could be used as an alternative fuel to natural gas in an in situ extraction process using ambient air for combustion;
2. to determine whether it is necessary to reduce the 33% water content of the "as recovered" bitumen prior to burning;
3. to compare the combustion and heat transfer characteristics of the emulsified bitumen with No. 6 oil as a reference fuel;
4. to compare the relative effectiveness of air and steam as atomizing media;
5. to assess the gaseous and particulate emissions produced during combustion.

FUEL PROPERTIES

The analyses of the raw bitumen and the No. 6 residual oil used as a reference fuel are shown in Table 1. The bitumen, which is usually recovered with 33 vol % moisture, was supplied in three lots containing 26 vol %, 18 vol % and nominally zero moisture respectively. Table 1 shows that the fuel on a dry basis contained 5.25% sulphur and 4.27% ash and had a slightly lower heat content than No. 6 fuel oil. The composition of the major ash elements by neutron activation analyses is shown in Table 2. In addition the sediment was found to contain 22% quartz, 62% dolomite, 12% kaolinite, 4% illite and traces of feldspar and anhydrite.

Hot stage microscopic examination revealed that the dispersed water in the bitumen coalesced into progressively larger droplets as the temperature was gradually increased from 20°C to 90°C. This indicated that atomization could deteriorate above a critical preheat temperature. Freezing the bitumen/water dispersions resulted in the water droplets coalescing into larger ice crystals, but reheating the sub-zero bitumen to 25°C produced water which could be readily redispersed.

DESCRIPTION OF COMBUSTION FACILITIES

CCRL TUNNEL FURNACE

The experimental program was carried out in the CCRL tunnel furnace, illustrated in Fig. 1.

The tunnel furnace, which has a maximum thermal input of 2 GJ/h, consists of a 1 m refractory lined pre-combustion chamber and 28 parallel-connected calorimeters which form a cylindrical combustion chamber 1 metre in diameter and 5.25 m long. Each colorimeter is part of a coolant circuit containing a flow control valve, and a variable area flow meter with inlet and outlet thermocouples. An axial slot located along the furnace length permits the use of combustion probes to measure flame properties. The tunnel furnace has been described in detail elsewhere (1).

DUAL-FLUID ATOMIZING TIP EMULSION BURNER

A schematic illustration of the emulsion burner is shown in Fig. 2. The burner, which operated at air atomizing pressures of 69 to 207 kPa and provided the full heat input to the furnace (2 GJ/h or 45 L/h of bitumen), was designed for use with heavy fuel oils such as Bunker C. In the case of bitumen the fuel temperature was maintained above 120°C in order to give adequate atomization and good flame stability. A comparative test using steam as the atomization medium, at a pressure of 570 kPa and 155°C, was also conducted.

FUEL SUPPLY SYSTEM

The fuel supply system, illustrated in Fig. 3, was located near the burner to facilitate purging the supply lines with No. 2 fuel oil after each test and to minimize both heat losses and pump energy requirements. The fuel supply system consisted of a 2000-L heated blending tank and a 600-L heated day tank, each mounted on electronic weigh scales. Both tanks were heated and equipped with a return loop from a controlled pressure surge tank which would operate in the event of a line blockage.

EXPERIMENTAL PROCEDURES

INDEPENDENT PARAMETERS

The following parameters were fixed for all tests on emulsified bitumen and on No. 6 fuel oil.

1. Thermal input - 1.7 GJ/h
2. Excess oxygen - 3 vol %
3. Combustion air temperature - ambient, except for steam atomized flame studies
4. Burner fuel temperature - 125°C

OPERATING VARIABLES

The following parameters or operating conditions were varied in order to compare the particular flame studied:

1. Fuel pressure and temperature
2. Atomizing medium, flow and pressure
3. Emulsion moisture content

MEASURED VARIABLES

The following parameters were measured for each test:

1. Total heat absorption in each furnace cooling circuit, (0 to 5 m).
2. Incident radiative heat flux by ellipsoidal radiometer, (0.5 and 3 m locations).
3. Incident total heat flux by heat flux probe, (0.5 and 3 m locations).
4. Radial flame temperature profiles by suction pyrometer (1.0 and 2.2 m locations).
5. Furnace exit gas temperature and composition, including particulate emissions.

FURNACE OPERATING PROCEDURES

The tunnel furnace was preheated for about 3 h with No. 2 fuel oil, prior to switching to emulsified bitumen or No. 6 fuel oil. Flame measurements were initiated when a series of thermocouples located along the inside of the furnace reached steady state temperatures, usually after 3 to 4 h.

At the end of each test, the fuel supply line was flushed with No. 2 fuel oil.

BURNER TIP WEAR

Examination of the burner tip before and after the combustion tests revealed some wear due to the sand in the fuel, as shown in Fig. 4. Although the burner tip wear did not cause the combustion performance to deteriorate noticeably during the short test period, an externally-atomized burner would appear to be more suitable for long-term use with sand-contaminated bitumen.

FUEL MOISTURE CONTENT

Evidence in the literature on the role of moisture in improving the combustion performance and in reducing the levels of emitted and deposited particulate material is contradictory. Some improved boiler performance has been reported by Hall (2), but Dooher (3), Whaley (4), Livingstone (5) and Cook (6) have all shown that combustion and environmental benefits may range from marginal in some combustion equipment to a measurable improvement in others.

DISCUSSION OF RESULTS

OBSERVATIONS

During operation with both No. 6 fuel oil and bitumen, the flames which were about 1 m long and 0.2 to 0.5 m in diameter, were bright and stable. In general, bitumen temperatures below 120°C, caused the flame to migrate downwards resulting in fuel impingement on the furnace wall with sporadic surface ignition. When operating with steam atomization a marked increase in sparklers (large droplets) was observed, especially with steam pressures in excess of saturation. In the case of air atomization, pressures above 172 kPa caused flame lift-off. The following technical criteria were found to be essential for reliable furnace operation:

a) Emulsion temperatures in the day tank and fuel lines must be maintained above 85°C for satisfactory pumping. All fuel lines require provision for flushing with a distillate fuel oil.

b) The emulsion supply system required a coarse filter before the day tank and a fine filter before the pump to remove grit and sand, and an indicator to give advance warning of filter plugging.

c) In-line heaters should use either low power density or steam to prevent coking of the heating elements and a subsequent deterioration in heat capacity.

d) Stable flames with good combustion required a minimum fuel temperature of 120°C.

e) With steam atomization, a maximum fuel temperature at the burner corresponding to 10°C below the saturation temperature prevented flashing of water to steam at the burner tip and eliminated flame instability and sputtering.

f) Good flame stability was obtained by using a refractory quarl or a continuous pilot-flame.

