Attachment 1A

ORIMULSIONR DEMONSTRATION TESTS AT NEW BRUNSWICK, CANADA: A NEW TECHNOLOGICAL STEP TOWARDS BITUMEN COMMERCIALIZATION

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INTRODUCTION

The largest known hydrocarbon accumulation in the world is located in Venezuela, north of the Orinoco river overlaying the eastern Venezuelan basin. It is estimated at 1.2 x 10^{12} barrels, 267 billion barrels of which are estimated to be recoverable reserves according to current technology. The Orinoco belt holds proven reserves of 26 billion barrels of extra-heavy hydrocarbons and bitumen. The energy content of these reserves is equivalent to approximately 4% of the world's conventional proven reserves of light, medium, and heavy oil. However, because the yield of light hydrocarbons is extremely low for these reserves and handling characteristics generally preclude direct utilization, the economics of major scale development have been unfavorable.

INTEVEP, S.A. and LAGOVEN, S.A. (affiliates of Petroleos de Venezuela - PDVSA) have developed a means for producing a premium fuel from bitumen in the form of a bitumen-in-water emulsion: ORIMULSION^R. The primary benefit of ORIMULSION^R is that the viscosity is reduced to a value similar to heavy fuel oil (at 122 ^{0}F), allowing its utilization with conventional firing equipment for power generation. INTEVEP and LAGOVEN have pursued an aggressive program to demonstrate the commercial viability of ORIMULSION^R since 1986. In addition to testing at Intevep's Los Teques, Venezuela test facility, pilot scale combustion tests (1,2) have also been conducted in the U.S. by Combustion Engineering Inc. and by Babcock and Wilcox, in England by NEI International Combustion Ltd., and in Japan by Mitsubishi Heavy Industries. Currently, INTEVEP and LAGOVEN are conducting the first full scale demonstration of ORIMULSION^R in cooperation with the New Brunswick Electric Power Commission (NB Power) in a 100 MW utility boiler at the Dalhousie Thermal Generating Station. NB Power is a publicly owned utility which has extensive experience in the utilization of a wide variety of fuels, including Venezuelan heavy oils. The objectives of the program are to demonstrate all aspects of ORIMULSION^R utilization in large steam generators under commercial on-line conditions, including fuel production and user operation, and to develop a data base for evaluating future applications. Approximately 500,000 barrels of ORIMULSION[R] have been burned at Dalhousie since September, 1988, with excellent overall results. This paper discusses preliminary short-term test results obtained from the first half of the Dalhousie demonstration.

FUEL PROPERTIES

ORIMULSION[R] is an oil-in-water emulsion based on the ORINOCO bitumen. As shown in Figure 1, it consists of a suspension of small droplets of bitumen in a continuous water phase. The size of the bitumen droplets in the emulsion is nominally 14 microns. ORIMULSION[R] viscosity is several orders of magnitude lower than the parent bitumen because of the continuous water phase. The water content is nominally 29% by weight. The stability of the emulsion is maintained by the use of a proprietary surfactant which was developed by INTEVEP specifically for this fuel. The surfactant prevents the oil droplets from agglomerating and coalescing, which could result in inversion or breaking of the emulsion. While the viscosity of ORIMULSION[R] is comparable to that of heavy fuel oil, the unique characteristics of emulsions require modifications to normal handling procedures to prevent inversion or breaking of the emulsion. Inversion of the emulsion can result if it is passed through a high shear region, such as pressure regulating valves or other areas of high pressure drop (above 100 psig), or if it is contaminated with normal fuel oil. Breaking also can occur if the emulsion is heated above 180 ^{0}F. These limitations can generally be accommodated in conventional firing systems with relatively minor changes.

Table 1 compares the properties of ORIMULSION[R] and the Venezuelan heavy fuel oil normally fired at Dalhousie. Analysis of ORIMULSION[R] delivered to the Dalhousie plant indicated that the water content is approximately 29% by weight. The gross (high) heating value (GHV) of ORIMULSION[R] is lower than fuel oil primarily due to the water. On a dry basis, the heating values are similar. The carbon/hydrogen ratio of ORIMULSION[R] is similar to the normal heavy fuel oil, while the sulfur content per Btu is approximately 40% higher. The other primary difference is that the ash content of ORIMULSION[R] is higher than fuel oil. Both the Venezuelan heavy fuel oil and ORIMULSION[R] have high concentrations of vanadium and nickel, typical of many South American heavy oils. However, magnesium is added to ORIMULSION[R], at an inherent Mg/V ratio in the fuel of approximately 1.4 by weight, which provides built-in protection against high temperature vanadium corrosion without separate injection of magnesium oxide. Nitrogen content of ORIMULSION[R] is also slightly higher than fuel on a Btu basis.

HOST BOILER

Dalhousie Unit 1 utilizes a tangentially-fired natural circulation boiler built by Combustion Engineering and began commercial operation in September, 1969. The steam generator maximum capacity rating (MCR) is 690,000 lb/hr at 1825 psig and 1005 ^{0}F of superheat, with a single reheat stage flow of 633,000 lb/hr and 1005 ^{0}F superheat. The boiler is a semi-tower design (Figure 2), with a relatively deep primary superheater tube bank and a split economizer bank. The boiler was designed to be coal capable, although it has only been fired on fuel oil. There are three elevations of oil burners in the corners. Because of the coal-capable design, the burners are located at a higher elevation than normal relative to the overall furnace dimensions resulting in a large furnace volume below the burners. Reheat steam temperature is controlled via oil burner tilt, while main steam temperature is controlled with attemperation spray. Reheat attemperation is also available if necessary. Tube bank spacing and velocities are typical of coal designed boilers, and bare tubes are used throughout. The heat release per furnace volume is 22,400 Btu/hr-ft^3 and the heat release per effective projected radiant surface (EPRS) is 114,000 Btu/hr-ft^2 at design MCR with fuel oil. The unit is equipped with two regenerative air preheaters, and has 14 existing sootblowers located in the tube banks.

FUEL HANDLING

A schematic of the fuel handling system is illustrated in Figure 3. Fuel is delivered to the plant by ocean tanker, and unloaded using positive displacement pumps through a 2.5 mile long, 12 inch diameter pipeline. Because the climate is severe in the winter (ambient temperatures of -20 to -40 ^{o}F), the pipeline is electrically heat traced to prevent freezing. The existing unloading system was not modified for the ORIMULSION^R demonstration.

One of the three existing 170,000 barrel oil storage tanks was modified for ORIMULSION^R. The existing steam heating system for the storage tank and in-line heaters was replaced with a circulating glycol system, limiting maximum heater surface temperature to 160 ^{o}F to avoid breaking the emulsion. The existing auxiliary steam supply was utilized for glycol heating. The tank was also fully insulated. Fuel temperature is maintained at approximately 90 ^{o}F in the storage tank, and is raised to 135-140 ^{o}F at the burners for atomization. Because a larger volume of ORIMULSION^R than fuel oil is required for the same heat input to the boiler, two screw type booster pumps were added to increase the capacity of the fuel delivery system. In-line mixers were also added to the fuel delivery lines for viscosity control by means of controlling particle size distribution; however, it has not been necessary to utilize them since the stability of the ORIMULSION^R has been extremely good. The plant normally fires heavy fuel oils with high vanadium and nickel content, therefore the existing MgO addition system was retained. Since ORIMULSION^R is sensitive to high shear, variable speed drives were installed on the existing main fuel pumps to control the flow of ORIMULSION^R to the burners, eliminating the high pressure drop across the existing flow control system. The fuel recirculation line back to the storage tank is not utilized.

Experience obtained thus far has indicated no major problems with handling or stability of ORIMULSION^R during storage over periods up to 3 months when recommended procedures are followed. The bitumen droplet size and viscosity of the ORIMULSION^R in the storage tank, determined on a daily basis to monitor emulsion stability, have remained within acceptable limits. There have been two inversions of ORIMULSION^R in the fuel lines due to contamination by fuel oil while switching fuels and due to excessive pressure drop across a partially open isolation valve. In both cases, the inverted ORIMULSION^R was succesfully burned in the boiler with no major problems by raising the fuel temperature to 175 ^{o}F.

BURNER DESIGN

Combustion tests were carried out at Combustion Engineering to establish the performance of the existing burner design (2). The only burner modifications required for ORIMULSION^R firing were conversion from mechanical to steam atomization and minor modification of the existing bluff-body diffusers. The burner and atomizer design are illustrated in Figures 4 and 5. The burner air passages were not modified. A stabilizing ring was added to the bluff body diffuser for enhanced flame stability. The atomizer is a standard internal-mix design with enlarged openings to accommodate ORIMULSION^R viscosity at firing temperature and to increase atomizing steam flow.

Table 2 summarizes atomizer performance at the nominal full boiler load. The atomizing steam consumption is relatively high compared to other fuel oil atomizer designs, with 12 lb of steam supplied per 100 lb of fuel fired. ORIMULSION^R temperature at the burners is normally maintained between 125 and 140 ^{0}F for burner front pressures between 270 and 300 psig.

Combustion performance with ORIMULSION^R is considerably better than expected, in that carbon in the fly ash has consistently been below 3%, compared to 30-35% achieved with fuel oil. Provision for fly ash reinjection was made during the retrofit, but this has not been necessary because of the low carbon content of the ash. Flame stability is very good over a range of atomizing steam conditions, and the existing infrared flame scanners have performed with no problems. Figure 6 compares CO emissions for oil and ORIMULSION^R as a function of excess air and atomizing steam/oil pressure differential, obtained early in the test program. Operation at excess O_2 levels well below 1% is possible for both fuel oil and ORIMULSION^R with very low CO emissions. Subsequent optimization of the atomizer with ORIMULSION^R has resulted in excess O_2 levels as low as 0.2% with CO below 300 ppm; however excess O_2 is maintained at approximately 0.5% (CO < 100ppm) during normal operation because the current control system cannot safely maintain lower levels. The optimum excess O_2 with ORIMULSION^R for maximum boiler efficiency is lower than with fuel oil because of lower fly ash carbon content.

BOILER PERFORMANCE

In general, the impact of converting to ORIMULSION^R on boiler performance has been as expected. Table 3 compares typical boiler operating conditions with oil and with ORIMULSION^R at full load. It is possible to achieve design main steam temperatures during ORIMULSION^R firing with low (1%) amounts of main steam (MS) attemperation. In order to maintain hot reheat steam temperature during ORIMULSION^R firing, approximately 2% reheat attemperation as well as maximum downward burner tilt is required. Boiler efficiency is approximately 5% lower with ORIMULSION^R compared to fuel oil, despite lower excess O_2, due to the water in the ORIMULSION^R and the increased temperature of the flue gas at the stack. Net heat rate at full load is approximately 1200 Btu/kWH higher with ORIMULSION^R, primarily due to decreased boiler efficiency and increased reheat attemperation.

Initially, the stack gas temperature with ORIMULSION^R is approximately 50 ^{0}F higher than fuel oil for equivalent boiler load, followed by a period of increasing temperature. The higher initial gas temperature is primarily due to the need for a higher firing rate with ORIMULSION^R to offset the decreased boiler efficiency caused by the water in the fuel. The subsequent rise in flue gas temperatures is due to increased ash deposition with ORIMULSION^R compared to fuel oil. In order to control ash deposits with the existing system, the sootblowers are operated once each shift. After approximately one week of firing, the deposits appear to reach steady state. Fouling in each tube bank section was evaluated by means of fouling probe data and calculation of fouling factors for each section based on plant data. It can be seen in Figure 7 that fouling in the high temperature regions (secondary superheater and reheater) is minimal, and that relatively heavy fouling occurs in the primary superheater and economizer sections. This has been confirmed by visual observations during boiler outage inspections. Surface deposits are effectively controlled with the sootblowers, except in those areas where sootblowers are not currently installed. This is particularly evident at the outlet of the primary superheater and in the economizer. Installation of additional sootblowers in these areas is expected to improve boiler efficiency considerably.

POLLUTANT EMISSIONS

The sulfur content per Btu fired is approximately 40% greater for ORIMULSION® than for fuel oil. Measured SO_2 emissions are commensurate with the sulfur content of the fuel. The ability to reduce SO_2 emission levels using in-furnace limestone injection will be evaluated during the second half of the demonstration. A limestone storage, handling, and injection system, designed by Steinmuller GMBH, has been installed. In order to maintain acceptable particulate emissions using limestone injection, the unit was retrofitted with a Flakt electrostatic precipitator and converted to balanced draft operation. The conversion was accomplished by adding two induced draft fans and associated breaching. Dry ash handling equipment was also installed to remove fly ash from the economizer outlet and the precipitator, and the ash is transported to an established landfill for disposal.

Average opacity during ORIMULSION® firing is generally maintained between 5 to 10% with the precipitator in operation; however, high opacity has been observed when the precipitator is not in operation. Table 4 compares precipitator performance predictions for design and actual operating conditions. Flue gas volumetric flow rate is approximately 7% higher and gas temperature is 100 °F hotter than design conditions, but measured (in-situ) ash resistivity is closer to the optimum value for good precipitator operation due to the low carbon content of the ash. ESP collection efficiency predictions were accomplished using the U.S. EPA-Southern Research ESP performance model (4). Predicted ESP collection efficiency for design conditions using the model agrees well with the manufacturer's predicted value of 96.4%. ESP collection efficiency for actual operating conditions is considerably lower. Actual ESP collection efficiency has not been measured but a preliminary estimate based on dust loading at the stack compared to theoretical dust loading from fuel composition is in good agreement with the predicted value.

NO_x emissions for ORIMULSION® and fuel oil are compared in Figure 8. NO_x emissions are similar for the two fuels and, in general, NO_x emissions are slightly lower with ORIMULSION® than with fuel oil, in spite of the slightly higher fuel nitrogen content. This is probably due to lower peak flame temperatures because of the water in the fuel and lower excess O_2.

PRELIMINARY CONCLUSIONS

The results of the ongoing Dalhousie demonstration obtained thus far have indicated no major problem in converting from heavy fuel oil to ORIMULSION®. Storage and handling experience has been completely satisfactory even during severe climate conditions. Combustion performance has been exceptionally good, with no flame stability or scanner problems and with very high carbon conversion efficiency even with excess O_2 as low as 0.2%. Boiler performance is generally acceptable, but boiler efficiency is lower than expected due to ash deposition. This results in high gas temperatures at the exit of the boiler. Ash deposits appear to be easily controlled by conventional sootblowers, and it is expected that installation of additional sootblowers will restore boiler performance to expected levels. Long term effects of the deposits on corrosion are not currently known, but are expected to be similar to the effects of firing high vanadium fuel oil with anticorrosion additives such as MgO.

FUTURE PLANS

Additional tests are currently in progress at NB Power's Dalhousie Thermal Generating Station to evaluate the impacts of ORIMULSION^R firing on plant performance. Specific tests planned for the second half of the demonstration include evaluation of long-term corrosion impacts via corrosion probe measurements. Additional characterization of fouling trends will be conducted to determine whether additional optimization of the existing sootblowers is possible. Testing with limestone injection is planned to begin in June, 1989 to evaluate the ability to reduce SO_2 emissions. The properties of the fly ash will also be evaluated to assess handling and disposal requirements.

Data from Dalhousie will also be evaluated using boiler performance models to determine the impacts of ORIMULSION^R conversion on thermal performance and steam generation. This information will be used to generalize the effects of ORIMULSION^R conversion to other applications, which are expected to be site-specific. For instance, the relative impacts of converting a coal fired boiler to ORIMULSION^R which is designed to operate with ash deposits in the furnace and on the tube banks may be completely different than for one designed for oil and clean heat transfer surfaces. Table 5 presents a preliminary assessment of ORIMULSION^R firing on a 70 MW coal fired boiler with a tangential firing configuration. The table shows that ORIMULSION^R is expected to produce slightly lower reheat attemperation rates compared to coal, and higher boiler efficiency. This is expected to increase plant heat rate considerably, which would be further enhanced by elimination of coal pulverizing equipment.

ACKNOWLEDGEMENTS

The authors would like to express their thanks and appreciation for the cooperation and dedication of the technical staff at NB Power in conducting this demonstration. In particular, the efforts of Mr. Daryl Daley, Mr. Maurice Legere, Mr. Roger Garvie, Mr. Robert Quondom, Mr. Rod Pickles, and Mr. Phillip Whelan are appreciated. The authors also wish to thank INTEVEP, S.A., LAGOVEN, S.A., and Petroleos de Venezuela, S.A. for approving the presentation of this paper.

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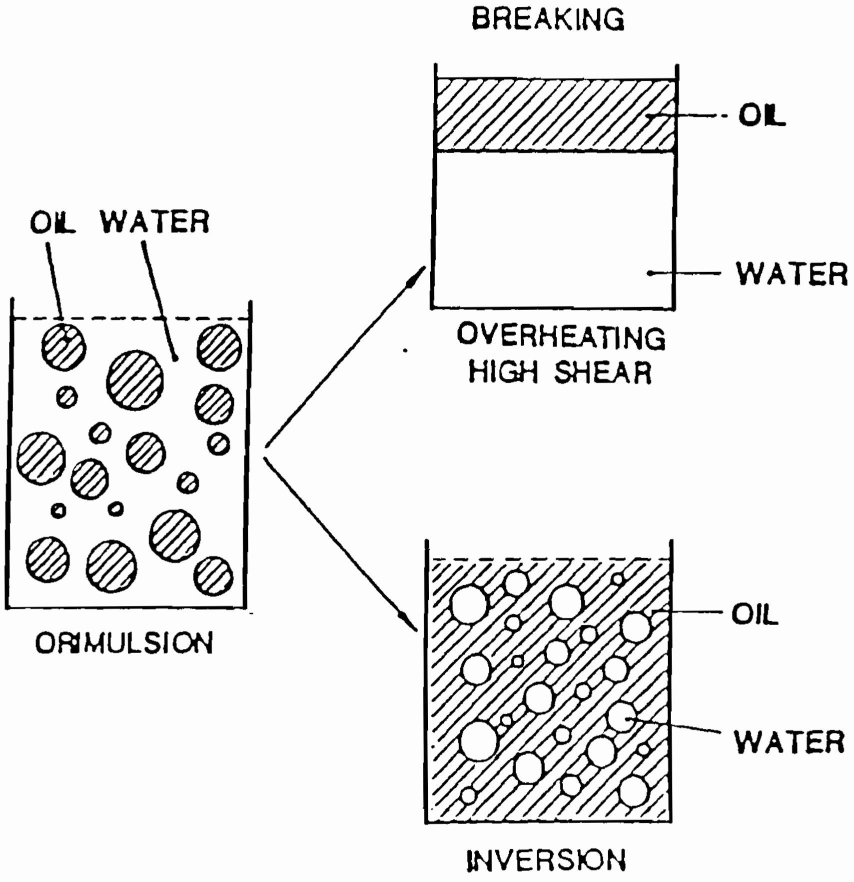
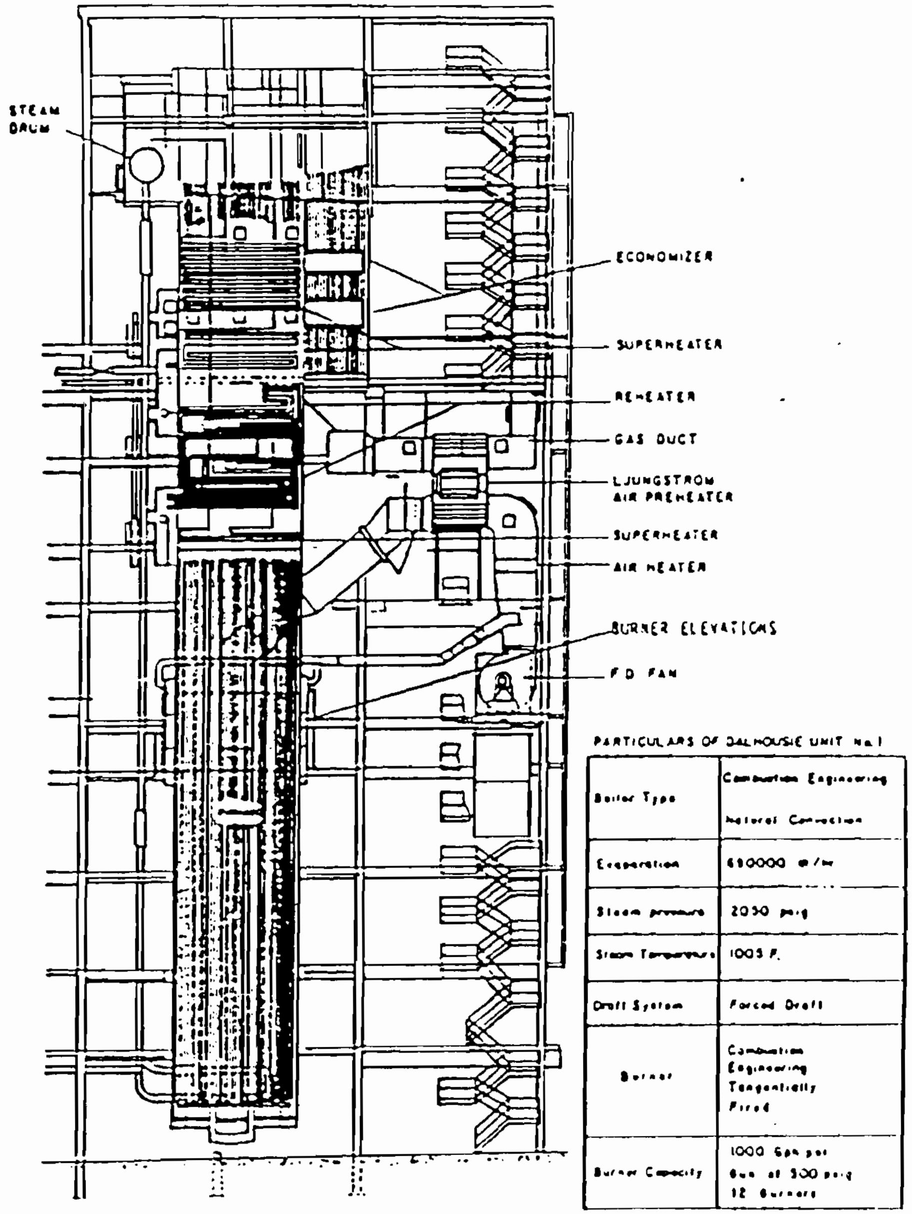


Figure 1. Physical emulsion states.



PARTICULARS OF DALHOUSIE UNIT No. 1

Boiler Type	Combustion Engineering Natural Convection
Evaporation	680000 #/hr
Steam pressure	2030 psig
Steam Temperature	1005 F.
Draft System	Forced Draft
Burner	Combustion Engineering Tangentially Fired
Burner Capacity	1000 Gph per Gun at 300 psig 12 Burners

Figure 2. New Brunswick Electric Power Comission Dalhousie Unit 1.

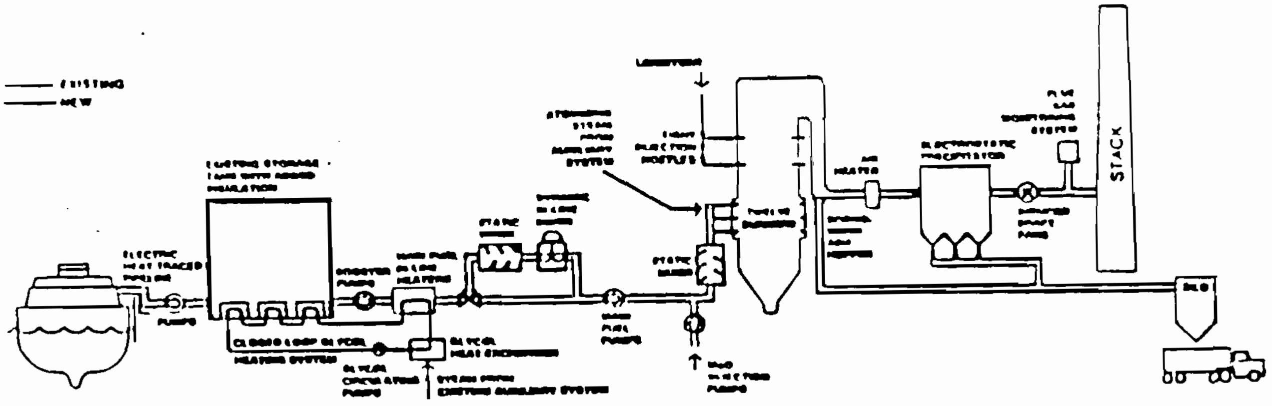


Figure 3. Fuel handling and boiler modifications for Orimulsion retrofit.

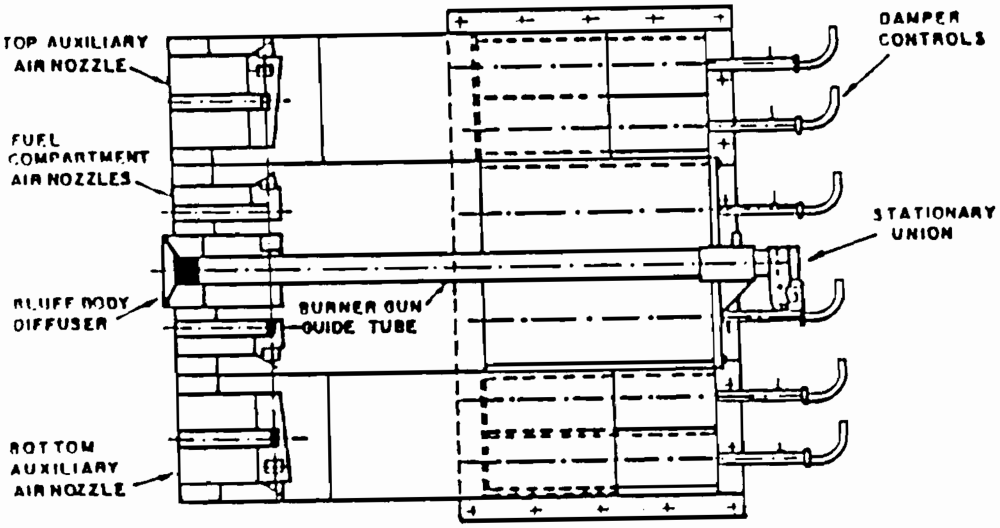


Figure 4. CE tangentially fired burner arrangement.

