CANMET

Canada Centre for Mineral and Energy Technology

Centre canadien de la technologie des minéraux et de l'énergie

Energy Research Laboratories

Laboratoires de recherche sur l'énergie

THE COMBUSTION AND HEAT TRANSFER CHARACTERISTICS OF PIPELINEABLE WATER-BITUMEN EMULSIONS

H. Whaley, J.K.L. Wong and G.N. Banks

COMBUSTION AND CARBONIZATION RESEARCH LABORATORY

Energy, Mines and Resources Canada

Énergie, Mines et Ressources Canada

Canada

THE ENERGY OF OUR RESOURCES • THE POWER OF OUR IDEAS

L'ÉNERGIE DE NOS RESSOURCES • NOTRE FORCE CRÉATRICE

THE COMBUSTION AND HEAT TRANSFER CHARACTERISTICS OF PIPELINEABLE WATER-BITUMEN EMULSIONS

H. Whaley, J.K.L. Wong and G.N. Banks

COMBUSTION AND CARBONIZATION RESEARCH LABORATORY

For presentation at the ASME 1991 International Joint Power Generation Conference & Exposition, October 6-10, 1991, San Diego, CA. U.S.A. and for publication in proceedings.

May 1991

ENERGY RESEARCH LABORATORIES
DIVISION REPORT ERL 91-46(OPJ)

This work supported in part by the Federal Panel on Energy R&D (PERD)

COMBUSTION AND HEAT TRANSFER CHARACTERISTICS OF PIPELINEABLE WATER-BITUMEN EMULSIONS

by

H. Whaley*, J.K.L. Wong** and G.N. Banks***

ABSTRACT

A research program was undertaken by CANMET's Energy Research Laboratories to compare the combustion and heat transfer characteristics of Western Canadian bitumen emulsions with those of heavy fuel oil. It has been shown that heavy bitumen burns and transfers heat in much the same manner as heavy fuel oil. It was concluded from this research program that bitumen emulsions would make excellent fuels for boilers and process combustors, providing proper attention is given to the combustion and handling equipment.

---

* Section Head, ** Physical Scientist, *** Research Scientist, Industrial Combustion Process Section, Combustion and Carbonization Research Laboratory, Energy Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, K1A 0G1

CARACTÉRISTIQUES DE COMBUSTION ET D'ÉCHANGE THERMIQUE DES ÉMULSIONS INVERSES TRANSPORTABLES PAR PIPELINE

par

H. Whaley*, J.K.L. Wong** et G.N. Banks***

RÉSUMÉ

Les Laboratoires de recherche sur l'énergie de CANMET ont entrepris un programme de recherche en vue de comparer les caractéristiques de combustion et d'échange thermique d'émulsions inverses en provenance de l'ouest du Canada et de mazout lourd. Les travaux ont révélé que la combustion et l'échange thermique se font presque de la même façon pour les bitumin lourds que pour le mazout lourd. On a conclu que les émulsions inverses constitueraient d'excellents combustibles pour les chaudières et les chambres de combustion industrielles, dans la mesure où l'on porte une attention suffisante aux équipements de combustion et de manutention.

---

*Chef de section, **spécialiste des sciences physiques et ***chercheur scientifique, Section des procédés de combustion industrielle, Laboratoire de recherches sur la combustion et la carbonisation, Laboratoires de recherche sur l'énergie, CANMET, Énergie, Mines et Ressources Canada, Ottawa, K1A 0G1

CONTENTS

TABLES

FIGURES

INTRODUCTION

In recent years a number of technologies have emerged in which water is used to produce an oil emulsion, either because of the recovery process or due to the requirement that the product be transported by pipeline to distant refineries. Questions often asked are, can these emulsions be directly used and if so, how similar are their combustion and heat transfer properties to those of heavy fuel oil? Are modifications required to the combustion handling equipment or for the fuels before they can be burned satisfactorily in industrial combustors?

The role of water in fuel combustion has a long history, which dates back to before the introduction of the steam atomized oil burner. The past half century has seen periodic resurgences of interest in emulsified fuel oils. More recently, stricter environmental regulations, pipelining and handling applications as well as enhanced oil recovery methods have focused attention on these products for combustion utilization. The reduction in emissions from emulsified oil combustion compared with fuel oil are postulated to be due to secondary atomization (Ivanov et al., 1957) which occurs as the water is rapidly heated when passing through the precombustion zone. This further disrupts the oil spray, producing enhanced atomization with better combustion and thereby reduces soot emissions. The resulting ash particles, which contain less soot, are able to pass through the boiler tube banks with a much lower deposition rate than would occur with the soot contaminated ash. Lower flame temperatures, due to the presence of water, should also result in lower NO_x production in the flame.

Many technologies have been developed which produce stabilized emulsions for combustion, pipelining or other forms of transportation and refining. Some are devices to produce mechanically-stabilized fuel emulsions, while others are the result of enhanced oil recovery technology in which steam is injected into the reservoirs, and the resulting bitumen emulsion is recovered for refining or may be used as a fuel for the in situ recovery steam production. Significant developments have also been made in the production of bitumen emulsions for pipelining, refining and combustion applications, notably in Venezuela, Canada, the U.K. and the U.S.A. (Pass and Schwarz, 1977, Olen et al., 1985 and 1986).