INFLUENCE OF MOISTURE LEVEL ON HEAT TRANSFER AND FLAME TEMPERATURE

The flame temperature profiles across the furnace at the 1.0 and 2.2 m locations downstream of the burner tip in Fig. 5, show that the high moisture bitumen flames produced higher flame temperatures at the 1.0 m location than did No. 6 fuel oil.

Measured total heat flux and radiative heat flux for all fuels decreased linearly with distance from the burner (Fig. 6). The radiative component, which was from 20 to 25% of the total heat flux, was typical of No. 6 fuel oil flames in pilot-scale equipment. Figure 7 shows the axial variation in heat absorption for all tests. When compared with Figure 6, it can be seen that only about half of the incident heat flux is actually obsorbed by the furnace.

Figure 8 shows the integrated total heat absorption for the furnace normalized with respect to the No. 6 fuel oil baseline for different fuel moisture contents. A plot of the normalized furnace efficiency (ASME indirect heat loss method PTC38) yields a similar trend because both data sets are a measure of furnace heat extraction. Previous work (6) indicated that peak efficiencies occurred at a critical moisture content. In this evaluation, however, heat absorption peaked at bitumen moisture levels from 10 to 20%, but the small variance relative to No. 6 oil fell within the experimental measurement error of ±2%. The significant deterioration in heat-transfer performance at high and low moisture content, compared with the baseline fuel oil, is evident in Figure 10. Calculations show that a 1% loss in efficiency occurred for each 10% increase in fuel moisture content.

INFLUENCE OF MOISTURE LEVEL ON PARTICULATE AND GAS CONCENTRATIONS AND EMISSION RATES

Figure 9 illustrates the CO_2 and O_2 profile measured across the flame at the 1.0 m location. It can be seen that the majority of the profiles show the usual O_2 deflection on the flame axis, particularly with the highest moisture-content bitumen flame. No variation occurred with the steam-atomized flame, indicating that the rapid fuel/air mixing in such flames is due to improved atomization. Figure 10 illustrates the variations in emissions of SO_2 and NO with fuel moisture content and Figure 11 shows that the particulate matter emission increased with fuel moisture content. Other oil emulsion combustion evaluations (4,6) have showed either no change or a reduction in solids emissions with increased moisture content. SO_2 emissions decreased linearly with fuel moisture content, due to the increased mass throughput at constant thermal input.

Although NO variation was slight from 0 to 20 wt % moisture, the highest level coincided with the peak heat transfer absorption and the maximum flame temperature. The uncontrolled SO_2 emissions, which were about 2 kg/GJ, were well in excess of the federal guideline of 0.258 kg/GJ, indicating that a sulphur capture system would be necessary for this fuel. NO emissions of about 0.1 kg/GJ marginally exceeded the federal guideline of 0.084 kg/GJ for new oil-fired boiler plant and could easily be reduced by appropriate combustion equipment design. The emissions of particulate matter were high relative to No. 6 fuel oil and would exceed the federal guideline of 0.043 kg/GJ for new oil-fired boiler plant.

CONCLUSIONS

Combustion tests conducted on emulsified raw bitumen, containing up to 26 wt % moisture, have demonstrated that:

1. The heavy bitumen emulsion obtained from an in situ extraction process was successfully burned with either air or steam atomization with fuel preheat temperatures at 120°C or above.
2. Fuel pumping was satisfactory, provided the temperature in the day tanks and fuel lines are kept above 85°C.
3. Minimal wear of the dual-fluid atomizing tip burner occurred during 20 h of operation. However, long-term atomizer trials are recommended before proceeding with a demonstration project to burn emulsified raw bitumen.
4. Fuel temperatures above 120°C produced satisfactory atomization with air and steam. However, with steam atomization a maximum fuel temperature corresponding to 10°C below the saturation temperature was required to prevent flame instability.

4. The combustion and heat transfer performance of the raw bitumen is similar to No. 6 fuel oil, for moisture contents from 10 to 20 wt %. Outside this range the performance of the raw bitumen deteriorated rapidly. Relative to air atomization, steam atomization with low moisture bitumen had only a slight effect on heat transfer rates.
5. Emissions of SO_2 and particulates were significantly above North American guidelines for new sources and would both require abatement technology. NO emissions, which marginally exceeded the guidelines, can be reduced by appropriate combustion equipment design.

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Table 1 - Fuel analyses (dry basis)

Fuel	No. 6 oil	Bitumen
Specific Gravity, (15.6/15.6°C)	0.99	1.06
Calorific Value, MJ/kg	42.9	40.1
Flash Point, °C	107	-
Kinematic Viscosity, cSt		
at 50°C	650	-
at 99°C	47	-
C wt %	87.6	81.5
H wt %	10.4	9.7
S wt %	1.5	5.2
N wt %	0.4	0.4
O wt %	0.1	0.1
Ash wt %	0.1	4.2

Table 2 - Elemental ash composition of bitumen sample

Major elements, % dry fuel basis*

Cu	0.02	Ni	0.01
Al	0.21	V	0.02
Ca	1.08	K	0.02
Fe	0.08	Na	0.06
Mg	0.63	Ti	0.02
Cl**	0.04 (aqueous component)	Si	0.45

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* Neutron Activation Analysis

** Wet Chemistry

Table 3 - Furnace operating conditions

Test	1	2	3	4	5
Parameters	(Baseline)				
Fuel	No. 6 oil	Bitumen			
Tank outlet temp, °C	68	92	93	98	106
Burner temp, °C	125	124	124	124	123
Pressure, kPa	441	655	392	448	427
Moisture in fuel, wt %[1]	0.1	26.0	18.0	0.2	0.2
Thermal input, GJ/h	1.67	1.67	1.65	1.67	1.70
Fuel input, kg/h (wet)	39.0	56.5	50.3	41.7	42.6
Input water-oil ratio	0.001	0.36	0.22	0.0002	0.19
Atomizing Medium	Air				Saturated Steam
Temperature, °C	32	36	35	33	155
Pressure, kPa	241	241	255	248	571
Flowrate, kg/h	10.5	8.2	10.5	10.9	8.2
Secondary Air					
Temperature, °C	26	26	26	26	158
Flowrate, kg/h	584	611	591	625	598
Exit furnace temp., °C	620	620	630	650	615
Exit furnace press., Pa					