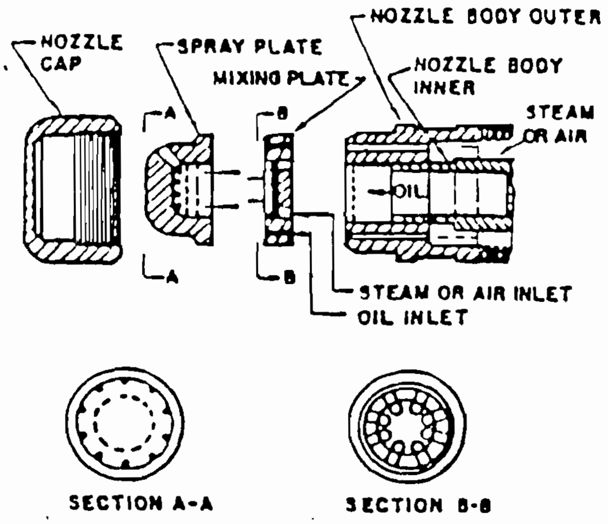


Figure 5. CE internal mix atomizer void for Orimulsion.

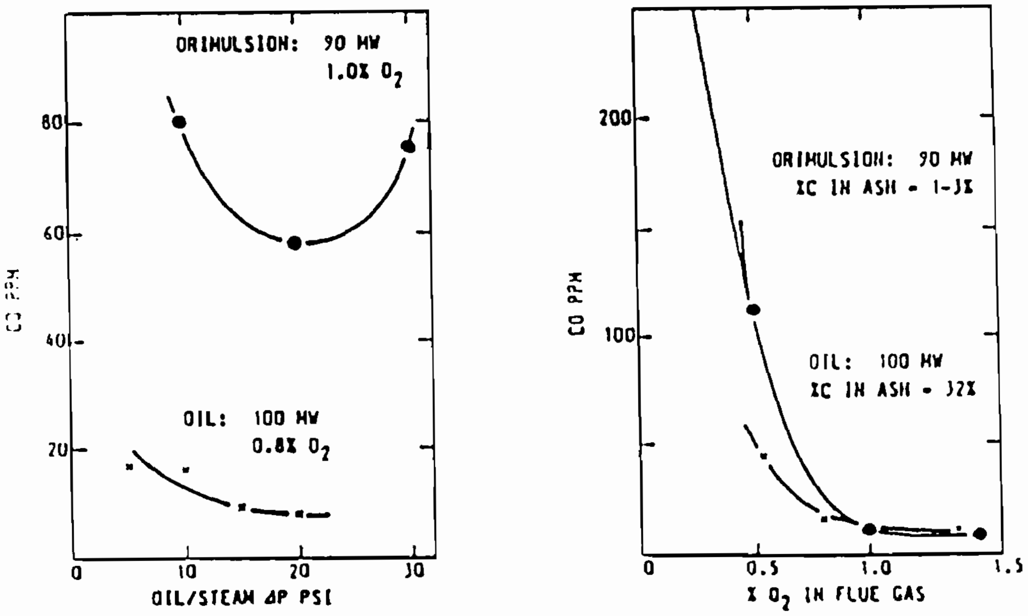


Figure 6. CO emissions.

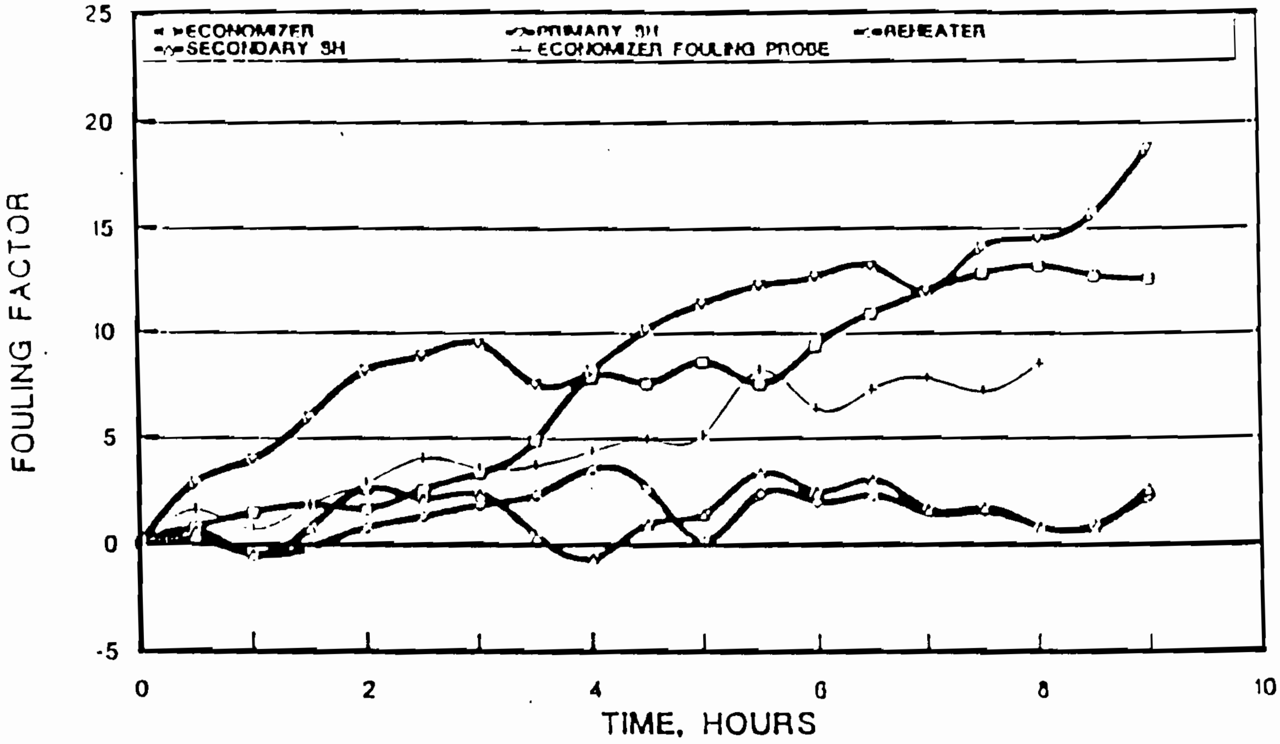


Figure 7. Fouling trends in boiler tube banks compared to economizer fouling probe (89·MW).

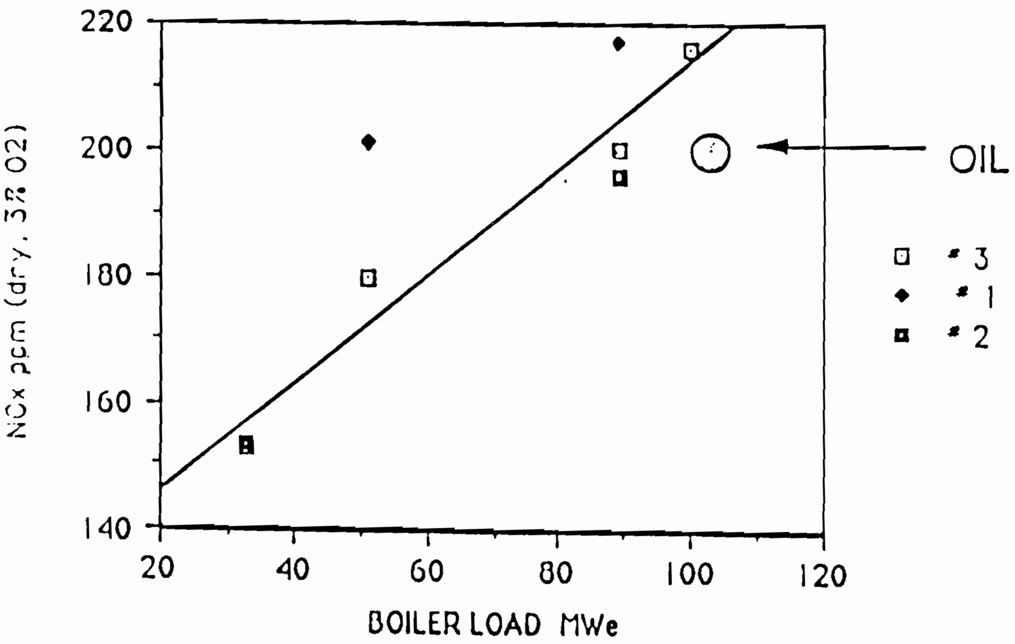


Figure 8. NO_x emissions versus boiler load for oil and Orimulsion.

TABLE 1. COMPARISON OF ORIMULSION AND VENEZUELAN HEAVY FUEL OIL PROPERTIES

		OIL	ORIMULSION
C	wt %	85.2	60.9
H	wt %	9.9	7.0
N	wt %	0.5	0.5
S	wt %	2.6	2.6
O	wt %	1.5	0.2
ASH	wt %	0.1	0.2
MOISTURE	wt %	0.4	28.6
GHV	BTU / lb	18150	13000
	kJ /g	42.2	30.2
Na	ppm	58	73
V	ppm	440	319
Ni	ppm	57	73
Mg	ppm	-	460

ORIMULSION MEAN DROPLET SIZE 14 microns

TABLE 2. ATOMIZER PERFORMANCE COMPARISON

NEW TWIN FLUID NOZZLES SUPPLIED BY COMBUSTION ENGINEERING

	ORIMULSION	OIL
MANIFOLD OIL-STEAM , psig	5 TO 10	
STEAM/FUEL MASS RATIO	0.12	0.16
FUEL PRESSURE, psig	275	170
FUEL TEMPERATURE, F	140	225
CARBON IN ASH, %	3	34

TABLE 3. PRELIMINARY BOILER PERFORMANCE FOR FUEL OIL AND ORIMULSION

		OIL	ORIMULSION
LOAD	MW	104	102
MS TEMP	F	991	1004
MS PRESS	psig	1000	1000
HRH TEMP	F	999	1012
MS ATTEMP	LB / HR	390	6475
RH ATTEMP	LB / HR	0	14638
EXIT GAS TEMP	F	335	422
ABSORPTION			
WATER WALL	%	53.8	51.8
PRI SH	%	13.3	12.5
SEC SH	%	13.7	15.1
ECON	%	4.2	5.1
REHEATER	%	14.9	15.8
BOILER EFFICIENCY	%	87.4	82.4
NET HEAT RATE	BTU /kWH	9743	10972

TABLE 4. ESP PERFORMANCE EVALUATION

MEASUREMENT/PREDICTION DESIGN COMPARISON

INPUT PARAMETER	MEASURED	DESIGN
Power (KVA)	48.5	114
Current (nA/cm^2) Density	13.5	16.3
Gas Velocity (fps)	3.7	3.5
Gas Flow (ACFM)	335,000	312,000
Temperature (^oF)	416	320
SCA (ft^2/1000 ACFM)	302	324
Resistivity (ohm/cm)	10^{11}	10^4
Particle MMD (μm)	0.2	Not Stated

Particle Collection Efficiency (%)	
Measured	
Predicted at Measured Conditions	86.9
Design	96.4
Predicted at Design Conditions	94.8

TABLE 5. IMPACT OF CONVERSION FROM COAL TO ORIMULSION ON A 70 MW TANGENTIALLY FIRED BOILER

	COAL	ORIMULSION	
		CLEAN	DIRTY
% OXYGEN	4.3	1.5	1.5
TILT	YES	NO	YES
MS STEAM Kg/s	67.7	70.2	69.8
MS ATT Kg/s	0.8	0.5	0
RH ATT Kg/s	1.86	1.4	1.4
MS TEMP K	814	814	810
EXIT GAS TEMP K	565	552	575
BOILER EFF %	89.8	90.9	90.1

70 MW T FIRED

Attachment 1B

EVALUATION OF HANDLING & COMBUSTION CHARACTERISTICS OF ORIMULSION™ IN A COMMERCIAL UTILITY BOILER

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ABSTRACT

Venezuela has identified in excess of 190 billion tonnes of heavy bitumen reserves in the Orinoco River area of the country. Due to its extremely high viscosity at ambient temperatures, the raw bitumen is unsuitable for conventional transport to utility stations for subsequent combustion. As a result, a bitumen in water emulsion known as *Orimulsion*™ has been developed to ease handling of the bitumen by reducing its viscosity to a range similar to heavy fuel oils.

In order to demonstrate the handling and combustion characteristics of *Orimulsion*™ on a commercial utility boiler, Petroleos de Venezuela, S.A. entered into an agreement with NB Power to convert the 100 MWe tangentially fired #1 boiler at its Dalhousie Generating Station to burn the fuel. A full scale demonstration program has been underway since July, 1988 and to date, approximately 125,000 tonnes of *Orimulsion*™ have been burned at the station, which is located in Northern New Brunswick. During this period, approximately 335,000 MWh of electricity have been produced while firing the unit with *Orimulsion*™ fuel.

The demonstration program conducted at Dalhousie has successfully proven that *Orimulsion*™ could become a technically viable fuel for utility boilers. The evaluation of the fuel storage, handling, combustion and emissions characteristics has provided a basis for future commercial designs. Preliminary indications are that proper recognition of the fuel's unique properties should permit conversion of both heavy fuel oil and coal fired boilers to *Orimulsion*™.

This paper presents a summary of the principal findings arising from the initial phase of the commercial *Orimulsion*™ demonstration program which has been conducted at NB Power's Dalhousie station.

PROJECT OVERVIEW

The Dalhousie combustion demonstration program was designed to be completed in three distinct phases. Initial testing has concentrated on the evaluation of *Orimulsion*™ fuel handling and combustion characteristics and a second phase will investigate the potential for sulfur dioxide emission reduction by furnace limestone injection. A final reliability phase will follow the limestone injection tests.

The major elements of the conversion of the Dalhousie #1 Unit to *Orimulsion*™ firing, are illustrated on Figure 1 and can be briefly described as follows:

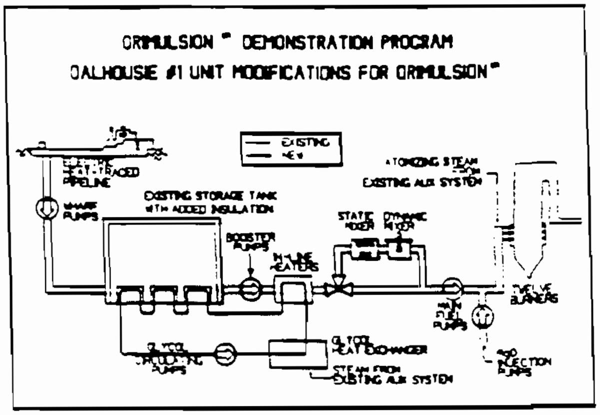

Figure 1 - Fuel Handling & Combustion Systems

Delivery : No changes to the existing #6 Fuel Oil delivery system were required to receive *Orimulsion*™ through positive displacement pumps and an electrically heat traced 2.5 mile long pipeline.

Storage : An existing 171,000 barrel #6 Fuel Oil storage tank was insulated and the 450 °F steam used in the internal heaters was replaced by a glycol water system which operates at approximately 160 °F.

Fuel Handling : Many elements of the existing #6 Fuel Oil handling system did not require changes to handle *Orimulsion*™, however two new booster pumps were added to provide the extra capacity necessitated by the lower heating value of the fuel due its 30% water content. In addition, the in-line fuel heaters were also converted to glycol and both static and dynamic mixers were installed in the supply line to the boiler as a precautionary measure against fuel viscosity variations. Variable speed drives were installed on the main fuel pumps to eliminate the sudden high pressure drop associated with control valves. As a result, fuel flowrate to the unit was controlled by varying pump speed.

Combustion : The original mechanically atomized #6 Fuel Oil burners were replaced with high swirl steam atomized burners, based on the results of earlier combustion trials conducted on behalf of Petroleos de Venezuela, S.A. at Combustion Engineering's KDL test facilities in Windsor, Connecticut. Details of the atomizer internals are

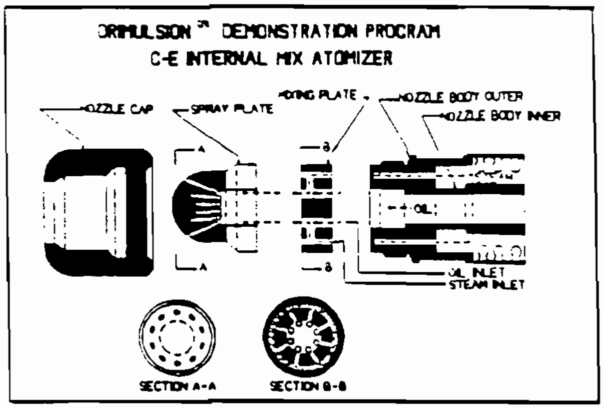

Figure 2 - Details of Atomizer Internals

illustrated in Figure 2.

Gas Handling : As NB Power's Dalhousie #1 Unit had been used mainly in peaking service in recent years, it was not equipped with appropriate dust collection equipment which was required for the limestone injection tests and as a result, a major portion of the modifications to the unit related to the installation of an electrostatic precipitator and associated equipment, as shown in Figure 3. In the process, the boiler was converted from a pressurized furnace to balanced draft with the addition of two induced draft fans.

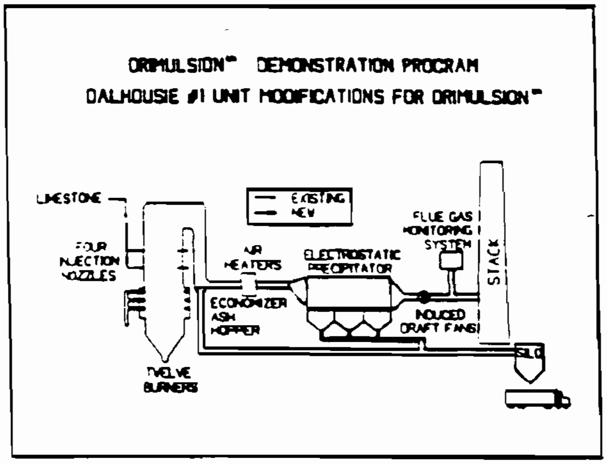

Figure 3 - Limestone Injection System

Following completion of the modifications, the unit was commissioned on *Orimulsion*™ with first fire in the boiler on August 30, 1988. On September 8 and December 14, 1988 loads of 92 and 104 MWe were achieved respectively.

FUEL CHARACTERISTICS

Orimulsion™ is a bitumen-in-water emulsion, as illustrated by Figure 4. An emulsion is an intimate mixture of two immiscible liquids, one of which is dispersed in the other in the form of fine droplets which can range in diameter between 0.1 and 100 μm. In general, it is possible to consider two types of bitumen-water emulsions wherein either the bitumen or water can be the dispersed phase. *Orimulsion*™ is an example of a bitumen-water emulsion where the bitumen is the dispersed phase.

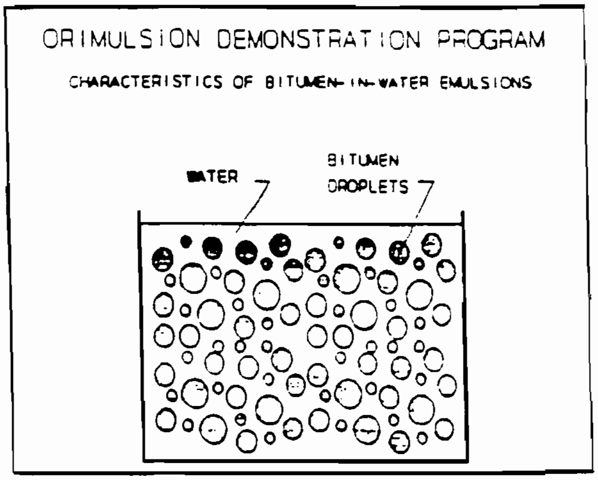

Figure 4 - Physical Consistency

Orimulsion™ exhibits non-Newtonian fluid flow behaviour which can be affected by the size and distribution of the bitumen droplets, bitumen-water ratio, shear rate applied (measured in reciprocal seconds,1/s) and temperature.

Non-Newtonian fluids are broadly defined as those which exhibit a relationship between shear stress and shear rate which is not constant. In other words, the shear stress does not vary in the same proportion when subjected to changing shear rates, as shown in Figure 5.

For all non-Newtonian fluids, measured viscosities are termed apparent viscosities, and they are a function of the applied shear rate. As shown in Figure 6, there are several types of non-Newtonian fluids. *Orimulsion*™ is characterized as a pseudoplastic fluid and displays a decreasing apparent viscosity with increasing shear rate.

For the same bitumen-water ratio, the viscosity of *Orimulsion*™ at a fixed shear rate increases as the mean droplet size decreases and the size

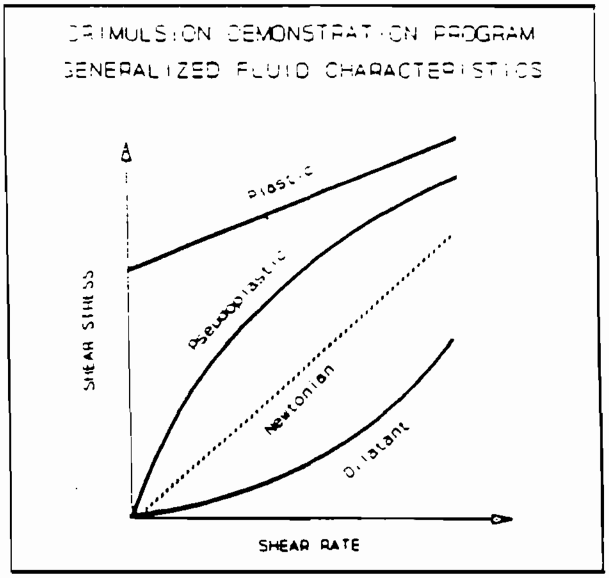

Figure 5 - Non-Newtonian Flow Curves

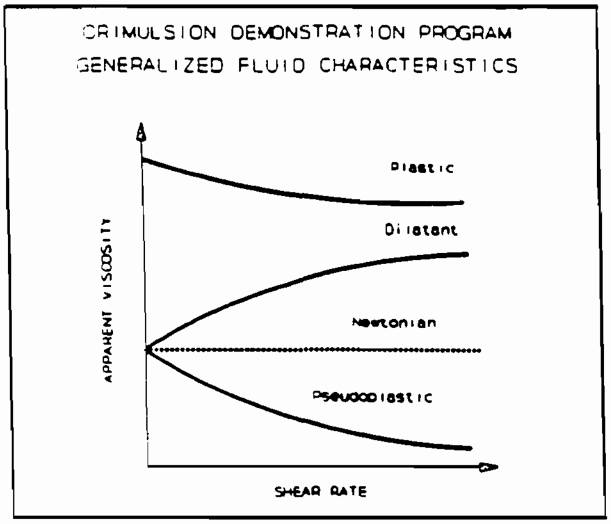

Figure 6 - Non-Newtonian Viscosity Behaviour

distribution becomes narrower. Similarly, the viscosity increases with increasing dispersed phase concentration for a given droplet size.

In addition, at a given shear rate, the viscosity of *Orimulsion*™ normally decreases as the temperature rises. A general comparison of this relationship with #6 Fuel Oil is presented in Figure 7. However, for *Orimulsion*™, the temperature must be controlled very carefully since the stability can be adversely affected by overheating.

Five shipments of *Orimulsion*™ have been received in Dalhousie to date. Table 1 summarizes the

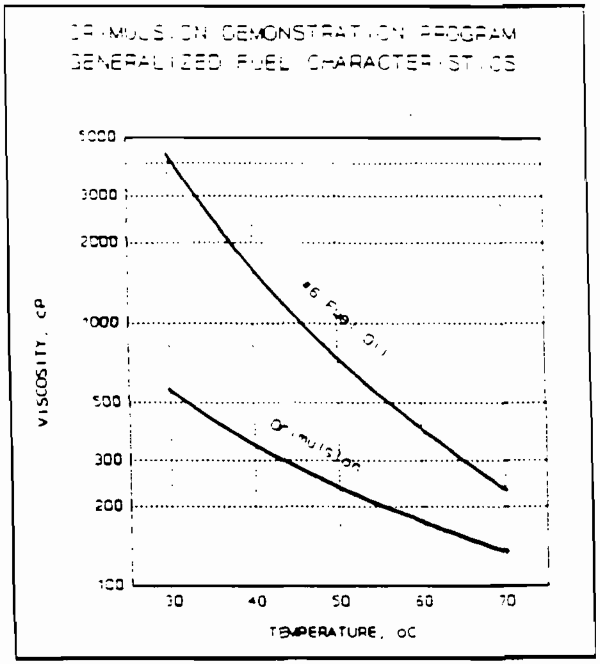

Figure 7 - Viscosity Comparison with #6 Fuel Oil

average physical and chemical properties of these shipments and presents Petroleos de Venezuela's commercial specification for comparison. All of the shipments received at Dalhousie complied with all aspects of the specification and exhibited a viscosity of between 500 and 750 cP measured at 30 °C and a shear rate of 100 1/s. It should also be noted that the mean droplet size has been less than 20 μm, whereas the specification consistently permits a mean size of up to 30 μm.

HANDLING CHARACTERISTICS

The evaluation of the handling characteristics of *Orimulsion*™ at Dalhousie, encompassed the following major objectives:

- Verify the adequacy of the specific equipment selected for *Orimulsion*™ service and identify specific items requiring further assessment or optimization.
- Establish operating procedures for fuel unloading, transfer to storage and delivery to the boiler with special emphasis on identifying critical operating conditions.
- Verify the integrity of the fuel over an extended period in storage at Dalhousie.