RESEARCH PROGRAM

A combustion and heat transfer evaluation of emusified water continuous bitumen (WCB) was undertaken by the Energy Research Laboratories (ERL), Combustion and Carbonization Research Laboratory (CCRL) of the Canada Centre for Mineral and Energy Technology (CANMET). The project was undertaken to assess the feasibility of using pipelineable bitumen emulsions as fuels for boilers, as an option to breaking and dewatering the pipelined emulsions for refining. The present paper describes the CCRL research facilities and gives an evaluation of the test results.

Fuel Properties

The analyses of the WCB sample and No.6 fuel oil are given in Table 1. The WCB sample contained 35 wt % water. On a dry basis, the bitumen has a slightly lower heating value than No.6 fuel oil and higher contents of sulphur and ash. The bitumen feedstock was from Western Canada.

Examination of the emulsion showed that the bitumen was dispersed in the water in droplets of 50 µm or less, with a mean diameter of about 10 µm, as shown in Figure 1. Heating and freezing tests indicated that the emulsions could be easily reconstituted by simple mixing, provided the WCB was warm (>25^{o}C). Water could be readily redispersed, should it be necessary to offset evaporative losses. The main difference between the WCB and No.6 fuel oil is their viscosity/temperature relationships. The latter can be pumped (<1000c_p) at 40^{o}C, whereas the WCB has a viscosity comparable to olive oil (100 c_p) at 10^{o}C.

Pilot-Scale Combustion Equipment and Procedures

The experimental program was carried out in the CCRL's tunnel furnace illustrated in Figure 2. This furnace has a maximum thermal input of 2.5 GJ/h (0.69 MW) and consists of 28 parallel connected calorimeters, which form a cylindrical chamber 1 metre in diameter and 4.25 metres long, plus a 1 metre long refractory-lined adiabatic burner combustion chamber. Each calorimeter is part of a cooling circuit and contains an individual flow control valve, a variable area flowmeter and inlet and outlet thermocouples. An access slot along the length of the furnace wall permits the use of probes to measure flame properties (Friedrich et al., 1971).

A burner developed by CCRL for the in-house coal-water fuel (CWF) combustion and heat transfer characterization program was used for this project and is shown in Figure 3. The secondary combustion air has a swirl number of about 0.5 from a 70^{0} fixed-vane swirler located at the burner exit. The air atomizer typically operates at 69 to 207 kPa and is recommended for use with heavier fuel oils. In the case of non-emulsified bitumen, the fuel temperature was normally maintained above 120^{0}C in order to achieve effective atomization and flame stability.

The fuel supply system is shown in Figure 4. The fuel tank was located close to the furnace which reduced fuel line heat loss and facilitated purging with the light fuel oil at the conclusion of each test. The fuel supply system consisted of a 600-L electrically heated fuel tank on an electronic weigh scale, with a blade impeller to maintain fuel mixing. A recycle loop from the pump back to the fuel tank allowed for increased mixing when required. The line from the pump to burner was heated by an electrical trace and provided with an electrical immersion heater to ensure that the required fuel preheat temperature was attained.

The following parameters were held constant:

- thermal input - 1.6 GJ/h
- excess oxygen - 3%
- combustion air temperature - ambient
- combustion air swirl level - 0.5 from a fixed vane swirler
- burner fuel temperatures;
    - No.6 oil (reference fuel) - 108^{0}C
    - WCB - 60^{0}C

The project required that the combustion air not be preheated, but some preheat could be applied to the atomizing air. The following parameters and operating conditions were varied in order to compare particular flames:

- fuel pressure and temperature
- atomizing medium, flow rate, temperature and pressure

The following parameters were measured for each test:

- total heat transfer to each furnace cooling circuit
- incident radiative heat flux by ellipsoidal radiometer at the 0.5 and 3.0-m locations
- incidental total heat flux by heat flux probe at the 0.5 and 3.0-m locations
- radial flame temperature profiles by suction pyrometer at the 1.0 and 2.2-m locations
- furnace exit gas temperature and composition, including particulate emissions

The tunnel furnace was preheated for about 3 h on light fuel oil before switching to emulsified bitumen or No.6 fuel oil. During this period the test fuel was recirculated in the burner supply line back to the fuel tank. The operating parameters for the flame were then set and about 2 h were required before thermal equilibrium was established. A similar period was required when furnace conditions were changed. Thermal equilibrium was assessed by a series of thermocouples located in the tunnel furnace (refractory temperatures, flue gas temperature at furnace exit and heat transfer fluid temperatures). At the end of each test series, the fuel lines were purged with light fuel oil, which remained in the line until the start of the next test.

DISCUSSION OF RESULTS

There is some evidence in the literature which suggests that water in liquid fuels can be beneficial with respect to both combustion performance and the levels of emitted and deposited particulate material (Hall, 1980). However, extravagant claims exist regarding improvements in boiler performance which must be disputed. Dooher et al., 1980; Whaley and Savignac, 1979; Livingstone and Kuntz, 1979; Whaley and Lee, 1980; Cook, 1977; have all shown that combustion and environmental benefits may only be marginal in some combustion equipment, while much greater improvements are possible in others. It is reasonable to expect that modern combustion equipment will gain the least benefit from emulsified fuels, whereas older and poorly maintained equipment will show the greatest improvement in combustion and heat transfer performance. Since raw bitumen was not supplied for these combustion tests, postulated soot emission reductions could not be evaluated. The main advantage of a WCB is that it allows the bitumen to be transported by pipeline, as well as handled and atomized readily in combustion equipment.

