SMALL (5 MILLION BTU/HR) AND LARGE (300 MILLION BTU/HR) THERMAL TEST RIGS FOR COAL AND COAL SLURRY BURNER DEVELOPMENT

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1. INTRODUCTION

Thermal test rigs have been used by NEI International Combustion over the past 25 years for the evaluation and development of burner systems for both industrial and utility boilers. Initially, the rigs were little more than open brick containers which have evolved to the water-cooled gas-tight chamber currently in use to enable the development of low excess air combustion systems as demanded by market forces and the need for more effective fuel utilisation. A major step forward in thermal test rig facilities occurred in 1973 with the construction of what is probably the largest and most comprehensively instrumented burner test rig in the Western Hemisphere. The rig design had to meet all of the known oil burner performance requirements at that time, and also be sufficiently flexible to meet the predicted requirements of the succeeding 10 - 12 years. This rig is still in operation today and is currently undergoing the next major step change in conversion to enable pulverised fuel, coal slurries and gas burner systems, sized up to 300 million BTU/Hr, to be developed.

A complementary small scale thermal test rig facility, rated at around 5 million BTU/hr was also provided in 1975 to allow fundamental combustion studies and the development of new ideas in burner design and operation to take place at a more economical level in comparison with the operation of the large test rig.

Both these major step changes in the large scale thermal test rig capabilities have been dictated by market forces. Initially the need was to develop low excess air oil burners utilising the almost continuously deteriorating quality fuel oils supplied to the utility boiler industry. The current need is to meet the renewed interest in coal utilisation now that it is realised that fuel oil supplies are not infinite and consequently will be subject to continual increases in price with little or no guarantee as to quality and availability.

Although it is not universal practice to test burner systems for large boilers prior to site installation, the availability of a full-scale thermal test rig enables the development of a tailor-made burner system to suit a particular installation. Customers can see a proposed burner system in operation and any changes required, because of alterations in operating procedures or variations in fuel properties, can be accommodated. These investigations, into altered conditions, can be made quickly and economically compared with on site investigations and without interruption to the customers operating schedule. Markets for new fuels, such as coal slurries, can be pursued without relying on potential customers to provide full-scale test facilities. In fact, until the firing of coal-water and coal-oil slurries becomes universally accepted, there should be an increasing demand for off-site demonstrations of the capabilities of these new burner systems. The operation of a full-scale thermal test rig is therefore an essential piece of equipment for any burner manufacturer to achieve and maintain a leading position in the supply of combustion systems to the International utility boiler market.

2. The Large (300 million BTU/Hr) Thermal Test Rig at Derby

2.1 General Description of the Rig and its Capabilities

The original design of the large thermal test rig at Derby was ambitious, as it had to meet the requirement of NEI International Combustion to maintain its leadership in oil burner performance in the Western Hemisphere. A major requirement was that of sheer size. The combustion chamber dimensions had to be such that complete combustion could be obtained, upstream of gas sampling positions, with burner systems (firing up to 9 tonnes/hr of fuel oil) designed to produce long narrow flames typical of burners designed for tangential firing applications and those designed to produce more compact large diameter flames typical of front wall firing applications. These considerations resulted in a combustion chamber of internal dimensions 21.34 m (70 ft) long by 5.49 ■ (18 ft) square cross section. Cooling of the combustion chamber is achieved by means of static water sandwiched between inner and outer steel skins on the side walls and end wall of the chamber remote from the burner. The centre section of the burner wall is built entirely of refractory to enable easy changing of burner configurations, the roof is also entirely water-cooled and the hearth covered with a layer of refractory pebbles on a bed of sand.

Oil storage is provided by two lagged and steam heated storage tanks, each of 45460 litres (10,000 gallons) capacity. Oil is transferred from the tanks, via a low pressure transfer pump, to a primary pumping and heating circuit capable of delivering oil at a pressure of 44.8 bar (650 lbs/in^2) at up to 13640 kg/hr (30,000 lbs) and a viscosity of 70 Redwood No 1 seconds (16 cS, 80 SSU). A second pumping and heating circuit was installed, at a later date, enabling an oil delivery pressure up to 83 bar (1200 lb/in^2) and oil temperatures up to 200°C (392°F) to be achieved. This secondary pumping heating system was used particularly in a study of the combustion of fuel oils containing a high percentage (up to 14%) of hard asphaltenes.

Combustion air is supplied to the burner windbox by a four-stage axial flow fan capable of supplying 37.77 m^3/sec (80,000 ft^3/m) of combustion air at a maximum pressure of 44.8 mbar (18 ins water gauge). Noise levels from the fan are controlled by axial flow silencers immediately upstream and downstream of the fans and air flow rate is indicated by a venturi meter. Coarse air flow control is via the number of fan stages brought into operation and fine control is achieved by a remotely controlled butterfly damper.

