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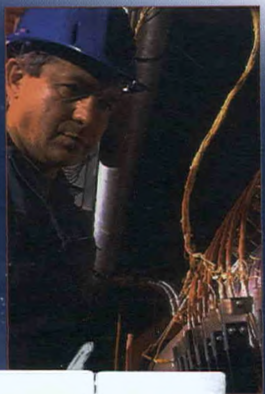
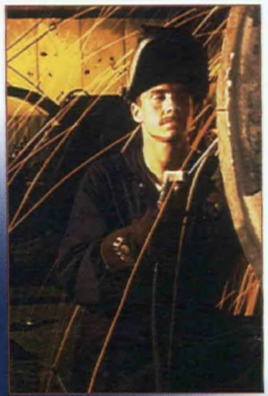
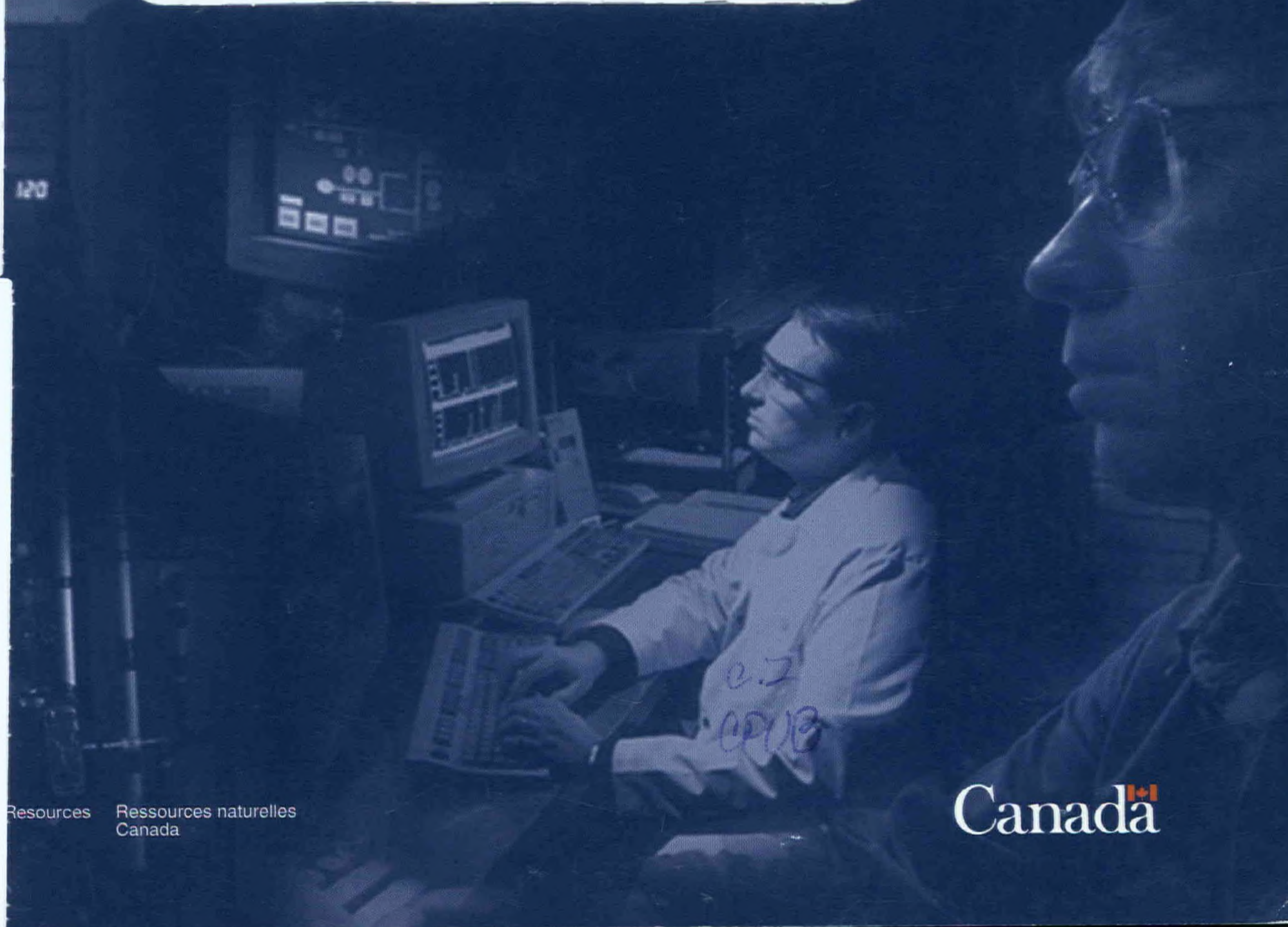