Preliminary tests on the WCB had shown that it was preferable to maintain fuel temperatures below 80^{o}C in the supply lines to the burner in order to avoid breakdown of the emulsion and to maintain a steady fuel flow. The use of preheated atomizing air improved the flame quality, reduced sparklers and gave a brighter more compact stable flame. However, as noted earlier, one of the objectives of this project was to conduct the tests with ambient combustion air, the atomizing air being one component of this.

The furnace operating conditions for the baseline and WCB tests are summarized in Table 2. These represent equilibrium conditions which are comparable but not necessarily optimum. The No.6 fuel oil produced a bright stable flame about 1.7 m long and 0.5 m in diameter, whereas the WCB flame was shorter, more intense and with fewer sparklers at the edge of the flame. The flame appearance improved as the fuel temperature was raised from ambient to the operating temperature of 60^{o}C.

Table 2 and Figure 5 show that the heat transferred for the emulsion fuel was about 5% less than that for No.6 fuel oil. This can be partly attributed to the higher transport temperature required for the reference fuel, which was not accounted for in the heat balance. Radial gas profiles of CO_2 and O_2 measured at 2.41 m and 3.61 m from the burner tip indicated flat profiles, with little difference between the emulsion and the reference fuel. Figure 6 shows that the radial temperature profiles of the WCB were 120^{o}C higher than those of the reference fuel on the axis at 1.51 m, and were still more than 50^{o}C higher on the axis at 2.41 m from the burner. A strong recirculation pattern with the WCB produced gases about 200^{o}C cooler near the walls of the furnace at 2.41 m from the burner. This can no doubt be attributed to the cooling effect of water in the fuel, which would tend to be more prominent in the recirculating gases. At greater distances from the burner the two fuels showed very little difference in temperature. Figure 7 shows the total and radiative heat flux variation with the axial distance from the burner and indicates very little difference between the two fuels. The radiative component represents about 80% of the total heat transposed, which is typical for oil flames.

Emissions of SO_2 and NO were higher for the WCB than for the No.6 fuel oil. This was to be expected because (a) the sulphur content of the WCB is 5% compared with 1.5% for the oil and (b) the shorter, more intense WCB flames would result in a higher thermal NO_x production. NO_x and SO_x reduction was not a part of the project objectives, but rather quantification of the emissions compared to that of fuel oil. Particulate emissions, comprised mainly of soot from either fuel, were slightly higher for the WCB. This is probably because WCB was not atomized as well as No.6 fuel oil. But as mentioned earlier, particulate emissions were probably less than they might have been for the raw bitumen.

CONCLUSIONS AND RECOMMENDATIONS

The pipelineable WCB can be successfully burned with excellent combustion and heat transfer. In this regard its properties are quite similar to those of No.6 fuel oil. Providing suitable handling systems are designed, it is expected that the WCB would make an excellent alternate fuel for most industrial applications such as the medium to large scale boilers currently using oil or gas.

As expected, due to the higher sulphur content of the WCB fuel, the SO_2 emissions were much greater than for No.6 fuel oil and appropriate sulphur emission containment measures may have to be taken in order to comply with environmental regulations. It is expected that the NO_x could be controlled using low NO_x burner technologies such as burner or furnace staging.

Because of the ease of handling WCB compared with No.6 fuel oil and heavier residues from refining, it is suggested that this emulsion technology be applied to heavier feedstocks such as pitches and tars. In addition, sulphur containment might be achieved through the use of LIMB type burners or by manufacturing a WCB with a sorbent for sulphur capture. Experience with coal-water fuel has shown that this can be effective, because of the lower temperatures prevailing in the flame fringes where the SO_2 capture occurs. However, an assessment would be required to determine the possibilities of slagging or fouling the combustion system or its heat exchange surfaces.

REFERENCES

Cook, T.D., "Water-in-oil emulsion firing in an industrial steam boiler", General Motors Report 415; 1977.

Dooher, J., Grenberg, R., Moon, S., Gilmartin, B., Jakatt, S., Skura, J. and Wright, D., "Combustion studies of water/oil emulsion on a commercial boiler using No.2 oil and low and high sulphur No.6 fuel", Fuel 59, p.883; 1980.

Friedrich, F.D., Mitchell, E.R., Lee, G.K. and Whaley, H., "The CCRL tunnel furnace: design and application", Second Members Conference; IFRF, Ijmuiden, the Netherlands, 1971.

Hall, R.E., "The effect of water/residual oil emulsions on air pollutant emissions and efficiency of commercial boilers", ASME Journal of Engineering for Power; 10, p.425; 1976.

Ivanov, V.M., Kantrovich, B.V., Rapiovets, L.S. and Khotunsev, L.L., "Fuel emulsions for combustion and gasification", J.Acad. Sci. U.S.S.R., 5, P.56; 1979.

Livingston, P. and Kuntz, A., "Combustion of water/oil emulsions", Pulp and Paper Canada Ltd., 12, p.147; 1979.

Mkpadi, M.C. and Igho, J.T., "Viscosity of salt-free oilfield mixtures", J. Inst. Energy, 63, No. 454, p.9; 1990.

Olen, K.R., Woodsworth, L.M. and Allen, J.W., "Large-scale combustion experience with emulsified petroleum fuel", Proceedings, Sixth International Workshop on Coal-liquid and Alternate Fuels Technology, Halifax, Canada, October 1986.

Pass, F. and Schwarz, F., "Combustion of liquid fuels: very heavy oils", V.G.B. Kraftswerktechnik 57, 11, p.723; 1977.