All the flows to the rig are controlled from an operating console situated at the end of the combustion chamber remote from the burner. From this position the rig operator can observe an end view of the flame through a glass porthole. A comprehensive gas analysis system is also housed adjacent to the control console.

During the operation of a burner test, gases are sampled from the 2.74 m (9 ft) diameter 18.29 m (60 ft) high refractory lined stack, at a point some 10.67 m (35 ft) above ground level located in the stack. At this same point a platform has been erected to enable the isokinetic sampling of the flue gases for determination of the solids burden. The gas analysis instrumentation provides a continuous record of O_2, CO, CO_2 and NOx in the flue gases throughout a test. A smoke density meter and facility for determining the Bacharach smoke number is also available. Observation ports are provided along the side wall of the combustion chamber to enable photographs to be taken of the flames as required.

Steam for oil heating and atomisation is available from a package boiler of 4994 kg (10,980 lb) per hour steam capacity at a delivery pressure of 17.24 bar (250 lb/in^2).

Most oil burner test work is carried out using cold combustion air. However, combustion air preheat can be achieved by means of duct burners located in the combustion air supply ducting after the axial flow fans. With this system in operation oxygen has to be supplied to the combustion air stream to maintain a 21% O_2 content in the combustion air at the burner windbox.

In order to provide a complete burner test facility, comprehensive laboratory facilities and expertise are available to provide chemical and physical analysis of fuels and particulates and also isothermal test facilities to assess the quality of atomisation of the various atomiser designs under test.

Figure 1 indicates the general layout of the test rig and the ancillary supply and analysis equipment.

2.2 <u>Conversion of the Rig to Provide a Coal and Coal Slurry Firing Capability</u>

The object of the conversion exercise is to maintain the existing oil firing capability and provide the facility for firing pulverised fuel, coal slurries (e.g. coal water or coal oil mixtures) and gas at similar maximum heat input rates of around 300 million BTU/hr. Both light and dense phase systems for the firing of pulverised fuel are incorporated and the coal slurry firing facilities are designed to handle coal water mixtures containing up to 75% coal and coal oil mixtures with up to 50% coal. A typical British East Midlands steam raising coal of 15% ash content (dry basis) and 7220 Kcals/kg (13,000 BTU/lb) calorific value, was used as the basis of design calculations for the conversion exercise.

The problems to be overcome in the conversion exercise were the deposition and collection of ash, both within and outside the test rig (to satisfy Local Authority regulations), the provision of a combustion air pre-heating capability, and the design of conveying systems for dense phase and lean phase pulverised fuel and for coal slurries.

Local Authority environmental requirements restrict solids discharge from the rig stack to 72 kg/hr (158 lb/hr). Therefore, in order to cope with the maximum coal firing rate of 10 tonnes/hr with a 15% ash coal, the waste gases leaving the rig, at about 1000°C (1830°F), must be conditioned and cleaned before being dispersed to the atmosphere. The system decided upon for gas conditioning and cleaning comprised a high pressure hot water waste heat boiler followed by a multi-cyclone dust collector. An induced draught fan after the dust collector conveys the cooled clean gases into the stack and thus to atmosphere. The incorporation of the waste heat recovery system allowed the provision of pre-heat to the combustion air and primary air (conveying lean phase pulverised fuel) via high pressure hot water heat exchangers located in the appropriate air ducts. Surplus heat from the waste heat boiler is dissipated via a series of forced draught dump coolers located remotely from the test rig and operating in the closed circuit mode in line with the waste heat boiler. Water is supplied from the waste heat boiler to the heat exchangers at a temperature of 218°C (425°F) and pressure of 30 bar (440 lbs/in^2) providing 121°C (250°F) pre-heat for the primary air lean phase pulverised fuel conveying and 177°C (350°F) preheat for the secondary combustion air. The system of duct burners and oxygen injection is retained in order to provide increased secondary (or combustion) air pre-heat as required.

In addition to collection of ash outside the combustion chamber it is anticipated that up to 50% of the total ash content of the coal could be collected inside the chamber. To facilitate the removal of this ash and any spillages of unburnt pulverised fuel the existing refractory pebble floor is to be replaced by a water-cooled floor of similar design to the side walls as mentioned in section 2.1. As the existing mode of operation for the development of low excess air oil burners is to be maintained a water-cooled door has been provided in the rig back wall enabling combustion gases to be diverted either directly, or via the waste gas conditioning system, to the existing stack

Coal conveying is to be based on a dense phase system either feeding directly to a purpose designed burner system or into a pre-heated primary air system giving the required air dilution to provide a lean phase pulverised fuel firing facility.