[1] Xylene distillation, ASTM D95-70

Table 4 - Furnace emission and heat transfer parameters

Test	1	2	3	4	5
Parameters	(Baseline)				
Fuel Gas Analysis					
O_2, vol %	2.9	2.8	2.7	2.9	2.7
CO_2, vol %	13.7	13.9	13.8	13.7	13.7
CO, vol ppm	100	200	170	180	160
NO, vol ppm	280	270	310	240	310
SO_3, vol ppm	1.0	2.0	3.0	13.0	6.0
SO_2, vol ppm	775	2400	2450	2500	2500
H_2S, vol ppm	100-125	100	100	100	100
CH_4 equiv., vol ppm	100	100	100	100	100
Soot in particulate, wt %	0.1	0.1	0.8	8	7
Particulate load, g/Nm^3	0.18	1.28	1.19	0.48	0.62
Particulate emission, Kg/GJ	0.05	0.38	0.35	0.14	0.18
NO emission, kg/GJ	0.10	0.10	0.12	0.09	0.12
SO_2 emission, kg/GJ	0.60	1.89	1.93	1.98	1.98
Moisture, loss, % [1]	0.08	2.17	1.51	0.02	1.26
Combustion efficiency, %	99.0	99.9	99.9	99.7	99.7
Normalized furnace efficiency [2]	1.0	0.97	1.00	0.98	0.99
Normalized heat absorption [2]	1.0	0.97	1.01	0.94	0.92
Flame length, m	1-1.5	1.5-2	1.5	1-1.5	1.0
Flame diameter, m	0.3-0.5	0.3-0.5	0.2-0.3	0.2-0.3	0.2