Thambimuthu, K.V., Whaley, H., Bennett, A. and Jonasson, K.A., "Development of a 16 MW_e coal-water heavy oil burner for front-wall firing", ASME Journal of Energy Resources Technology, 112, pp.136-141; 1990.

Whaley, H. and Savignac, D.G., "An evaluation of water in fuel oil emulsions in a small package boiler", Energy Research Laboratories, Division Report ERL 79-67(TR); 1979.

Whaley, H. and Lee, G.K., "Efficiency trials on unit No.3 central experimental farm heating plant, Ottawa: A comparative evaluation of untreated and water emulsified No.6 fuel oil", Energy Research Laboratories, Division Report ERL 79-19 (CF); 1980.

Whaley, H., Banks, G.N. and Wong, J.K., "An evaluation of heavy oil emulsions for potential industrial combustion applications", ASME Fourteenth Annual Energy Sources Technology Conference and Exhibition, Emerging Energy Technology, PD-36; 1991.

Table 1 - Fuel analyses (dry basis)

Components	No.6 fuel oil	WCB
Density, ASTM D71 at 15°C	0.981	-
Calorific value, MJ/kg	43.1	39.5
Flash point, ASTM D92, °C	119.5	-
Kinematic viscosity, cSt at 10°C	-	100
at 20°C	-	58
at 50°C	695	-
at 100°C	49	-
Chemical analyses, wt %		
Water by distillation	0.00	35.00
Carbon	86.80	83.40
Hydrogen	10.50	10.50
Sulphur	1.47	5.00
Nitrogen	0.38	0.40
Oxygen (by difference)	0.80	0.70
Ash	0.05	trace

Table 2 - Furnace operating conditions

	No.6 fuel oil	WCB
Fuel		
Flowrate, kg/h (wet basis)	38.5	64.1
Thermal input, MJ/h	1659	1635
10^6 BTU/h	1.57	1.55
kW	461	455
Temperature, °C		
at tank outlet	88	50
at burner	108	60
Atomizing air		
Flowrate, kg/h at NTP	29.21	29.96
Temperature at burner, °C	142	142
Pressure at burner, kPa	496	496
Combustion air		
Flowrate, kg/h at NTP	435	435
Temparature at burner, °C	35	34
Thermal heat transfer, kW		
Circuits 1-10	252.2	228.3
Circuits 11-20	55.2	58.7
Circuits 21-28	21.7	26.0
Total (1-28)	329.1	312.9
Total W/cm^2 of thermal surface	2.54	2.39
Heat transfer rate, kW/MJ of fuel input .	0.198	0.191
Per cent of thermal fuel input extracted in thermal plates	71.4	68.8
Flue gas		
Temperature, °C	443	457
Flowrate, Nm^3/MJ of fuel*	0.274	0.296
Particulate loading, g/Nm^3	0.075	0.090
Flue gas analyses		
O_2 vol %	3.2	3.2
CO_2 vol %	13.6	13.2
CO vol ppm	37	28
NO vol ppm	252	281
SO_2 vol ppm	766	2520
H_2O wt % *	5.5	8.6
Flue gas emissions, g/MJ of fuel		
NO	0.092	0.171
SO_2	0.600	3.278
Particulates	0.021	0.041

* Calculations based on stoichiometric combustion and oxygen content of flue gases.