The dense phase system comprises a pressurised double-blow tank unit fed from a 20 tonne pulverised coal storage silo. Nitrogen purge facilities and continuous temperature monitoring of the storage silos are provided in order to minimise the explosion risk. The dense phase system will allow pulverised fuel to be conveyed in relatively small diameter pipelines, compared to the more conventional lean phase firing systems, which could be an important consideration when boiler changeovers from oil to coal firing are contemplated and the existing access to the boiler fronts is limited. Fuel flow rates from the dense phase system will be monitored by load cells located in the blow tank system.

The slurry feed system comprises a storage tank which can be stirred and heated continuously, and a mono-pump with facilities for flushing out the complete system after any particular firing exercise. Slurry flow will be monitored by a 'Doppler Effect' flow meter, with the slurry continuously circulated around the pump and storage tank and taken off as required to the burner system.

A facility for continuous data logging of fuel flows, gas flows, gas analysis and temperature is to be provided and this microprocessor controlled unit will also provide a central control over all the operating parameters, giving a continuous visual display of the levels of the parameters throughout a test run. An instant print-out of these parameters can be obtained at any selected point in the test run. Figure 2 shows the general layout of the test rig after the conversion to provide this multi-fuel burner development facility and Figures 3 and 4 show details of the pulverised fuel and coal slurry conveying systems.

The conversion programme is to take place in two phases - the first phase will provide facilities to enable a maximum of 3.5 tonnes/hr of coal to be fired either in dense phase or slurry form. Limiting the firing rate to this level removes the necessity for the provision of gas cleaning to meet the environmental emission levels and enables experience of operating the rig under coal firing conditions to be obtained more quickly. Phase 2 of the conversion involves installation of the gas conditioning dust cleaning plant to allow the operation at the full fuel rating. The conversion work is expected to be completed and the rig fully operational during the first half of 1983.

Attention has also had to be given to the sound levels from equipment to be provided in the conversion work. Firstly, for the protection of operating personnel, the sound pressure level from any individual item of plant will not exceed 90 dBA at 1 metre and secondly, because the rig will operate within the proximity of a local housing estate, the maximum sound power level from the complete plant is limited to 117 dBA, ref. 10^{-12} watts, with a boundary condition of 65 dBA at 200 metres.

3. The Small (5 million BTU/hr) Thermal Test Rig at Derby

Fundamental combustion studies and particular aspects of burner systems development work can be carried out quickly and economically on this small rig. The rig is linked to the same gas analysis system as the large rig and is equipped for oil, gas and coal slurry firing, additionally a combustion air preheater is available capable of delivering combustion air at up to 425°C (800°F).

The combustion chamber comprises a water-cooled mineral wool lined steel cylinder 4 m (13 ft) long by 1.1 m (3.75 ft) diameter, with a 5.2 m (17 ft) refractory lined stack equipped with gas sampling and temperature measurement points. Observation ports are provided on the combustion chamber axis, close to the burner and in the chamber rear wall. Compressed air and steam are available for fuel atomisation purposes as are pumping and circulating trains for oil fuels and coal slurries. At a 5 million BTU/hr rating this rig is capable of burning 125 kg/hr (275 lbs) of gas oil and 205 - 230 kg/hr (450 - 500 lbs) of coal water slurry or their equivalent. Figure 5 shows the general layout of the small scale rig and its ancillary equipment.

4. Work on Coal Slurry Utilisation

4.1 Coal Water Mixtures

Recent work based on the small scale rig has concentrated on investigations into the properties of coal water mixtures and their influence on handling equipment and burner design. In the initial stages of the work considerable problems were encountered with blockages in pipelines and burner heads because of the instability and excessive proportion of oversize coal particles (ca 500μm) in the coal water mixtures.

These early experiences enabled the compilation of a general specification for coal water mixture properties and associated handling equipment to be used as a basis for the successful development of a coal water combustion system. These desirable features can be listed as follows:-

4.1.1 Combustion and Handling Equipment

Atomisers should be based on an external mix air atomiser design avoiding sudden changes in direction and diameter in the coal water mixture conveying system which tends to deposit the coal from the slurry and can be points of excessive wear, particularly in atomiser components. Steam atomisation is to be avoided since the additives used to stabilise the coal water mixture can break down at temperatures above 60°C (140°F).

Coal water mixtures should be fed to the burners via a continuous recirculation system (see Fig. 5) and particularly in the case of intermittent rig work, facilities should be provided for water flushing of all the feed lines and valves after each run. It should also be noted that a coal water mixture can freeze in ambient temperatures of 0°C (32°F) or less and provision should be made for some form of trace heating, subject to the temperature limitations mentioned above, where these conditions can occur.