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Table 1 - Characteristics of *Orimulsion*™ Received at Dalhousie

ORIMULSION DEMONSTRATION PROGRAM

COMPARISION OF ORIMULSION PROPERTIES

ORIMULSION FUEL PROPERTIES	COMMERCIAL SPECIFICATIONS (RANGE)	AVERAGE DETERMINED AT DALHOUSIE
WATER, %VOL	29 - 30	29.6
SPEC. GRAVITY	1.0129 - 1.0025	1.010 (8.6 API)
FLASH POINT, oC	> 122	102 (min)
TBP DIST., %VOL		
IBP-343 oC	13	10.9
VISCOSITY, cP		
100 1/S at 30 oC	800 max	570
DROP SIZE, Microns	< 30	15.5
HHV, BTU/LB	12700 - 13100	12970
LHV, BTU/LB	11710 - 12080	12020
ELEMENTS, %WT (Wet)		
CARBON	55.5 - 61.9	60.85
HYDROGEN	7.0 - 7.8	7.12
OXYGEN	0.18 - 0.61	0.09
NITROGEN	0.42 - 0.50	0.48
SULFUR	2.40 - 2.90	2.69
METALS, ppm (Wet)		
VANADIUM	280 - 360	324
NICKEL	66 - 86	73
IRON	7 - 18	14
SODIUM	< 80	78
MAGNESIUM	0 - 500	473
ASPHALTENES, %WT	6.4 - 9.5	9.0
ASH, %WT	0.04 - 0.25	0.21

Orimulsion™ was delivered to Dalhousie by conventional oil tankers carrying #6 Fuel Oil in the wing tanks to provide an indirect method of maintaining the desired pumping temperature of *Orimulsion*™ between 85 to 100 °F. This requirement was due to the inability to use the onboard steam heaters to directly heat *Orimulsion*™ in order to ensure that its surface heating temperature did not exceed the maximum acceptable limit of 176 °F.

During a typical 11 day journey from Venezuela to Dalhousie, water content and viscosity of *Orimulsion*™ were monitored aboard the vessel. As can be inferred from Figure 8, no deterioration in these properties of *Orimulsion*™ was observed during the transportation period.

Transfer of *Orimulsion*™ to storage tank was accomplished by the existing #6 Fuel Oil unloading system, using positive displacement pumps through a 12"ϕ insulated and electrical heat traced 2.5 mile long pipeline. This pipeline between the booster pumping station and the tank farm was maintained charged full of #6 Fuel Oil between *Orimulsion*™ deliveries. *Orimulsion*™ unloading was accomplished by first purging the equivalent line volume into a #6 Fuel Oil storage tank, such that when the level in the tank indicated the complete displacement of the #6 Fuel Oil left in the pipeline from the previous delivery, the flow was diverted to the *Orimulsion*™ storage tank. Once tanker unloading was completed, a similar procedure was followed to displace *Orimulsion*™ from the line with #6 Fuel Oil, this time switching the flow from the *Orimulsion*™ tank to the #6 Fuel Oil tank.

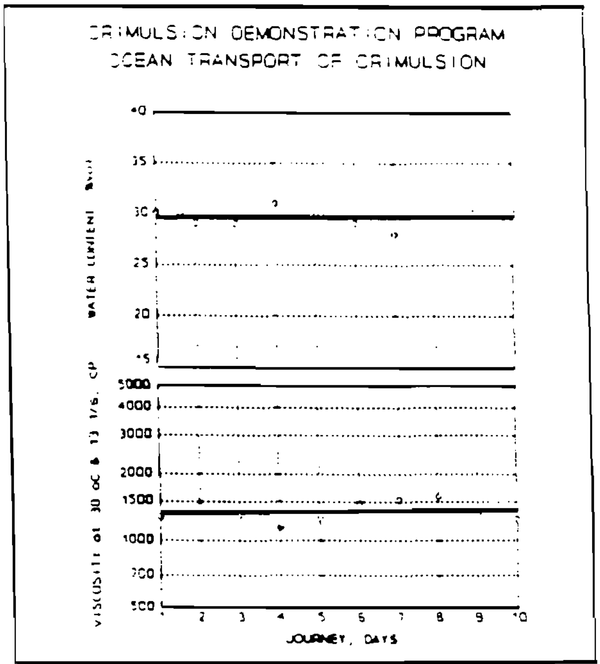

Figure 8 - Fuel Stability During Ocean Transport

In future commercial applications, it is recommended that pigging of delivery lines be used to ensure complete separation of the products, especially when long, large diameter pipelines are to be used.

Orimulsion™ was successfully kept in storage between 85 and 95 °F by internal glycol heating elements, even during extreme winter conditions (-30 °F). For all shipments stored in Dalhousie, the stability of the product was monitored by determining its viscosity, mean droplet size and water content. Figure 9 shows that the apparent viscosity of *Orimulsion*™ for each storage period, measured at 30 °C and 100 1/s of shear rate, remained essentially stable within the 400 to 750 cP range, except in the case of third shipment, when the viscosity increased from approximately 500 to

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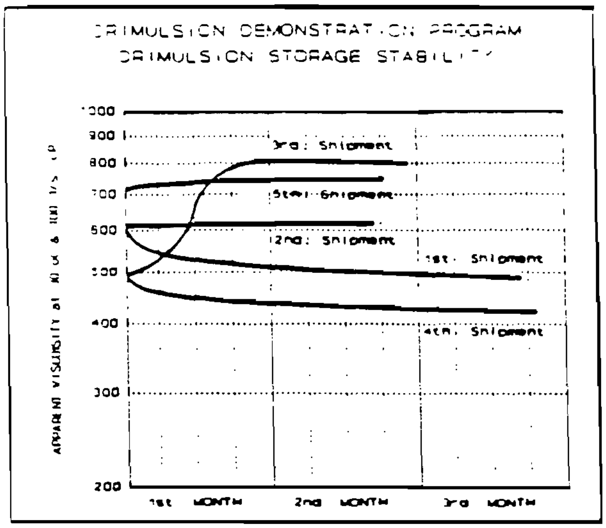

Figure 9 - Variation in Apparent Viscosity

800 cP after four weeks in storage. However, this viscosity increment was still within the commercial specification and below limits with respect to the allowable pressure drop from the tank to the booster pumps.

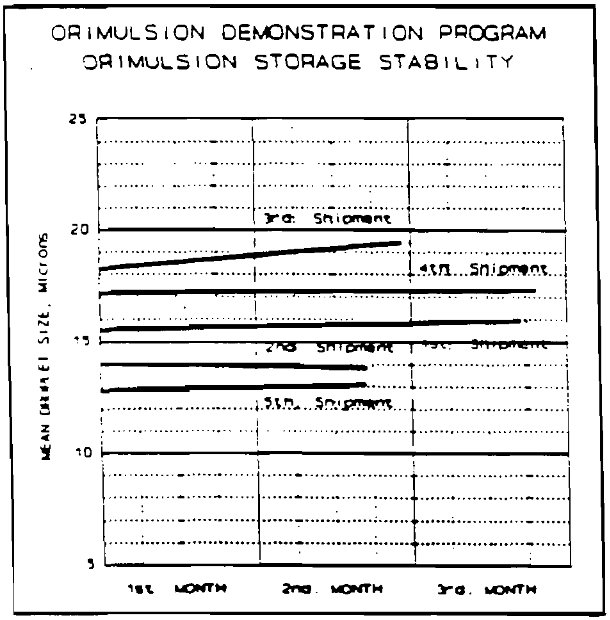

Figure 10 - Droplet Size Variation During Storage

The mean droplet size results are presented in Figure 10 showing that the mean droplet size remained relatively stable during storage between 12 to 20 μm.

Figure 11 shows water loss from *Orimulsion*™ during storage between 1 to 2 % by volume. This is thought to be primarily a result of the tank heating requirements during the winter months in Northern New Brunswick. Aside from the third shipment, no effect on the rheological properties of *Orimulsion*™ was observed to result from this evaporation of water.

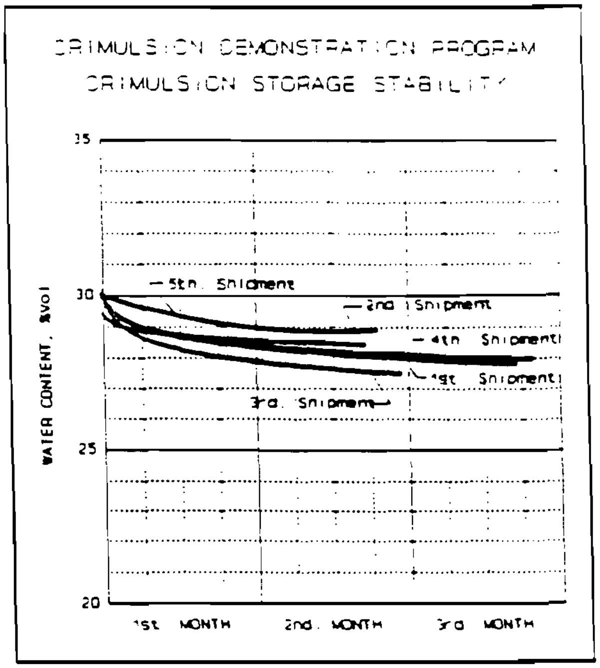

Figure 11 - Water Content Variation

In terms of handling *Orimulsion*™ in the storage tank, it was possible to operate below the minimum allowable pumping level set for #6 Fuel Oil. This was feasible due to a higher net positive suction head at the pump resulting from the lower viscosity and higher vapour pressure exhibited by *Orimulsion*™ at the storage temperature. As a result, a gain in the working volume of the storage tank was achieved during *Orimulsion*™ service.

Tests also confirmed that tank mixing devices were not required to avoid temperature stratification since uniform temperature through the storage volume was achieved by natural convection.

FUEL SUPPLY SYSTEM

Figure 12 illustrates the main elements of the fuel supply system used at the Dalhousie Generating Station. The new booster pumps, with a capacity of 180 USgpm each and a design pressure of 500 psig, were used to draw #6 Fuel Oil or *Orimulsion*™ from the storage tank. These pumps were normally operated at a maximum discharge

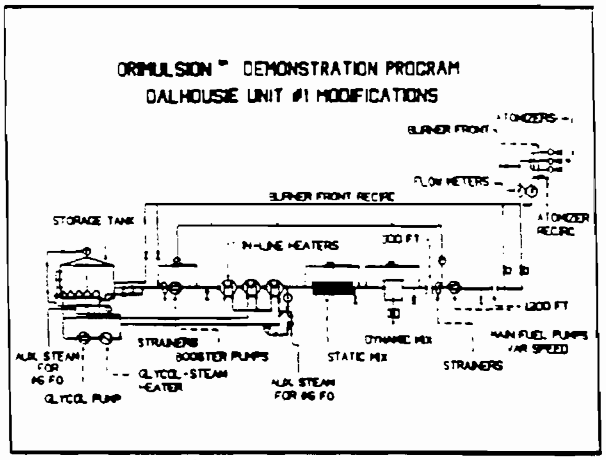

Figure 12 - Fuel Supply System

pressure of 100 psig, each using a 25 HP drive operating at a fixed speed of 1200 rpm. A pressure control valve was provided to maintain a constant positive main pump suction by means of recirculating the excess flow around the booster pumps. This control scheme proved to have no effect on the rheological properties of *Orimulsion*™ since pressure drop across the valve was always less than 100 psi.

Three existing shell & fin tube heat exchangers were operated in series between the booster and main fuel pumps to heat #6 Fuel Oil or *Orimulsion*™ to the required atomizing temperature of 230 or 140 °F respectively. Auxiliary steam, at a minimum temperature of 400 °F was supplied during #6 Fuel Oil operation and glycol, at a maximum temperature of 170 °F was used during *Orimulsion*™ service. The in-line heaters were operated in series to ensure a gradual temperature increase on the *Orimulsion*™ side, thereby reducing any possible deleterious effect on the properties of the fuel.

Static and dynamic mixers were installed after the fuel heaters. Both mixers were originally installed to provide a means of adjusting *Orimulsion*™ properties, if required due to an unexpected deterioration in the rheological properties of the fuel. However, since the fuel was found to be very stable during storage in Dalhousie, continuous use of these devices was not necessary.

The two screw type main fuel pumps had a rated capacity of 180 USgpm each and a maximum design discharge pressure of 1500 psig. These pumps were operated at speeds varied between 250 and 1100 rpm corresponding to a load range of 32 to 105 MWe.

Full bore gate, butterfly and ball valves were successfully used in *Orimulsion*™ service at Dalhousie. These valves, considered typical for #6 Fuel Oil handling systems, proved to be adequate for *Orimulsion*™.

UPSET CONDITIONS

The following operating conditions are known to potentially affect the stability and/or cause inversion of *Orimulsion*™ in a particular fuel supply system:

- Temperature exceeding 176 °F
- Sudden pressure drop exceeding 100 psi
- Centrifugal pump shearing at greater than 1800 rpm
- Mixing with greater than 1% #6 Fuel Oil

It was found that the fuel supply system at the Dalhousie Generating Station was generally capable of avoiding these conditions. However, inversion of *Orimulsion*™ occurred twice due to contamination with #6 Fuel Oil while switching fuels and once due to excessive pressure drop through a partially open valve. In both cases, inverted *Orimulsion*™ in the fuel supply system was successfully delivered to the burner front at a temperature of 170 °F, using glycol as the heating medium. The incineration of inverted *Orimulsion*™ was, however, performed at a reduced firing rate, limited by the maximum allowable burner front pressure.

Recirculation of *Orimulsion*™ through the fuel system was minimized to prevent any possible detrimental effect on its properties. However as a precaution in winter conditions at Dalhousie and during periods of shutdown exceeding one week, the fuel supply system was placed in recirculating mode for up to 20 minutes per 8-hour shift to prevent freezing of the fuel lines.

COMBUSTION CHARACTERISTICS

The evaluation of the combustion characteristics of *Orimulsion*™ encompassed the following major objectives:

- Establish the necessary burner design and atomizing conditions required to achieve a stable flame and maximum output.
- Evaluate combustion air to fuel ratios over a range of operating loads to identify the optimum carbon conversion.

- Establish the effect of fuel water content on overall combustion efficiency and heat transfer within the radiant section of the boiler.

- Identify the extent, nature and ability to control fouling within the boiler and examine its effect on heat transfer.

The results of tests completed to date address most of the above objectives and the principal findings are summarized below. For purposes of comparison Figure 13 provides a summary of typical fuel properties for *Orimulsion*™, #6 Fuel Oil and a typical Colombian thermal coal.

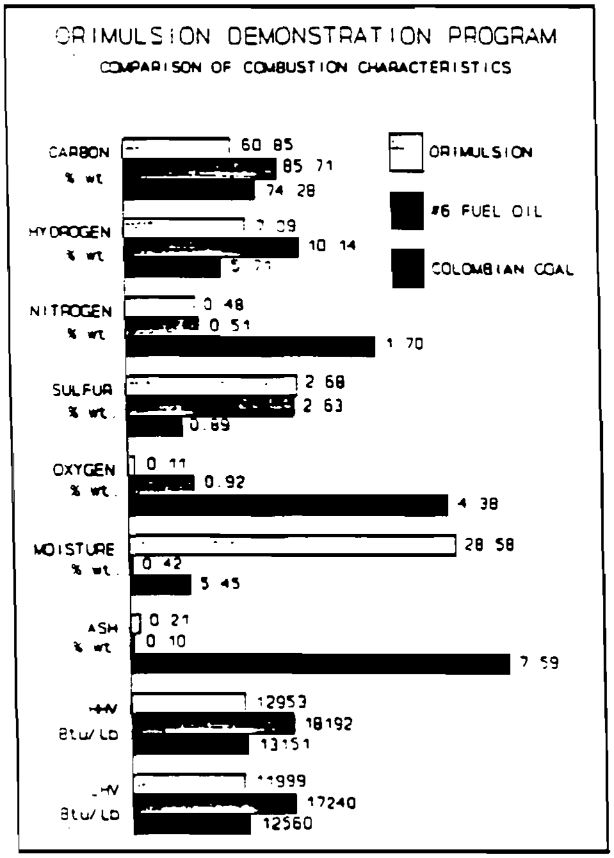

Figure 13 - Comparison of Fuel Characteristics

BURNER & ATOMIZER DESIGN

The Dalhousie #1 Unit is a three-level, 12 burner, corner fired boiler designed by Combustion Engineering (CE). In order to fire *Orimulsion*™, the basic original burner configuration was retained and a diffuser plate was installed to achieve better combustion air recirculation and mixing. *Orimulsion*™ was satisfactorily fired using internal mix steam atomizers of the type illustrated in Figure 2 and denoted as N36 and N31 by CE. The numbering scheme reflects the size of the fuel ports, with the N31 tip having approximately 10% larger ports thereby providing an estimated 20% higher throughput capacity. The performance of both tips was satisfactory, although at extremely low oxygen concentrations of 0.2% at the boiler exit, the N31 tip produced somewhat higher carbon monoxide concentrations in the flue gas. With the N36 tip a maximum load of 98 MWe was achieved with 12 guns, while with the N31 tip it was possible to obtain a load of 104 MWe using only 11 guns. Inspections revealed no evidence of visible erosion on either tip after more than 3000 hours of operation.

As noted earlier, the burner system for the Dalhousie #1 Unit was originally designed for mechanical atomization. Based on prior test rig evaluations conducted at CE's KDL research facilities, it was decided to retrofit the system to operate with steam atomization for *Orimulsion*™ service. Atomizing steam supply conditions to the burners were adjusted to be within the following ranges:

- Temperature: 400 to 500 °F
- Pressure: 200 to 300 psig

Due to the piping configuration at Dalhousie, the pressure difference between steam and fuel at the supply headers varied from -15 to -35 psi, with the optimum depending on load. Measured atomizing steam to fuel pressure differential at the burner gun inlet ranged between +4 to +10 psi, depending on burner elevation and corner. These atomizing conditions for *Orimulsion*™ resulted in a steam consumption of 10 to 12% of fuel mass flow. Since atomizing steam consumption and differential pressures depend on fuel supply system configuration and burner tip designs, a comparison between #6 Fuel Oil and *Orimulsion*™ is not particularly relevant. However, for the Dalhousie installation, atomizing steam consumption was found to be approximately 16% of fuel weight when firing #6 Fuel Oil through the same type of atomizer, denoted by CE as N25. It should be noted that steam consumption for *Orimulsion*™ is actually somewhat higher per unit of energy input due to the lower heating value of the fuel as compared to #6 Fuel Oil.

Within the abovenoted ranges, the combustion efficiency, as indicated by the concentration of CO in the flue gas, was found to be relatively insensitive to atomizing conditions. However, it is important to

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point out that all of the sensitivity analyses were conducted at 0.5% excess O_2 in the flue gas, this being the normal operating level determined for *Orimulsion*™. It was later noted that the formation of CO was very sensitive to slight changes in excess oxygen concentration in this range. As a result, the sensitivity to changes in atomizing conditions may have been masked somewhat and it is planned to perform additional tests at higher excess O_2 levels during the combustion of a later *Orimulsion*™ shipment.

WATER CONTENT EFFECTS

The principal direct effects of the water content of the fuel was to reduce the effective heating value of *Orimulsion*™ and increase the mass gas flow per unit of energy input. Calculations and measurements indicated that the net effect equates to an approximate 6% increase in mass gas flowrate as compared to #6 Fuel Oil firing at the same excess O_2 level for a given load. This increase was a result of the following two factors:

- The weight of water included in the fuel resulted in an increased gas weight of approximately 2.7%
- The portion of fuel and air required to vaporize the water accounted for the remaining 3.3% increase in gas weight.

It should be noted that this effect became even more significant as the overall boiler efficiency decreased due to high back-end temperatures, resulting in even higher fuel and air flows. However, this effect was unique to the configuration of the Dalhousie boiler and would not be expected to affect units specifically designed or retrofitted for *Orimulsion*™ firing.

For purposes of comparison, the theoretical flame temperature projections and flue gas production quantities were determined for *Orimulsion*™, #6 Fuel Oil and a typical Colombian thermal coal. As shown in Figure 14, the combustion of *Orimulsion*™ produces a greater mass of flue gas per unit of energy input as compared to #6 Fuel Oil, while the quantity of gas produced is somewhat lower than for coal firing. In addition, although the technique used to estimate flame temperature indicates a relatively minor difference in the peak value, calculations of the adiabatic flame temperatures suggests somewhat higher figures. It is therefore concluded that the relationship presented in Figure 14 can be considered as the minimum difference between the fuels, at a given O_2 concentration in the flue gas. However, it should be noted that different optimum O_2 levels are typically required for the three fuels, and a comparison should consider this factor.

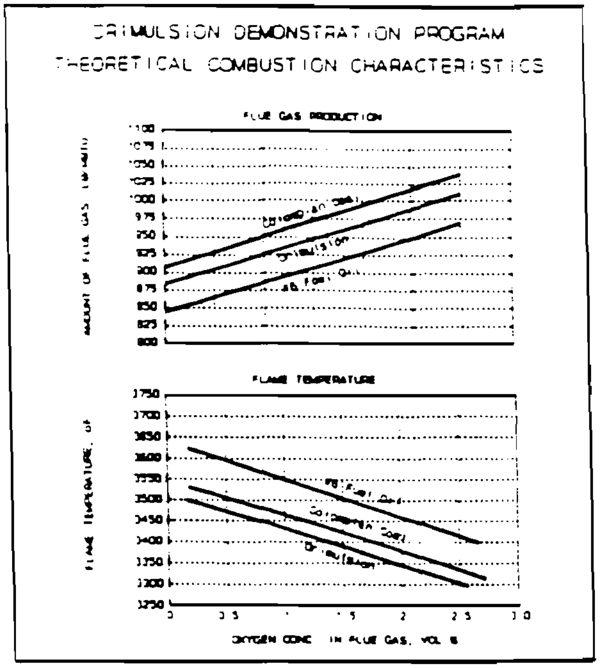


Figure 14 - Comparison of Fuel Characteristics

OXYGEN REQUIREMENTS & IMPLICATIONS

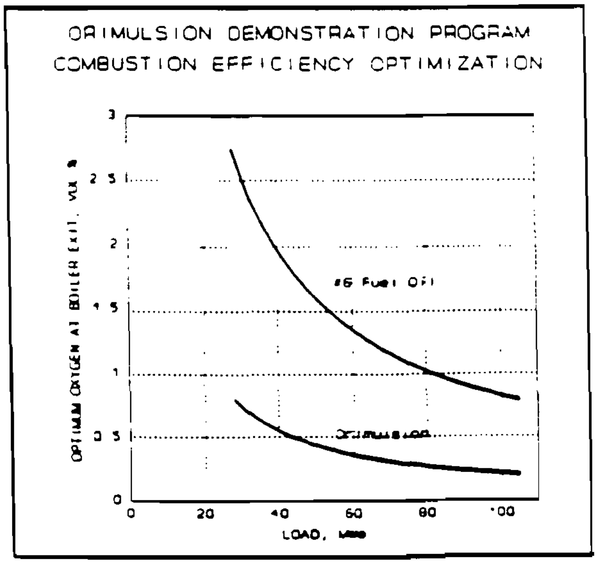


Figure 15 - Optimum Excess Oxygen

The tests at Dalhousie consistently demonstrated that combustion air requirements while burning *Orimulsion*™ at any boiler load were significantly lower than requirements for #6 Fuel Oil firing, assuming approximately equal carbon utilization efficiencies. At a load of 90 MWe, the optimum excess O_2 concentration at the boiler exit while firing *Orimulsion*™ was determined to be 0.2%, while the carbon conversion efficiency for #6 Fuel Oil firing was optimum at a level of 0.8% O_2. Figure 15 illustrates the comparison of optimum O_2 levels for both *Orimulsion*™ and #6 Fuel Oil and shows that this trend applies over the full range of unit loads. In fact, the Dalhousie trials indicated that excess oxygen levels while burning *Orimulsion*™ may be as much a safety consideration as an efficiency concern. Given the sensitivity of the controls at Dalhousie, it was normal practice to fire *Orimulsion*™ at an excess O_2 level of approximately 0.5%.

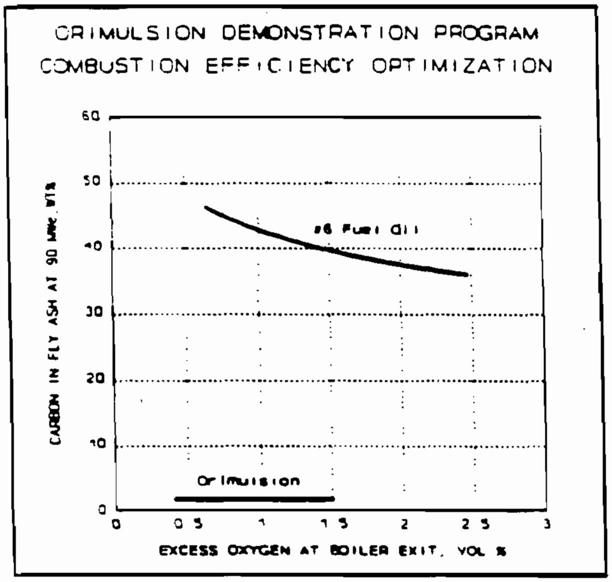


Figure 16 - Carbon in Ash at 90 MW

Figures 16 and 17 present data on CO emissions and carbon in fly ash for *Orimulsion*™ and #6 Fuel Oil as a function of excess oxygen in the flue gas. Figure 16 shows that the excess O_2 level was found to have little effect on the carbon content of the fly ash produced while firing the boiler with *Orimulsion*™ while significant variations were observed with #6 Fuel Oil. As a result CO emissions were used as the prime indicator for assessing optimum O_2 levels. A comparison at a 90 MW load is presented in Figure 17 for both fuels.

