COOPERATION

COOPERATION AGREEMENT ON
ALTERNATIVE ENERGY DEVELOPMENT
AND ENERGY EFFICIENCY

ENTENTE DE COOPÉRATION
SUR LE DÉVELOPPEMENT DES
ÉNERGIES DE REMPLACEMENT
ET L'EFFICACITÉ ÉNERGÉTIQUE

PRINCE EDWARD ISLAND WOOD CHIP-FIRED BOILER PERFORMANCE

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Canada

Prince Edward Island
Île-du-Prince-Édouard

Canada - Prince Edward Island
Cooperation Agreement
on
Alternative
Energy Development
and
Energy Efficiency

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INTRODUCTION

In February 1990, Federal and Provincial Ministers entered into the Canada-Prince Edward Island Cooperation Agreement on Alternative Energy Development and Energy Efficiency.

This Agreement sets out to:

- enhance the strategic energy infrastructure and augment energy security and energy-use efficiency in P.E.I.;
- increase production of renewable energy from local resources and to hasten the adoption of innovative energy production and conservation technologies; and
- stimulate local employment, entrepreneurial and industrial opportunities in wood chip harvesting and transportation and in biomass heating system fabrication and engineering.

The alternative energy component of the Agreement consists of a federally-delivered program of technical and financial support to aid in the conversion of existing commercial/institutional heating systems and the installation of new systems to utilize biomass fuels, particularly whole-tree wood chips produced from local resources.

Energy, Mines and Resources Canada (Energy Sector) administers the Agreement on behalf of the federal government.

As part of its on-going developmental work for wood-chip combustion systems in P.E.I, Energy, Mines and Resources Canada engaged CANMET's Energy Research Laboratories to conduct and supervise tests to determine emission and efficiency performance of five wood-chip fired boilers in Prince Edward Island with rated capacities ranging from 75 kW to 1.8 MW. The tests were conducted in early April 1992.

During the course of the testing, flue gases were monitored using continuous on-line analyzers which allowed boiler operating characteristics to be determined during testing. Moisture and fuel analysis on two wood samples collected from the feed system of each boiler were also carried out. Particulate and PAH tests on each unit were conducted by Air Testing Services Inc. (ATS) of Toronto who were subcontracted to undertake this work.

This report presents the findings of these tests.

TEST UNITS

Ratings are approximations used to identify the unit, and may not correspond to actual outputs. The test units are either European designs or local modifications of these systems. The Sylva system uses a D.C. motor to continuously vary the fuel feed; all the other units control the fuel feed rate by providing a set number of seconds of fuel delivery auger operation and a set number of seconds of delay. Settings are typically 10 to 60 seconds in each mode. A separate automatic control senses boiler water temperature and cycles to a hold-fire condition when it reaches a pre-set limit. At this setting there is just sufficient auger operation to maintain a minimum fire in the boiler.

In practice, the relative length of the feed cycle would be adjusted occasionally during the heating season to minimize the amount of hold-fire operation, so that the feed auger would operate for short, well spaced periods during milder temperatures and more continuously in colder periods. During the test period temperatures were generally in the -10° to 0°C range, which provided a reasonable load for most of the systems with some dumping of hot water as required. The controls were adjusted to ensure that the systems did not go onto the hold-fire mode during the particulate and PAH sampling.

Bio-Blast 75 kW Unit is a prototype derived from a larger Bio-Blast unit discussed below. The system consists of a chip hopper of approximately 1.2 m^3 capacity that feeds into the side of the combustion chamber near the bottom by an auger. A blower provides primary combustion air to the chamber, and an adjustable opening provides secondary air. The test installation's heat exchanger is an ETNA vertical tube boiler venting through a single wall 0.203 m diameter flue pipe into a vertical factory-built chimney. No mechanical flue gas extraction is provided. For test purposes the flue pipe was rerouted to provide sufficient straight length within the test room for sampling purposes. The test unit is installed in a large residence (converted barn), and provides building heat and domestic hot water.

Bio-Blast 125 kW Unit consists of a chip hopper of approximately 5.4 m^3 capacity that feeds by auger into the bottom side of the combustion chamber. A blower provides forced air to the burner. In this installation the flue gases from the combustion chamber enter a Renfyre water tube boiler for heat exchange before venting directly up a 0.203 m diameter single wall vertical steel stack. No mechanical flue gas extraction is provided. The test unit is installed at a pig farm, where it heats the floors in the barn.

440 kW Unit consists of an auger system that carries fuel to the top of the combustion chamber where it falls by gravity onto a sloping grate. Underfire air is provided through the sloping grate and secondary air is provided downstream. Flue gases pass through a vertical baffle heat exchanger to an exhaust blower. Chips are supplied from a live-bottom trailer-based storage system of approximately 43 m^3 capacity that feeds the fuel supply augers. Flue gases exit the exhaust blower to a Joy Multiclone, then to a vertical 0.502 m diameter uninsulated steel stack. The test unit is installed in a dedicated building at the rear of a 66-unit hotel where it provides heat and domestic hot water.

Sylva 600 kW Unit consists of an auger system that supplies fuel from the chip storage to a ready-use hopper from which the chips are fed by a D.C. auger to a sliding step grate. The system tested uses a below-ground chip storage hopper underneath the combustion chamber/boiler system. Chips are dumped through a trap door into the bin where they are fed by floor scrapers to a collection auger and to the feed augers. Flue gases from the combustion chamber are fed to a hot water firebox boiler equipped with auxiliary swing-away oil burner. Flue gases exit the boiler to a Joy Multiclone and then to an induced draft blower and a vertical 0.254 m diameter double wall insulated steel stack. The unit is installed at a composite high school where it provides building heat and hot water.

KMW 1800 kW Unit consists of an auger system that supplies a small ready-use hopper from which an auger supplies fuel to the base of the combustion chamber. Flue gases exit the combustor directly to the heat exchange boiler. This unit is located so that gases exiting the combustor near the top enter the boiler near the bottom. Flue gases exiting the boiler make a 180° bend to a Joy Multiclone and an exhaust blower. Flue gases then pass to a common manifold which also serves two oil-fired boilers before exiting to a large brick-faced chimney.

TEST EQUIPMENT

i) Flue gas temperature and composition monitoring equipment:

- Infrared continuous CO_2 analyzer (Horiba PIR 2000), 0-20% range.
- Infrared continuous CO analyzer (Horiba PIR 2000), 0-1% range.
- Paramagnetic continuous O_2 analyzer (Beckmann), 0-25% range.
- Infrared continuous SO_2 analyzer (Horiba PIR 2000), 0-1500 ppm range.
- Chemiluminescent NO_x analyzer (Thermo Electron model 10) 0-1000 ppm range.
- Flame ionization hydrocarbons analyzer (Scott) 0-5000 ppm range.
- Flue gas conditioning train

Voltage signals from these analyzers plus thermocouple readings of flue gas temperature were processed by a Hewlett Packard 3497A data acquisition system. The resulting information was stored on floppy disk using a desktop computer.

ii) Particulate sampling equipment (Fig. 1) consists of a sampling train as described in EC Report EPS 1-AP-74-1 Method E and including the following features:

- All parts in contact with the sample are constructed of glass, stainless steel, or teflon.
- Heated probe is enclosed in stainless steel tubing.
- Pyrex filter holder contains a 0.3µm 10 cm nominal diameter filter in a heated box maintained at 120°C.
- Four Greenburgh-Smith impingers are connected in series. The first, third, and fourth are modified by replacing the tips and impaction plates with glass tubes extending to within 13 mm of the flask bottom. The first two impingers contain 100 mL of distilled water and the fourth 200 g of silica gel. The impinger assembly is cooled by an ice bath.
- Vacuum pump, flowmeter, manometer, and control assembly permit operation of the system as described in the test method.

iii) PAH sampling equipment (Fig. 2) consists of a sampling train based on the requirements of EC Report EPS 1/RM/2 June 1989 "Reference Method for Source Testing: Measurement of Releases of Selected Semi-volatile Organic Compounds from Stationary Sources" and includes the following features:

- All parts in contact with the sample are constructed of glass or teflon.
- Heated probe is enclosed in stainless steel tubing.
- Pyrex filter holder contains a 0.3µm - 10 cm nominal diameter filter, in a heated box maintained at 120°C.
- Condenser and XAD-2 resin trap assembly are continuously cooled by circulating ice water.
- Four Greenburgh-Smith impingers are connected in series. The first, third, and fourth are modified by replacing the tips and impaction plates with glass tubes extending to within 13 mm of the flask bottom. The first two impingers contain 100 mL of distilled water and the fourth contains 200 g of silica gel. The impinger assembly is cooled by an ice bath. Note: this assembly does not conform to the requirements of EPS 1/RM/2 but has been used in all previous testing by ATS.
- Vacuum pump, flowmeter, manometer, and control assembly, permit operation of the system as described in the test method.