4.1.2 Coal Water Mixture Properties

Coal particle size in the coal water mixture should be a maximum of 250µm and the coal volatile matter (dry basis) a minimum of 25%. There should be little or no settling out during transportation and any settling which does occur should be easily overcome by a simple recirculation system as described earlier.

The properties of the coal water mixture used in the small scale test work at Derby are given in Table 1.

TABLE 1

Coal Water Mixture Properties

1.1 Proximate Analysis

	Original Coal	Coal in Slurry
Ash % (dry basis)	3.0	1.8
Volatile Matter (dry basis)	35.5	37.4
Fixed Carbon	61.5	60.8
Sulphur	1.24	1.02

Inherent coal moisture 4%

1.2 Ultimate Analysis

	Original Coal	Coal in Slurry
C	83.4	84.5
H_2	5.2	5.4
N_2	1.8	1.8
Ash	3.0	1.8
S (pyritic)	0.55	0.34
S (sulphatic)	0.04	0.05
S (organic)	0.65	0.63
O_2 (by difference)	5.36	5.48

1.3 Confirmatory Analysis

The above analyses were supplied by the coal water mixture supplier, confirmatory proximate analysis carried out at the Derby laboratories on the coal slurry was as follows:-

	As Received	Dry Basis
Moisture %	26.9	-
Ash %	1.36	1.86
Volatile Matter %	28.85	35.36
Fixed Carbon %	45.89	62.78

1.4 Physical Analyses

Sieve Analysis of Dry Sample	%
+ 30 mesh (570µm)	Nil
- 30 mesh + 60 mesh (250µm)	0.42
- 60 mesh +100 mesh (150µm)	5.02
-100 mesh +200 mesh (75µm)	18.55
-200 mesh +300 mesh (45µm)	9.93
-300 mesh	66.08

Viscosity Data up to 60°C

Taken by a Contraves RM15 viscometer shear prior to measurement 30 sec^{-1}.

Temperature (°C)	Viscosity (centistokes)
19.5	989
30.0	765
40.5	621
50.0	641
60.0	576

Surface Tension

Liquor extracted from the slurry 57 dyne cm^{-1}.

The coal water slurry is in fact derived from a coal beneficiation process and the properties of the original coal are included in Table 1 for comparison purposes. The coal water mixture meets the desired specification levels with regard to coal particle size, coal volatile matter and stability and has proved very easy to handle through the small scale thermal test rig pumping system described earlier.

4.2 The Influence of Coal Water Mixture Properties on Burner Design

Although, generally speaking, coal water mixtures can, as claimed by the proprietary slurry producers, be handled like a fuel oil there is a significant difference in the viscosity temperature relationship of the fuels which must be taken into consideration in designing a burner to handle a coal water mixture. Normally, to produce good atomisation, heavy fuel oils are heated to around 140°C (280°F), which helps to achieve oil droplet sizes ex - the atomiser in the 60 - 100µ, mean size range. Equally good atomisation is required for coal water mixture combustion in order to achieve rapid evaporation of the water content and release of the coal volatiles necessary to establish stable ignition conditions.

Typical viscosity/temperature curves for fuel oil and coal water mixtures are shown in Figure 6 and these, together with the slurry temperature/ stability relationships mentioned in Section 4.1.1, preclude heating as a method of significant viscosity reduction with coal water mixtures.

Two possibilities were considered for the required viscosity reductions:

1) the addition of viscosity reducing chemicals, and 2) aeration of the coal water slurry. In order to be effective both techniques have to be applied to the fuel as close to the atomiser tip as possible and aeration was chosen as the more practical proposition being more compatible with known twin fluid atomiser design techniques.

Figure 7 shows the theoretical viscosities obtainable by aeration of coal water mixtures, based on calculation techniques used in viscosity blending of oils[1].

4.3 Development of a Coal Water Mixture Burner

Figures 8 and 9 show the general arrangement of the burner used for the small scale development work and a diagrammatic representation of the burner nozzle configuration, incorporating the viscosity reduction by aeration principle.

For the initial exercise on burner nozzle development cold combustion air was used with the gas burner (Figure 8) supplying the initial preheating, ignition and stabilisation of the coal water mixture flame, as required.

The nozzle design incorporates two sets of atomising air holes designated 'shear holes' which give rise to the initial aeration (or viscosity reduction) process and 'swirl holes' which produce a coherent spray from the nozzle tip. Initial qualitative spray trials resulted in three nozzles, designated C, D and E, of varying shear hole/swirl hole diameter ratios, being selected for thermal tests.

Isothermal spray work, using glycerine to represent the viscous coal water mixture, indicated that the nozzles produced good quality atomisation. Figure 10 shows the results of these isothermal tests. Extrapolation of the curves indicates that perhaps nozzle E will produce better atomisation at higher fuel flow rates.