[1] ASME PTC 38

[2] Normalized to No. 6 oil

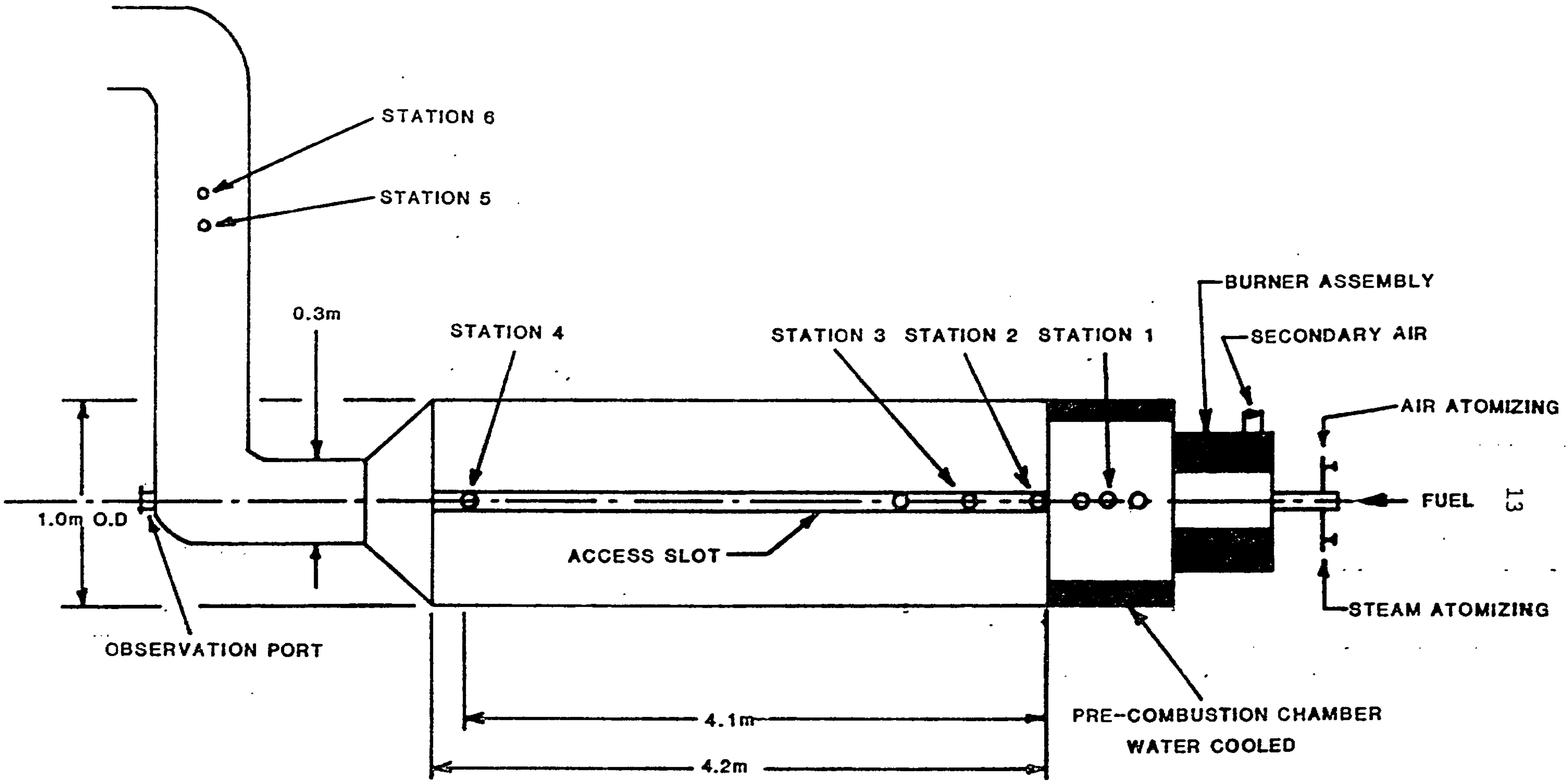


Fig. 1 - CCRL flame tunnel furnace

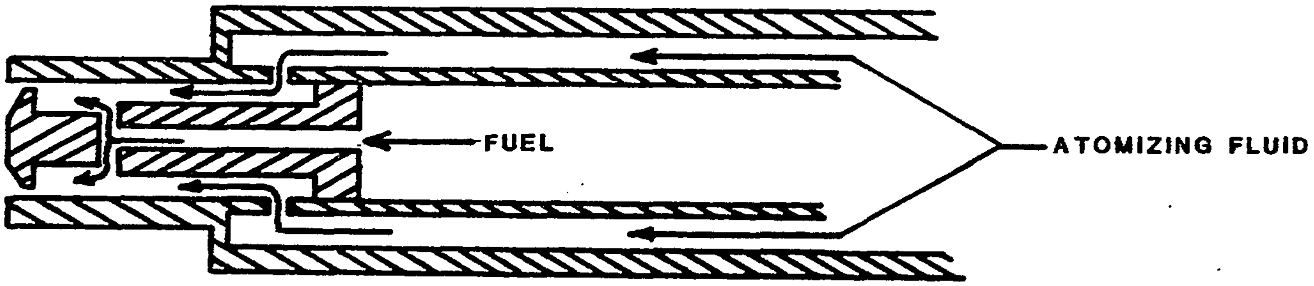


Fig. 2 - Schematic illustration of burner

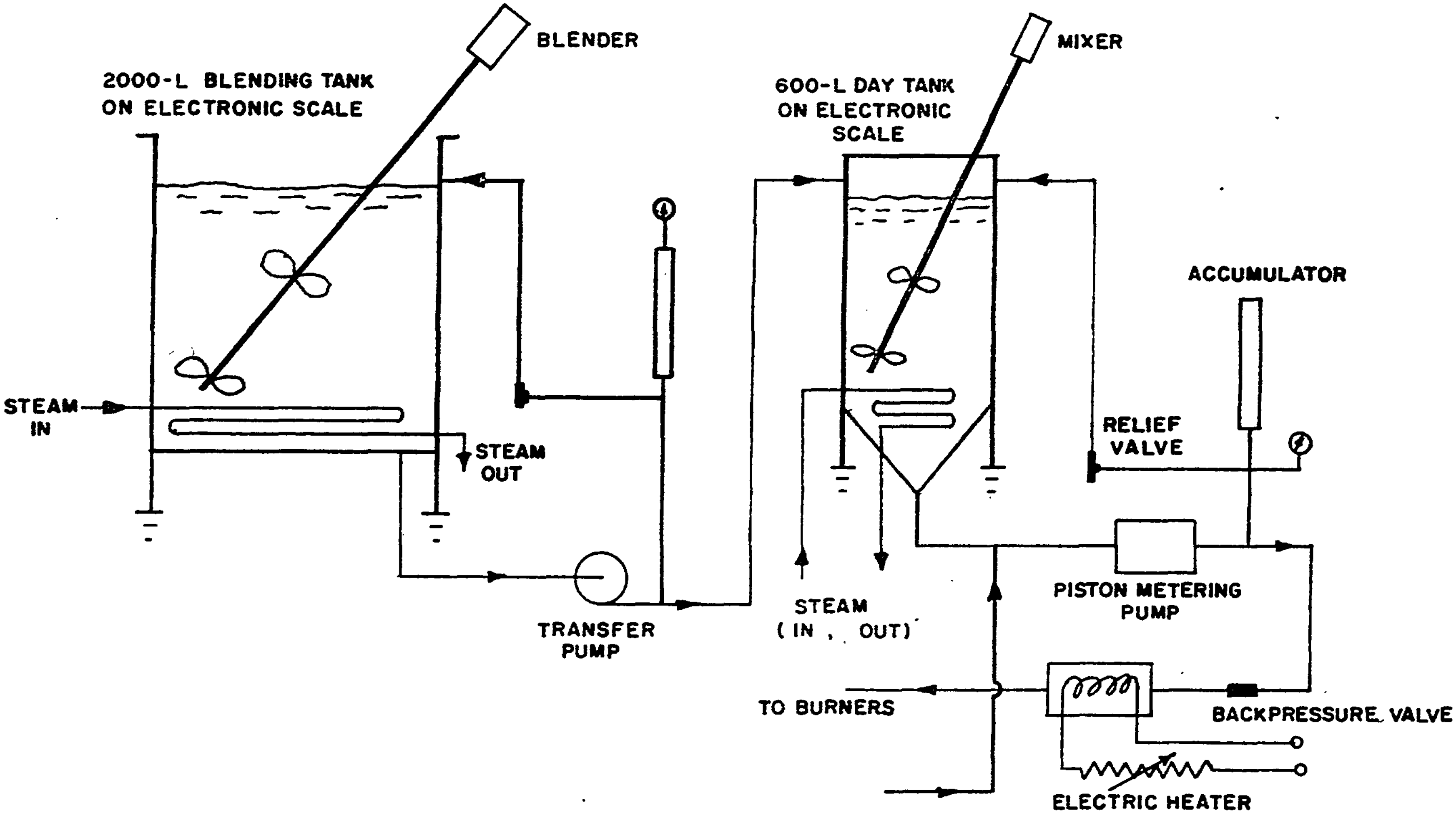
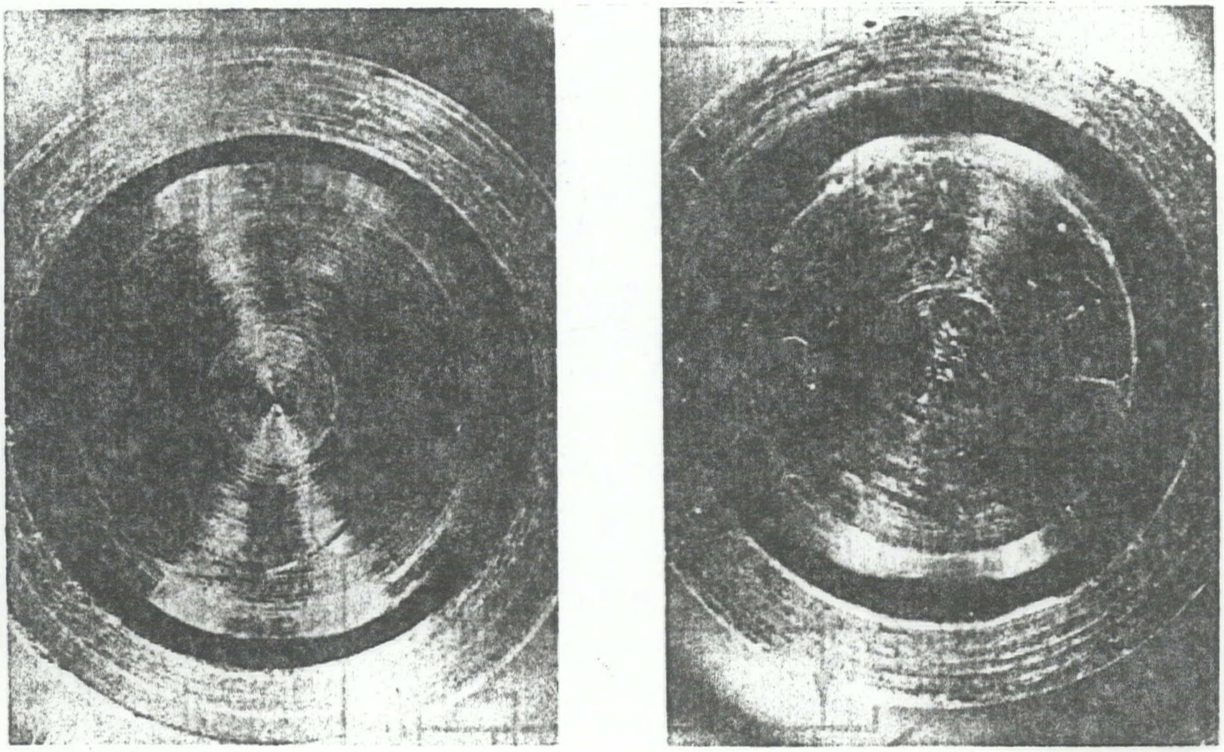