PROCEDURE

Two trailers were used to transport the test equipment, one for the continuous gas analysis equipment, which is permanently installed in the trailer, and the other for the PAH and particulate train transport, preparation, and operation. Generally, the flue gas sample for the continuous analyzers was withdrawn near the base of the chimney, while the particulate and PAH samples were taken from a point on the chimney eight duct diameters past the last bend. A particulate sample was collected, followed by a PAH sample, with continuous flue gas analysis being done concurrently.

The continuous flue gas sampling train consists of a slotted probe that collects sample from across the duct diameter. The sample passes a dry filter and moisture trap before passing to the trailer by a heated sample line. Remaining moisture is removed by a chiller and silica gel trap. Samples are filtered to remove particulates before entering the analyzers. Analyzers were spanned using primary standard span gases.

Flue gas temperature was determined by a thermocouple located at the flue gas sampling point and, where appropriate, at the exit of the boiler. Flue gas and temperature readings were taken at least every 3 min throughout the PAH and particulate sampling periods.

Particulate stack sampling was conducted in accordance with EPS 1-AP-74-1 Method E. PAH sampling was conducted in accordance with EPS 1/RM/2. Samples were stored in accordance with test requirements for transport to ATS headquarters in Toronto for analysis.

Wood samples were collected from the boiler feed system halfway through each test. The sample was placed in a plastic bag, then placed in a metal container for transport to the CANMET laboratory where moisture content, ultimate analysis, and calorific value were determined in accordance with ASTM procedures.

The developers and operators had very limited previous access to test equipment for optimization of performance of the units, and the time constraints of the test program (two days for each site including travel and setup) did not permit fine tuning of the systems in advance of the testing. At several sites, developers and/or operators observed the testing, and obtained valuable information from the real-time flue gas analysis. They were sometimes able to make adjustments to improve system performance and, as noted below, in some cases made adjustments while test equipment was being changed. The resulting improvements mean that in some cases pollutants measured early in the testing are overstated compared with potential levels. Specifics for each site are noted below.

Bio-Blast 75kW Unit is rather large for the heat demand of the house where it is installed. It was tested during the night to maximize load, and domestic hot water was dumped when boiler water temperature began to approach the high limit. The cycle controller was set to provide 8 s of fuel feed every 26 s. Particulate sampling was conducted for 1 h, with the system being put on hold-fire between traverses. The sampling was carried out in the flue pipe exiting the boiler, and did not provide for 8 duct diameters upstream and 2 diameters downstream of the sample port. Accordingly, the number of sample points were increased in accordance with the test protocol. Before beginning the PAH testing the secondary air port in the combustion chamber was blocked and the combustion air blower inlet opening was reduced.

Bio-Blast 125 kW Unit (heating the floors of a pig barn) has a reasonable load for its size, while a large thermal lag makes this application well suited to this type of heating system. The flue exits straight up in a building having a high ceiling, making it possible to test indoors. Particulate sampling was conducted with the feed controls set at 40 s on/30 s off intervals while for the PAH sampling the interval was changed to 20 s on/15 s off (to try and reduce periodic cycling in flue gas readings) together with a slight reduction in the secondary air setting. Between the first and second PAH traverse the grates were poked to remove ash and clinker.

440 kW When the test crews arrived on site, difficulties were being experienced with this unit. Smoke emissions were readily visible. The operator thought the performance degradation was due to poor quality fuel. The fuel had a $104\%_{db}$ moisture content, and lumps of ice were apparent when the fuel was examined. This unit was the first test site and, though the particulate sampling had to be conducted then, the PAH testing was deferred until the end of the test program when better fuel was available. The test equipment arrived on site the afternoon before the PAH testing was conducted. This allowed the operator to make adjustments to the system, primarily improving the sealing of the drying zone.

A backhoe excavating for the provincial Environment Ministry was in operation adjacent to the boiler shed during the last half hour of the test. It is unclear whether the operation of this machine affected test results.

The unit is designed to accommodate a significant expansion of the hotel where it is located. Therefore it is considerably oversized for the current demand. During testing it was necessary to continuously dump domestic hot water to avoid cycling to hold-fire.

Sylva 600 kW Unit provides heat to a composite high school. Since it was tested on the weekend more flexibility in loading was possible then might have been the case otherwise; however some complications occurred in overriding the automated load management system. The unit had shut down the night before the test crew arrived and had to be manually restarted. However steady-state conditions were reached fairly quickly. No problems were encountered in maintaining operation during testing beyond the need to go to low fire when changing traverses or between tests to avoid overheating the school. This system uses a continuously variable D.C. feed motor, which was set to 4.0 rpm for testing, or about 4.25 kg/m.

KMW 1800 kW Since the unit is normally base loaded, it was possible to operate it at the normal cycling interval for the time of year with adequate load. The unit vents through a rather long rectangular duct into a common manifold serving the oil-fired boilers used for peaking, from which the duct exits into a brick chimney. The only location feasible for testing (in the duct leading to the manifold) did not meet the 8 and 2 duct diameter requirement, necessitating additional sampling points (25 in all) in order to comply with the Source Test Code requirements.

RESULTS

Figures 3 to 12 show the instantaneous carbon dioxide, oxygen, carbon monoxide, and flue gas temperatures for the test periods.

Table 1 summarizes the average flue gas values and Table 2 shows boiler performance as determined from the stack measurements. Table 3 gives flue gas emissions, Table 4 gives particulate emissions, and Tables 5 and 6 give PAH emissions. The are some irregularities in the plots due to the following factors:

75 kW:

- The absence of high CO peaks after 01:55 followed adjustments to the primary and secondary air supplies to the system (Table 2 and Fig. 4).

125 kW:

- The decrease in CO levels for the second traverse of the PAH testing followed deashing of the grate (Fig 6).

440 kW:

- No CO levels were available for the first particulate traverse. Average values for this test are based on results for the second traverse only (Fig 7).

- The decrease in CO emission levels between the two tests followed the use of better quality fuel and extensive sealing of the system to prevent uncontrolled air entry. The CO levels in the second test were about a twentieth of those in the first, and HC levels about a tenth.

600 kW:

- The CO levels for the PAH tests were less than half those for the particulate tests. This could be attributable to changes to the system (primarily adjustments to the extraction blower) or to a change to a CO analyzer with a lower range.

Wood moisture content results for the two samples from each unit are summarized in Table 2.

All units showed fluctuation in flue gas constituent levels, including CO levels. These appeared to corresponded to cycling of the fuel feed system. While some systems would have a small range, others showed much larger swings.

CONCLUSIONS

Prior to the test program, equipment settings were made primarily based on visual observation of smoke stack emissions. During set-up or testing, several operators were able to significantly reduce pollutant emissions by making control or operational adjustments based on real-time flue gas analyzer readings. The ease with which performance was improved indicates the pressing need for proper analytical equipment for product development and setup in order to optimize the performance of these units.

One unit had considerably higher emission levels than the others. However, the operator was able to improve performance considerably between the particulate and PAH tests. He also was able to identify design changes likely to further improve performance but which could not be made in the time available. With CO and HC reductions of more than an order of magnitude and a change from readily visible smoke emissions to barely visible emissions, it is likely the particulate emission levels would have been significantly lower if another test had been conducted.

All other units had emission levels well below what would be anticipated based on experience with domestic or industrial systems.

ACKNOWLEDGEMENTS

This program would not have been possible without the cooperation of a number of people. The authors would like to acknowledge Nick La Valle and Jon Lennartz of Air Testing Services Inc. for their painstaking work during the testing. Thanks to Norman Hall, Vince Court, Eldon King, Carl Brothers, Bruce McCallum, and Rob Brandon who made a hectic schedule work, and to Sandor Derrick, who arranged the financial and moral support to make the whole project possible.