The results of these initial thermal tests together with the variations in nozzle geometry are given in Table 2. In this table the 'apparent viscosities' calculated are based on the assumption that the atomising air supplied to the nozzle divides into shear and swirl air in direct proportion to the shear/swirl hole area ratios.

TABLE 2

Results of Preliminary Small Scale Thermal Tests on

Coal Water Mixture Atomisers

2.1 Nozzle C - Shear Hole/Swirl Hole Area Ratio 0.50

Coal Water Mixture (CWM) feed rate kgs/hr (lbs/hr)	110 (242)	148 (325)	192 (400)
Coal Water Mixture feed pressure bar (psi)	0.6 (8)	0.9 (12.5)	1.2 (16)
Atomising air pressure bar (psi)	4.1 (60)	4.1 (60)	4.1 (60)
Atomising air ratio wt air : wt CWM	0.48	0.36	0.29
Heat input to test rig % MCR	58	76	92
Heat input ratio CWM : gas	6.8	9.2	11.3
Excess O_2 % in flue gas	1.6	1.5	1.4
Flue gas temperature °C	779	805	820
Apparent aerated CWM viscosity cS	300	350	400

2.2 Nozzle D - Shear Hole/Swirl Hole Area Ratio 0.98

Coal Water Mixture (CWM feed rate kgs/hr (lbs/hr)	110 (242)	148 (325)	182 (400)
CWM feed pressure bar (psi)	0.6 (8)	0.9 (12.5)	1.2 (16)
Atomising air pressure bar (psi)	4.1 (60)	4.1 (60)	4.1 (60)
Atomising air ratio wt air : wt CWM	0.48	0.36	0.29
Heat input to rig % MCR	58	76	92
Heat input ratio CWM : gas	6.8	9.2	11.3
Excess O_2 % in flue gas	1.5/4.4	1.5/4.7	1.5/4.6
Flue gas temperature °C	803/795	806/806	820/817
Apparent viscosity aerated CWM cS	100	150	250

2.3 Nozzle E - Shear Hole/Swirl Hole Area Ratio 2.0

Coal water mixture (CWM) feed rate kgs/hr (lbs/hr)	110 (242)	148 (325)	182 (400)
CWM feed pressure bar (psi)	0.6 (8)	0.9 (12.5)	1.2 (16)
Atomising air pressure bar (psi)	4.1 (60)	4.1 (60)	4.4 (60)
Atomising air ratio wt air : wt CWM	0.48	0.36	0.29
Heat input to rig % MCR	58	76	92
Heat input ratio CWM : gas	6.8	9.2	11.3
Excess O_2 % in flue gas	1.5/4.0	1.5/4.0	1.5/4.0
Flue gas temperature °C	792/820	846/862	925/937
Apparent viscosity aerated CWM cS	60	100	150

The results indicate that at a heat input equivalent to the rated maximum of the small rig (5 million BTU/hr) the ratio of heat input by coal water mixture to that of stabilising gas is 11.29 : 1 when firing with cold combustion air in a relatively cold furnace, which is equivalent to supplying pre-heated combustion air in the temperature range 200 - 315°C (400 - 600°F) depending upon the excess air ratios required for combustion.

Although no heat balances were performed during these first atomiser development tests, the flue gas temperature in Table 2 indicates a tendency for improved burning of the coal water mixtures as the apparent viscosity of the fuel was reduced by aeration. E.g. at the maximum firing rate of 182 kg/hr (400 lbs) of coal water mixture flue gas temperature increased from 820°C - 925°C (1500 - 1700°F) at 1.5% excess oxygen for viscosity changes from 400 - 150 cS.

The thermal work was carried out on the small scale rig with some of the refractory wool lining removed in an attempt to produce conditions similar to those in utility boiler practice with the flame exposed to cool surfaces and adjacent hot flame gases.

A completely refractory brick lined combustion chamber would obviously facilitate combustion stability when firing coal water mixtures, but work is continuing at Derby to study the effect of gas recirculation, the use of pre-heated air and possible a refractory quarl as an aid to combustion stability.

Gas recirculation is controlled by swirler design. The current swirler has a 45° vane angle and overall dimensions giving a swirl number of 1.1. A range of swirlers will be tested to assess the affect of recirculation of hot flame gases on the flame development. Pre-heated combustion air, in the range 100°C - 427°C (200°F - 800°F) will be utilised for this purpose also. It is considered that these two methods of increasing combustion stability are the important factors when considering the application of coal water mixture firing in utility boilers. If further initial heating is considered necessary the use of a refractory quarl to supply radiant heat to the flame root will also be studied.