Fig.3 - Illustration of fuel supply system



New

After 20 h

Fig. 4 - Photographs showing burner-tip wear

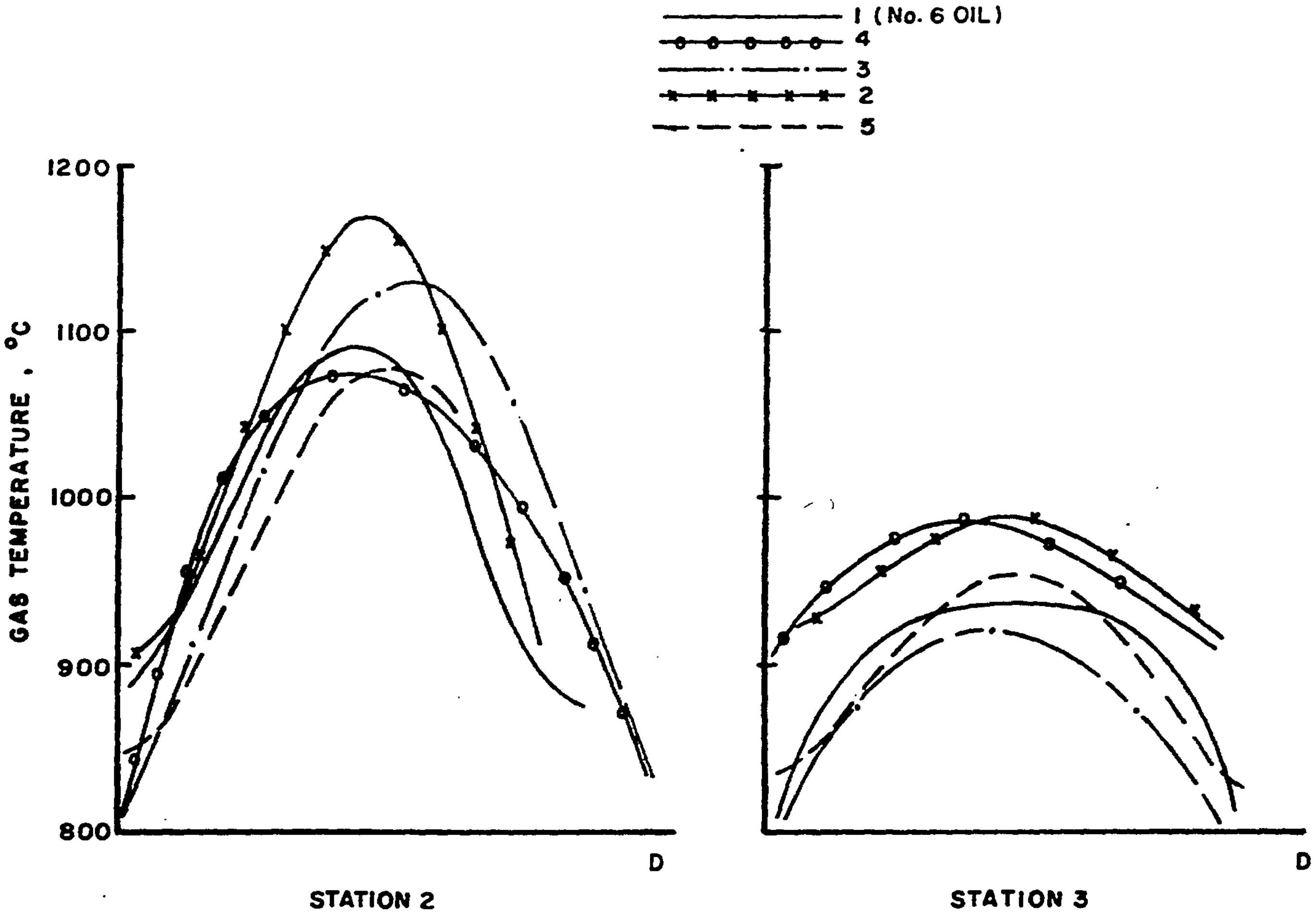


Fig. 5 - Radial flame temperature profiles at station 2 (1.0 m) and station 3 (2.2 m) locations