Table 1: Average flue gas analysis values

Unit nominal size (kW)	CO_2 %	O_2 %	CO ppm	NO_x ppm	SO_2 ppm	HC ppm	Temp °C
75	6.7	13.6	548	78	<5	101	260
	9.4	10.9	329	109	<5	72	277
125	9.0	11.3	614	78	<5	497	304
	8.9	11.4	527	74	<5	9	293
440	10.3	9.5	18815	34	125	555	149
	14.1	6.0	1126	51	11	65	187
600	8.1	12.5	73	61	9	43	251
	8.2	12.3	29	59	<5	14	241
1800	11.4	9.1	44	123	<5	3	266
	11.1	9.2	63	129	7	406	264

Table 2: Boiler performance

Unit nominal size	Fuel H_2O	Burn rate dry basis	Excess air	Effic.	Test output
(kW)	(% wb)	(kg/h)	(%)	(%)	(kW)
75	40	12	186	59	37
	39	15	107	65	55
125	42	17	113	56	52
	42	18	119	58	57
440	51	32	56	56	99
	36	34	38	73	138
600	47	138	141	58	442
	49	131	138	59	425
1800	46	535	71	63	1855
	46	530	74	63	1837

Table 3 - Flue gas emissions

Unit nominal size (kW)	CO		HC		NO_x		SO_2	
	g/h	g/MJ	g/h	g/MJ	g/h	g/MJ	g/h	g/MJ
75	105	0.46	11	0.049	25	0.109	0	0.000
	61	0.20	8	0.025	34	0.110	0	0.000
125	131	0.39	60	0.179	27	0.081	0	0.000
	121	0.34	1	0.003	28	0.079	0	0.000
440 [1]	5645	8.85	95	0.149	17	0.026	85	0.134
[2]	313	0.46	10	0.015	23	0.034	7	0.011
600	137	0.05	90	0.033	291	0.106	69	0.025
	52	0.02	16	0.006	176	0.068	0	0.000
1800	212	0.02	11	0.001	1090	0.103	0	0.000
	315	0.03	11	0.001	1144	0.109	84	0.008

1 as found

2 after adjustments and fuel change

Table 4 Particulate emissions

Unit nominal size		Emissions	
(kW)	g/h	g/MJ	mg/Sm^3@12% CO_2
75	11	0.047	94.8
125	11	0.032	76.4
440	270	0.423	1408.1
600	126	0.046	87.7
1800	533	0.050	148.7

Table 5 PAH emissions - µg/DSm³

			Unit	(kW)		
	75	125	440	600	1800	Blank
Acenaphthene	1.09	0.167	102.	0.060	<0.06	33.8
Acenaphthylene	16.6	0.186	1060.	0.124	0.218	129
Acridine	<0.012	<0.011	<4.63	<0.009	<0.011	1.02
Anthracene	3.63	0.297	211.	0.053	<0.06	59.5
Benzo(a)Anthracene	2.38	0.204	650.	<0.009	<0.06	16.2
Benzo(b)Fluoranthene	4.35	0.796	46.7	0.051	<0.18	3.08
Benzo(k)Fluoranthene	<0.036	<0.032	81.2	<0.028	<0.18	6.41
Benzo(b)Fluorene	<0.048	<0.043	<18.5	<0.028	<0.24	4.1
Benzo(g,h,i)Perylene	1.93	<0.043	<19.5	<0.037	<0.24	2.82
Benzo(a)Pyrene	1.78	<0.043	34.7	<0.037	<0.24	6.15
Benzo(e)Pyrene	1.06	0.175	17.	0.023	<0.09	2.82
Chrysene/Triphenylene	1.44	0.425	82.2	<0.009	<0.06	7.18
Coronene	<0.030	<0.027	<11.6	<0.023	<0.15	2.56
Dibenzo(a,h)Anthracene	0.118	0.088	<23.3	<0.046	<0.3	10.5
9,10-Dimethylanthracene	<0.018	<0.016	6.95	<0.014	<0.09	1.54
7,12-Dimethylbenz(a)Anthracene	<0.030	<0.027	11.6	<0.023	<0.015	2.565
Fluoranthene	20.3	3.21	930.	0.331	0.186	95.4
Fluorene	3.	0.255	324.	0.0758	0.5	75.1
Indeno(1,2,3-cd)Pyrene	1.39	0.066	<24.5	<0.046	<0.3	5.13
2-Methyl-Anthracene	<0.012	<0.012	<4.63	<0.009	<0.06	1.02
2-Methyl-Phenanthrene	<0.012	<0.010	<4.63	<0.009	<0.06	1.02
Naphthalene	42.4	26.6	463	3.02	12.3	92300.
Perylene	0.154	<0.021	<9.4	<0.018	<0.12	2.05
Phenanthrene	28.4	60.39	1830	0.66	<0.06	195.
Pyrene	18.5	1.98	148	0.204	<0.06	62.

Table 6 - PAH emissions µg/h

			Unit	(kW)	
	75	125	440	600	1800
Acenaphthene	163.	30.8	22500.	87	<261.
Acenaphthylene	2480.	34.2	235000.	181	949.
Acridine	<1.8	<1.95	<1020.	<13.4	<47.4
Anthracene	541.	54.7	46500.	76.9	<261.
Benzo(a)Anthracene	355.	37.6	144000.	<13.4	<261.
Benzo(b)Fluoranthene	648.	147	10300.	73.6	<783.
Benzo(k)Fluoranthene	<5.4	<5.86	17900.	<40.1	<783.
Benzo(b)Fluorene	<7.2	<7.82	<4090.	<40.1	<1044.
Benzo(g,h,i)Perylene	287.	<7.82	<4300	<53.5	<1044.
Benzo(a)Pyrene	265.	<7.82	7670.	<53.5	<1044.
Benzo(e)Pyrene	158.	32.2	3750.	32.8	<391.
Chrysene/Triphenylene	241.	78.2	18200.	<13.4	<261.
Coronene	<4.5	<4.89	<2560.	<33.4	<652.
Dibenzo(a,h)Anthracene	17.6	16.1	<5160.	<66.9	<1300.
9,10-Dimethylanthracene	<2.7	<2.93	1540.	<20.1	<391.
7,12-Dimethylbenz(a)Anthracene	<4.5	<4.89	2560.	<33.4	<652.
Fluoranthene	3020.	590.	206000.	482.	810.
Fluorene	446.	46.9	71600.	110.	2610.
Indeno(1,2,3-cd)Pyrene	207.	12.2	<5410.	<66.8	<1300.
2-Methyl-Anthracene	<1.8	<1.95	<1020.	<13.4	<261.
2-Methyl-Phenanthrene	<1.8	<1.95	<1020.	<13.4	<261.
Naphthalene	6310.	4890.	102000.	4390.	53600.
Perylene	23.	<3.91	<2080.	<26.8	<522.
Phenanthrene	4240.	1180.	404000.	961.	<261.
Pyrene	2750.	364.	32600.	298.	<261.