PIPELINEABLE COAL SLURRIES

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

DIVISION REPORT ERL 90-47(OP)



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COMBUSTION AND ATOMIZATION TESTS ON TWO PIPELINEABLE COAL SLURRIES

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Report to be presented at IEA Coal Liquid Mixtures Technical meeting, Vancouver April 17, 1990

ENERGY RESEARCH LABORATORIES
COMBUSTION AND CARBONIZATION RESEARCH LABORATORY

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COMBUSTION AND ATOMIZATION TESTS ON TWO PIPELINEABLE COAL SLURRIES

by

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

ABSTRACT

The combustion performance of two pipelineable slurry products prepared from Alberta foothills coal was assessed in CCRL's pilot-scale utility boiler. A commercial coal water fuel (CWF), prepared from Cape Breton coal, was used as the reference fuel.

Combustion tests indicated that ignition was very unstable for these slurries when compared with the commercial CWF and neither slurry could be recommended as an acceptable boiler fuel. One of the major problems with the two pipelineable slurries was the settling of the fuel in transit. It is recommended that a fuel which has been kept in suspension, subsequent to manufacture, be tested at CCRL.

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ESSAIS DE COMBUSTION ET D'ATOMISATION DE SUSPENSIONS DE CHARBON TRANSPORTABLES PAR PIPELINE

par

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

RÉSUMÉ

Le rendement en combustion de deux suspensions de chardon des Contreforts de l'Alberta, transportables par pipeline été évalué dans la chaudière expérimentale du LRCC. Un combustible charboneau (CCE) commercial, préparé à partir de charbon du Cap-Breton, a été utilisé comme combustible de référence.

Les essais de combustion ont révélé que ces suspensions s'enflamment beaucoup plus difficilement que le CCE commercial et qu'aucune des deux suspensions ne peut être recommandée comme combustible de chaudière acceptable. Un des grands problèmes qu'ont posé les deux suspensions a été la décantation du combustible en cours de transport. Il est recommandé de mettre à l'essai au LRCC tout combustible qui a été maintenu en suspension après sa fabrication.

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INTRODUCTION

Under an agreement between Canada and Germany; the Department of Energy, Mines and Resources Canada and the Alberta Office of Coal Research and Technology (AOCRT) collaborated with the Germany government in a research, development and demonstration program. The objective was to use Alberta coals as a feedstock for producing coal water slurries for pipelineing and combustion applications. As part of this program, the Combustion and Carbonization Research Laboratory (CCRL) of CANMET's Energy Research Laboratories evaluated the combustion performance of two coal water fuels (CWF), prepared from the Alberta foothills coals. A commercial CWF prepared from Cape Breton coal was used as the reference fuel; 5000 t of the reference CWF had been used for a demonstration in a 20-MWe compact oil-designed boiler in Charlottetown, P.E.I.

FUEL QUALITY ASSESSMENT

Two pipelineable slurry products, made in Germany were shipped to CCRL. The shipment, comprising 40 100-L drums of each product was stored in a heated enclosure to prevent freezing prior to the combustion tests. During boat and truck transport from Germany to Canada, the two slurries had been in a thermally-controlled container maintained above 5°C to prevent freezing. One of the products, slurry S, was prepared from a medium-volatile Alberta foothills coal containing a stablizer to prevent heavy settling. The other product, slurry B, a 60/40 blend of the above coal and a high-volatile bituminous Alberta coal, did not contain a stablizer because of the coals' inherent stabilizing properties. Slurry S contained 30.3% and slurry contained 32.4% water respectively. Both of the Alberta coal feedstocks have been burned successfully as a pulverized-coal fuel.

From particle size distribution (PSD) data provided by Germany for the parent coals, it was expected that 90% of slurry S would contain coal particles less than 75 μm, whereas the blend would be coarser with about 80% of particles less than 75 μm. However, PSD conducted on the CWF used at CCRL showed that the blend was much finer than anticipated.

Figures 1 and 2 show the PSD data provided by West Germany and as measured by NRC for CCRL. This suggests that much of the coarser material contained in the blend, i.e. >100 μm, had not been successfully removed from the drums prior to the combustion tests. The actual impact on the combustion tests remains unknown but it may be speculated that the coarser particles, had they been in the "as fired" CWF, would not have improved combustion because larger particles normally take longer to burn.

Examination of the slurry products on their arrival at CCRL indicated that the unstablized slurry B was more viscous than the stabilized slurry S. This was confirmed by rheology and spray atomization tests undertaken at Nova Scotia Research Foundation Corporation (NSRFC) by CCRL. When the stabilized slurry was discharged into the day tank it was noted that about 3 cm of soft sediment remained on the bottom of each drum. This sediment was then transferred from the drums to the day tank, where it was readily re-suspended by a mechanical mixer.