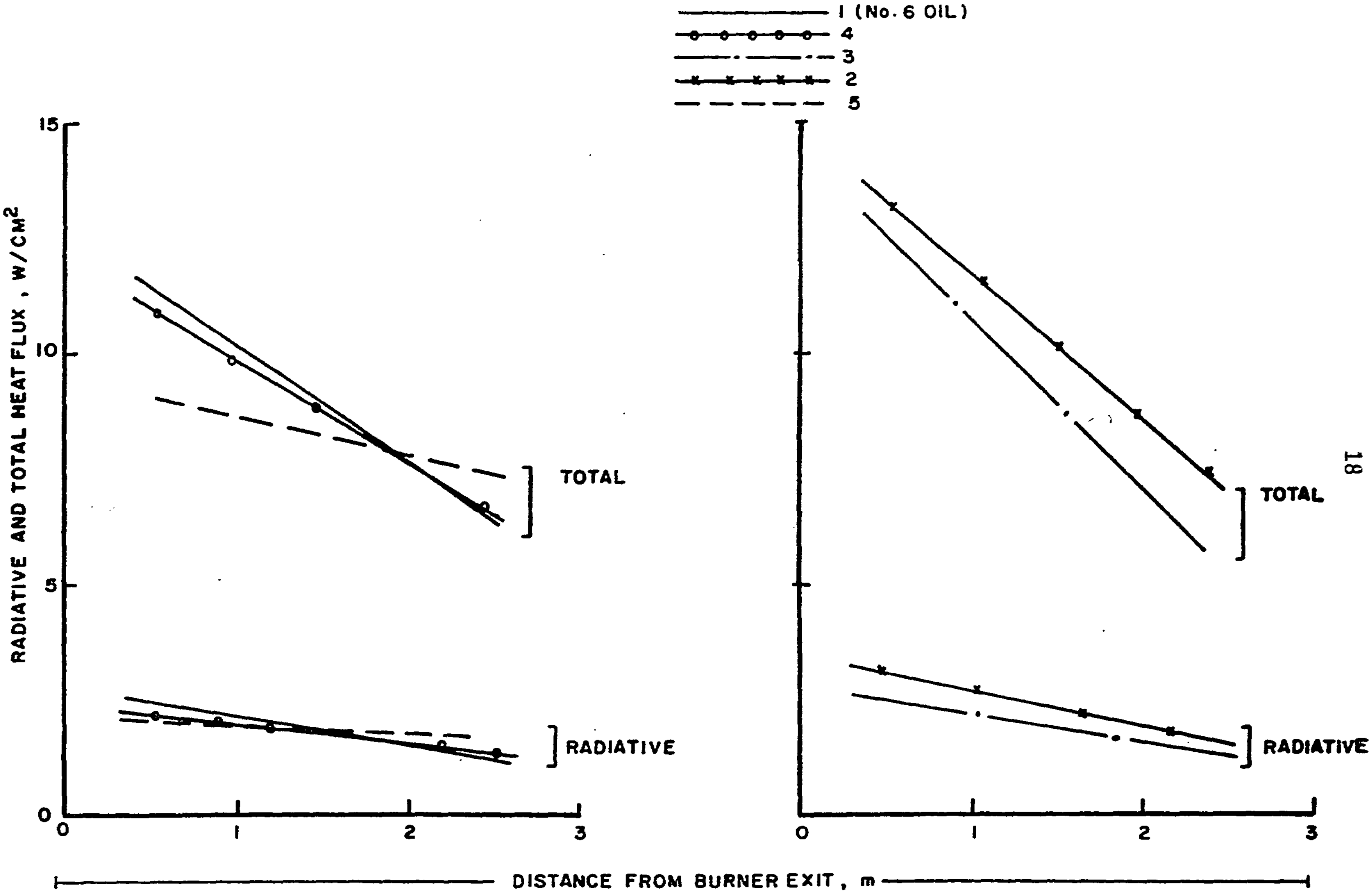


Fig. 6 - Variation of radiative and total heat flux along axis of furnace

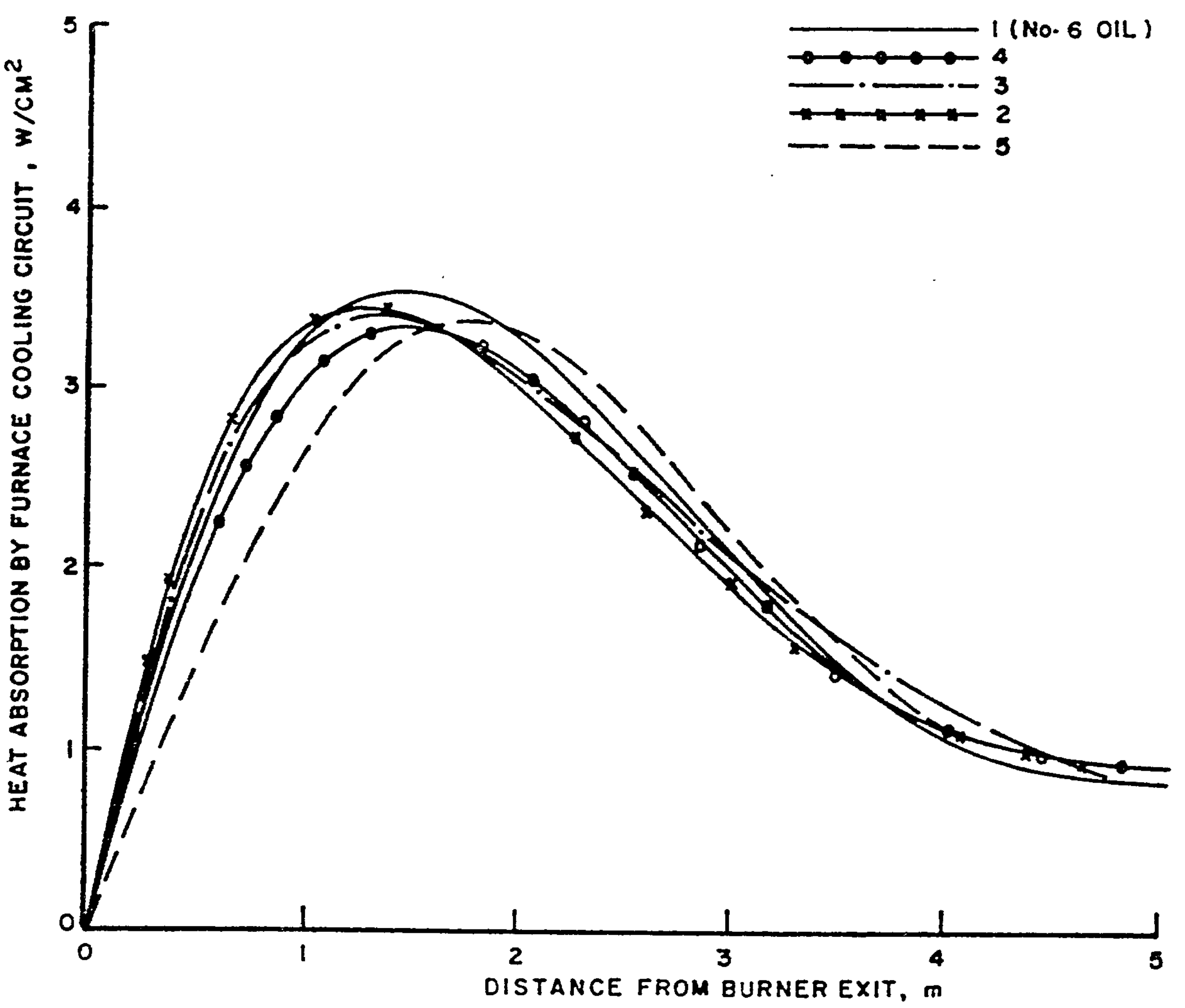


Fig. 7 - Variation of axial heat transfer to furnace cooling circuits

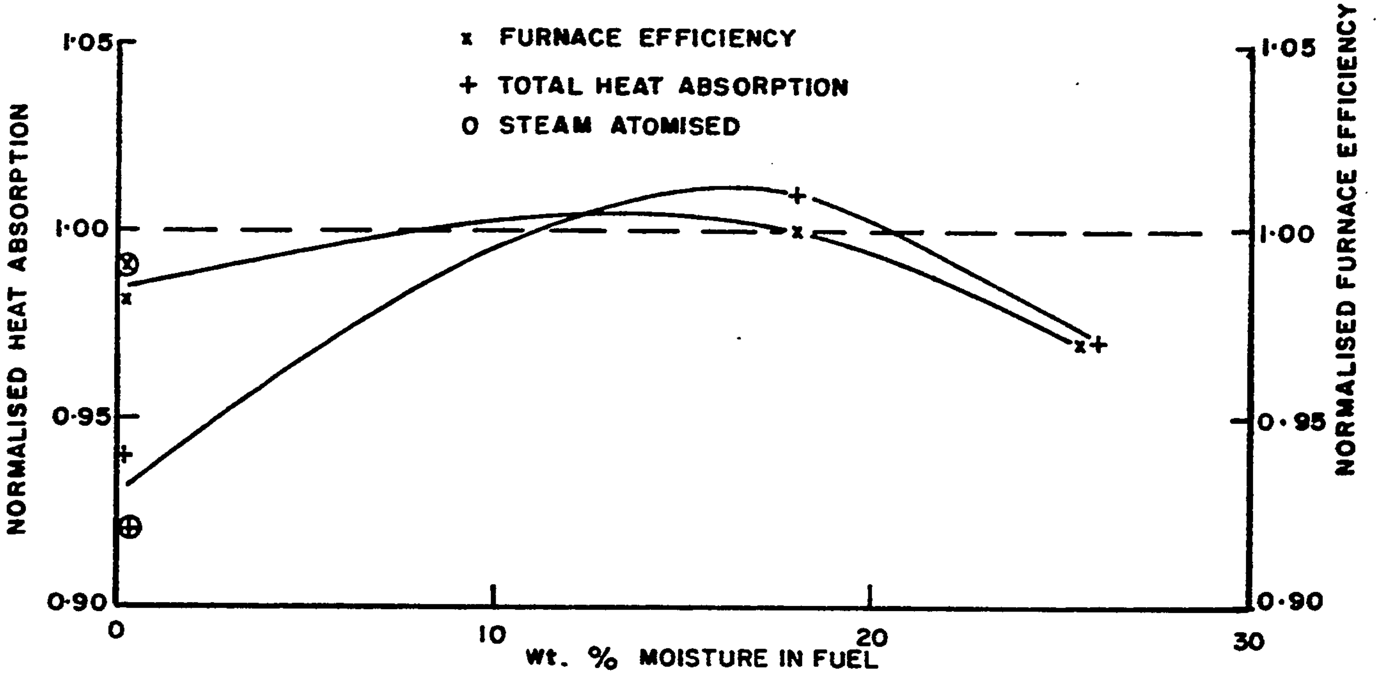