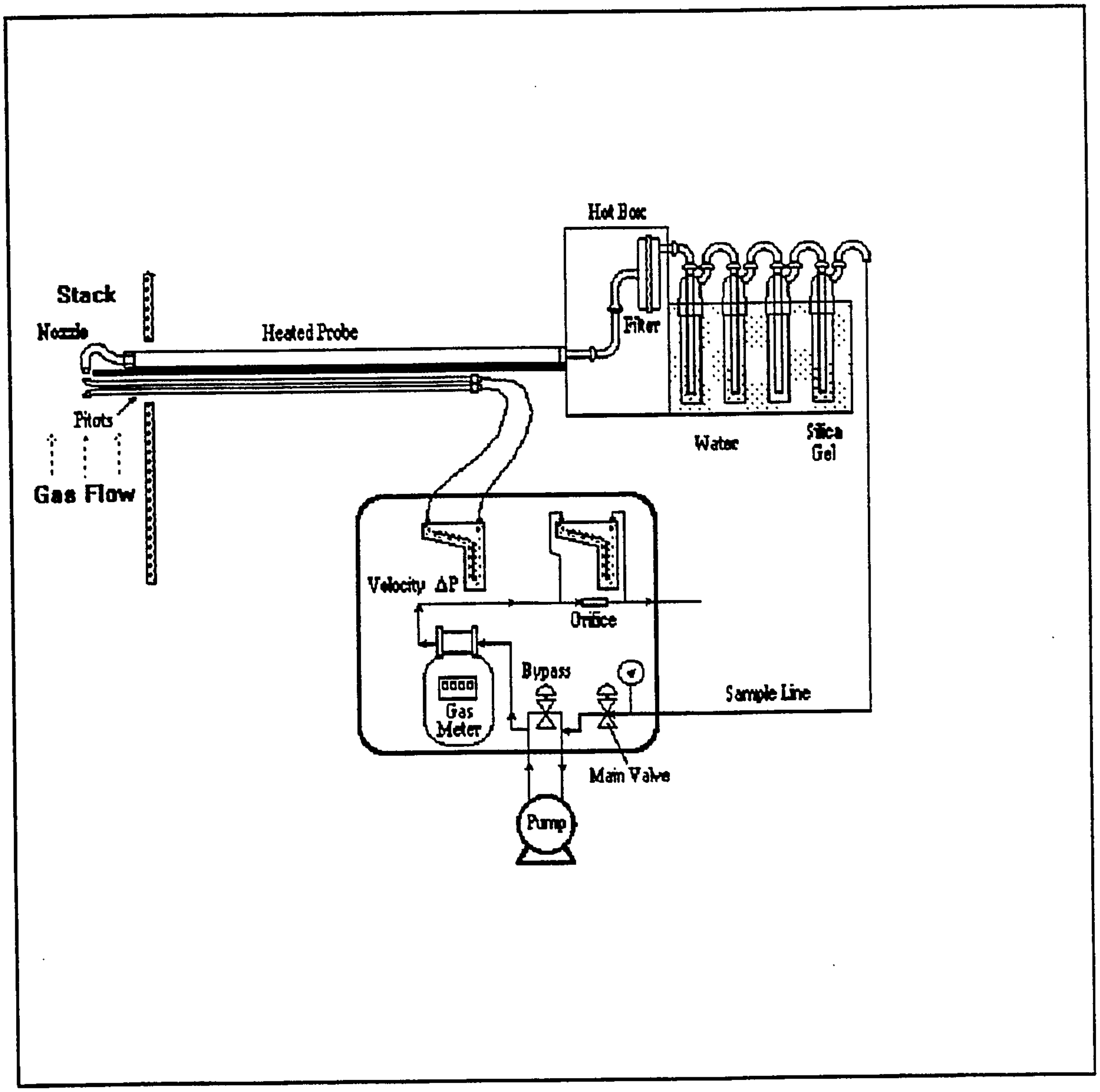

Fig. 1 - Method 5 particulate sampling train

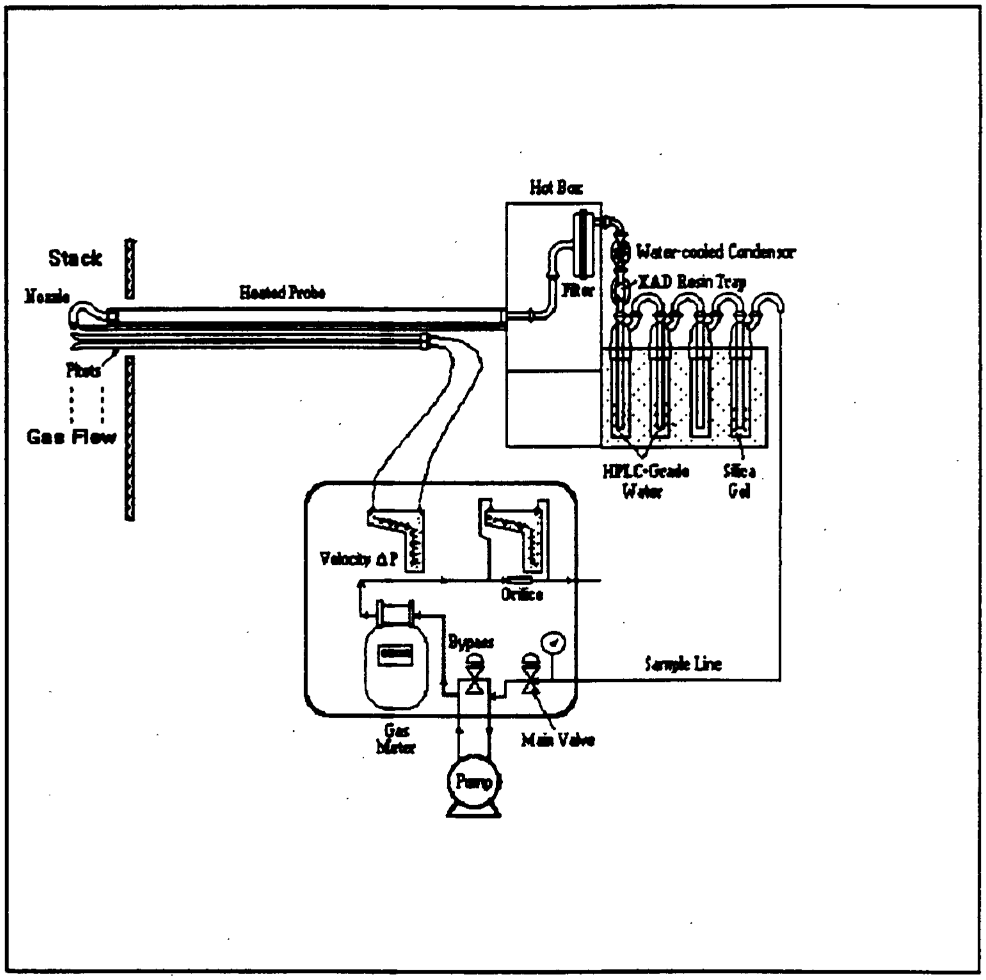

Fig. 2 - Modified method 5 PAH sampling train

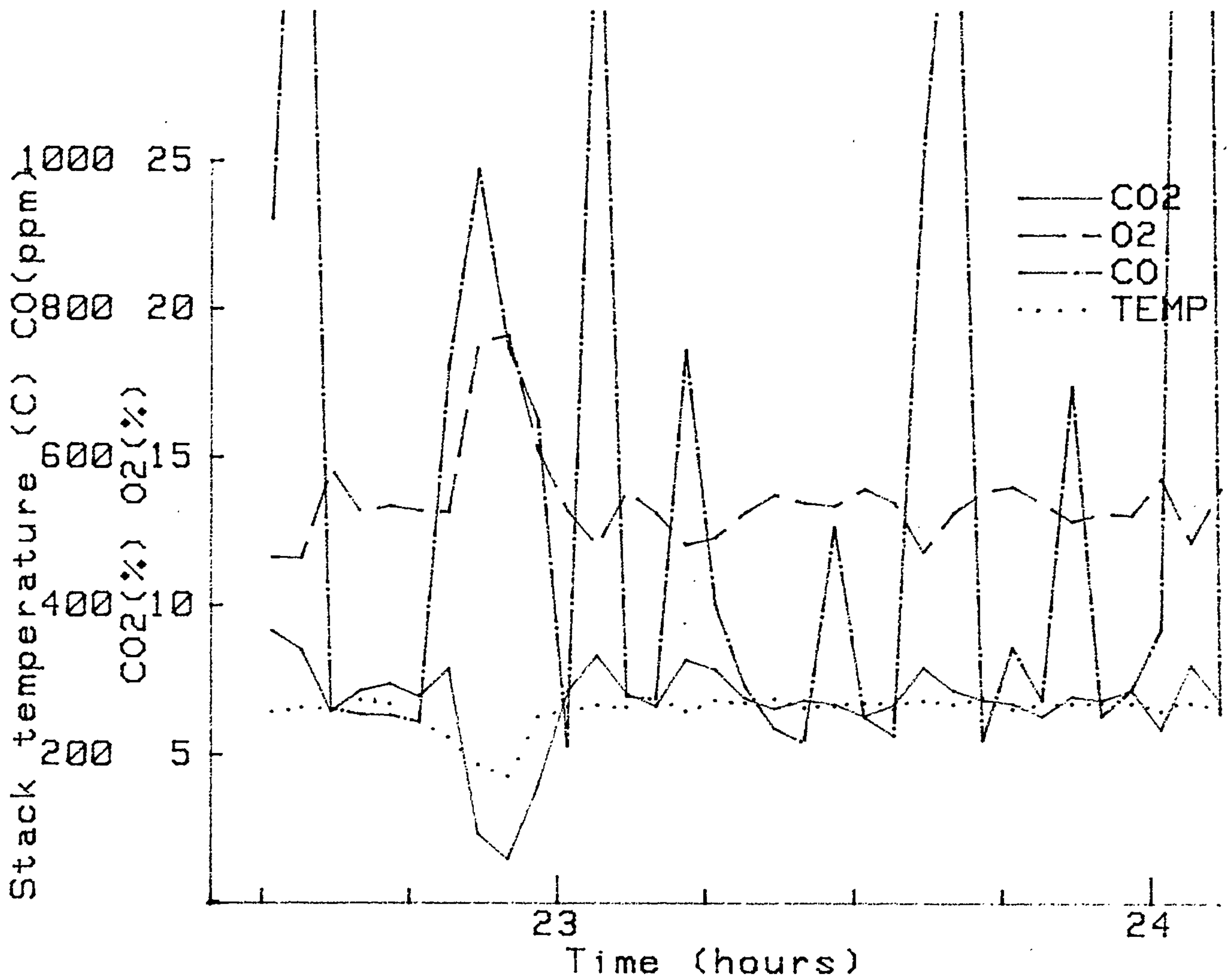