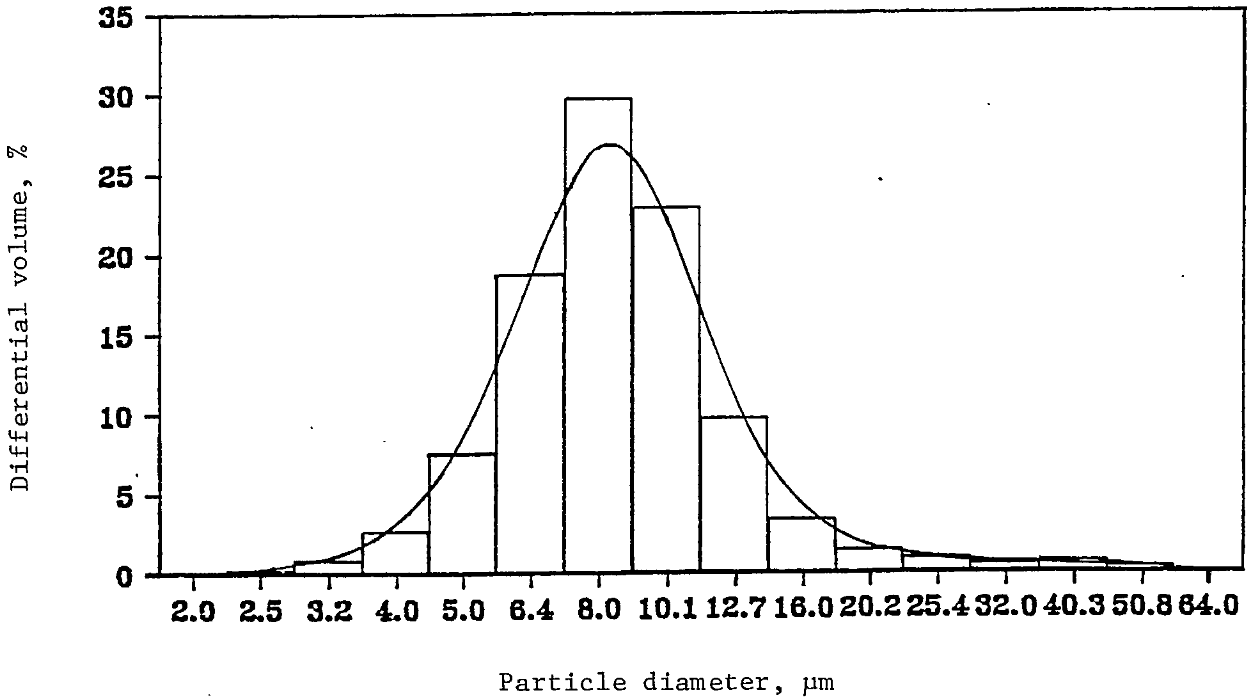

Fig. 1 - Particle size distribution of WCB sample

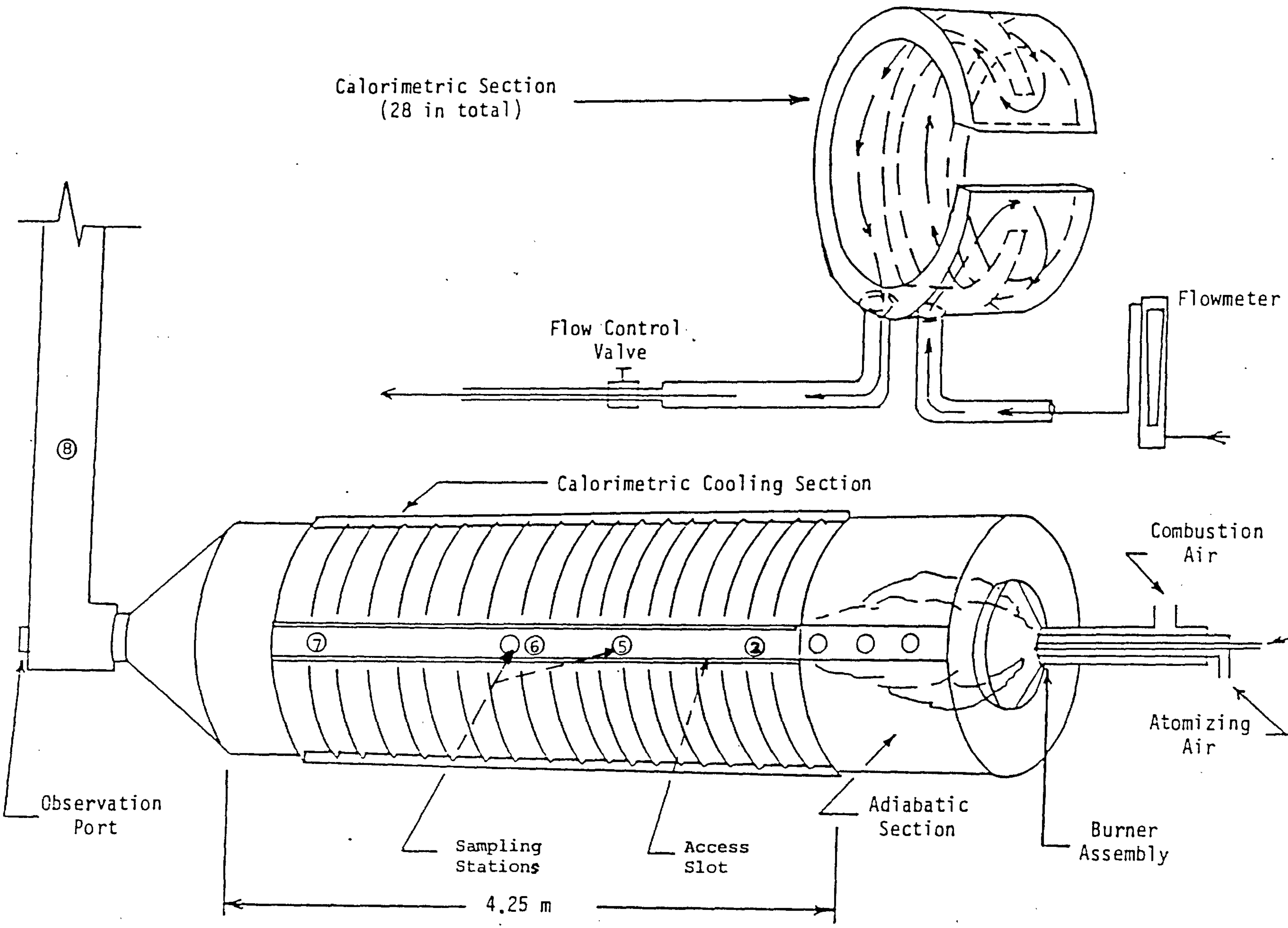

Fig. 2 - Schematic of CCRL flame tunnel furnace