Fig. 8 - Variation of furnace efficiency and total heat absorption with moisture content of fuel

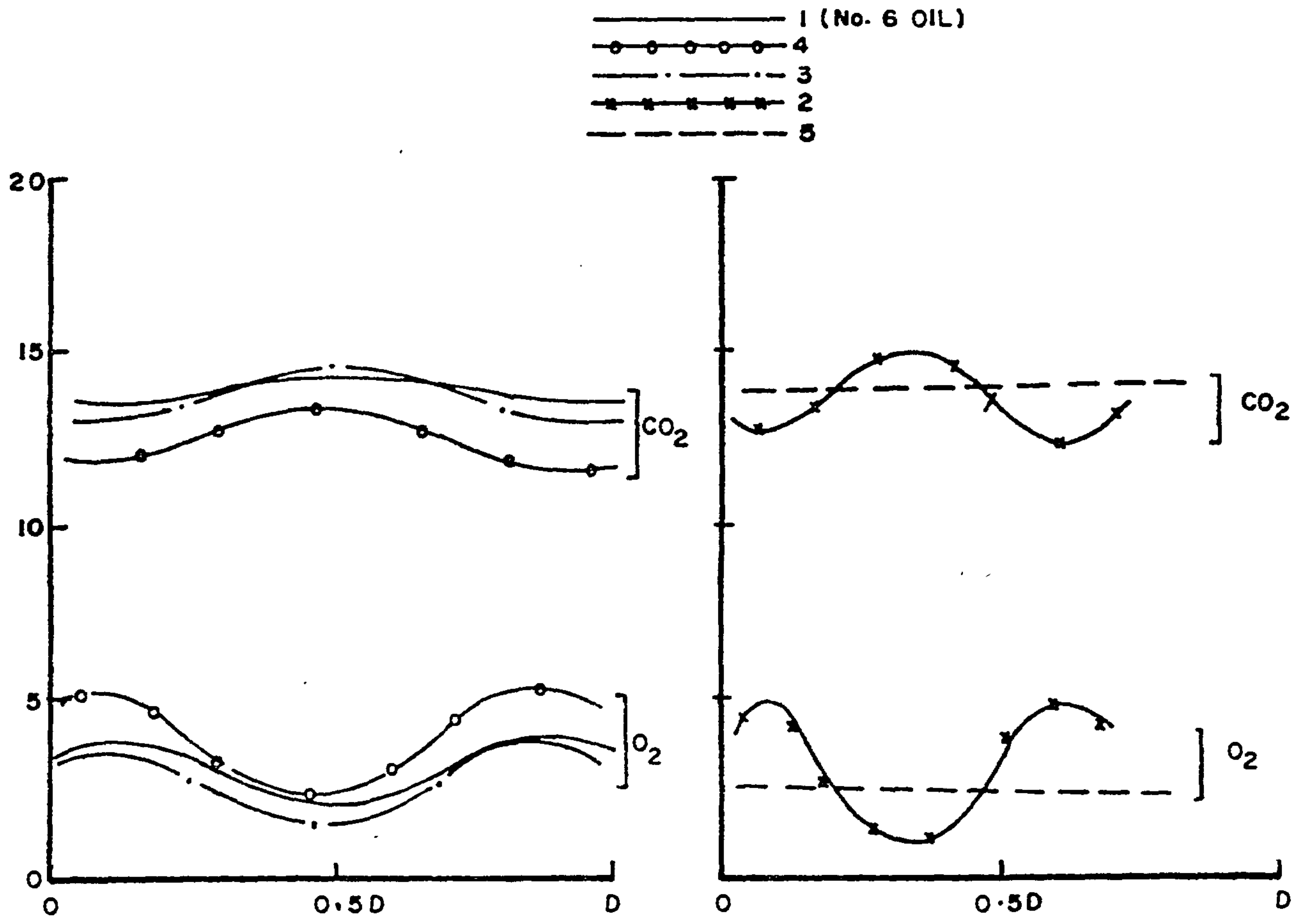


Fig. 9 - Radial profiles of oxygen and carbon dioxide concentrations at station 2 locations (1.0 m)