Fig. 3 - 75 kw unit flue gas values during particulate testing

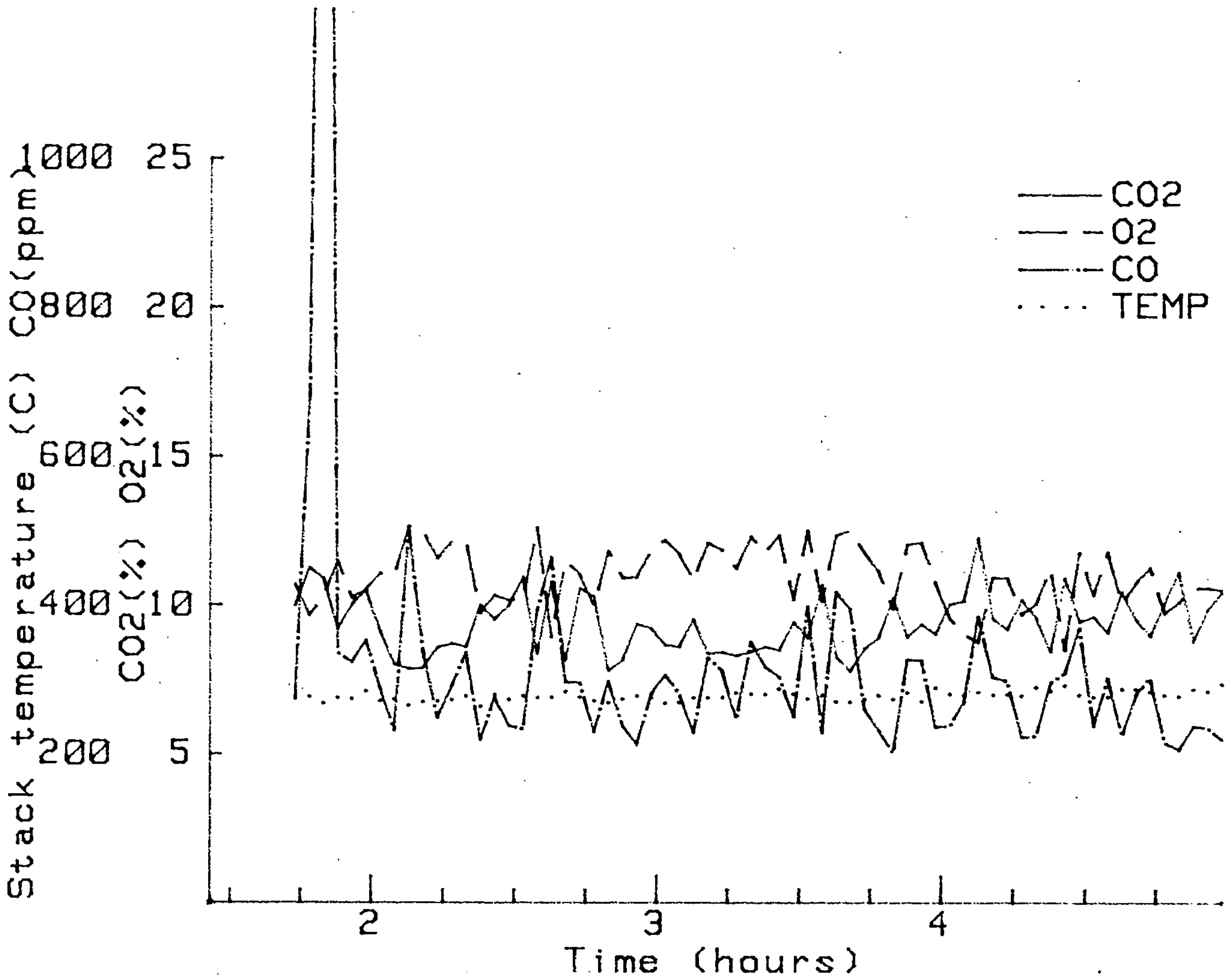

Fig. 4 - 75 kW unit flue gas values during PAH testing

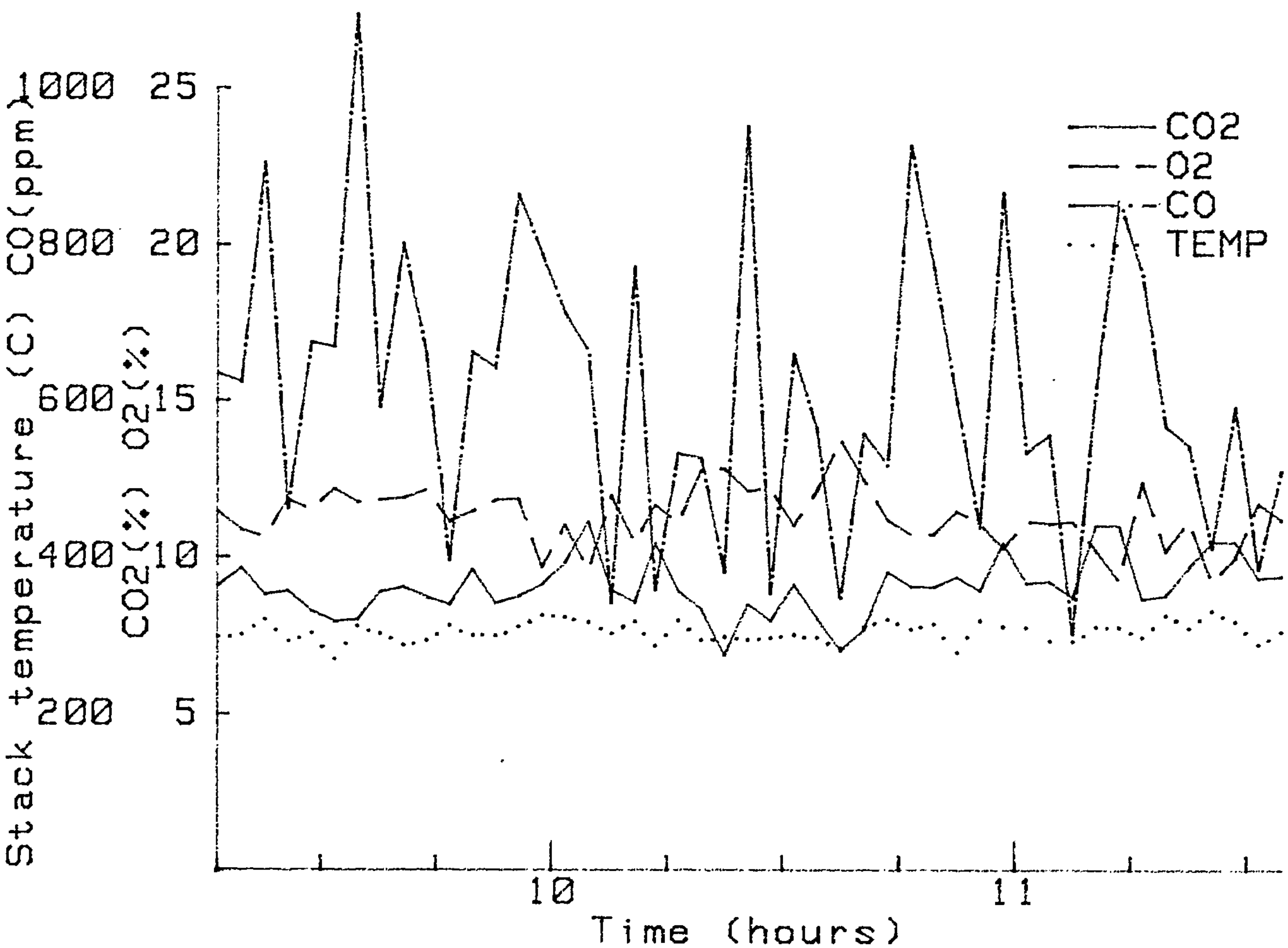

Fig. 5 - 125 kW unit flue gas values during particulate testing