5. Large Scale Thermal Test Rig Work

The availability of the large rig for coal water mixture work depends on the progress of the conversion programme outlinedin Section 2.2. However, it is probable that this will be one of the first exercises carried out on the converted rig, using firing rates in the 2 - 5 tonnes/hr range. The burner design will be based on that used for firing a 40% coal 60% oil mixture on the rig and subsequently on a utility boiler, but incorporating the design features discussed in Section 4.3, in order to produce a coherent coal water mixture spray. The current small scale test work will indicate the level of combustion air preheat and swirl required to achieve stable combustion conditions. With the larger flames it is anticipated that radiation from the main body of the flame, back to the flame root, will obviate the need for incorporation of a refractory quarl.

Reference

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Acknowledgement

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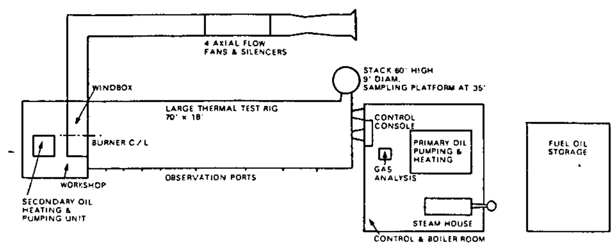


FIGURE 1

GENERAL LAYOUT OF LARGE THERMAL TEST RIG FOR LOW EXCESS AIR OIL BURNER DEVELOPMENT

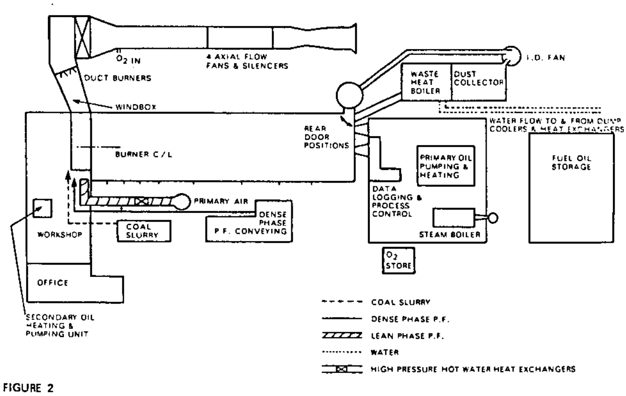


FIGURE 2

GENERAL LAYOUT OF LARGE THERMAL TEST RIG FOR MULTI-FUEL BURNER DEVELOPMENT

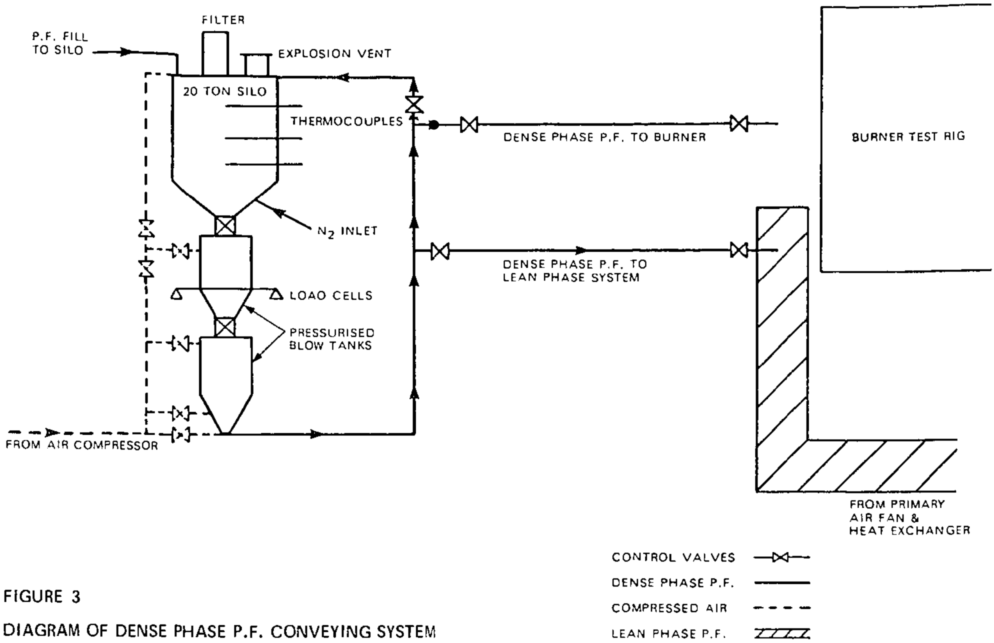


FIGURE 3

DIAGRAM OF DENSE PHASE P.F. CONVEYING SYSTEM