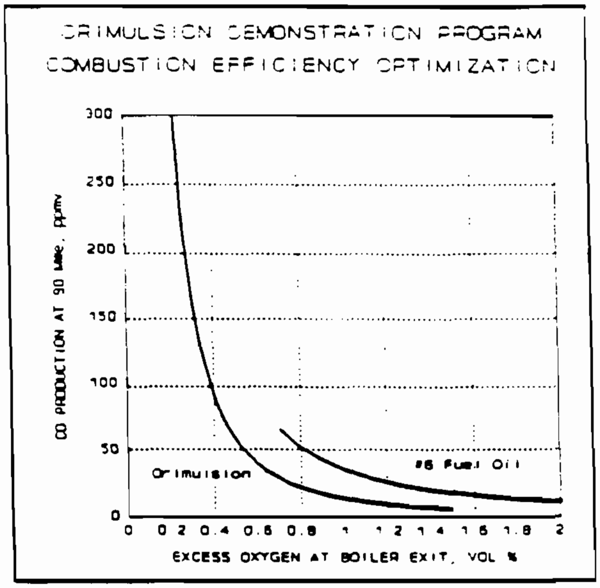


Figure 17 - CO Production at 90 MW

This finding that *Orimulsion*™ can be successfully combusted at lower excess O_2 levels than that required for #6 Fuel Oil represents perhaps the most significant achievement of the Dalhousie demonstration program with regard to the combustion of *Orimulsion*™ fuel. Air requirements impact on several important areas, including the following:

Mass Gas Flowrate : is directly proportional to the quantity of air required to combust the fuel. The ability to burn *Orimulsion*™ at an excess O_2 level of 0.2% versus a level of 0.8%, resulted in nearly a 3% reduction in mass gas flowrate, thereby partially offsetting the increase due to the water content of the fuel. Clearly the benefits compared to coal combustion would be far greater when the required flue gas O_2 concentrations are considered.

Flame Temperature : is inversely proportional to the total weight of combustion products produced per pound of fuel. Therefore, the greater the quantity of air required per pound of fuel, the lower the peak flame temperature. The ability to combust *Orimulsion*™ at 0.2% O_2 in the flue gas, permits the flame temperature to approach #6 Fuel Oil conditions, and is estimated to be significantly higher than that which would result from the combustion of a bituminous coal of the same approximate heating value when required excess O_2 concentrations are considered.

Boiler Efficiency : is inversely proportional to the mass flowrate of flue gas entering the stack.

SO_3 & NO_x Formation : are both a function of several factors including excess O_2 concentrations in the boiler.

The implications for the conversion of future candidate units to *Orimulsion*™ fuel should be significant in that units which were originally designed for most coals should be capable of equal or better performance on *Orimulsion*™. In addition, properly retrofitted #6 Fuel Oil designed units should expect minimal performance degradation.

TEMPERATURE PROFILE - HEAT TRANSFER IMPLICATIONS

For a given heat input of *Orimulsion*™ at normal excess O_2 levels, peak flame temperatures have been estimated and measured in test rigs at between 50 and 250 °F lower than that achieved while firing #6 Fuel Oil. This finding has negative implications for peak radiant heat fluxes within the boiler since this parameter is directly proportional to the fourth power of the absolute temperature. As a result, it has been estimated that, all other things being equal, peak radiant heat flux to the waterwalls achieved while burning *Orimulsion*™ could be up to 20% lower than for #6 Fuel Oil.

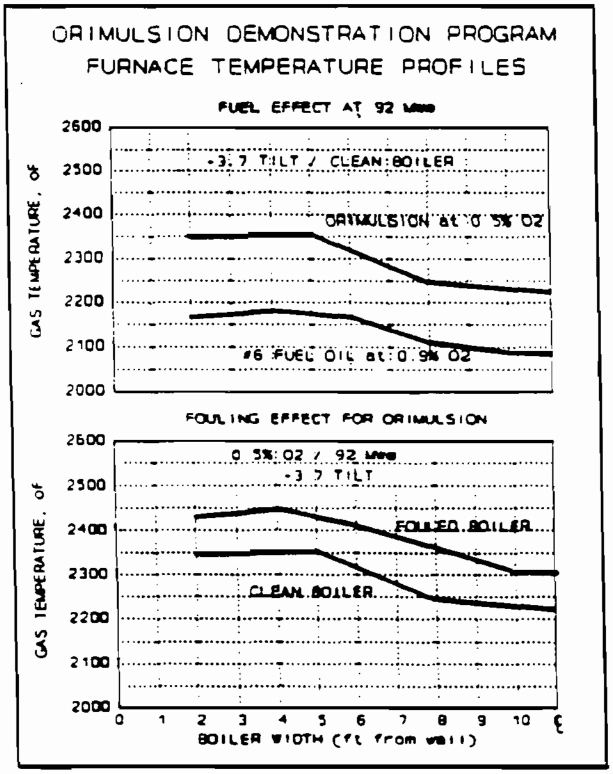


Figure 18 - Furnace Exit Temperature Comparison

In general, for a given fixed boiler configuration (waterwall surface area, burner location, etc.), a higher temperature bulk gas would be necessary at higher elevations within the radiant zone in order to obtain the same amount of steam generation in the waterwall. This implies a requirement for a higher furnace exit temperature entering the convective section when firing *Orimulsion*™ at the same boiler steam output. Figure 18 presents measured furnace exit temperatures entering the Dalhousie #1 unit superheater at a load of 92 MW for both fuels at the same burner tilt.

This data clearly shows that, at normal operating flue gas O_2 concentration and the same unit load, burner tilt and furnace condition, the furnace exit gas temperature was found to be approximately 150 °F higher when firing *Orimulsion*™ as compared to #6 Fuel Oil.

In addition, the effect of waterwall fouling while firing *Orimulsion*™ was found to increase the furnace exit gas temperature by approximately an additional 75 °F.

It should be noted that the above conclusions are considered to be indicative only in that the accuracy of the measuring device in the conditions encountered are subject to error. However, the relative comparison is believed to be generally valid in view of other substantiating temperature data observed within the convective zone of the boiler. Based on measured boiler exit temperatures and the calculated heat absorption in the various convective sections of the boiler, it was estimated that the furnace exit temperature while firing *Orimulsion*™ should be a minimum of 80 °F higher than for #6 Fuel Oil at the same load.

The higher furnace exit temperature required when burning *Orimulsion*™ to achieve a given load implies that in order to operate within the design economizer exit temperature and achieve the rated unit capacity, more convective heat transfer surface area would be required within this particular boiler. Essentially, the temperature profile produced from the combustion of *Orimulsion*™ is somewhat different than that associated with typical oil firing and a slightly modified distribution of heat absorbtion surface within the boiler could be required to take full advantage of the available energy input. Without such modifications, the higher available heat within the convective zone could result in higher tube metal temperatures, increased steam attemperation requirements and lower overall boiler efficiency. Naturally, the specific requirements to optimize the boiler efficiency for *Orimulsion*™ firing on candidate retrofit units will be dependent on the original boiler design fuel. For example, while units originally designed to fire #6 Fuel Oil may benefit from modifications, coal designed boilers could be expected to require few, if any, boiler changes. Individual cases will require analysis by the boiler designer.

BOILER FOULING EFFECTS

To date, five shipments of *Orimulsion*™, comprising approximately 25,000 tonnes each, have been fired in the Dalhousie #1 Unit. During this period the ash content of *Orimulsion*™ ranged between 0.2 and 0.3 wt.%, and the total Magnesium to Vanadium ratio varied between 1.3 and 1.7. In addition, due to test requirements and changes in the characteristics of individual shipments, a boiler wash was conducted after the combustion of each shipment.

Boiler inspections confirmed that the calculated heat transfer reductions in the convective section were due to increased fouling in the primary superheater and economizer areas. It is believed however, that this fouling can be addressed by an adequate number of suitably located sootblowers, since the deposits are easily removed. In the remaining areas of the convective zone of the boiler, optimization of soot blowing conditions and frequency resulted in no significant fouling buildup. Inspections carried out at the conclusion of each test shipment revealed no evidence of strongly bonded deposits on any of the high temperature surfaces.

COMBUSTION EFFICIENCY

Carbon conversion was consistently demonstrated at greater than 99.8% when firing *Orimulsion*™ at Dalhousie. This figure reflects both the CO content of the flue gas and unburned carbon in the fly ash. As previously shown in Figure 17, operation at a load of 90 MWe and an optimum excess oxygen level of 0.2% at the economizer exit, resulted in approximately 400 ppmv of CO in the combustion gases. Operation at 0.5% excess oxygen resulted in a reduction in CO emissions to approximately 50 ppmv. Nevertheless, the heat loss associated with the increased quantity of flue gas at higher O_2 levels was not compensated for by the heat saved through a reduction in CO emissions.

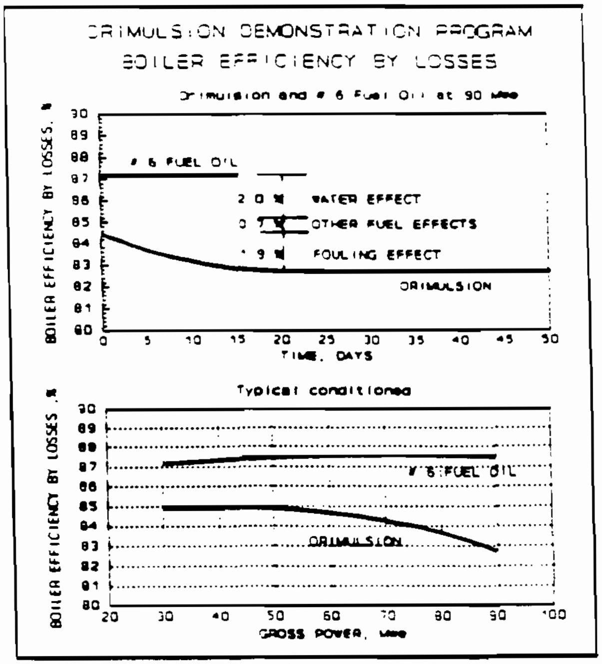


Figure 19 - Boiler Efficiency Comparison

Boiler efficiency at a load of 90 MWe and 0.5% excess oxygen, as calculated by the heat loss method, varied between 84.5% (clean boiler) and 82.6% (fouled condition) when burning *Orimulsion*™. The comparable figures for the combustion of #6 Fuel Oil in the unit showed boiler efficiency varying from 87.2% (clean boiler) to 86.4% (fouled boiler) at 90 MWe and 0.9% excess oxygen. The 2.7% difference in clean boiler efficiencies between the two fuels was largely due to increased heat loss arising from a higher flue gas mass flowrate, together with losses resulting from the water content of *Orimulsion*™ and higher flue gas temperatures throughout the convective section of the boiler. Figure 19 illustrates this comparison and further indicates that fouling of boiler surfaces increased the efficiency difference between the two fuels. This additional loss was due to increasing furnace exit temperatures and reduced heat transfer in the convective section.

The overall average fouling effect on boiler efficiency may be estimated from the difference between efficiencies for a conditioned boiler firing #6 Fuel Oil versus that obtained with *Orimulsion*™ (86.4 vs. 82.6%). The major portion of this difference is accounted for as discussed above. The additional 1.1% reduction appears to be attributable to higher stack gas losses caused by increased fouling of heat transfer surfaces when firing *Orimulsion*™.

Figure 19 also shows that at lower loads the efficiency difference between *Orimulsion*™ and #6 Fuel Oil was reduced due to lower temperatures throughout the convective section, such that the observed difference was primarily due to the water content of the fuel.

BOILER CAPACITY LIMITATIONS

Although it was possible to reach 104 MWe while burning *Orimulsion*™ with the N-31 burner tips in a clean boiler without exceeding tube metal temperatures, it was necessary to drop load to 90 MWe after approximately four days, in order to operate with a precipitator inlet gas temperature under 450 °F. Figure 20 illustrates a typical trend in precipitator inlet temperature for *Orimulsion*™ and #6 Fuel Oil, after start-up with a clean boiler at 104 MWe. The maximum precipitator inlet temperature was established by the manufacturer, although guaranteed performance was based on a design value of 380 °F. It should be noted, however, that no changes to the boilers convective tube banks were made at Dalhousie in order to optimize the efficient extraction of the available heat in the flue gas. Commercial conversions would need to consider this aspect of a retrofit carefully in order to minimize efficiency losses and maximize boiler capacity while firing *Orimulsion*™.

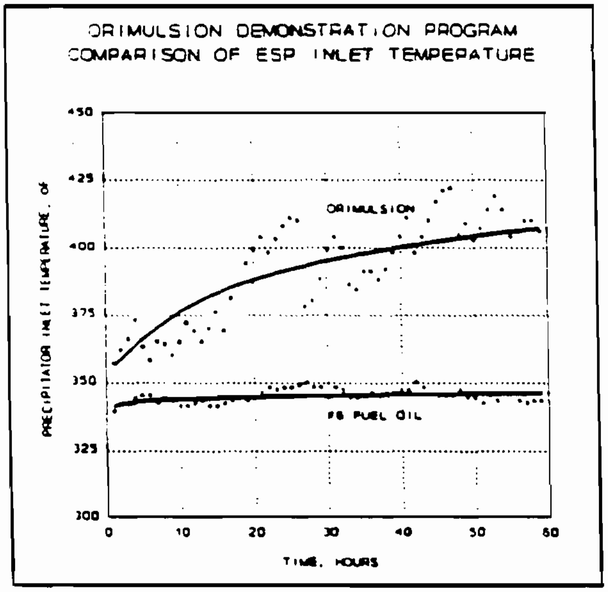


Figure 20 - ESP Inlet Temperatures

During the combustion of the five *Orimulsion*™ shipments, the maximum long term sustainable load was between 88 and 90 MWe, as limited by the precipitator inlet temperature.

PARTICULATE & GASEOUS EMISSIONS

Emissions tests conducted at Dalhousie pursued the following major objectives related to the combustion of *Orimulsion*™:

- Evaluate the need for fly ash re-injection to maximize carbon conversion.
- Evaluate the ability to collect *Orimulsion*™ ash with an electrostatic precipitator and confirm the required design specifications.
- Evaluate the physical and chemical characteristics of *Orimulsion*™ ash, particularly from an ash handling and disposal viewpoint and also investigate the potential of utilization for vanadium recovery.
- Determine the emissions of SO_x and NO_x; the former particularly during trials with furnace limestone injection to evaluate the potential for partial sulfur capture.
- Evaluate the potential for corrosion of both high and low temperature surfaces due to components of the combustion gases.

The results of tests completed to date address most of the above objectives and the principal findings are summarized below.

Figure 21 presents a comparison of the typical composition of *Orimulsion*™ and #6 Fuel Oil fly ash. As discussed earlier, the major difference between the two, relates to the carbon content of the ash. It was also observed that the sulfur content of the *Orimulsion*™ fly ash was significantly higher, which was due to the higher conversion of the magnesium present in the *Orimulsion*™ to the sulfate form.

Various tests conducted at Dalhousie provided the following additional characterization of the ash arising from the combustion of *Orimulsion*™:

- *Ash resistivity* was on the order of magnitude of 3 to 5 x 10^{11} ohm-cm compared to a design value of 5 x 10^{10} ohm-cm.
- *Ash particle size* was 98 wt% less than 10 µm and 50 wt% less than 0.3 µm.
- *Ash density* was on the order of 5 to 10 Lbs/ft^3 compared to a design value of 25 Lbs/ft^3.

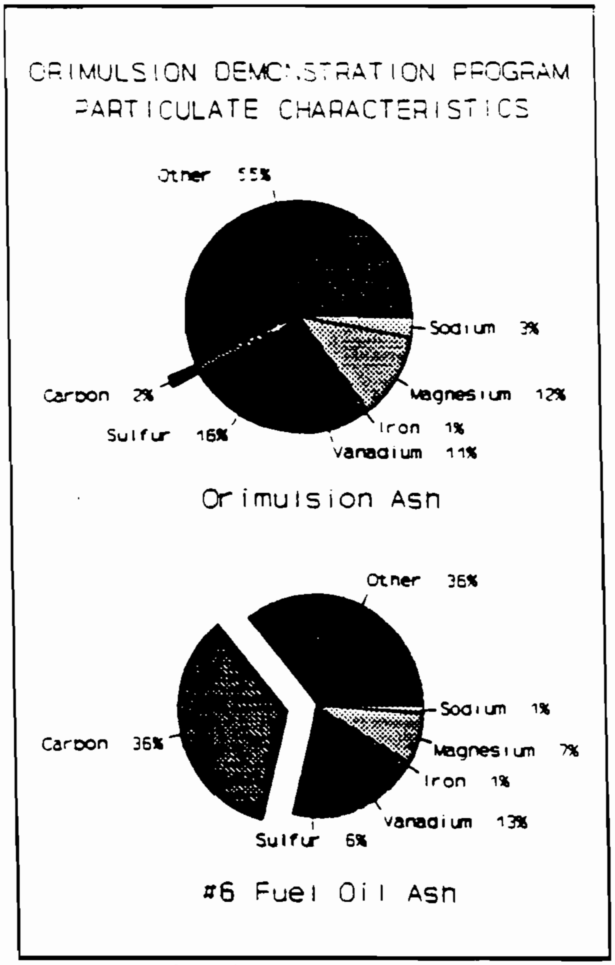


Figure 21 - Fly Ash Comparison

Figure 22 provides a comparison of the size distribution of ash from the combustion of *Orimulsion*™ and #6 Fuel Oil. The much higher proportion of fine fly ash particles which are produced from *Orimulsion*™ result in extremely low densities compared to #6 Fuel Oil ash.

ELECTROSTATIC PRECIPITATOR PERFORMANCE

The Electrostatic Precipitator (ESP) collected *Orimulsion*™ fly ash at all loads. When the unit operated below 50% load, the ash collection efficiency was greater than 95 %. However, the collection efficiency dropped to approximately 86 % when the unit was operated at full load. It is considered that this was primarily due to the increased gas volume which resulted from an inlet temperature of up to 450 °F experienced at full load. As a result, the ash particles would have been travelling at higher velocities than the precipitator was originally designed to handle.

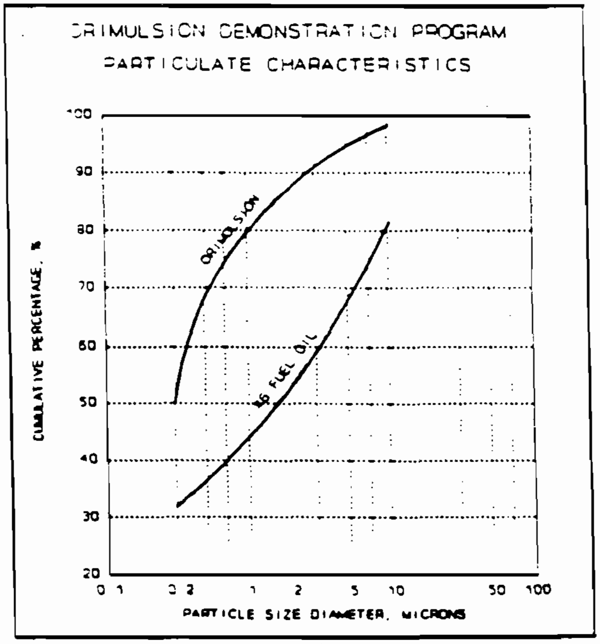


Figure 22 - Comparison of Fly Ash Particle Size

In addition, the previously noted low density of *Orimulsion*™ ash is believed to have been a contributing factor to the poor performance of the ESP equipment. The rapping sequence on the unit worked well in cleaning the sector plates and wires and it was noted that the sequence could be altered to improve opacity at various loads.

In summary, if flue gas mass flowrate, temperature, ash density, particle resistivity and particle size are accounted for, an electrostatic precipitator should effectively collect *Orimulsion*™ ash.

ASH HANDLING AND DISPOSAL

The ash handling system successfully transported ash from the economizer and precipitator hoppers to the ash silo. Re-injection of the *Orimulsion*™ fly ash into the boiler was also successful but was not necessary due to the low carbon content of the ash. In view of this finding, it is expected that this system would not be required on commercial units.

The dry fly ash unloading system installed on the storage silo was found to be adequate for discharging the material to a vacuum truck, provided a layer of water was present inside the truck to assist with the separation of the ash from the conveying air. In addition, short term tests were also conducted using a modified wet ash unloading system in order to improve the ash handling characteristics. For this evaluation, a sealed vessel containing an agitator was used to mix known quantities of dry fly ash and water. The mixing time was varied, although the best results were observed after a contact time of approximately 90 seconds. This procedure was successful in producing a pelletized ash containing approximately 17% moisture and exhibiting a density on the order of 65 pounds per cubic foot. As a result of this test, it was concluded that a larger system based on this concept, with accurate metering provisions to control the water content of the pellets, would provide the best handling system for *Orimulsion*™ fly ash.

During the demonstration program, the fly ash collected was being land filled on NB Power's coal ash disposal site. To date, approximately 250 tons of *Orimulsion*™ fly ash have been disposed of at the ash site and inspections and sampling have revealed some evidence that leaching of metals from the ash has occurred. Preliminary analysis indicates that the major elements present in the leachate are magnesium and vanadium. Further detailed studies of *Orimulsion*™ ash at the disposal site will be necessary in order to fully address this issue and establish leachate treatment procedures. However, it was also confirmed that the ash should be a marketable material to specialty chemical firms for the recovery of vanadium, which is present in relatively high concentrations. Discussions held with industry participants indicated that the major concern relating to the potential for vanadium recovery lies with control of the moisture content of the pellets to ensure ease of handling.

Finally, it should be noted that the leaching of metals from the ash is not considered to be a unique problem for *Orimulsion*™ fuel, but is considered to be applicable to any petroleum derived fuel (eg. #6 Fuel Oil) where ash is collected for subsequent disposal. The problem arises in these instances as a result of the acidity of the ash produced.

SO_x, NO_x AND PARTICULATE

Orimulsion™ contains essentially the same sulfur content as the #6 Fuel Oil in use by NB Power. However, when corrected on the basis of equivalent heat input, the sulfur dioxide concentration in the flue gas was approximately 50% higher. Measurements at Dalhousie showed that at a load of 90 MWe, the sulfur dioxide concentration in the flue gas varied from 2270 to 2350 ppmv normalized at 3% O_2 (0.5% O_2 at economizer exit) as compared to 1540 to 1560 ppmv normalized at 3% O_2 with #6 Fuel Oil (0.9 % O_2 at economizer exit). As illustrated by Figure 23, both of these emission levels are substantially higher than the 0.6 Lbs of SO_2 per million BTU's of energy input, which is the standard in Canada and the United States for utility boilers. Although it is planned to conduct future tests evaluating the potential for partial sulfur capture with limestone injection, it is expected that flue gas scrubbing would be necessary in order to meet Government new source performance standards.

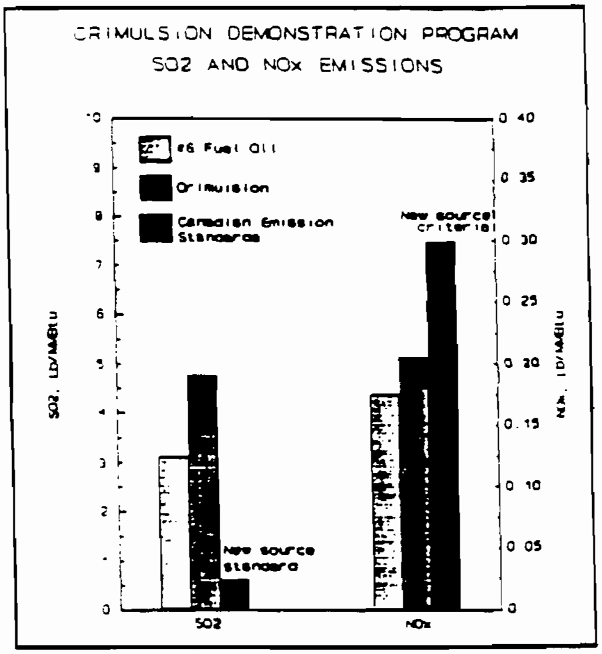


Figure 23 - Emissions Comparison

In addition, the fuel nitrogen content of *Orimulsion*™ was 40 % higher for *Orimulsion*™ on the basis of equivalent heat input. However, NO_x emissions measured during *Orimulsion*™ firing were found to be in the same range as for #6 Fuel Oil. NO_x emissions at a load of 90 MWe and normalized to 3% O_2 varied from 180 to 215 ppmv for *Orimulsion*™ as compared to a range of 180 to 190 ppmv with #6 Fuel Oil. Apparently this result was due to the lower *Orimulsion*™ flame temperature and excess O_2 levels compensating for the higher fuel nitrogen content. Figure 23 presents these results in terms of pounds of NO_x per million BTU's of energy input and indicates that the US EPA's standard of 0.3 could be achieved while firing *Orimulsion*™ at Dalhousie. It should be noted however, that NO_x emissions are known to be a function of furnace design and other manufacturers designs may yield different results.

The measured dust loading with *Orimulsion*™ firing at 0.5% excess O_2 at the economizer exit was approximately 250 mg/m^3 at 70 °F or the equivalent of 0.196 Lbs per million Btu with a corresponding uncontrolled opacity exceeding 45%. However, during periods of operation with the electrostatic precipitator in service, the regulatory requirement of less than 20% stack opacity was easily achieved, in spite of lower than expected dust collection efficiencies resulting primarily from high inlet temperatures. For reference purpose, the dust loading with #6 Fuel Oil firing at 0.8% excess O_2 was estimated at 105 mg/m^3 at 70 °F or the equivalent of 0.085 Lbs per million Btu.