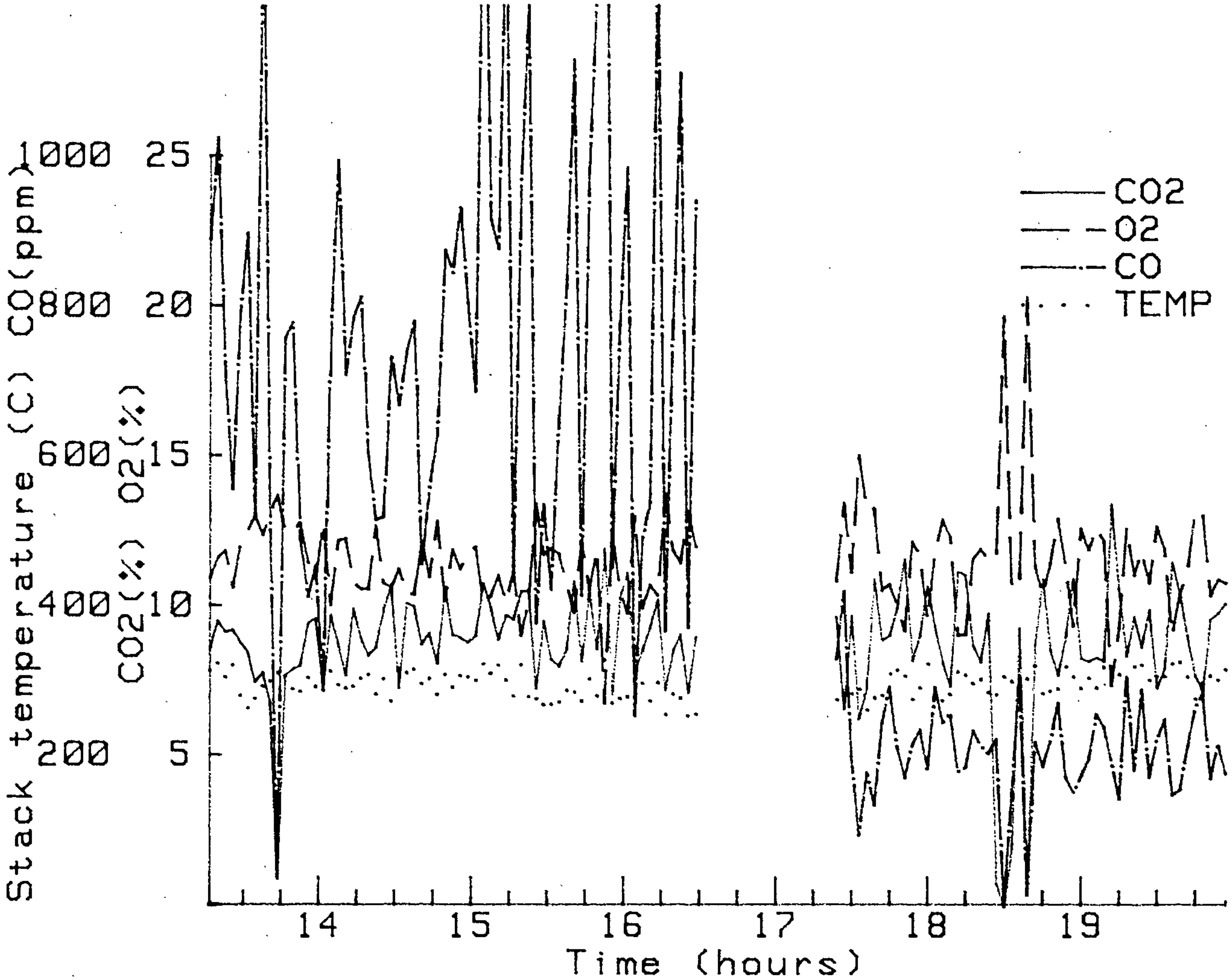

Fig. 6 - 125 kW unit flue gas values during PAH testing

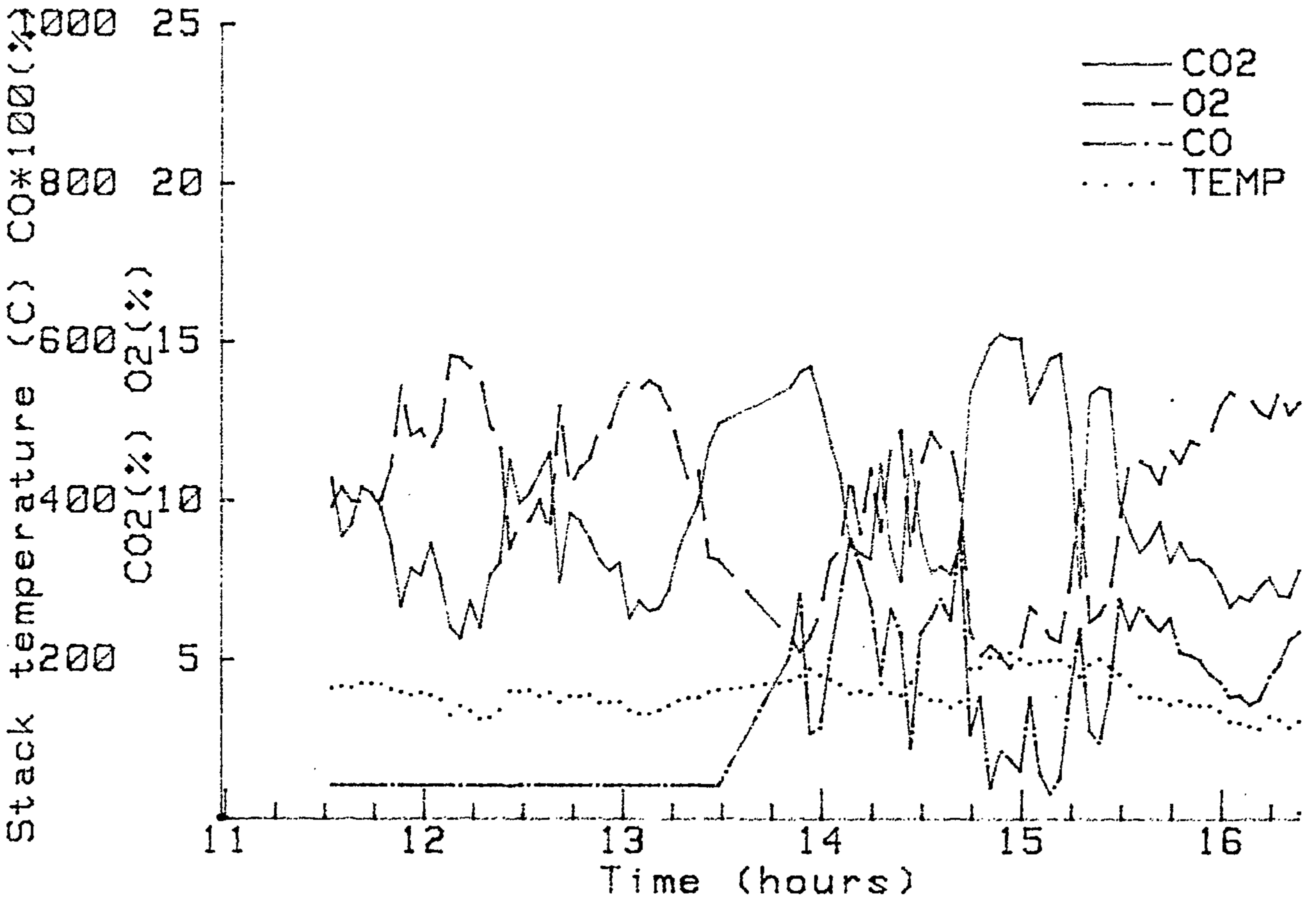

Fig. 7 - 440 kW unit flue gas values during particulate testing

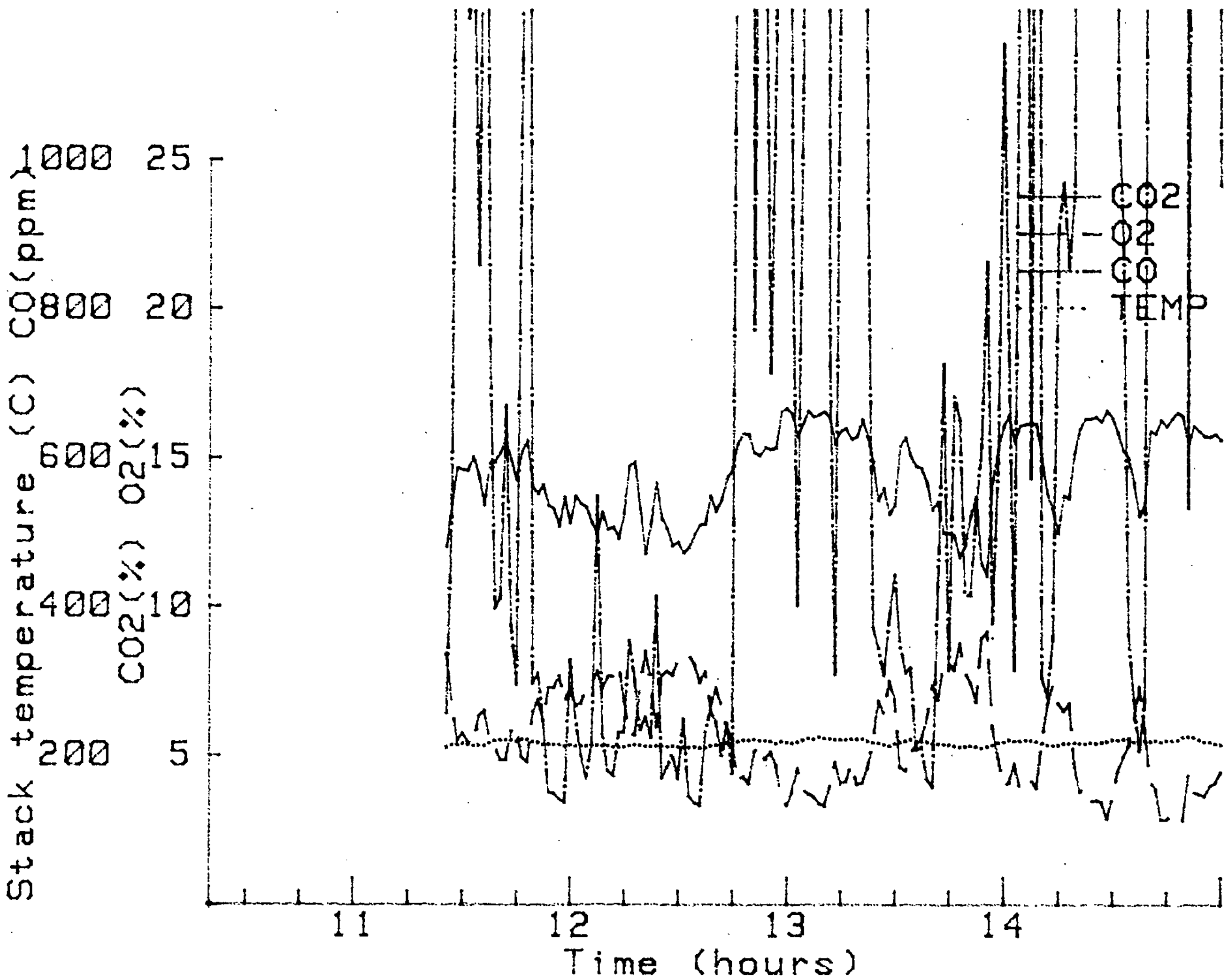