Personnel from Germany and AOCRT were present within a week of the arrival of the slurries to observe the transfer of the unstabilized slurry blend to the day tank for the combustion evaluation. Although these drums had been turned upside down on arrival, there was still about 15 cm of hard sediment remaining in the bottom of the emptied drums. This sediment was re-suspended in the day tank, but with much more difficulty than was encountered with the stabilized slurry.

The reference CWF, containing 32% water and prepared by the Cape Breton Development Corporation (CBDC), had been at CCRL for over a month and no observable settling had occurred. Transfer to the day tank was achieved with negligible residue remaining in the storage drums.

PARENT COALS

The CWF were prepared from coals containing about 7% ash and over 28% volatile matter. The proximate and ultimate analyses of the parent coals for each CWF are given in Table 1.

Table 1 - Analyses of parent coals

	Medium-volatile coal	High-volatile coal	CBDC coal
Proximate, wt % dry			
Ash	7.7	8.3	6.9
Volatile matter	28.7	34.3	34.4
Fixed carbon (by diff.)	63.6	57.4	58.7
Ultimate, wt % dry			
Carbon	81.2	72.1	78.9
Hydrogen	4.6	4.5	4.9
Nitrogen	1.2	1.1	1.6
Sulphur	0.2	0.3	2.2
Ash	7.7	8.3	6.9
Oxygen (by diff.)	5.1	13.7	5.5
Calorific value, MJ/kg	33.1	29.0	33.1

ATOMIZATION CHARACTERISTICS

The test protocol used and the data obtained from the spray atomization tests done at room temperature for the slurries and the reference CWF are described elsewhere (1). The atomization theory and data reduction methodology developed for CWF (1, 2) are summarized as follows:

SUB-SONIC REGIME

The sub-sonic spray droplet correlations usually take the form:

$$SMD/Do = A\ W_e^{-n}\ (1+(F/A))^m \qquad \text{Equation 1}$$

where SMD = Sauter mean droplet diameter

Do = atomizer liquid orifice

F, A = fuel and air mass flowrates

W_e = Weber Number, a dimensionless group representing the ratio of disrupting aerodynamic force to the cohesive surface tension force as noted previously (1)

A, n and m are constants determined from model fits of the experimental data.

SONIC REGIME

As the flow in the orifice approaches sonic velocity the correlation takes the form:

$$SMD/Do = A\ W_e^{-n} \qquad \text{Equation 2}$$

in which A and n are also constants but have values different from those in Equation 1.

SPRAY DATA

Figure 3 shows the correlations of spray quality data for the reference CWF and Fig. 4 to 7 show the data for the slurries. Separate correlations were possible in both sonic and sub-sonic regimes with the reference CWF (Fig. 3a and 3b). However, Fig. 4 shows a poor correlation in both regimes for the two slurries. Figure 5 indicates that the fuel index, m, determined for slurry S is 1.45, and 1.13 for slurry B. The reference CWF has an m index of 0.86 and an additional dependence on We, which indicates that the atomization process is more efficient, i.e. takes less energy to produce smaller droplets. The higher index value for slurry S indicates a more inefficient atomization process, leading to coarser droplets and inevitably a poorer combustion performance than the reference CWF or slurry B. Tables 2 and 3 show the relevant numerical constants for the three CWF.

Table 2 - Sub-sonic spray data

CWF	A	n	m
Slurry S	0.03	0	1.45
Slurry B	0.005	0	1.13
Reference	0.08	0.3	0.86

Table 3 - Sonic spray data

CWF	A	n
Slurry S	-	0
Slurry B	-	0
Reference	70.54	0.96

Figures 6 and 7 show the variable air and fuel rate spray data for slurry S and slurry B respectively.

COMBUSTION TEST PROCEDURES

Combustion tests were conducted in CCRL's pilot-scale research boiler using the roof-fired "J" configuration shown in Fig. 8. A quantitative assessment of combustion performance was obtained from:

- ignition stability
- flame shape and size
- sparkler density
- ash distribution characteristics
- carbon in ash

Each CWF, including the reference fuel, was fired at about 2.0 GJ/h for about 6 h. As mentioned earlier, the reference CWF was selected as a baseline fuel because it has been successfully burned in both the CCRL pilot-scale research boiler and in a 20-MWe utility boiler at Charlottetown, P.E.I. In the latter case, the reference CWF had been manufactured from the same coal feedstock using the same process, but had been cleaned to about half the ash level of that used at CCRL in the present study (3.5% vs 6.9%).