CORROSION POTENTIAL

Complete boiler inspections and preliminary corrosion probe analyses conducted following the combustion of the first two shipments of *Orimulsion*™ revealed no sign of corrosion. During these tests, the Mg/V weight ratios in the boiler ranged between 1.3 and 2.8. Preliminary results indicate that the magnesium added to the fuel during its manufacture, which results in an Mg/V ratio of 1.3, is adequate to inhibit the corrosive potential of high temperature ash.

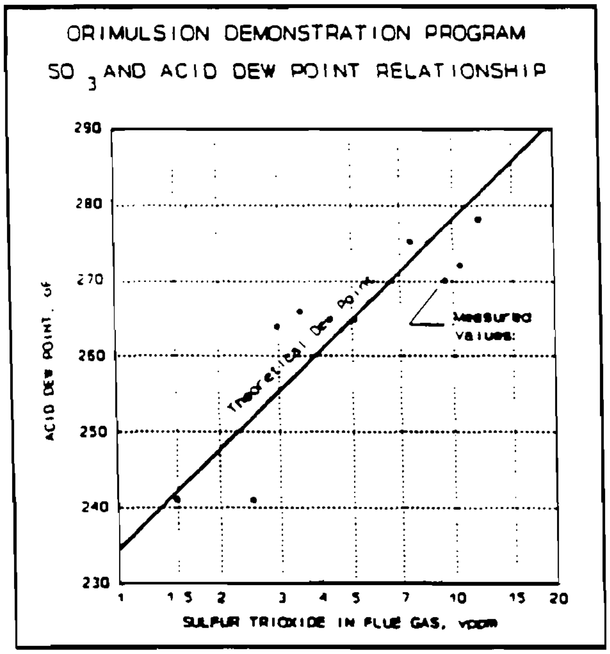


Figure 24 - Acid Dew Point

Although SO_3 emissions measured at the stack during the combustion of the first *Orimulsion*™ shipment were unusually high at 30 to 35 ppmv, concentrations measured during the combustion of the following shipments consistently ranged between 2 to 15 ppmv. This dramatic reduction was possible due to the ability to successfully burn *Orimulsion*™ at low excess O_2 levels, while maintaining high carbon conversion efficiency. The SO_3 values observed in the flue gas correspond to an acid dew point of between 245 and 290 °F, which was considered safe under normal operating conditions.

Low SO_3 concentrations, corresponding to low acid dew points, were observed during the combustion of *Orimulsion*™ with clean boiler conditions. The observed relationships between these parameters is compared to theoretical correlations in Figure 24.

CONCLUSIONS

The demonstration program being conducted on NB Power's Dalhousie 100 MW unit has been designed to establish critical fuel handling and combustion criteria in a commercial operating environment. The results of this program will be directly utilized for the design and operation of future stations for this unique fuel.

The principal results arising from the first phase of the Dalhousie demonstration program are summarized as follows:

FUEL HANDLING

- No deterioration in rheological properties during 3 months in storage.
- Similar fuel handling and controls as for # 6 Fuel Oil.
- Commercial specifications consistently achieved.
- Operating conditions to avoid potential detrimental effects on the emulsion were established.

COMBUSTION

- Internal mix steam atomizer provided excellent carbon burnout and a stable flame.
- Optimum excess O_2 levels established at 0.2% in flue gas.
- Mass gas flowrates were determined to be approximately 6% higher than for oil firing at same unit output.

- Boiler efficiency reduced by approximately 2.7% primarily due to the water content of the fuel.
- Ash deposits were easily removed with soot flowers and no high temperature corrosion potential was observed.
- Unit maintained at 90% of rated output for extended test period.

EMISSIONS

- Fly ash reinjection was not required due to less than 5% carbon in ash.
- ESP performed as per design although high inlet temperature reduced collection efficiency.
- Commercial recovery of vanadium from fly ash was demonstrated.
- NO_x emissions were virtually identical to oil firing.
- As expected, SO_x emissions were approximately 50% higher for #6 Fuel Oil firing.
- Low SO_3 concentrations in flue gas due to low O_2 requirements.

The demonstration program conducted at Dalhousie to date, has successfully proven that *Orimulsion*™ could be a technically viable fuel for utility boilers. The evaluation of fuel storage, handling, combustion, and emissions characteristics has provided a basis for future commercial designs. Preliminary indications are that proper recognition for the unique properties of the fuel should permit conversion of both #6 Fuel Oil and coal fired boilers to *Orimulsion*™ firing. The extent of the modification required for individual units would of course be dependent upon the original design configuration.

At present, tests are being conducted to evaluate the potential for partial removal of sulfur dioxide from the flue gas by in-furnace injection of limestone. The results of this series of test should be available in December of 1989.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Mr. Phil Whalen (Technical Consultant to the *Orimulsion*™ project team) and Mr. Julio Alcantara (Petroleos de Venezuela's resident engineer at Dalhousie) for their assistance in preparing this paper.

Attachment 1C

INSTITUTE OF ENERGY CONFERENCE ORIMULSION: THE WONDER FUEL?

BOILER PERFORMANCE

by B. C. Mackintosh
Consulting Mechanical Engineer

INSTITUE OF ENERGY CONFERENCE
ORIMULSION : THE WONDER FUEL?

Paper : BOILER PERFORMANCE

By B.C.Mackintosh

Synopsis

The principal properties of ORIMULSION which impact on boiler performance are its water and solids content.
Combustion efficiency has been found to be better than heavy fuel oil, producing lower carbon in ash and CO concentration at equal or lower excess air levels.
Furnace performance is reduced by a combination of lower flame temperature and emisivity, higher specific heat and mass of combustion products, and increased furnace fouling.
Convective surface performance is enhanced by the higher temperature and heat capacity of the flue gas but is degraded by ORIMULSION's increased fouling potential, the effect of which is dependent on the extent of on-load cleaning equipment available, ash deposits being readily removed where sootblowers are located.
The effect on the back end is an increase in final gas temperature, the magnitude of which is dependent on the cleanliness of heating surfaces and the means of reheat temperature control.
The water content of the fuel has the effect of reducing thermal effeciency by almost 2.5%. A further reduction in efficiency will occur due to the increase in final gas temperature, unless additional heating surface is installed.
The ability to operate at full capacity will depend on factors such as the allowable superheater and reheater metal temperatures, the available capacity of fans, and the effectiveness of on-load cleaning equipment. However, most of these deficiencies are amenable to correction by relatively simple and cheap modifications.

Introduction

Orimulsion was first burned in a utility boiler in September 1988, this being boiler one at Dalhousie power station, a 100MWe unit belonging to New Brunswick Power. This unit operated almost continuously on ORIMULSION until February this year, during which time a considerable amount of operational data and experience was obtained and the commercial viability of ORIMULSION as a fuel for utility boilers was established.

This experience was verified in the summer of 1989 by a trial burn of a 40,000 tonne shipment in one of the

500MWe oil fired units at Power Gen's Ince B power station in Cheshire, which is now being converted for continuous operation on this fuel.

This paper is based mainly on an analysis of data obtained at Dalhousie.

Fuel Characteristics

The characteristics of ORIMULSION having the greatest impact on boiler performance are its water content and solid incombustibles. Fig. 1 shows a comparison of the analysis of heavy fuel oil (HFO) with that of ORIMULSION, from which it can be seen that the 28+% water content has a dramatic effect on the properties of a fuel which, on a dry basis, is chemically very similar to HFO.

The metals content of ORIMULSION is also significant (Fig. 2), being characteristic of Venezuelan crudes with the exception of Magnesium. This element is added in organic compound form at the production stage as an anti-ageing agent, but it also performs a useful service as a conditioning agent on the products of combustion.

Flue Gas Properties and Efficiency

On a unit energy basis the theoretical air for combustion is virtually identical to that for HFO, and it therefore follows that combustion air for equal excess Oxygen is also similar (Fig. 3). The effect of water in fuel, however, is to increase combustion gas weight by 2.5% on a unit energy basis at an excess Oxygen of 1%.

Water vapour also has a significant effect on the thermal capacity of the flue gas. Fig. 4 shows the comparison between HFO and ORIMULSION produced flue gas enthalpy at a typical furnace outlet temperature of 1,350° C, and the mean specific heat at a typical final gas temperature of 150° C.

Gas mass per unit heat release and specific heat of flue gas determine the heat content of the stack gas and therefore the thermal efficiency which, compared with fuel oil, is degraded some 2.3% at the same back end temperature (Fig. 5). The actual thermal efficiency difference will be higher in practice due to an inevitable increase in final gas temperature resulting from the increased gas mass flow rate, assuming no changes to the heating surfaces. The actual reduction in thermal efficiency will depend on additional factors such as the difference in the extent of heating surface fouling and unit configuration. For an escallation of

20°C in final gas temperature the reduction in efficiency will be of the order of 3.2% of GCV.

Combustion efficiency of ORIMULSION has been found to be better than HFO, both in terms of unburned carbon in ash (Fig.6) and in CO concentration at equal or lower excess air levels.

Fig. 7 shows how the weight of combustion air and gas at 1% excess Oxygen, and stack gas at 3% O2 are likely to increase compared with HFO, as a function of final gas temperature.

Thermal Performance at Dalhousie

Before firing each new shipment of ORIMULSION (a shipment lasted approximately four weeks) the boiler heating surfaces were restored to a base line cleanliness by water washing. As was to be expected from the fuel's charactics, there was an immediate increase in heat absorption in the superheaters and reheater, the latter being offset by a downward tilt of the burners. There was also an increase of some 15°C in gas temperature leaving the airheaters. A further increase in gas temperature throughout the unit would also be expected with time as the heating surfaces aged. In practice the gas temperatures continued to rise as shown by the trend in final gas temperature in Fig. 8, with burner tilt being progressively increased to its maximum negative value, followed by spray water injection into the reheater inlet steam and increasing spray into the superheater, until equilibrium conditions were reached after about 15 to 20 days. High back end temperatures required load to be reduced progressively to about 90% due to limitations imposed by induced draught fan capacity and acceptable gas temperature into the electrostatic precipitator.

Figs. 9 and 10 show the gas and steam temperature profiles through the boiler at similar loads when firing HFO and ORIMULSION with burner tilts of -8° and -30° respectively. The effect of the higher heat capacity of ORIMULSION flue gas can be seen in the increased slope of the air temperature rise through the airheater. The lower fluid temperature rise in the economiser and primary superheater, in spite of increased temperature heads and lower fluid mass flow resulting from higher attemperator spray water flow, is evidence of considerable fouling of these heat exchangers, in contrast to the final superheater where the steam temperature rise is more in keeping with the increased gas temperature, revealing a negligible change in surface cleanliness. Furnace exit temperature shows the effects of increased gas mass flow and heat capacity, reduced furnace effectiveness from fouling and modified flame radiation characteristics, plus increased combustion air temperature, offset by increased negative tilt of the burners.

Fouling

Off load inspection of the boiler showed considerable fouling of heating surfaces. The furnace walls, which are not provided with sootblowers, had accumulations of mainly lightly sintered, friable deposits which would be readily dislodged by normal furnace wall on-load cleaning equipment. Adjacent to the upper burners deposits were thicker and denser with some fusing of the surface; it is probable that had the deposit build-up been prevented by sootblowers the deposit temperature would have remained below the fusion point.

Convective surface deposits were most severe in the low temperature close pitched heat exchangers where the on-load cleaning equipment (steam sootblowers) were fewer and poorly located (Fig.11). Vertical stringers supporting the heting surfaces effectively introduce a vertical baffle where the tubes are closely pitched, as in the primary superheater and economiser. In the former the absence of blowers in the outer two lanes meant that tubes in these were effectively uncleaned, as demonstrated by the deposits filling the vertical inter-tube spaces. Tubes within the effective cleaning radius of a sootblower remained acceptably clean, as shown by the relatively unchanged performance of the reheaters and high temperature superheaters. Both the very deep single bank of primary superheater and the top bank of the economiser were not equiped with blowers in the top cavities and hence the upper part of these banks became heavily fouled.

The nature of convective surface deposits varied from light, dusty, easily removed deposits in the primary and economiser, to lightly sintered, friable deposits in the higher temperature banks where sootblowers were able to maintain an acceptable degree of cleanliness.

Deposit Characteristics

Furnace wall deposits consisted mainly of $MgSO_4$ plus $MgO.V_2O_5$, which also made up most of the deposit in the platen superheater. Deposits in the reheater consisted of a mixture of $MgSO_4$, $2MgO.V_2O_5$ and $3MgO.V_2O_5$. The surfaces downstream held mixtures of $MgSO_4$ and $3MgO.V_2O_5$. All deposits had Mg/V concentrations of around 1:1 from fuel with a Mg/V ratio of 1.3:1. Nowhere was there evidence of Sodium Vanadyl Vanadate ($Na_2O.V_2O_4.5V_2O_5$)

which is associated with bonded deposits and high temperature corrosion.

Ash fusion temperature measurements carried out on deposit samples showed figures in excess of 900°C, supported by the absence of any sign of high temperature corrosion.

The beneficial effects of Magnesium and low excess air combustion were seen in the low measured levels of SO_3, which fell within the range of 2 to 15vppm dry. Correspondingly low levels of dew point temperature were also measured. There was a tendency for dew point temperature to rise with time, possibly indicating higher catalytic conversion of SO_2 to SO_3 as deposit thicknesses increased. Fig.12 shows the upper limit curve of measured dew point as a function of excess Oxygen.

Performance Analysis

With comparative HFO and ORIMULSION performance data from the boiler following washing and with the surfaces aged with ORIMULSION, it has been possible to separate the effects of the different radiating charactics of the two fuels and the effect of fouling on the furnace performance. To make the analysis meaningful it has been necessary to eliminate the effects of burner tilt and furnace heat input. The results of this analysis are shown in Fig.13, giving furnace exit gas temperature (FEGT) as a function of the log. of heat release flux. Approximately one third of the increase in FEGT can be attributed to the difference in flame and gas radiating properties, the remaining two thirds being due to fouling, giving approximately an 80°C rise in FEGT at equal heat input. However, in practice the heat input will rise with ORIMULSION at a given boiler load due to reduced efficiency, so the increase in FEGT will be somewhat higher unless offset by burner tilt.

The thermal resistance of ORIMULSION ash deposits in excess of those for HFO firing are tabulated in Fig.14. The figures reflect the sootblower effectiveness, but other possibly significant variables are gas velocity/ tube cross pitch, and gas temperature. Tube pitch in the primary superheater and economiser banks is constant at 4.5" (114mm) and 3.75" (95mm) respectively, giving intertube gaps of 2.375" (60mm) and 1.75" (44.5mm). As there were no intermediate steam temperature measurements available in the secondary superheater and reheater the resistances are the average of three banks in the former, pitched at 27/9/4.5" (686/228/114mm) with gaps of 25.25/7/2.5" (641/178/63.5mm); that of the reheater was the average of two banks pitched at 27/9" (686/228mm), with gaps of 24.875/6.875" (632/165mm). There was insufficient data to calculate fouling thermal resistance of the airheater deposit so this is shown in Fig.14 as a multiplier on the overall heat transfer coefficient relative to that for HFO.

Effect on Auxiliaries

The effect on the duty of forced draught fans is indicated by the increased combustion air weight demand shown in Fig.7, the increase in fan head being approximately the square of the weight increase, plus some allowance for increased air pressure loss through a regenerative airheater due to fouling.

Induced draught fans will have to handle the increased volume of gas resulting from increase mass and temperature. Fig.15 shows the effect of gas temperature on gas volume at the back end per unit of heat output, where an increase in gas temperature of 20°C with ORIMULSION for the same excess oxygen level would result in a volume increase of about 12%. With the increase in draught loss resulting from the gas volume change and surface fouling the combied effect is likely to consume the available fan margins.

Besides producing a higher dust concentration the fly ash from ORIMULSION has a very much smaller particle size (Fig.16), producing a much more visible plume from the stack, requiring electrostatic precipitators to be fitted in most cases. Of the total ash produced between 5 and 10% was deposited in the furnace hopper at Dalhousie, but this may vary slightly with burner arrangement and furnace rating. It is a factor which must be bourne in mind when considering a conversion, particularly where weight may be a limiting criterion, such as could be the case in a once-through boiler constructed with inclined tubes in the furnace walls with the load taken by constant load springs.

Conclusions

1. ORIMULSION can be fired with very low levels of excess oxygen whilst maintaining negligible unburned carbon in ash and CO concentration.

2. There will be a reduction in thermal efficiency, part of which is a consequence of the fuel's analysis and is unavoidable. The remaining reduction will depend on factors specific to the unit, such as the extent and effectiveness of on-load cleaning equipment.

3. There will be an increase in furnace exit gas temperature, the effect of which may be partly offset if tilting burner are fitted or there is significant gas recirculation already being used at full load.

4. There will be an increase in superheater and reheater absorption which will require increased spray attemperation in the former and may require attemperation to be introduced in the latter.

5. The ability to operate at full load will depend on the fan margins available and allowable metal temperatures in superheaters and reheaters.

6. Additional sootblowers may be required and could be economically justified in the convective surfaces to control fouling, improve efficiency, reduce metal temperatures and reduce fan duties.

7. Additional heating surface in the economiser and /or airheater may also be similarly justifiable economically.

8. Environmental requirements are likely to be the most costly part of a conversion.

Acknowledgements

The author wishes to thank Petroleos de Venezuela and BP Bitor Ltd for support in preparing this paper and for the access to data and information pertaining to ORIMULSION and the firing trials at Dalhousie.

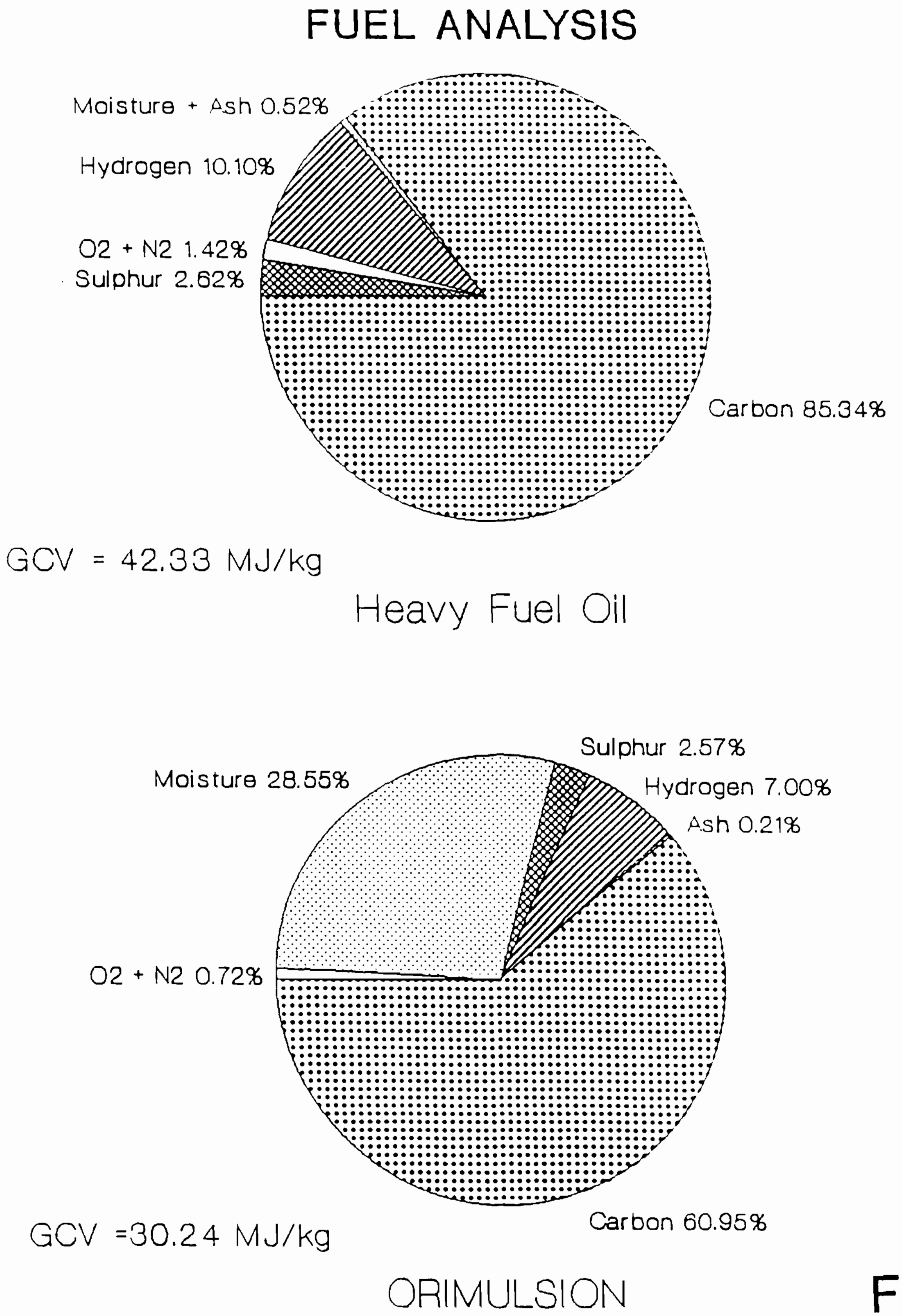

FUEL ANALYSIS
Moisture + Ash 0.52%
Hydrogen 10.10%
O2 + N2 1.42%
Sulphur 2.62%
Carbon 85.34%
GCV = 42.33 MJ/kg
Heavy Fuel Oil
Sulphur 2.57%
Moisture 28.55%
Hydrogen 7.00%
Ash 0.21%
O2 + N2 0.72%
Carbon 60.95%
GCV =30.24 MJ/kg
ORIMULSION

Fig. 1

ORIMULSION
Metals Content

Metal	Concentration - ppm	
	Average	Maximum
Vanadium	300	360
Sodium	70	90
Magnesium	390	500

Fig. 2

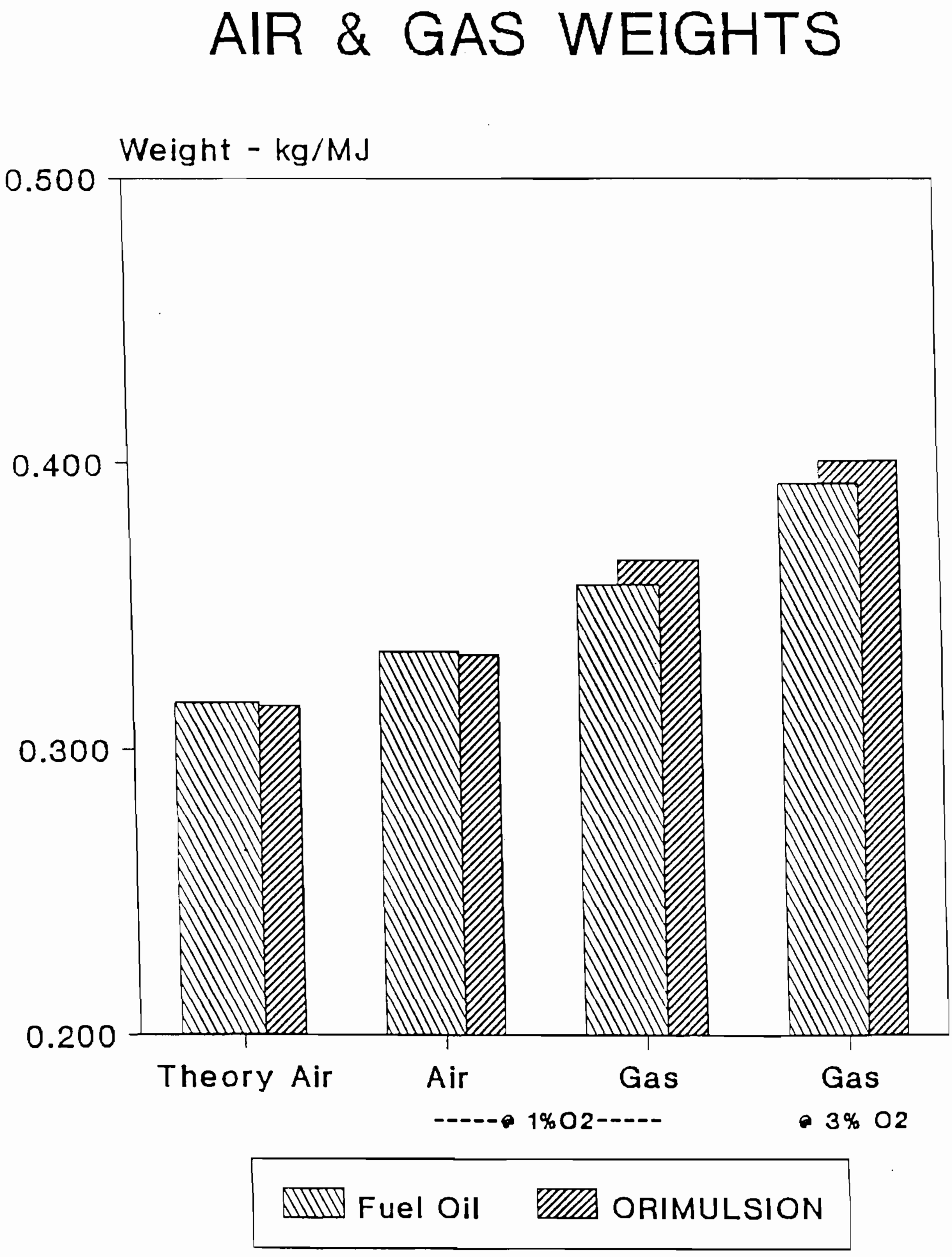

AIR & GAS WEIGHTS
Weight - kg/MJ
0.500
0.400
0.300
0.200
Theory Air
Air
Gas
Gas
-----@ 1%O2-----
@ 3% O2
Fuel Oil
ORIMULSION