Fig. 8 - 440 kW unit flue gas values during PAH testing

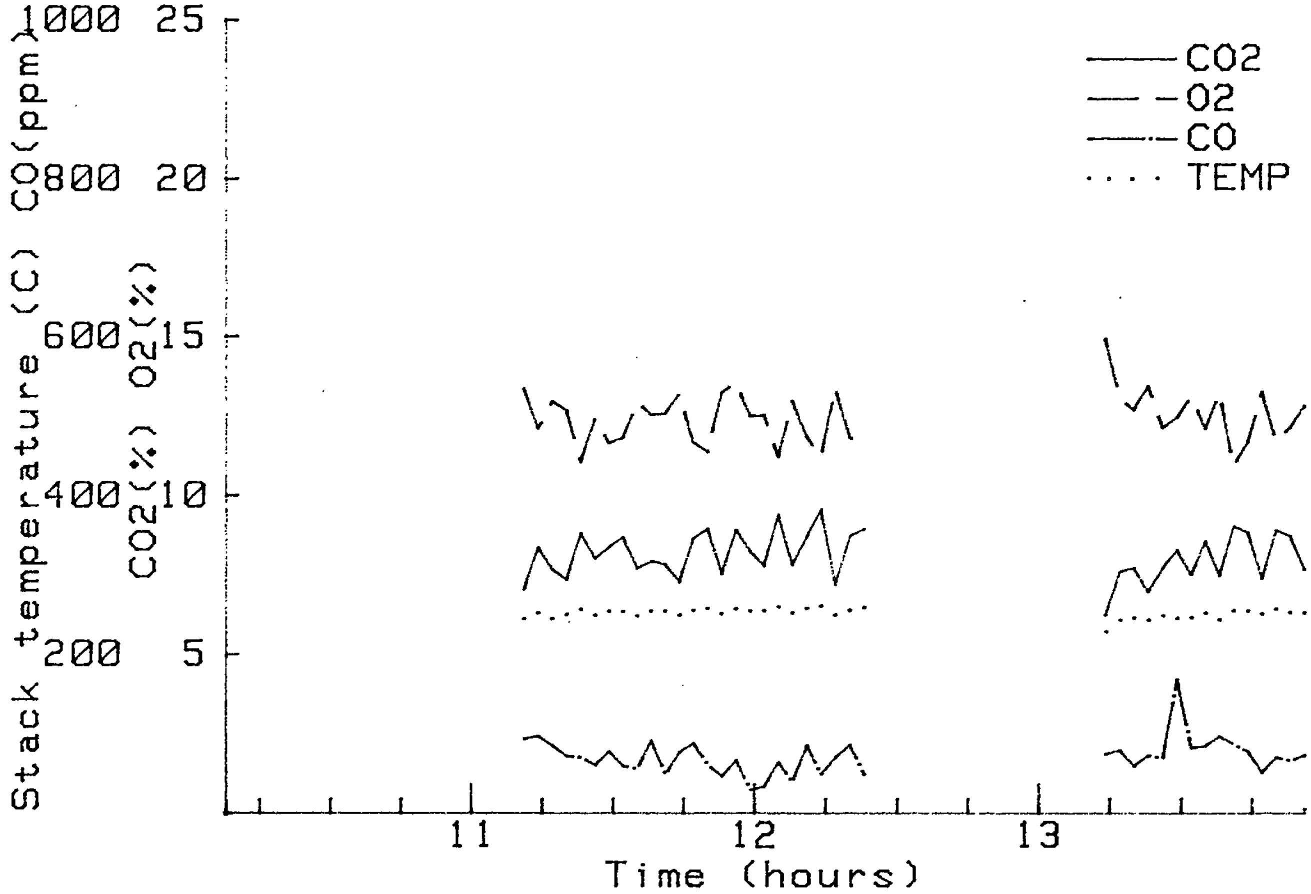

Fig. 9 - 600 kW unit flue gas values during particulate testing

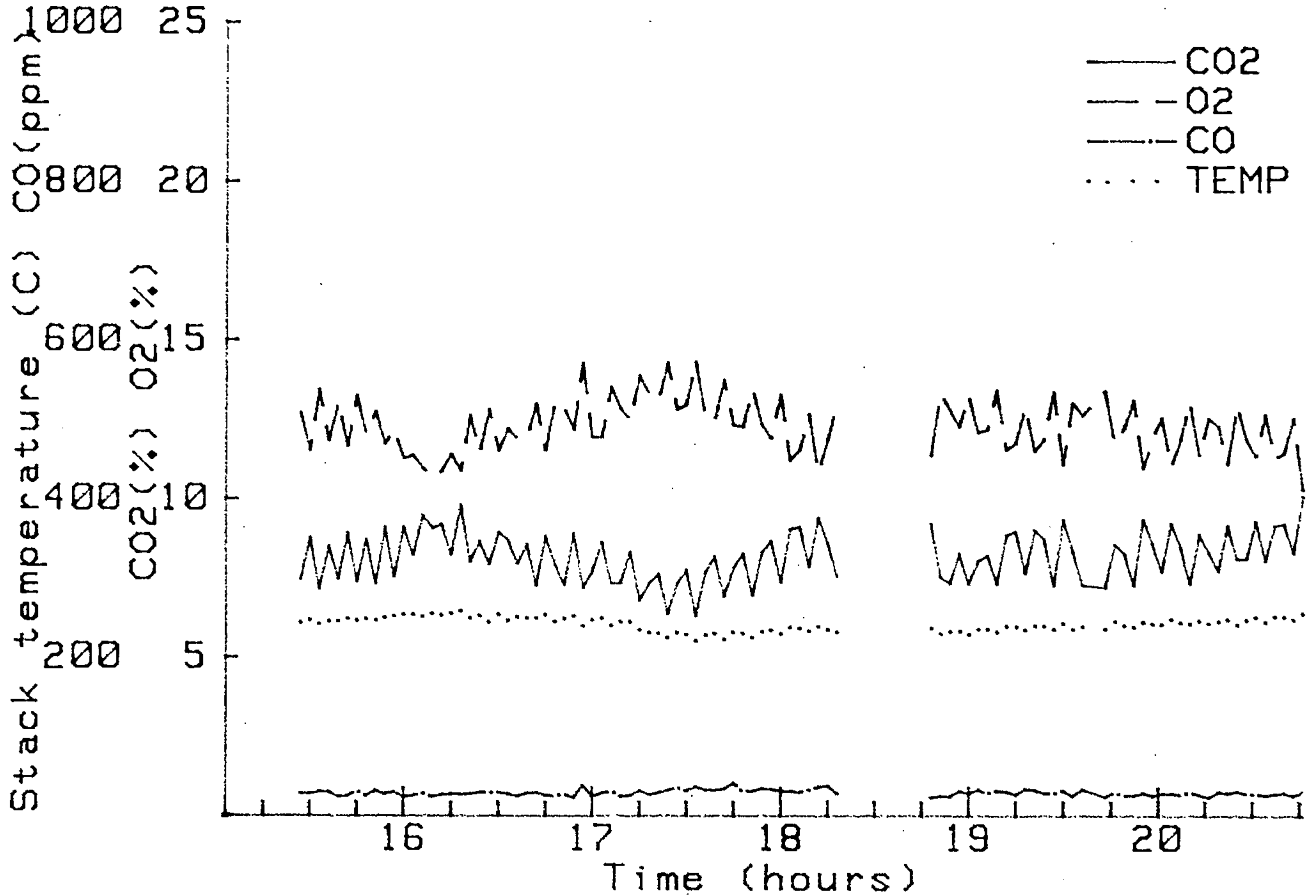