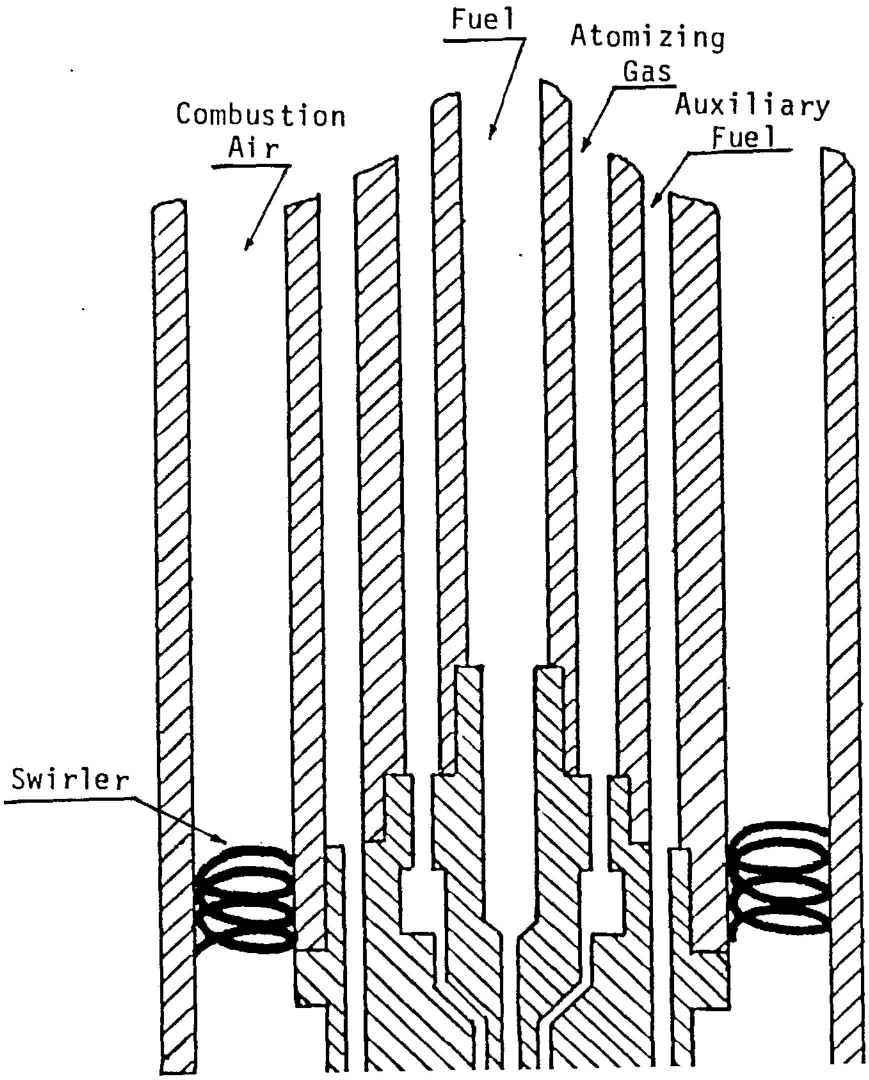

Fig. 3 - CCRL pilot-scale coal liquid mixture burner

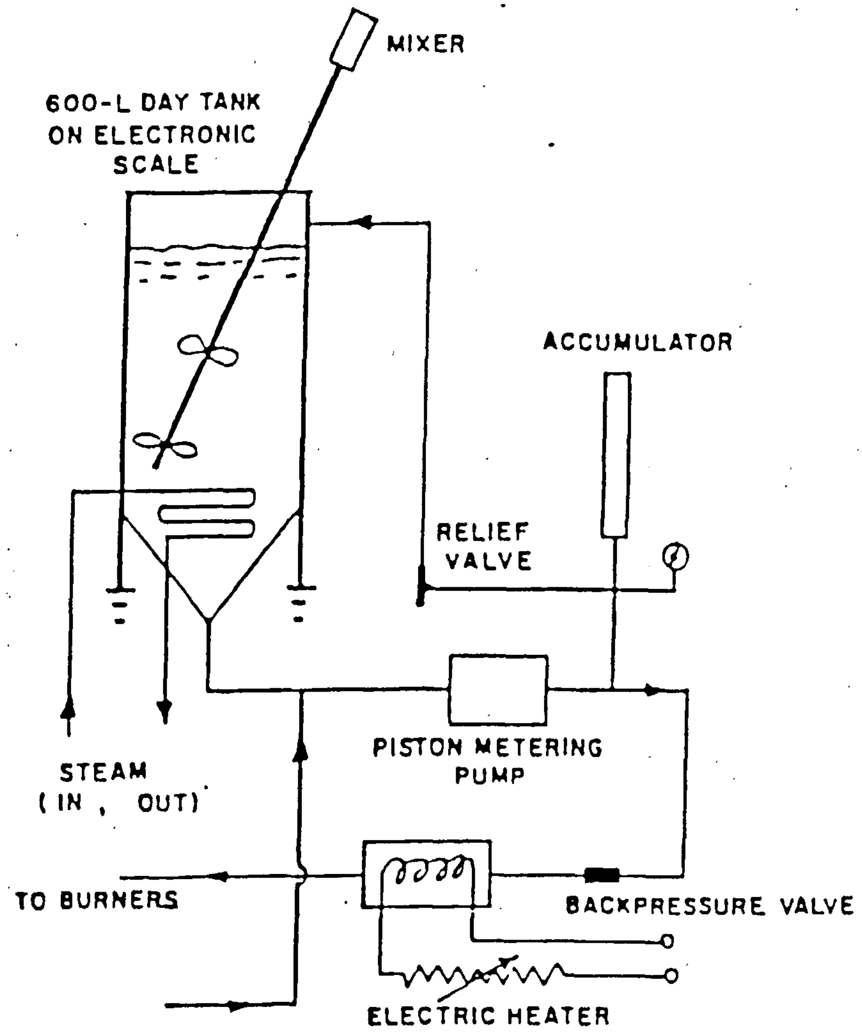