Fig. 3

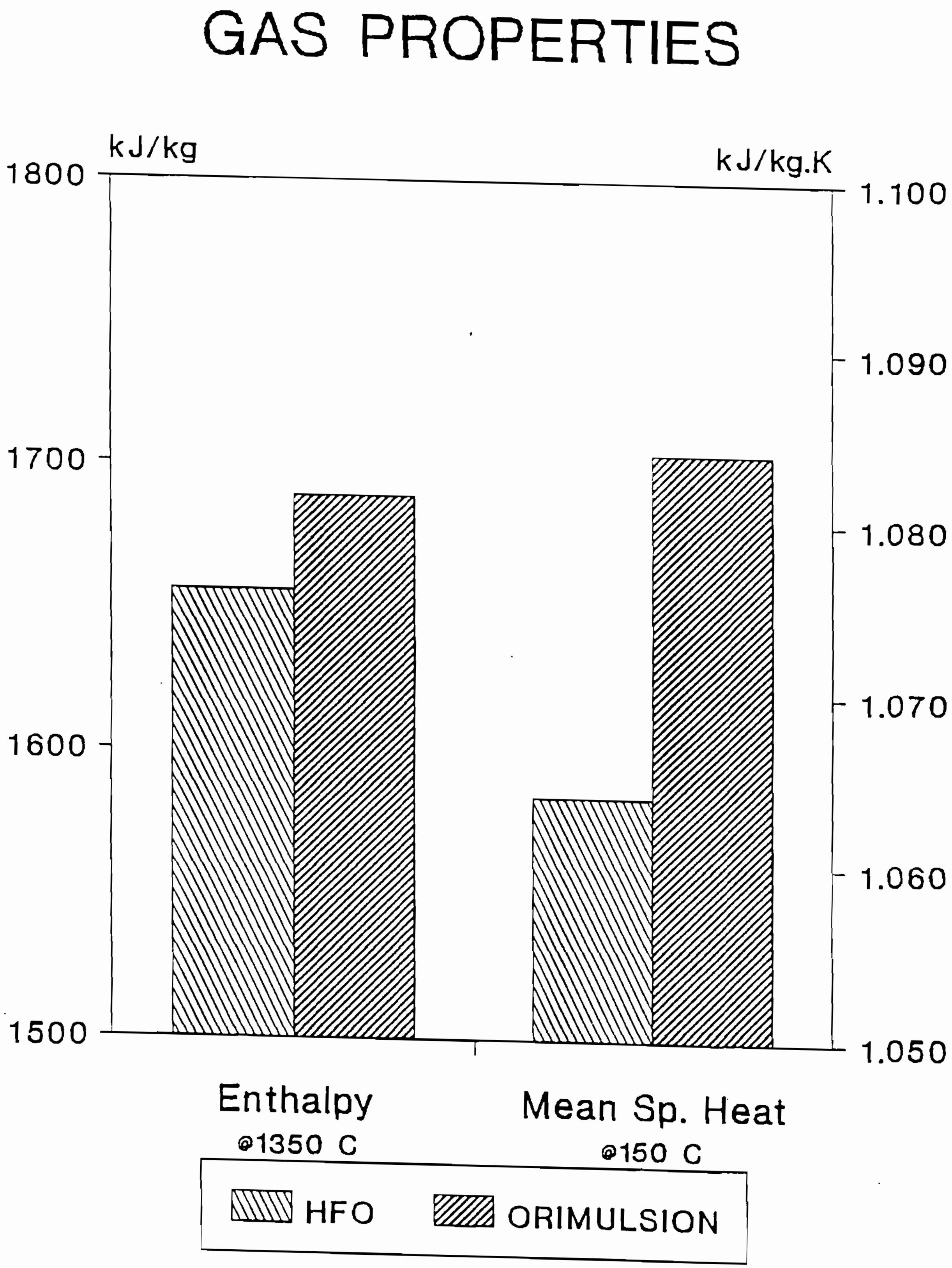

GAS PROPERTIES
kJ/kg
kJ/kg.K
1800
1700
1600
1500
1.100
1.090
1.080
1.070
1.060
1.050
Enthalpy
@1350 C
Mean Sp. Heat
@150 C
HFO
ORIMULSION

Fig. 4

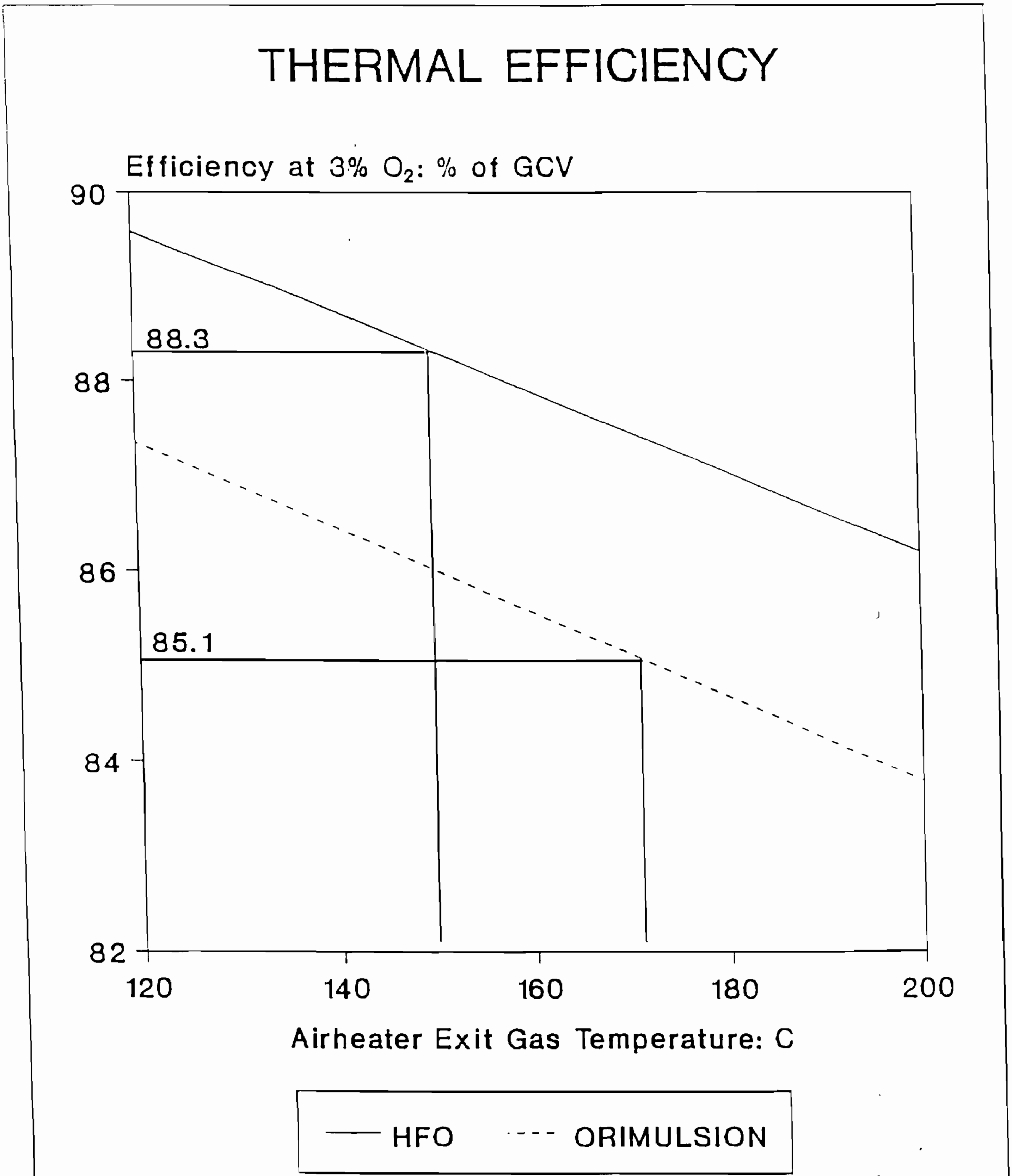
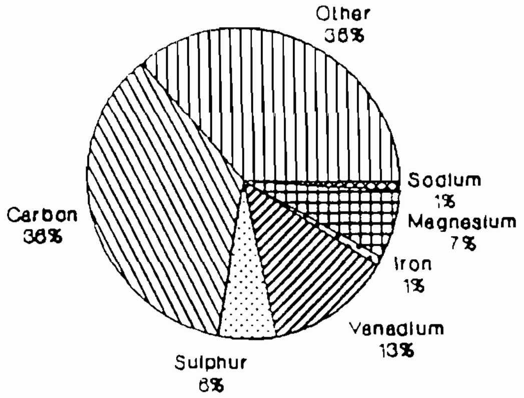

THERMAL EFFICIENCY
Efficiency at 3% O_2: % of GCV
90
88
86
84
82
88.3
85.1
120
140
160
180
200
Airheater Exit Gas Temperature: C
HFO
ORIMULSION

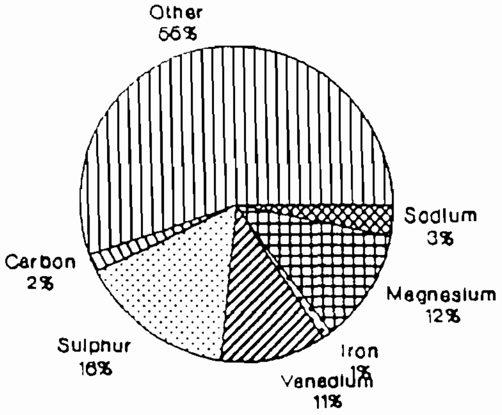
Fig. 5

FLY ASH ANALYSIS



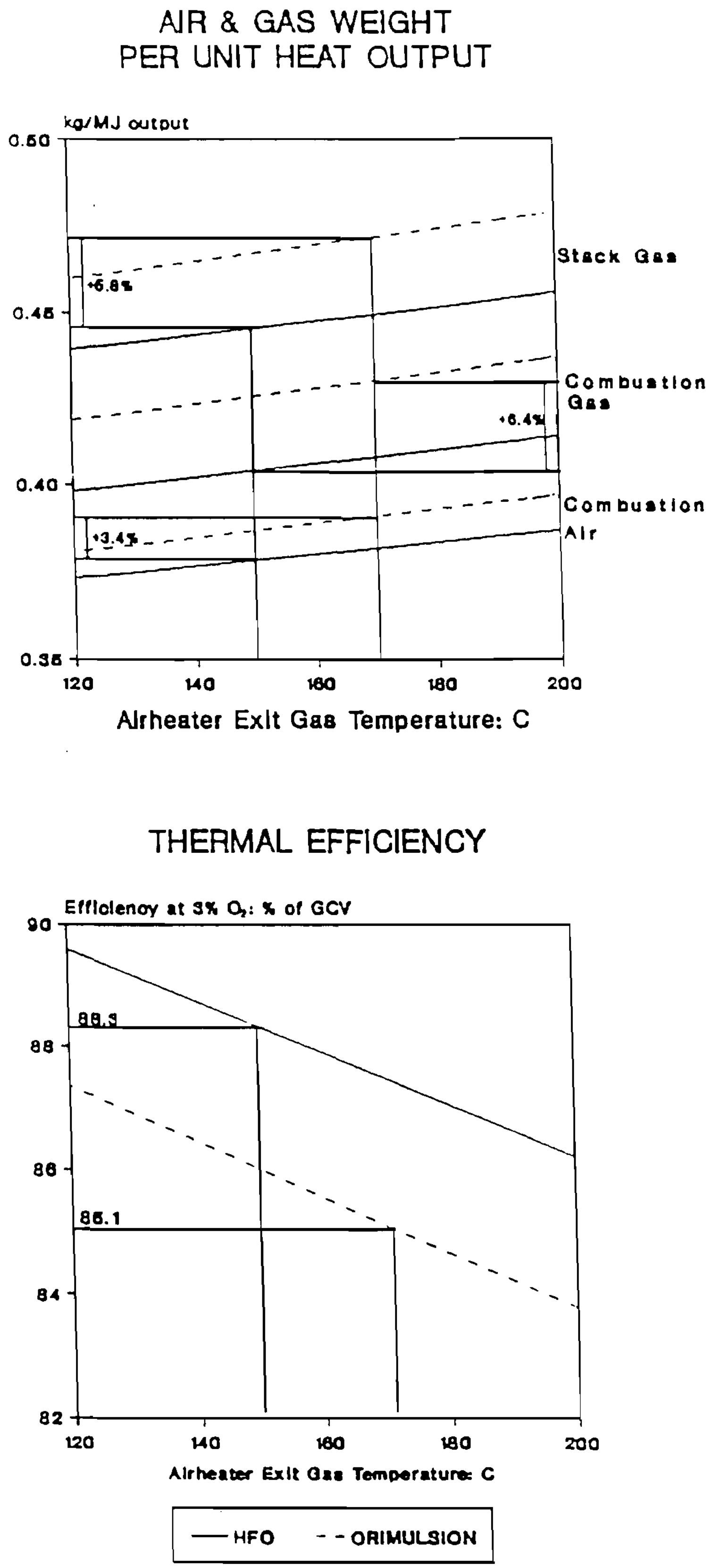
Heavy Fuel Oil

Other: Oxygen + Hydrogen & Nitrogen



ORIMULSION

Fig. 6


AIR & GAS WEIGHT PER UNIT HEAT OUTPUT

THERMAL EFFICIENCY

Fig. 7

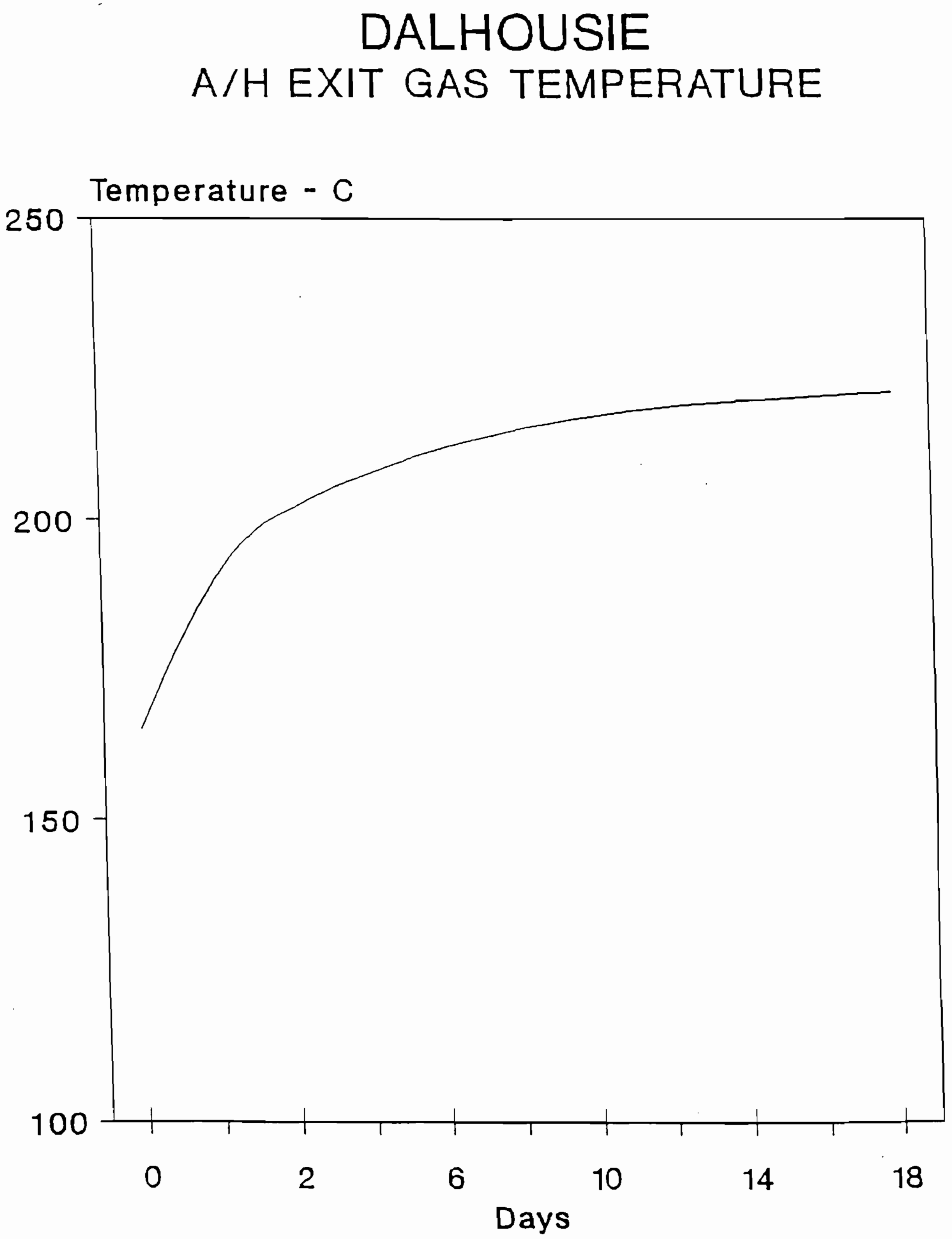

DALHOUSIE
A/H EXIT GAS TEMPERATURE
Temperature - C
250
200
150
100
0
2
6
10
14
18
Days