Fig. 10 - 600 kW unit flue gas values during PAH testing

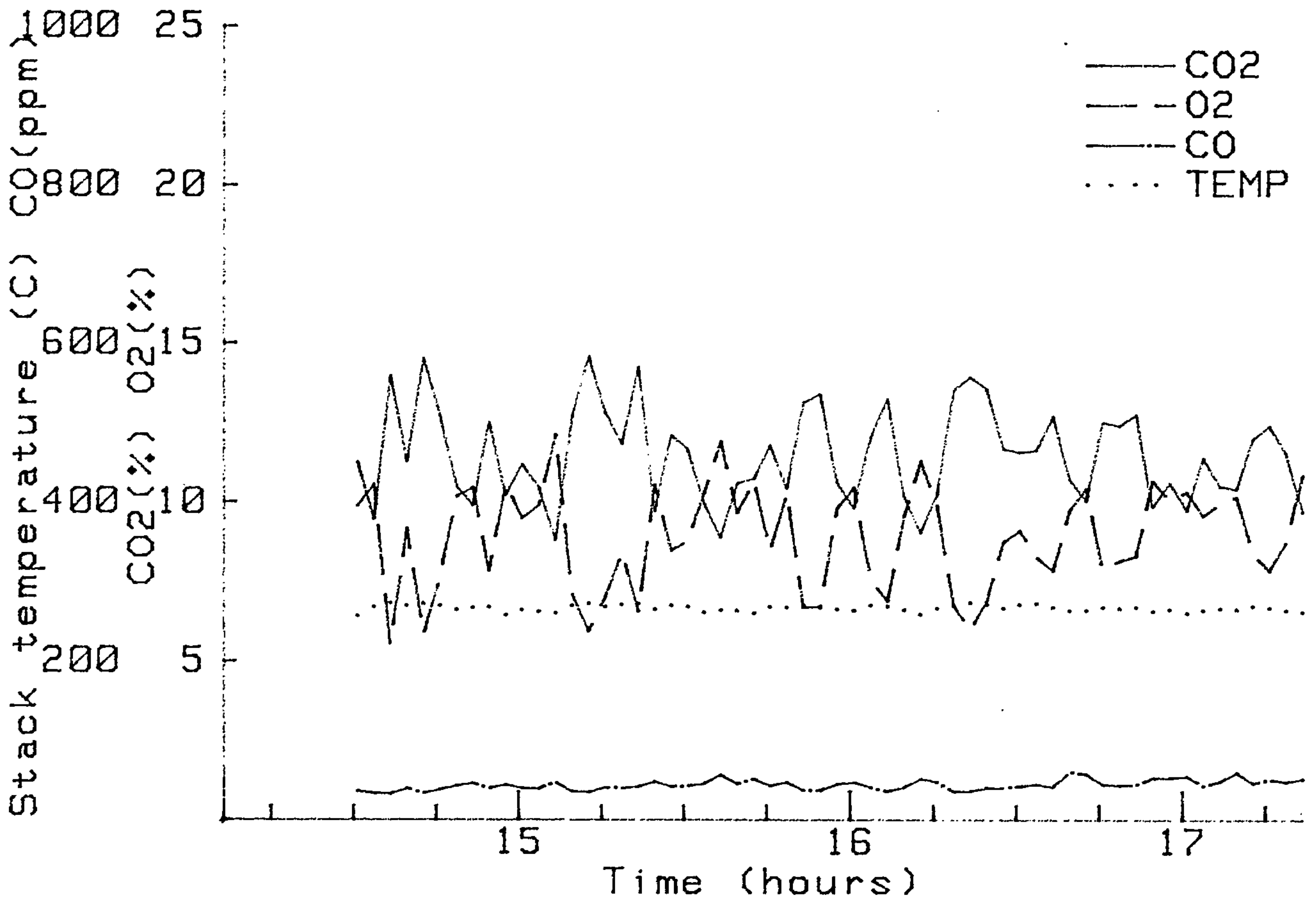

Fig. 11 - 1800 kW unit flue gas values during particulate testing

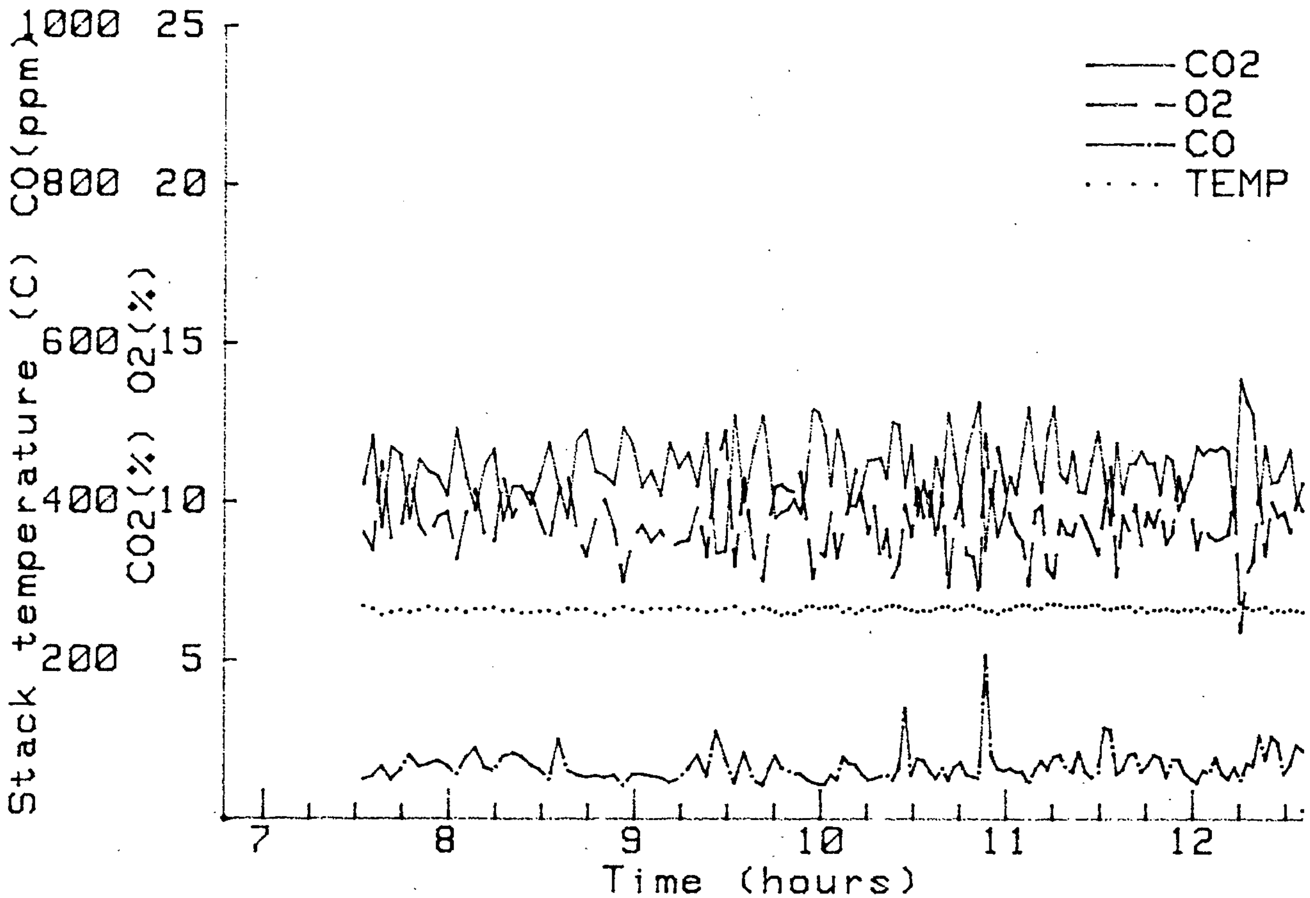

Fig. 12 - 1800 kW unit flue gas values during PAH testing