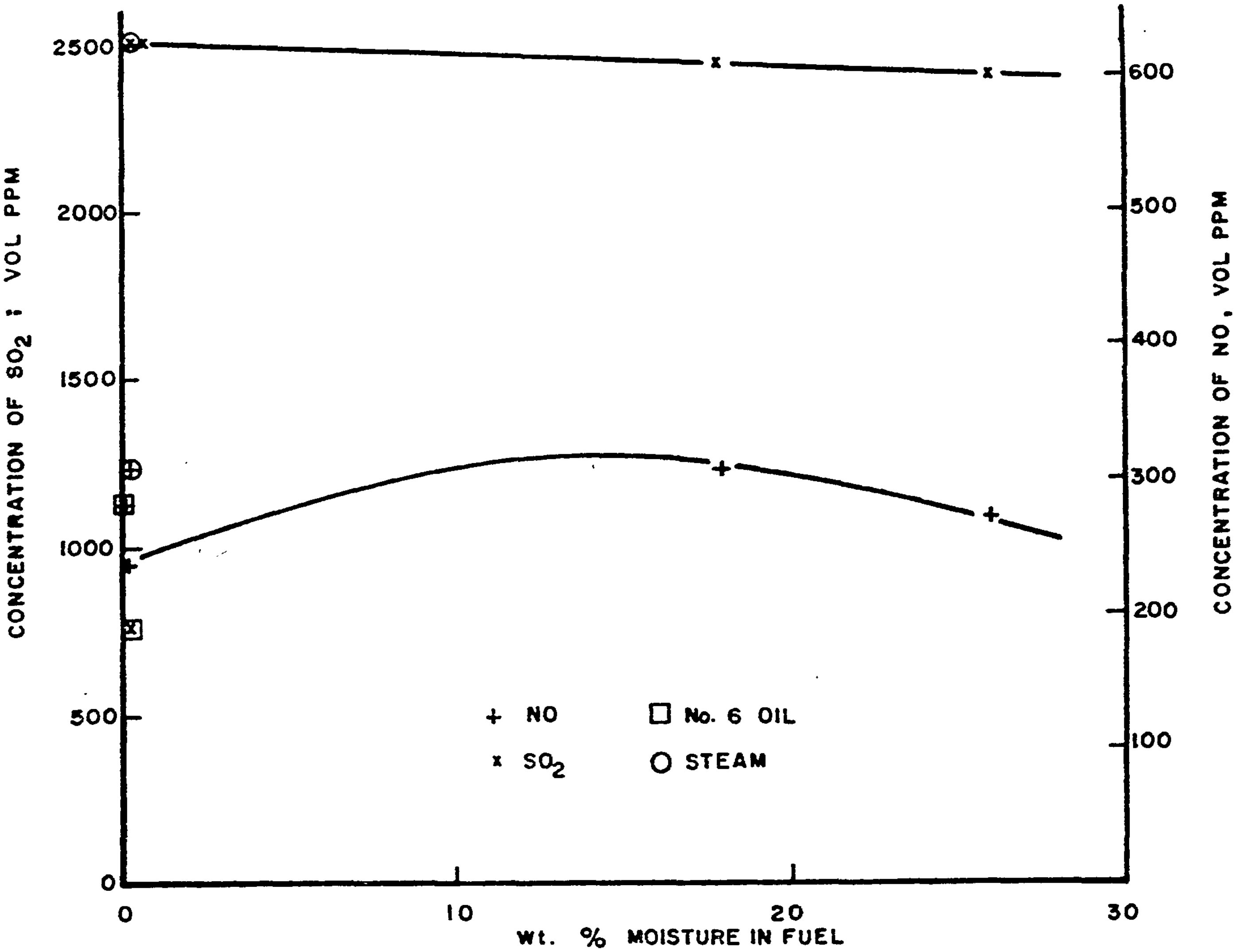


Fig. 10 – Variation of SO_2 and NO concentrations with per cent moisture in fuel

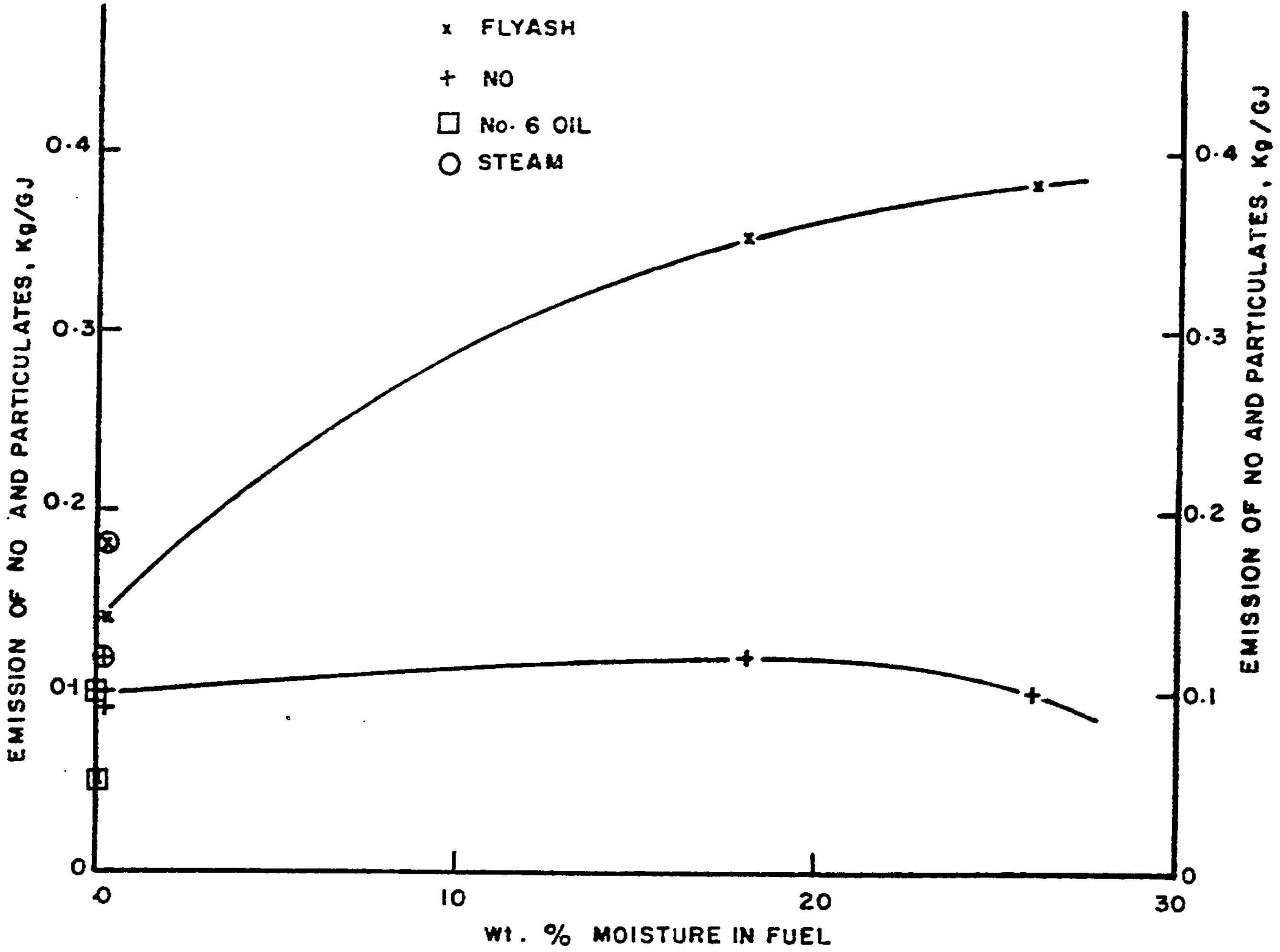


Fig. 11 - Variation of emission rates of NO and particulate material with per cent moisture in fuel