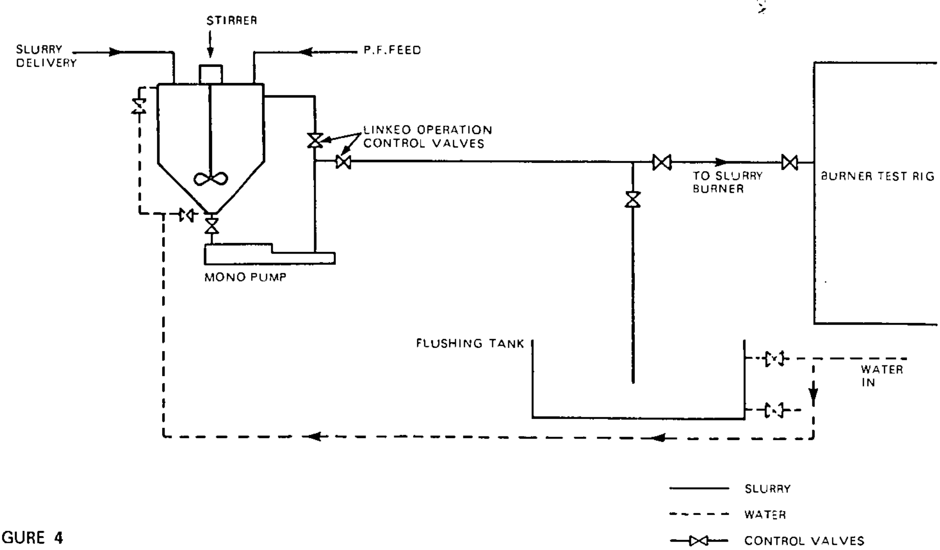


FIGURE 4

DIAGRAM OF COAL SLURRY CONVEYING SYSTEM

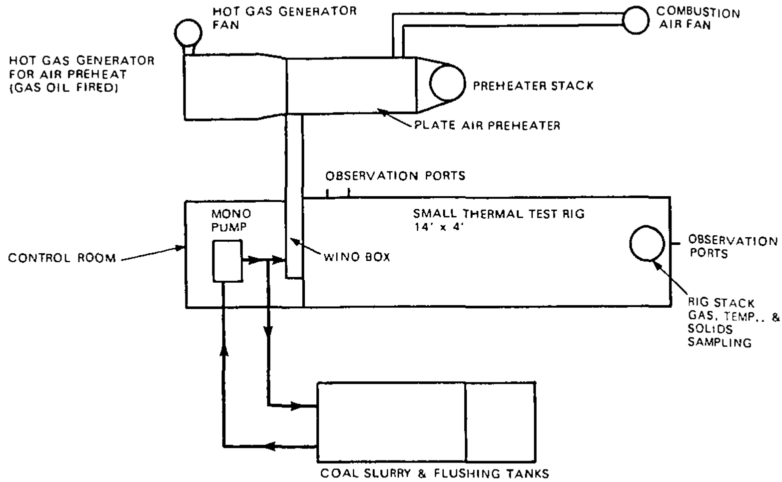


FIGURE 5

GENERAL LAYOUT OF SMALL SCALE THERMAL TEST RIG

FIGURE 6

COMPARISON OF COAL WATER MIXTURE & HEAVY FUEL OIL VISCOSITIES

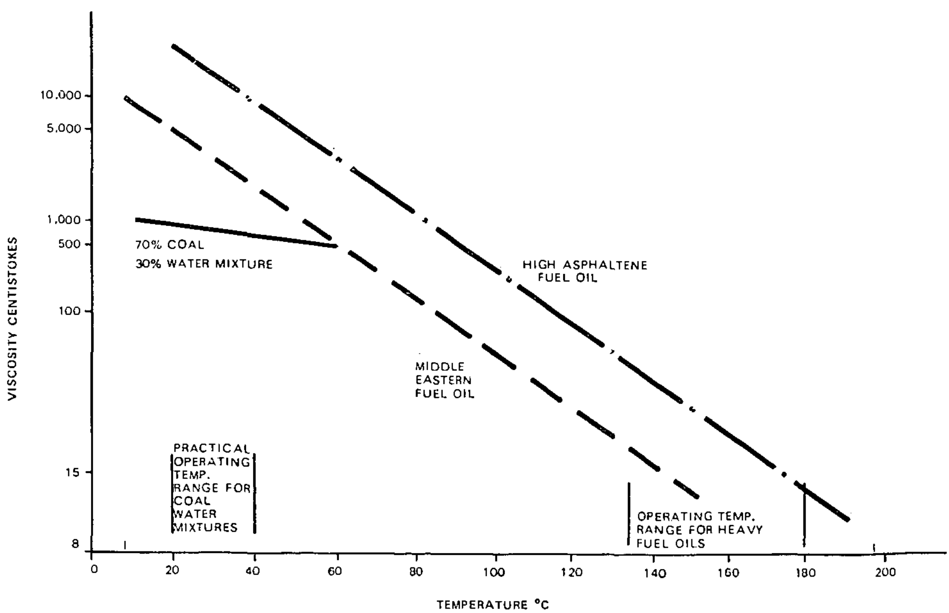


FIGURE 7

VISCOSITY VARIATION, BY AERATION, OF COAL WATER MIXTURES AT 20°C

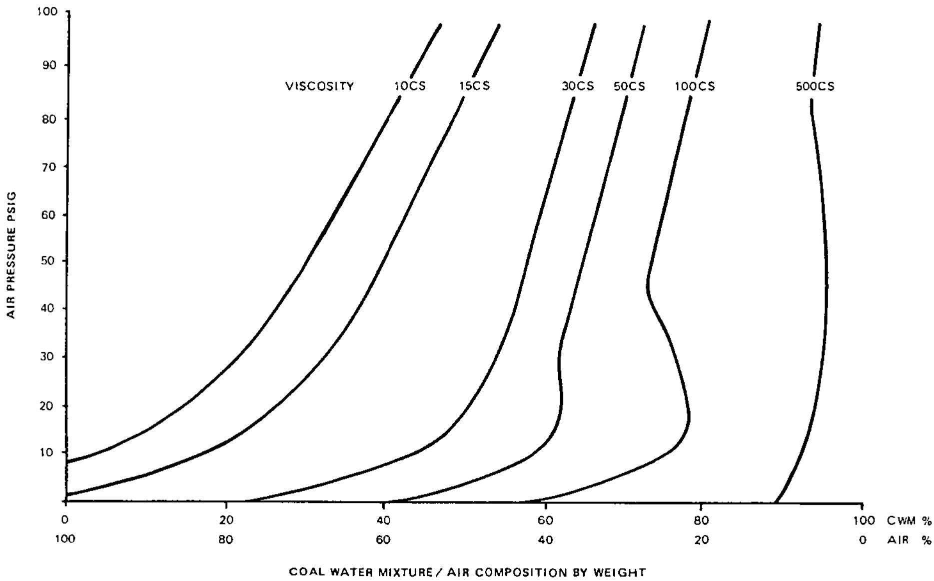
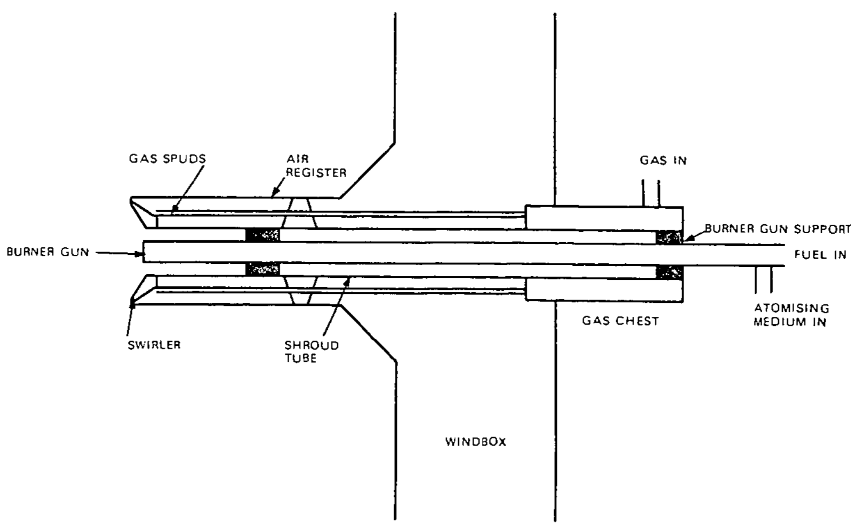


FIGURE 8

GENERAL ARRANGEMENT OF SMALL SCALE RIG BURNER



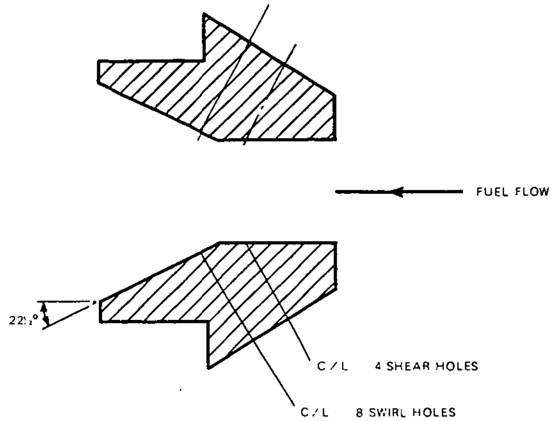


FIGURE 9

DIAGRAM OF COAL WATER MIXTURE BURNER NOZZLE

FIGURE 10

ISOTHERMAL BURNER NOZZLE COMPARISON