Fig. 8

DALHOUSIE PERFORMANCE
GAS & STEAM TEMPERATURES
HFO - Load: 90MW

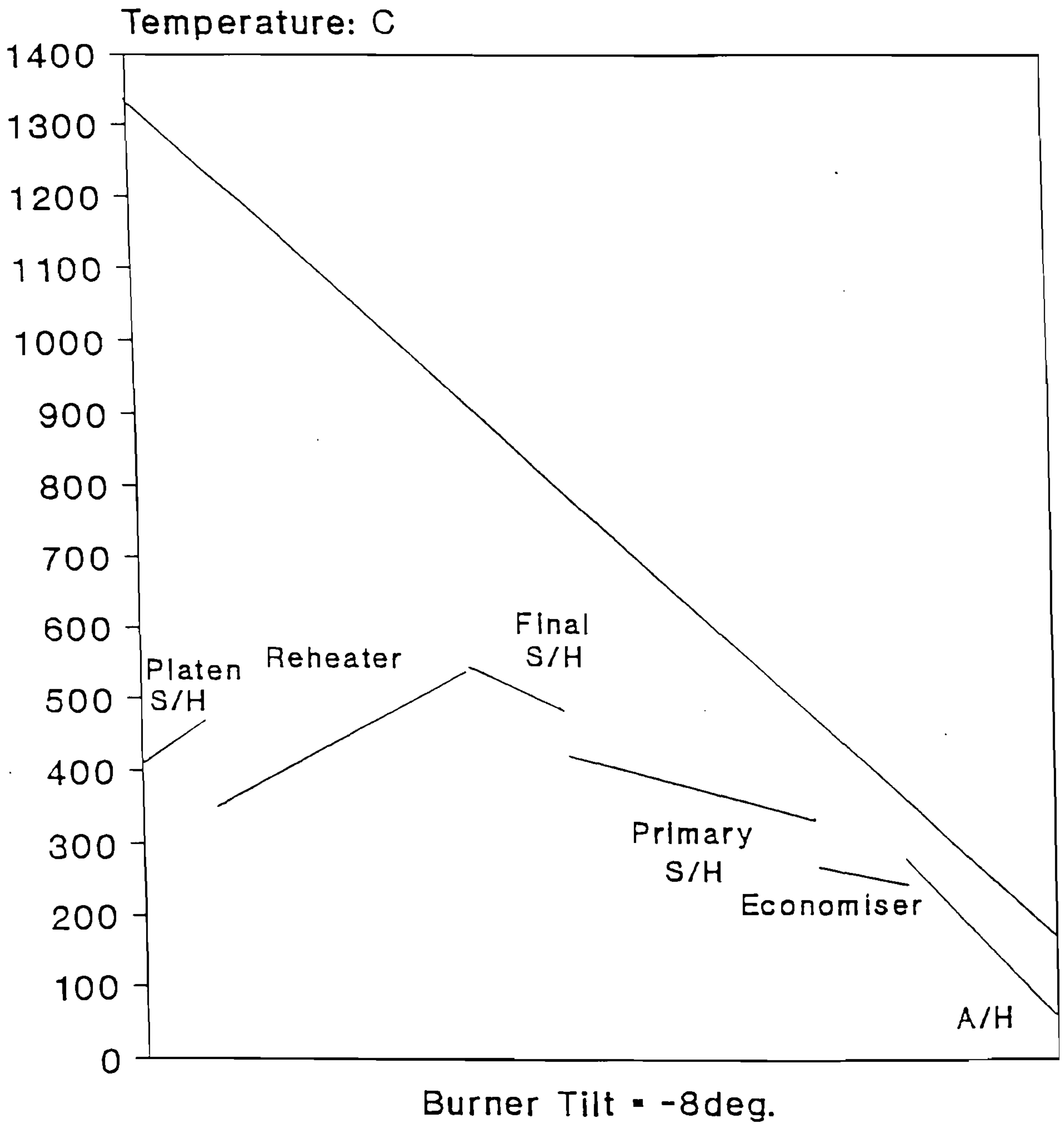


Fig. 9

DALHOUSIE PERFORMANCE
GAS & STEAM TEMPERATURES
ORIMULSION - Load: 91MW

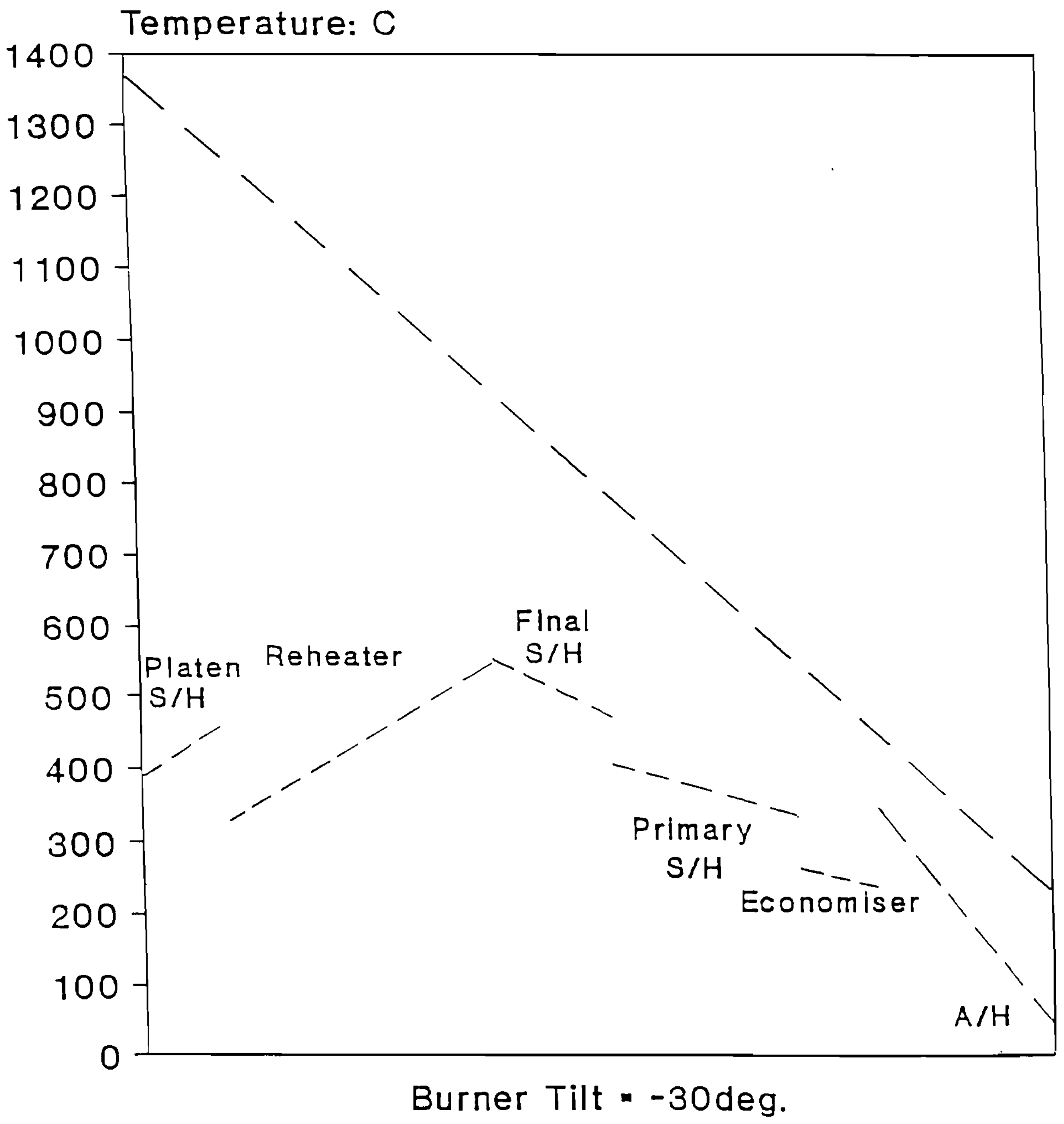


Fig. 10

DALHOUSIE SOOTBLOWER LOCATIONS

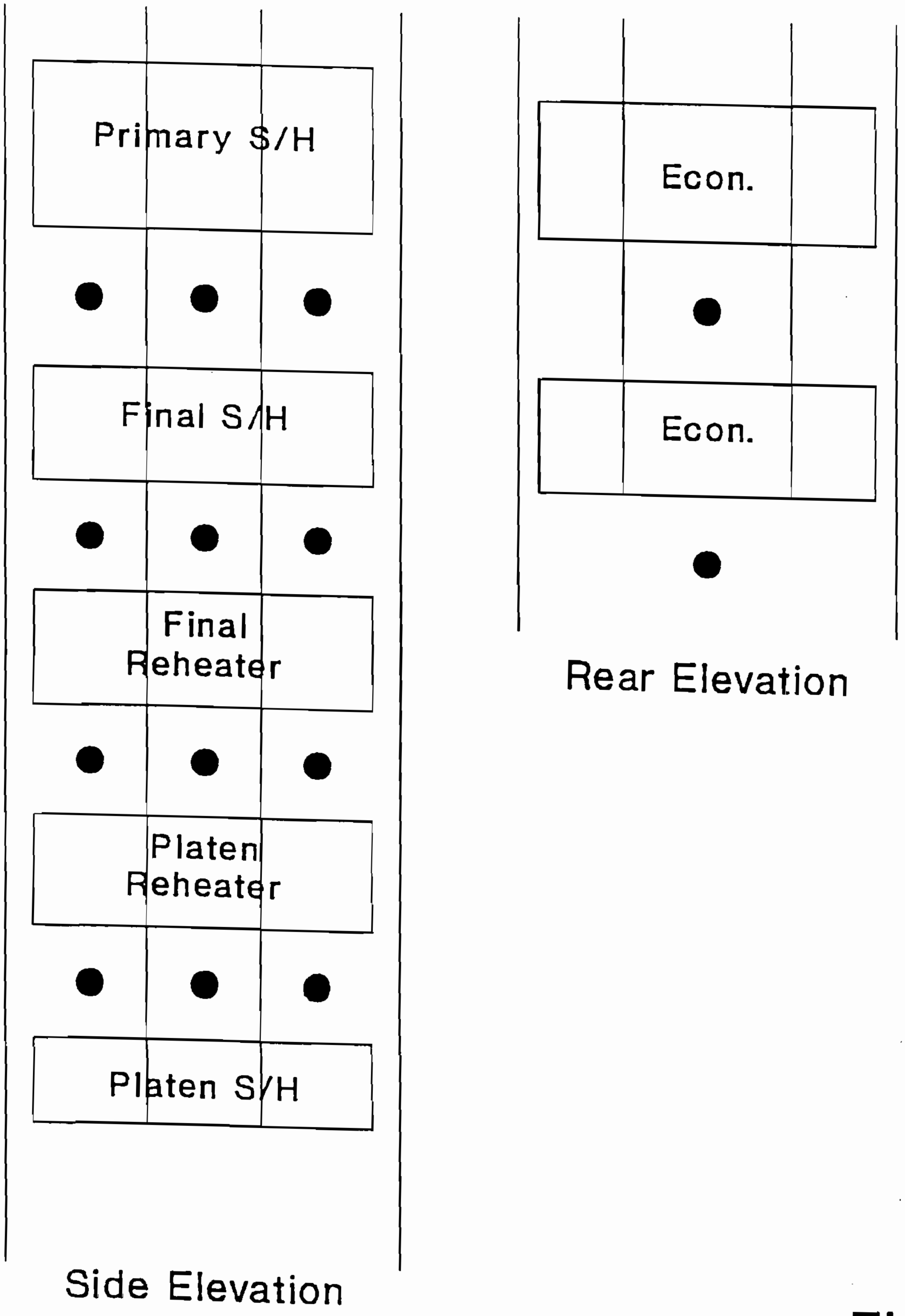
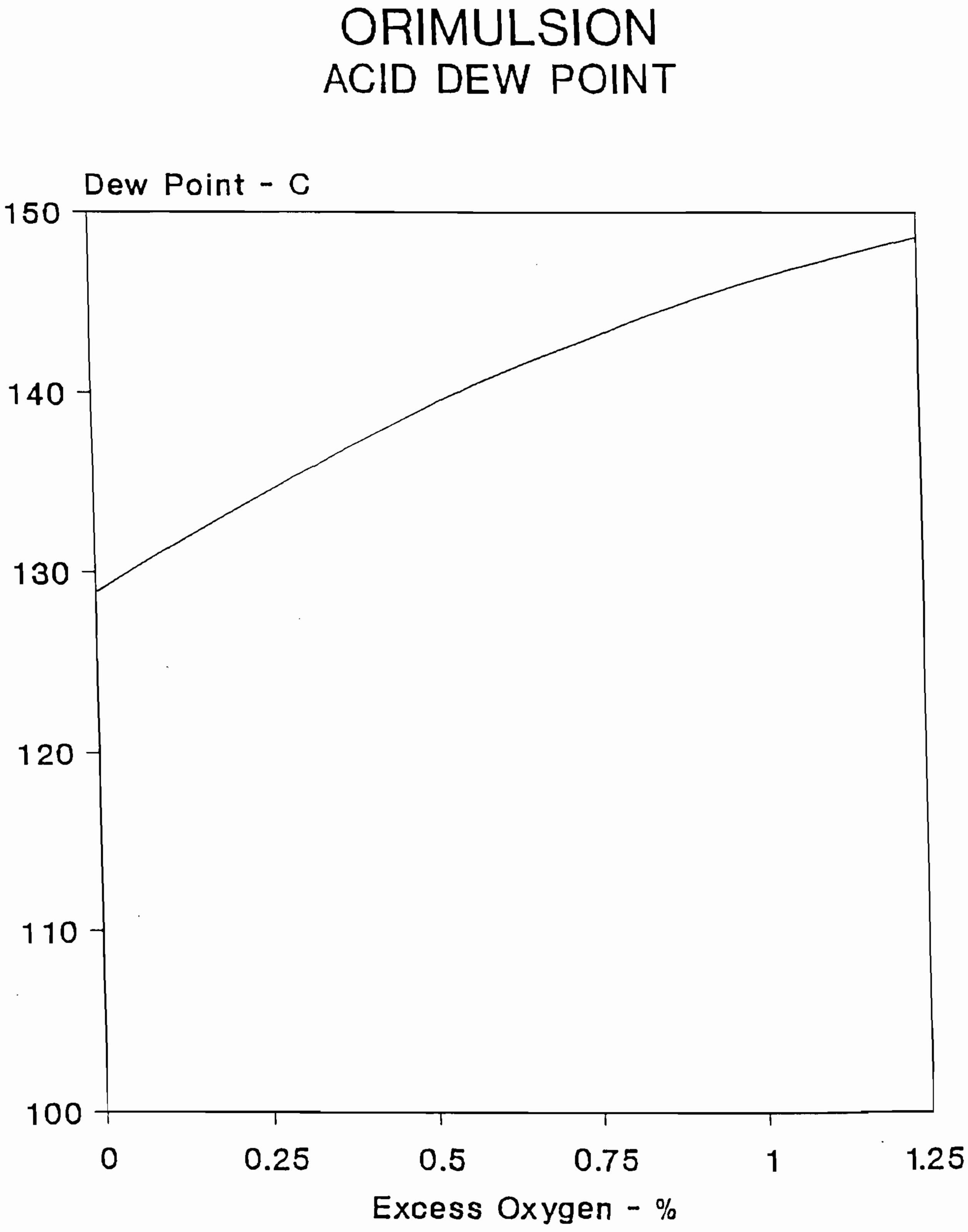


Fig. 11



ORIMULSION
ACID DEW POINT

Fig. 12

FURNACE EXIT GAS TEMPERATURE
ORIMULSION RELATIVE TO HFO

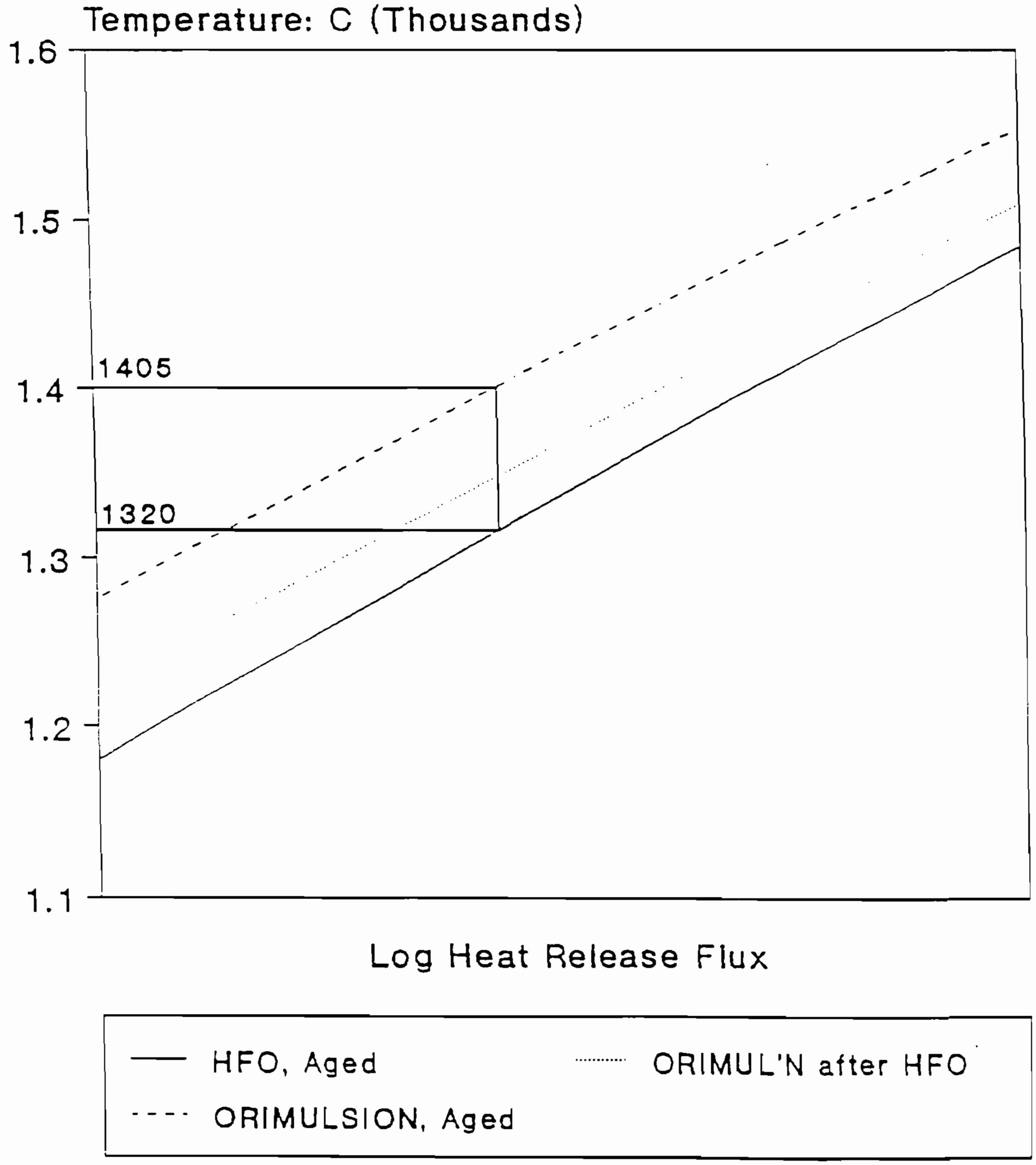


Fig. 13

HEATING SURFACE FOULING
ORIMULSION AT DALHOUSIE

Surface Type	Sootblower Coverage	H.T Resistance m2.K/W x 1000
Secondary S/H	3 sets of 3 racks	0
Reheater	2 sets of 3 racks	1.2
Primary S/H	1 set of 3 racks	8.8
Economiser	1 set of 2 half-tracks	7.0
		Factor on H.T Coefficient
Airheater	Standard Air Preheater Corp.	0.84

Relative to Oil

Fig. 14

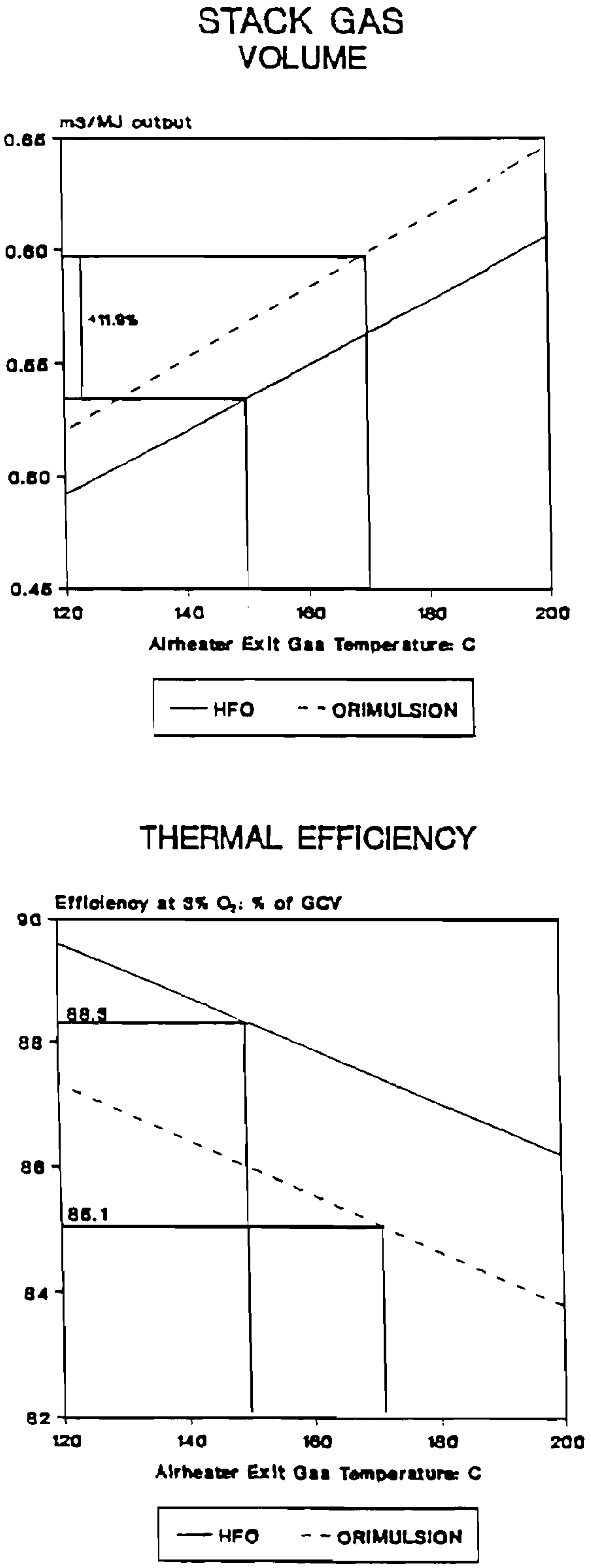

STACK GAS
VOLUME
m3/MJ output
0.65
0.60
0.55
0.50
0.45
+11.9%
120
140
160
180
200
Airheater Exit Gas Temperature: C
HFO
ORIMULSION
THERMAL EFFICIENCY
Efficiency at 3% O₂: % of GCV
90
88
86
84
82
88.3
85.1
120
140
160
180
200
Airheater Exit Gas Temperature: C
HFO
ORIMULSION

Fig. 15

EMISSIONS

FLY ASH PARTICLE SIZE DISTRIBUTION

Size micron	% Passing	
	HFO	ORIMULSION
75	100	100
50	90	100
10	38	98
5	23	91
0.3	-	50

Fly Ash Concentration: 250 mg/Nm3

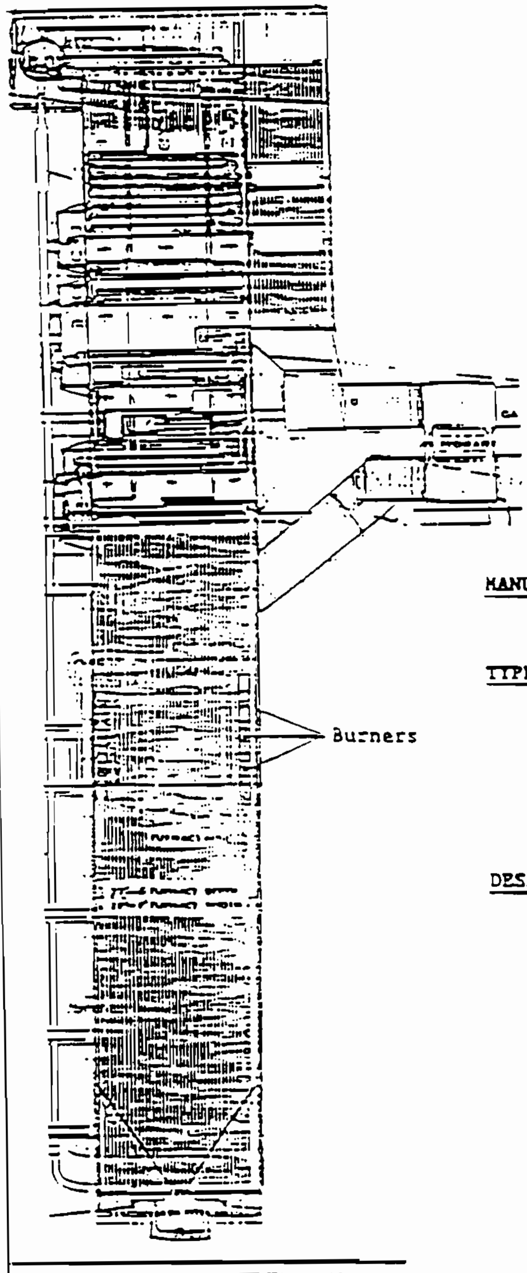
Ash Resistivity = 3 - 5 ohm cm

GASEOUS EMISSIONS

Gas	Concentration - mg/Nm3
SOx	6500 - 6750
NOx	370 - 400 (similar to HFO)

Fig. 16

DALHOUSIE UNIT ONE
NEW BRUNSWICK POWER



MANUFACTURER : Combustion Engineering Superheater Ltd.

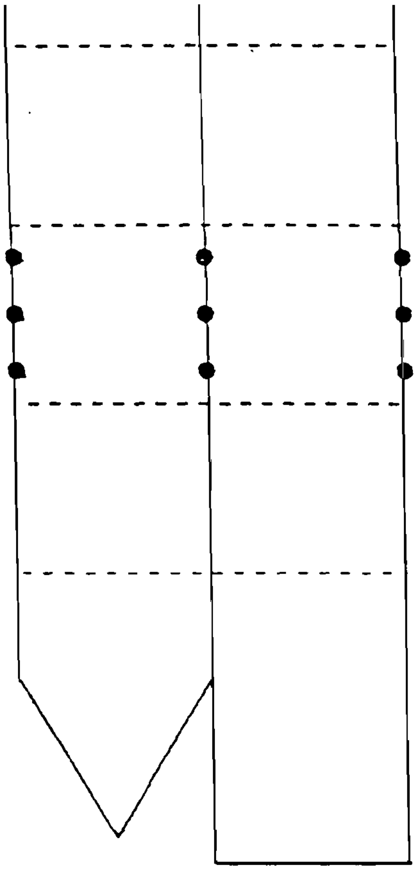
TYPE : Tangentially oil fired two-pass tower natural circulation boiler with convection surface arranged horizontally and fully water cooled furnace designed for possible conversion to coal firing.

DESIGN OPERATING CONDITIONS (Oil Firing)

Evaporation : 89.8 kg/s (690,000 lb/h)
Superheater outlet pressure : 125.9 bar.g (1825 psig)
Superheater outlet temperature : 540°C (1005°F)
Feed water temperature : 238°C (461°F)
Reheater steam flow : 79.7 kg/s (633,000 lb/h)
Reheater inlet steam temperature : 335°C (461°F)
Reheater outlet steam temperature : 540°C (1005°F)
Reheater inlet steam pressure : 28.3 bar.g (411 psig)
Gas temperature leaving airheater : 142°C (287°F)

Fig. 17

DALHOUSIE FURNACE
ASH DEPOSITS



Thin, fused, moderately/
strongly bonded
Mg/V = 0.73

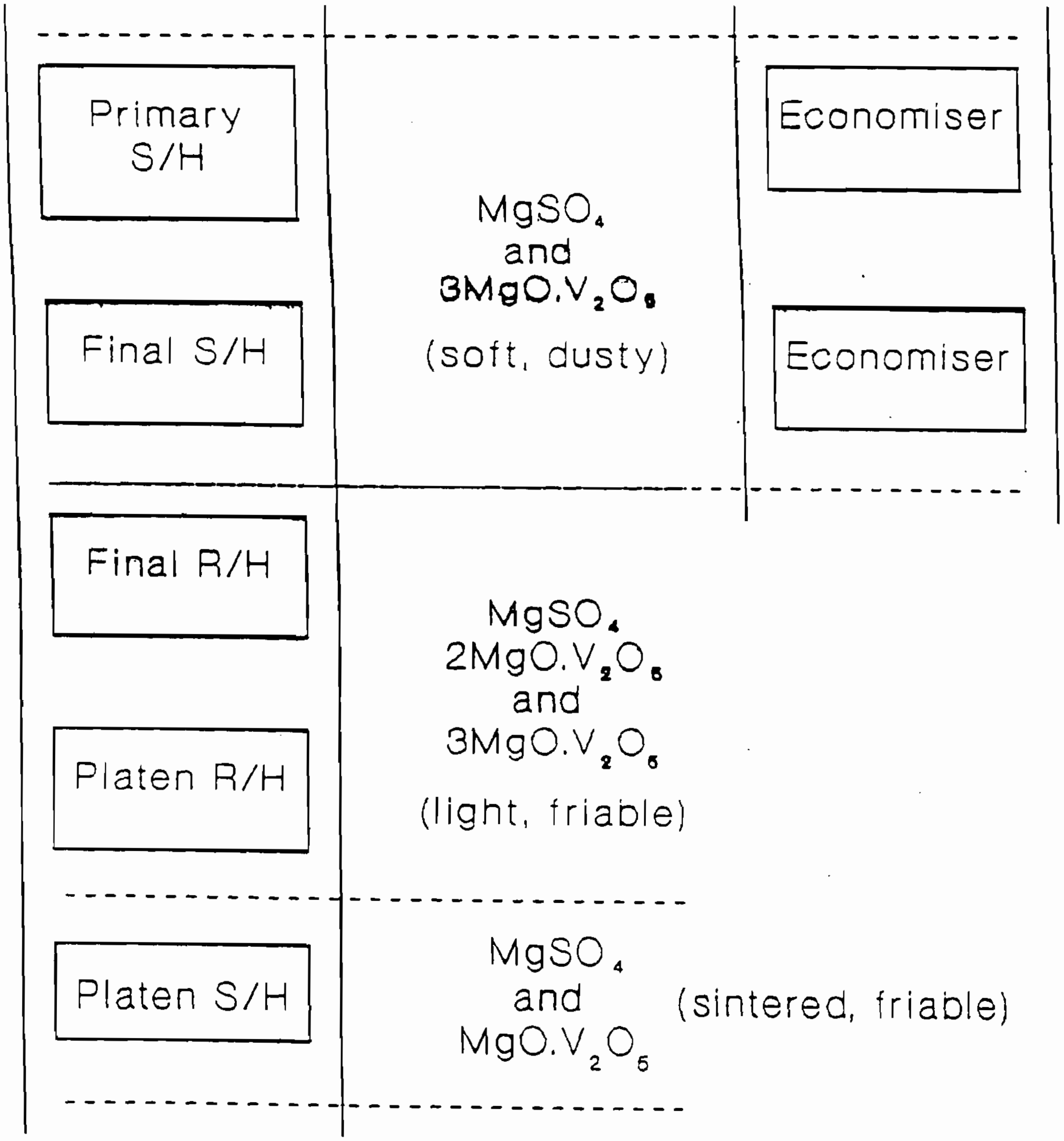
Sintered, crusty, adherent
Mg/V = 1.25

Thin: sintered at top,
dusty at bottom
Mg/V =1.25

Thin, lightly adherent
Mg/V = 1.18

DALHOUSIE TUBE BANKS

ASH DEPOSITS



Primary S/H

Final S/H

$MgSO_4$
and
$3MgO.V_2O_5$
(soft, dusty)

Economiser

Economiser

Final R/H

Platen R/H

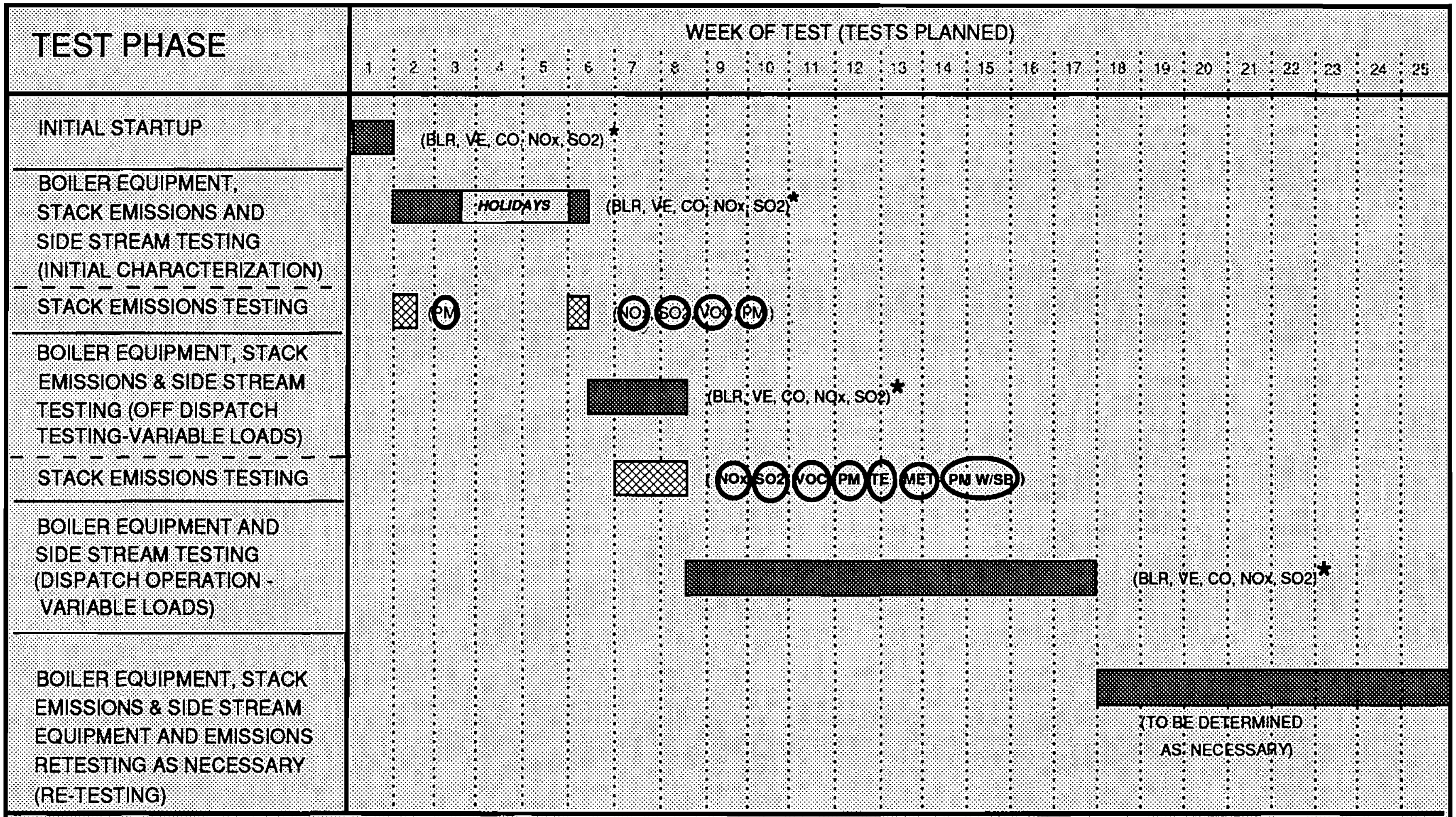
$MgSO_4$
$2MgO.V_2O_5$
and
$3MgO.V_2O_5$
(light, friable)

Platen S/H

$MgSO_4$
and
$MgO.V_2O_5$
(sintered, friable)

TESTBURN
7/06/90

ORIMULSION TEST BURN SCHEDULE (PRELIMINARY)



TEST CODES:

BLR = BOILER
PM = PARTICULATE MATTER
PM W/SB = PARTICULATE WITH SOOT BLOWERS

SO2 = SULFUR DIOXIDE
NOx = NITROGEN OXIDES
CO = CARBON MONOXIDE
VOC = VOLATILE ORGANIC COMPOUNDS

VE = VISIBLE EMISSIONS
TE = TRACE ELEMENTS
MET = METALS
○ = STACK TESTS (EXTRACTIVE)

* VE, CO, NOx, SO2 CEM'S IN STACK THROUGHOUT TEST PERIOD

Attachment 2

Attachment 3A

1 MWe Flue Gas Slipstream

The 1 MWe slipstream pilot test equipment will consist of a spray dry absorber, a reagent preparation system, and ~~a~~ 2 pulse jet baghouses The spray dryer, which is rated at 4500 acfm and uses slaked lime, is an existing unit currently located at the University of Alabama. The vendor, ASEA Brown Boveri (formerly Combustion Engineering), is providing the unit free of cost for the test. FPL will bear the costs of reconditioning the equipment, which has been out of service since February 1989. The spray dryer is capable of 90 percent or better removal of SO_2 from the flue gas.