Fig. 4 - Schematic illustration of fuel handling system

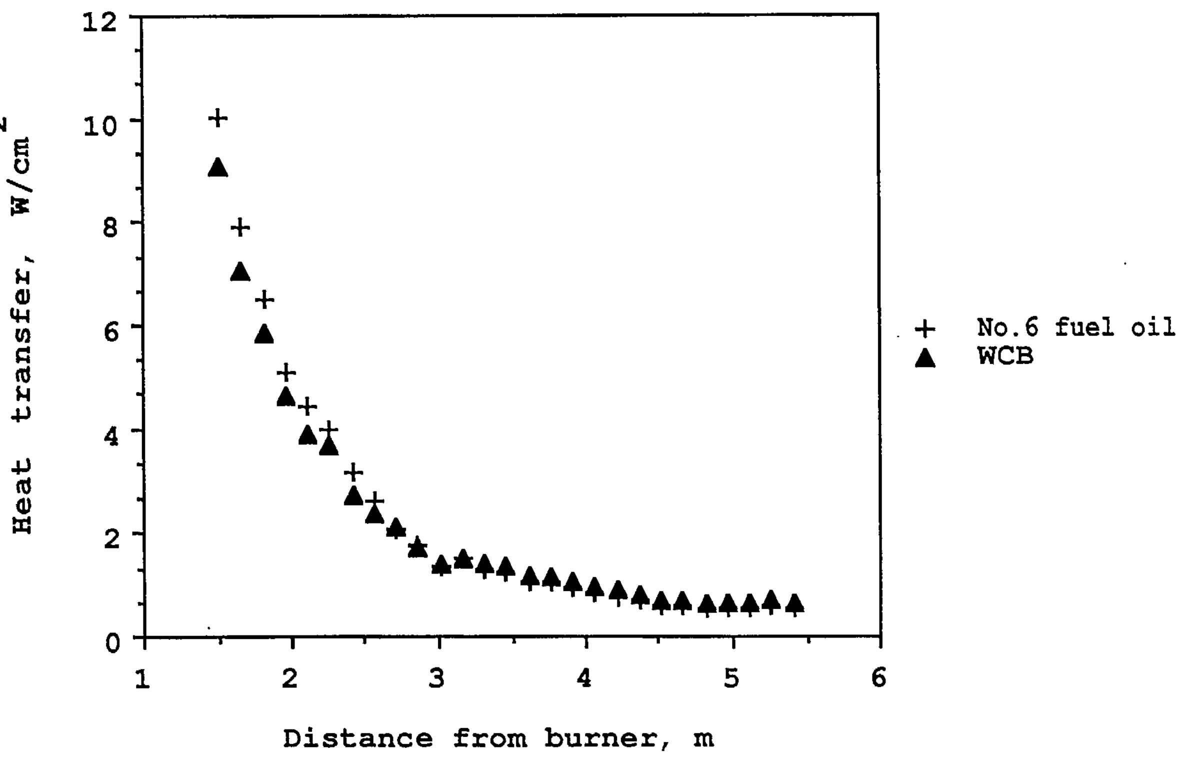

Fig. 5 - Axial distribution of total heat absorbed