Flue gas at air preheater outlet temperature enters the spray dryer and passes through a fine spray of lime slurry. The flue gas is adiabatically humidified and cooled by the evaporating water droplets, while SO_2 reacts with the lime. The slurry droplets are dried to less than a few percent of free moisture before leaving the spray dryer and are transported with the flue gas to the baghouse. Additional SO_2 removal (about 10%) takes place in the baghouse.

A paste slaker which is part of the spray dryer pilot plant will be used to produce slaked lime. The slurry flow rate will vary between 0.2 to 1.6 gpm.

The baghouse is an existing unit manufactured by Howden and used for pilot testing by the Electric Power Research Institute (EPRI). This equipment will also be provided free of charge for the test, with FPL bearing the cost of shipping and erection. This is a low pressure, pulse-jet baghouse rated for approximately 5000 acfm at an air-to-cloth ratio (A/C) of 4 ft/sec. The anticipated particulate removal efficiency is in the 99.8% range.

Different bag fabrics will be evaluated during the test. Needled felts, such as RYTON or Teflon, are recommended. Bags are 20 feet in length. An initial precoat with limestone may be necessary to prevent "blinding" of the fabrics by the Orimulsion fly ash.

2.5 - 5 MWe Flue Gas Slipstream

The 2.5 - 5 MWe slipstream pilot test equipment will consist of a reverse gas/sonic and shake/deflate baghouse, a sodium-based scrubber, and a regenerative sorbent process with salable byproduct. The baghouse is an existing unit manufactured by Ecolaire for pilot testing by EPRI. It has four (4) compartments, each rated for 3600 acfm, for a total capacity of 14,400 acfm (5 MWe). In two of the compartments, cleaning is achieved by forcing a gentle flow of clean flue gas backwards through the compartment to be cleaned. Low-frequency pneumatic horns are also utilized to add energy to the cleaning process. The other two compartments employ a gentle reverse gas flow to deflate the bags, which are then mechanically shaken to remove the accumulated fly ash.

The baghouse will have bags of woven fiberglass fabric. Bags are about 24 feet in length and 8 inches in diameter. There are 36 bags in each compartment. Prior to each startup it will be necessary to precoat the bags with limestone to prevent "blinding" of the fabric by the Orimulsion fly ash.

EPRI is providing the baghouse to FPL for the cost of shipping it to the site and assembly.

After passing through the baghouse, the flue gas will enter a vertical packed absorber rated for 10, 800 acfm and designed for 90+% SO_2 removal. This absorber will be used in conjunction with a recently developed regenerable flue gas desulfurization technology known as SOXAL and supplied by Aquatech Systems, a subsidiary of Allied Signal Corporation. The SOXAL process uses a bipolar membrane to recover and regenerate the spent reagent, producing a highly concentrated SO_2 stream which may be sold as liquid SO_2. Aquatech will contract the design and fabrication of the pilot absorber to complement a pilot SOXAL plant being developed for this test.

The SOXAL regeneration plant will be sized for 65% of the absorber capacity, to account for cycling loads. Reagent holdup tanks, both for spent and regenerated sorbent, will provide the needed surge capacity to feed spent reagent to the SOXAL process at a steady rate. There are four (4) tanks total, each sized at 13,000 gallons, to provide a holdup capacity of up to three (3) days.

The SOXAL regeneration plant and accessories (but not including the reagent holdup tanks) will cost FPL a maximum of $1.3 million. This includes construction, startup, testing, and technical support from Aquatech, which will also evaluate the test findings for application to a possible full size retrofit. The cost of the absorber and the absorber vendor are still in the process of being determined.

POLLEQU
7/09/90

ORIMULSION TEST BURN
POLLUTION CONTROL EQUIPMENT

SLIP STREAM	TYPE OF EQUIPMENT	SOURCE	ESTIMATED COST	ANTICIPATED CONTROL EFFICIENCY
1	SPRAY DRY ABSORBER	ASEA BROWN BOVERI (ABB)	$100,000 (ESTIMATED-PROPOSAL PENDING)	90% +
1	PULSE JET FABRIC FILTER	MANUFACTURER: HOWDEN (VIA EPRI)	$80,000 (ESTIMATED-PROPOSAL PENDING)	99% +
2	REVERSE AIR/SONIC & SHAKE/DEFLATE FABRIC FILTER	MANUFACTURER: ECOLAIRE (VIA EPRI)	$100,000 (ESTIMATED-PROPOSAL PENDING)	99% +
2	ALKALI SCRUBBER	MANUFACTURER: AIRPOL (VIA AQUATECH)	$220,000	90% +
2	SOXAL (ALKALI SORBENT REGENERATION SYSTEM)	AQUATECH	$1.3 MILLION (INCLUDES REAGENT HOLD UP TANKS FOR SPENT & REGENERATED SORBENT)	N/A (NOT EMISSIONS CONTROL EQUIPMENT)

Attachment 4

CONTEMIS
7/09/90

ORIMULSION TEST BURN
PLANNED CONTINUOUS EMISSIONS MONITORING OF SLIP STREAMS

SLIP STREAM	CONTROL EQUIPMENT	C E M
1	SPRAY DRY ABSORBER	SO_2 (UPSTREAM & DOWNSTREAM)
1	PULSE JET FABRIC FILTER	NON-STANDARD OPACITY*
2	REVERSE AIR/SONIC AND SHAKE/DEFLATE FABRIC FILTER	NON-STANDARD OPACITY*
2	ALKALI SCRUBBER	SO_2 (UPSTREAM & DOWNSTREAM)

*CALIBRATED TO PARTICULATE EMISSION RATE

Attachment 5

CONTEMIS
7/18/90

ORIMULSION TEST BURN
PLANNED EMISSIONS ANALYSIS OF SLIP STREAMS

AMENDED ATTACHMENT 5

SLIP STREAM	CONTROL EQUIPMENT	EMISSIONS ANALYSIS METHOD
1	SPRAY DRY ABSORBER	AUTOMATED INTERMITTENT SO2 SAMPLER (UPSTREAM & DOWNSTREAM)
1	PULSE JET FABRIC FILTER	ISOKINETIC PM SAMPLING WITH & W/O SPRAY DRYER (UPSTREAM) & DOWNSTREAM
2	REVERSE AIR/SONIC AND SHAKE/DEFLATE FABRIC FILTER	ISOKINETIC PM SAMPLING (UPSTREAM & DOWNSTREAM)
2	ALKALI SCRUBBER	AUTOMATED INTERMITTENT SO2 SAMPLER (UPSTREAM & DOWNSTREAM)

ORIMWAS
07/09/90

ORIMULSION TEST BURN
ANTICIPATED SOLID AND LIQUID WASTES *

WASTE SOURCE	WASTE TYPE	TEMPORARY STORAGE	FINAL DISPOSAL
PULSE JET FABRIC FILTER W/LIME SPRAY DRYER IN OPERATION	CALCIUM SULFITE & FLY ASH	SILO NO. 1	OFF-SITE APPROVED LANDFILL
PULSE JET FABRIC FILTER W/O LIME SPRAY DRYER IN OPERATION (SPRAY DRYER BY-PASSED)	FLY ASH	SILO NO. 2 &/OR PLASTIC LINED FABRIC BAGS	TO BE SOLD AS VANADIUM ORE
REVERSE AIR FABRIC FILTER	FLY ASH	SILO NO. 2 &/OR PLASTIC LINED FABRIC BAGS	TO BE SOLD AS VANADIUM ORE
SOXAL REGENERATION PLANT	SODIUM SULFATE AQUEOUS SOLUTION	HOLDING TANK	DEMINERALIZER WASTE STREAM (PROPOSED)

* DOES NOT INCLUDE STACK PARTICULATE EMISSIONS.
SLIP STREAM EMISSIONS RETURNED TO UNIT NO. 4 STACK.

Attachment 6

Table 1. Potential Emissions During Orimulsion Test Burn at FPL Sanford Unit No. 4 (Page 1 of 3)

Data	Potential Emissions Oil Firing	Potential Emissions Orimulsion Testing	Total Potential Emissions
Heat Input (10^6 Btu/hr)	4,050	4,050	
Full Power Days	245.0	120	
Sulfur Dioxide			
Emissions Basis	Actual[a]	Proposed[b]	
Emissions Basis (lb/10^6 Btu)	2.2	4.3	
Emissions (lb/hour)	8,901	17,415	26,316
Emissions (tons/year)[c]	26,169	25,078	51,247
Particulate Matter			
Emissions Basis	Allowable[d]	Proposed[e]	
Emissions Basis (lb/10^6 Btu)	0.125	0.338	
Emissions (lb/hour)	506	1,369	1,875
Emissions (tons/year)[c]	1,488	1,971	3,460
Particulate Matter (PM10)			
Emissions Basis	AP-42[f]	Proposed	
Emissions Basis (lb/10^6 Btu)	0.09	0.338	
Emissions (lb/hour)	359	1,369	1,728
Emissions (tons/year)[c]	1,057	1,971	3,028
Nitrogen Oxides			
Emissions Basis	AP-42[g]	AP-42[h]	
Emissions Basis (lb/10^6 Btu)	0.70	0.70	
Emissions (lb/hour)	2,834	2,834	5,668
Emissions (tons/year)[c]	8,332	4,081	12,412
Carbon Monoxide			
Emissions Basis	AP-42	AP-42	
Emissions Basis (lb/10^6 Btu)	0.03	0.03	
Emissions (lb/hour)	135	135	270
Emissions (tons/year)[c]	397	194	591

Table 1. Potential Emissions During Orimulsion Test Burn at FPL Sanford Unit No. 4 (Page 2 of 3)

Data	Potential Emissions Oil Firing	Potential Emissions Orimulsion Testing	Total Potential
Volatile Organic Compounds			
Emissions Basis	AP-42	AP-42	
Emissions Basis (lb/10^6 Btu)	0.002	0.002	
Emissions (lb/hour)	8	8	15
Emissions (tons/year)[c]	22	11	33
Lead			
Emissions Basis	AP-42	AP-42	
Emissions Basis (lb/10^6 Btu)	2.80E-05	2.80E-05	
Emissions (lb/hour)	0.11	0.11	0.23
Emissions (tons/year)[c]	0	0.16	0.50
Sulfuric Acid Mist			
Emissions Basis	AP-42	AP-42	
Emissions Basis (lb/10^6 Btu)	2.90E-02	5.41E-02	
Emissions (lb/hour)	117	219	337
Emissions (tons/year)[c]	345	316	661
Total Fluorides			
Emissions Basis	EPA (1980)	EPA (1980)	
Emissions Basis (lb/10^6 Btu)	3.47E-04	3.47E-04	
Emissions (lb/hour)	1.40	1.40	2.81
Emissions (tons/year)[c]	4.13	2.02	6.15
Mercury			
Emissions Basis	EPA (1989)	Test Sample[f]	
Emissions Basis (lb/10^6 Btu)	3.28E-06	1.54E-05	
Emissions (lb/hour)	1.33E-02	6.24E-02	0.076
Emissions (tons/year)[c]	0.039	0.09	0.129
Beryllium			
Emissions Basis	EPA (1989)	Test Sample[f]	
Emissions Basis (lb/10^6 Btu)	4.37E-06	1.54E-05	
Emissions (lb/hour)	1.77E-02	6.24E-02	0.080
Emissions (tons/year)[c]	0.052	0.09	0.142

Table 1. Potential Emissions During Orimulsion Test Burn at FPL Sanford Unit No. 4 (Page 3 of 3)

Data	Potential Emissions Oil Firing	Potential Emissions Orimulsion Testing	Total Potential Emissions
Arsenic			
Emissions Basis	EPA (1989)	Test Sample[i]	
Emissions Basis (lb/10^6 Btu)	4.37E-05	3.85E-05	
Emissions (lb/hour)	1.77E-01	1.56E-01	0.333
Emissions (tons/year)[c]	0.520	0.22	0.745

[a] 2.0 percent sulfur and 18,200 Btu/lb.

[b] 2.8 percent sulfur and 13,000 Btu/lb.

[c] Calculated based on 245 full-power days for oil firing and 120 full-power burn days for Orimulsion testing.

[d] Based on an average emission of 0.1 lb/10^6 Btu for 21 hours and excess emissions of 0.3 lb/10^6 Btu for hours.

[e] Based on an average emission of 0.3 lb/10^6 Btu for 21 hours and excess emissions of 0.6 lb/10^6 Btu for 3 hours.

[f] PM10 emissions is 71 percent of PM emissions (from AP-42).

[g] Based on vertical fired boilers, could be as high as 1 lb/10^6 Btu due to low excess air burners.

[h] Emissions on Orimulsion equivalent to oil firing. Emissions of total reduced sulfur, reduced sulfur compounds, hydrogen sulfide, asbestos, vinyl chloride, benzene, and radionuclides are negligible for oil and orimulsion firing.

[i] Determined from sample analyses. Parameters below the minimum detectable limit of the method.

References

U.S. Environmental Protection Agency (EPA). 1980. Health Impacts, Emissions and Emission Factors for Noncriteria Pollutants Subject to De Minimis Guidelines and Emitted from Stationary Conventional Combustion Processes. Office of Air Quality Planning and Standards. Research Triangle Park, NC. EPA-450/2-80-074

U.S. Environmental Protection Agency (EPA). 1989. Estimating Air Toxics Emissions from Coal and Oil Combustion Sources. Office of Air Quality Planning and Standards. Research Triangle Park, NC. EPA-450/2-89-001

Explanation of Table

Table 1 presents, as additional information, the most conservative interpretation of potential emissions as suggested in EPA's letter dated May 22, 1990. The table presents the potential emissions, assuming 120 full-power burn days, of Orimulsion testing under the conditions proposed by FPL. In addition, potential emissions for 245 full-power burn days when firing No. 6 fuel oil are also presented in Table 1. For oil firing, a typical maximum sulfur content of 2 percent was assumed.

FPL

P. O. Box 078768, West Palm Beach, FL 33407-0768
6001 Village Blvd.

July 10, 1990

FEDERAL EXPRESS

RECEIVED
JUL 11 1990
DER - BAQM

Ms. Cindy Phillips
Division of Air
Department of Environmental Regulation
2600 Blair Stone Road, Third Floor
Tallahassee, FL. 32399-2400

Re: FPL Orimulsion Test Burn
Sanford Unit No. 4

Dear Cindy:

By letter dated June 20, 1990, you requested additional information in connection with Florida Power & Light Company's Request for Approval of a Test Burn of Orimulsion at Sanford Unit No. 4. As you know, in order to respond as quickly as possible to some of the questions posed informally by the department, Dr. Marty Smith prepared a submittal information packet which he sent out prior to receiving your June 20 letter. His letter was dated June 22, 1990. Because your letter asked some questions that he did not address, and because some of the information that he provided on June 22 has now been updated, we thought it would be helpful to prepare a complete response to your June 20 letter at this time.

1. <u>DER Request:</u>

As stated in the application, there was a successful long-term burning of Orimulsion in the 100 MW corner-fired Dalhousie Generating Station Unit 1 in New Brunswick, Canada. Please submit the results of those tests. What were the pollution control devices tested and what were their efficiencies?

<u>FPL Response:</u>

The additional test information gathered from the Dalhousie Generating Station Unit 1 in New Brunswick, Canada consisting of three reports was submitted by Dr. Smith in his June 22 letter and is resubmitted as Attachments 1A, 1B & 1C hereto. To our knowledge there has been no further information published in connection with that test.

It is our understanding that an electro-static precipitator achieved 86% removal at full load at the Dalhousie Unit. That removal efficiency, we believe, was the result of an imperfect design and FPL has determined that such a device would not be optimum for a multiple-fuel unit such as Sanford Unit No. 4 would be if permanently converted to the use of Orimulsion. Dalhousie also tested furnance injection of a dry limestone sorbent; although the report for that device has not been completed, FPL is not considering such a device for Sanford No. 4. Thus, the report will not be helpful to us.

2a. DER Request:

The requested permitted equipment operating time is 120 full-capacity equivalent burn days when Orimulsion is fired. How much time will each pollution control device spend in operation?

FPL Response:

The exact time needed to test each pollution control device is presently unknown. The pollution control equipment is expected to begin operation in week no. 2 of the test burn and to continue to operate throughout the test.

2b. DER Request

Please submit a detailed schedule of testing of the pollution control devices.

FPL Response:

An updated schedule of the various phases of the test burn and planned emissions tests is contained in Attachment 2 hereto. Parametric testing of the pollution control modules will begin within the first two weeks of Orimulsion use and will continue throughout the test burn period. The data generated will allow FPL to establish performance trends and the design of full-scale equipment.

2c. DER Request

How long will Unit #4 be burning Orimulsion before the stack emissions are tested?

FPL Response:

FPL intends to begin boiler performance testing within one week of startup on Orimulsion and to conduct particulate emissions stack tests during the following week. The detailed estimated stack testing schedule is also contained in Attachment 2. Continuous emissions monitors (CEM's) will be installed and operated to track CO, O2, NO_x and SO_2 at the economizer outlet of Unit No. 4, and stack opacity will be measured during the entire test burn period.

2d. DER Request:

Will the test scale and duration be sufficient to size full-scale equipment or will future tests be necessary?

FPL Response:

FPL believes that the scale and duration of the proposed tests will be sufficient to enable the design of full scale equipment without the need for future Orimulsion burn tests. It should be noted that an additional thirty full power burn days of testing can be conducted should DER concur that it becomes necessary. The proposed testing of pollution control equipment involves two (2 side streams (or "slip streams"), the use of which has proven effective at other facilities for test purposes. A brief description of the details of the control equipment to be tested on each slip stream is contained in Attachment 3A and 3B.

FPL also intends to continue testing the pollution control equipment when no. 6 oil is burned, after the burning of Orimulsion is completed. This will enable the Company to obtain more detailed information concerning the performance of the control equipment when burning no. 6 fuel oil, one of the fuel capabilities that the Company wishes to retain even in the event of conversion to Orimulsion. This information will further expand the data base on the equipment in question.

3 and 4. DER Request:

What is the estimated cost to FPL for the individual components of the proposed pollution control pilot study?

What are the model names and expected efficiencies of each of the pollution control devices to be tested?

FPL Response:

Details on the pollution control pilot equipment costs and efficiencies are tabulated for your convenience in Attachment 4.

5. DER Request:

What type of continuous emissions monitors (opacity, SO_2, NO_x, etc.) will be used on the inlet and outlet pilot test gas streams? Will these be in use the entire time the pilot test control equipment is being operated?

FPL Response:

Continuous emissions monitoring proposed on the two slip streams is summarized in Attachment 5 hereto. The lime spray dryer and the alkali scrubber will be fitted with SO_2 monitors. Visible emissions will be tracked with transmissometers. These CEM measuring devices will be in use the entire time that the pilot pollution control units are in operation.

6. DER Request:

What type of continuous emission monitors will be used on the Unit No. 4 exhaust stack while Orimulsion is being burned? Will these monitors also be used while No. 6 fuel oil is being fired?

FPL Response:

CEMs for SO_2, NO_x, CO, O_2 and opacity will be operated at Sanford Unit No. 4 throughout the test period (See response to 2C). Although EPA suggested in their comment letter to DER that CEM's for opacity, NO_x and SO_2 be installed in the stacks of Units No. 3 and 5 at Sanford as well, in subsequent discussions with FPL on this matter EPA indicated that it would reconsider its suggestion.

FPL does not intend to use the Unit No. 4 CEM's when burning No. 6 oil unless such oil is burned intermittently with Orimulsion during the test period.

7. DER Request:

What is the expected cost of No. 6 fuel oil per BTU during the next year? What is the expected cost of Orimulsion per BTU during the next year?

FPL Response:

As noted in the June 22 letter from Dr. Smith, Orimulsion will be marketed at coal-equivalent prices. For FPL, the price of coal received at the St. Johns River Power Park, jointly owned with Jacksonville Electric Authority, is approximately $1.76 per million BTU's of energy content. The price of medium sulfur oil like that currently burned at the Sanford Plant, is approximately $2.63 per million BTU's heat equivalent. Based upon this information 90 full power burn days would require $15.5 Million Dollars worth of Orimulsion fuel as compared with $23.1 Million Dollars worth of NO. 6 oil.

8. DER Request:

The solid waste generated during the test should go to a lined landfill with a leachate collection system. Is this type of landfill available for disposal of the solid waste?

FPL Response:

The Orimulsion test is expected to generate only minimal quantities of solid waste. A small amount of fly ash and lime spray dryer product will be collected from the pilot scale pollution control equipment. Small quantities of bottom ash resulting from Orimulsion combustion will be combined with the fly ash and sold as vanadium ore.

Attachment 6 summarizes the solid and liquid waste sources that will be associated with the pollution control equipment tests and the routes for disposal. The spray dryer/pulse jet fabric filter waste is expected to be disposed of in a DER-approved landfill. The pulse-jet and reverse-air fabric filter fly-ash products will be sold as vanadium ore.

Florida Institute of Technology (FIT) will study the leachability and solubility of the dry lime spray dryer wastes produced during the test. It is expected that these wastes will be mixed with water, or water and a cement-like additive, then compacted or compressed into a form that can be easily handled. After curing, these "shapes" will likely be stored in a dumpster for future off-site disposal.

FPL believes that is can obtain sufficient data from the Orimulsion test burn and the FIT project to enable it to design a leachate collection system for permanent conversion, if such a system is needed. FPL does not intend at this time to develop a landfill cell. Stabilized spray dryer solid waste will be stored on site for characterization and it will then be disposed of off-site in a landfill approved by DER for this type of waste as characterized. It is too early to tell whether or not a lined landfill with a leachate collection system will be necessary.

9. DER Request:

For PSD purposes, potential emission increases from a modification are compared to past actual emissions on a tons per year basis. Why were the potential emissions resulting from any fuel oil burning (which could occur the remainder of the year when Orimulsion is not being burned) not included in the potential emissions?

FPL Response:

A table of revised potential emissions calculations, taking into account EPA's letter to Mr. Clair Fancy of May 22, is enclosed as Attachment 7 hereto.

10. DER Request:

Past actual emissions listed in Table 3-2 do not correspond to values calculated from information submitted in the 1989 annual operating reports. Please explain the discrepancies.

FPL Response:

The emissions calculations listed in Table 3-2 assumed 120 days of operation rather than the unrepresentatively low 27 days per year of operation in 1988-9. The calculations of actual particulate matter emissions employed the permitted emission limitation because the values obtained from historical stack tests were almost the equivalent of the regulatory limit. So_2 emissions calculations assumed that all fuel-bound sulfur is converted into SO_2, a conservative assumption. NO_x emissions were based upon AP-42 values for front-fired boilers.

If you have any questions or need supplemental information, please let me know. Your cooperation and assistance in this matter are very much appreciated.

Sincerely,
Florida Power & Light Company

Elsa A. Bishop

Elsa A. Bishop
Senior Environmental Coordinator, FPL

cc: Clair Fancy (w/o attachments) - FDER, Tallahassee