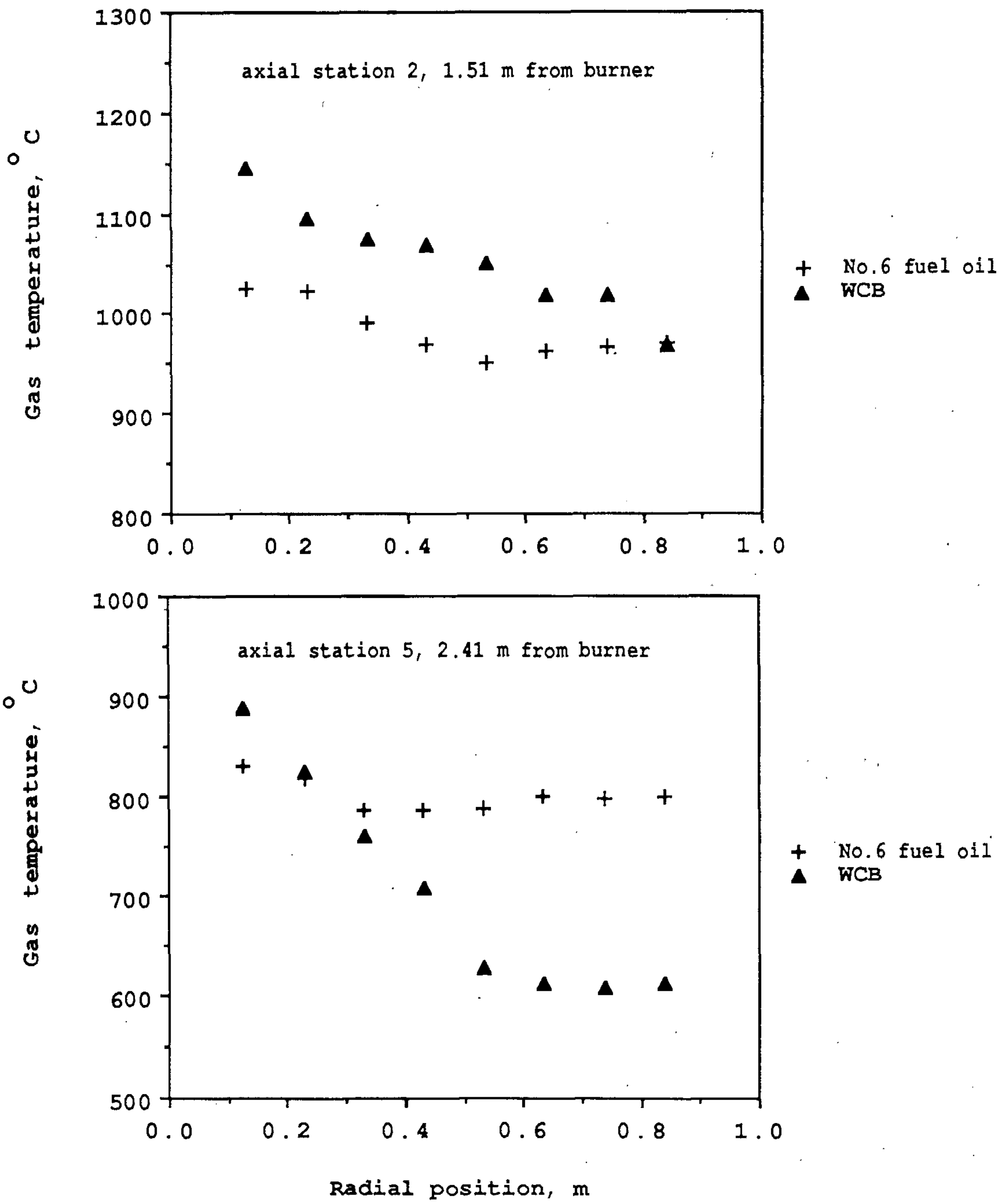

Fig. 6 - Radial temperature profiles, axial stations 2 and 5

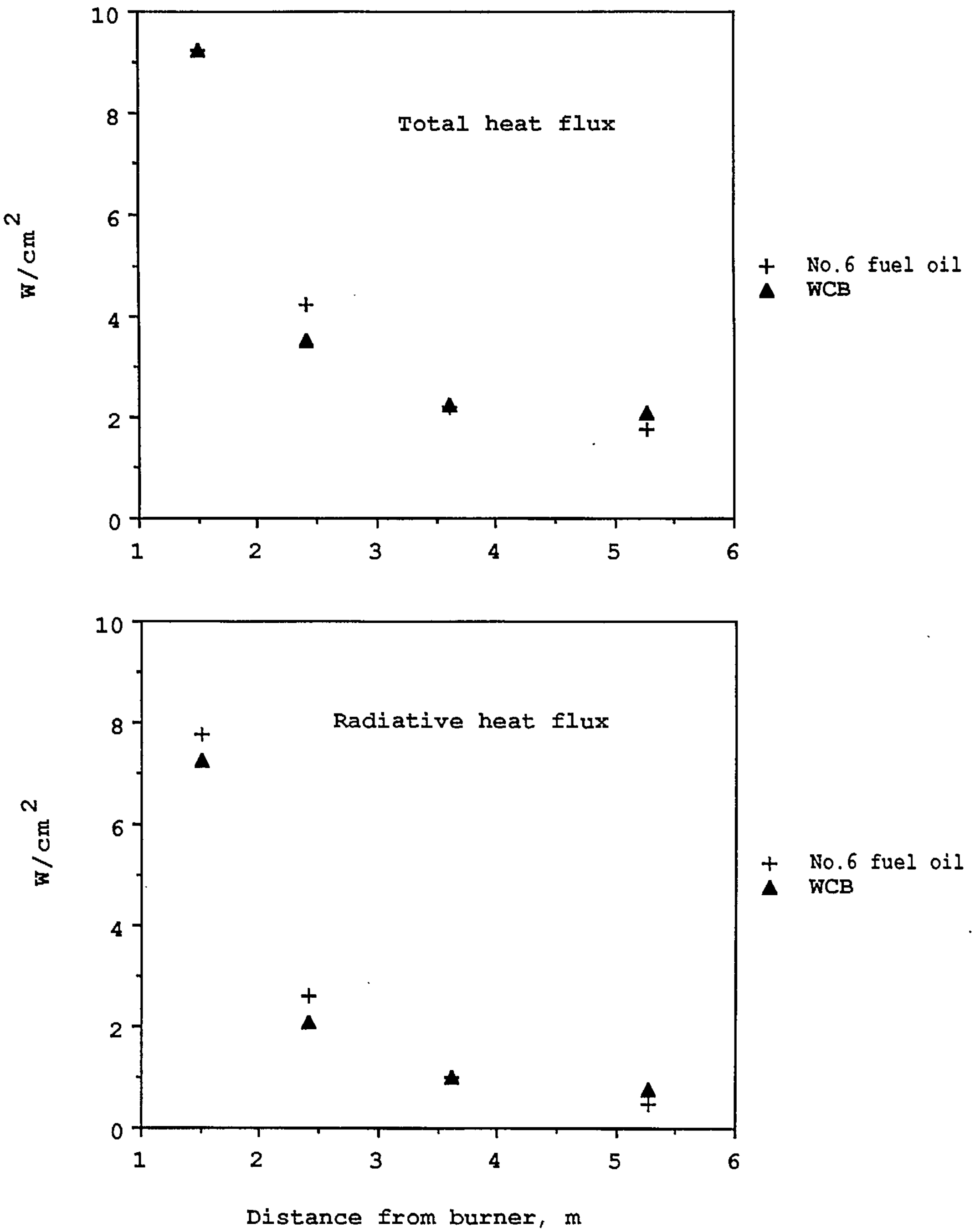

Fig. 7 - Total and radiative heat flux