OBSERVATIONS

Tests were conducted on the two slurries and reference CWF, respectively. Results indicated that ignition was very unstable for slurry S and only marginally satisfactory for slurry B. Unlike the stable flame produced by the reference CWF the slurry flames (which were not anchored to the burner quarl) were long and ragged, extending to the full length of the furnace bottom into the base of the boiler (Fig. 8). A very heavy concentration of sparklers was observed particularly with slurry S. Both slurries showed a much higher production of furnace bottom ash and char than the reference fuel which produced virtually no bottom ash under similar combustion conditions. The unstabilized slurry B produced less bottom ash and char on a volume basis than the stabilized slurry S. Table 4 compares the combustion data for each.

Table 4 - Comparison of combustion data of pipelineable slurries with those of reference fuel

	Slurry "S"		Slurry "B"		Reference CWF	
	1	2	3	4	5	6
Moisture in CWF, wt %	30.3	30.3	32.4	32.4	32.0	32.0
CWF rate, kg/h	91.3	91.5	98.9	98.3	87.3	87.8
Thermal input, MJ/h	2106	2111	2103	2090	1965	1976
Atomizing air						
Temp, °C	28	24.8	25.8	24.3	25.0	21.0
Flowrate, kg/h	29.40	30.0	29.20	29.75	29.80	23.0
Combustion air temp, °C	247	226	245	222	235	201
Flue gas analyses, dry volume basis						
O_2 %	5.0	2.0	4.9	2.0	5.0	2.0
CO_2 %	14.0	17.4	16.0	17.5	14.2	16.0
CO ppm	44	25	39	36	31	47
NO ppm	542	554	548	684	656	728
SO_2 ppm	171	204	161	214	1296	1269
Furnace exit temp, °C	975	966	992	984	903	879
Combustible in fly ash, wt %	15.9	14.3	12.2	10.7	11.3	30.0
Bottom ash, approx.						
Depth, cm	> 15	> 18	> 9	> 12	> 0.5	> 1
Char, %	High	Very high	Moderate	High	Very low	Low

Figure 9 shows the amount of combustible in the ash samples deposited at various locations in the boiler. These data must be qualified by noting that the slurries deposited more ash in the PSRB system than the reference CWF and the distribution was quite different. Table 5 shows the distribution and quantity of ash in the PSRB system for the 5% O_2 combustion trials.

Table 5 - Percent distribution of ash in PSRB system*

	Slurry "S"	Slurry "B"	REFERENCE CWF
Furnace bottom (FB)	40	40	25
Furnace wall (FW)	10	10	12
Superheater tubes (SHT)	0	0	0
Flue pipe & heat exchangers (END)	27	26	36
Electrostatic precipitator (ESP)	23	24	27
Total weight, kg	15.0	17.6	8.4

* 5% O_2 tests

The main difference between the reference and slurries was the lower overall ash deposition and the reduced proportion in the furnace bottom section for the reference fuel. This result is comparable with that obtained at Charlottetown in the 20 MWe boiler where deposited ash has been negligible, i.e., bottom ash and tube deposits. The higher concentration of furnace bottom deposits with the slurries is consistent with the poorer quality spray and hence the ignition and combustion efficiency.

CONCLUSIONS

1. Examination of slurry B suggested that many of the larger particles (> 100 µm) remained in the drums when the CWF was transferred to the CCRL day tank. This did not occur with the reference CWF or the slurry S.
2. Atomization data indicate that the two slurries will produce larger droplets than the reference CWF and will require more atomizing fluid and higher pressures to attain an optimum spray quality.
3. The two slurries had poor to marginal ignition stabilities and poor flame characteristics, probably resulting from poorer spray quality when compared with the reference CWF.
4. There was a noticeable improvement in combustion performance with slurry B compared with slurry S, probably due to the slightly better spray quality and higher volatility.

5. CCRL does not recommend either of the two slurries for demonstration trials in the Charlottetown boiler. It is suggested that fuel rheology and particle size distribution of the coal be modified in order to produce better spray quality and also that the fuel volatility be increased through a higher proportion of more volatile coal in the parent coal feedstock.
6. It is strongly recommended that combustion tests be undertaken on a stabilized slurry product that has been kept in proper suspension subsequent to manufacture.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the invaluable efforts of B.C. Post and the technical staff of the Industrial Combustion Processes Section for their expeditious execution of the combustion evaluation experiments. The meticulous work of N.S. Stover of the Nova Scotia Research Foundation Corporation in providing the spray atomization test data is also gratefully acknowledged.

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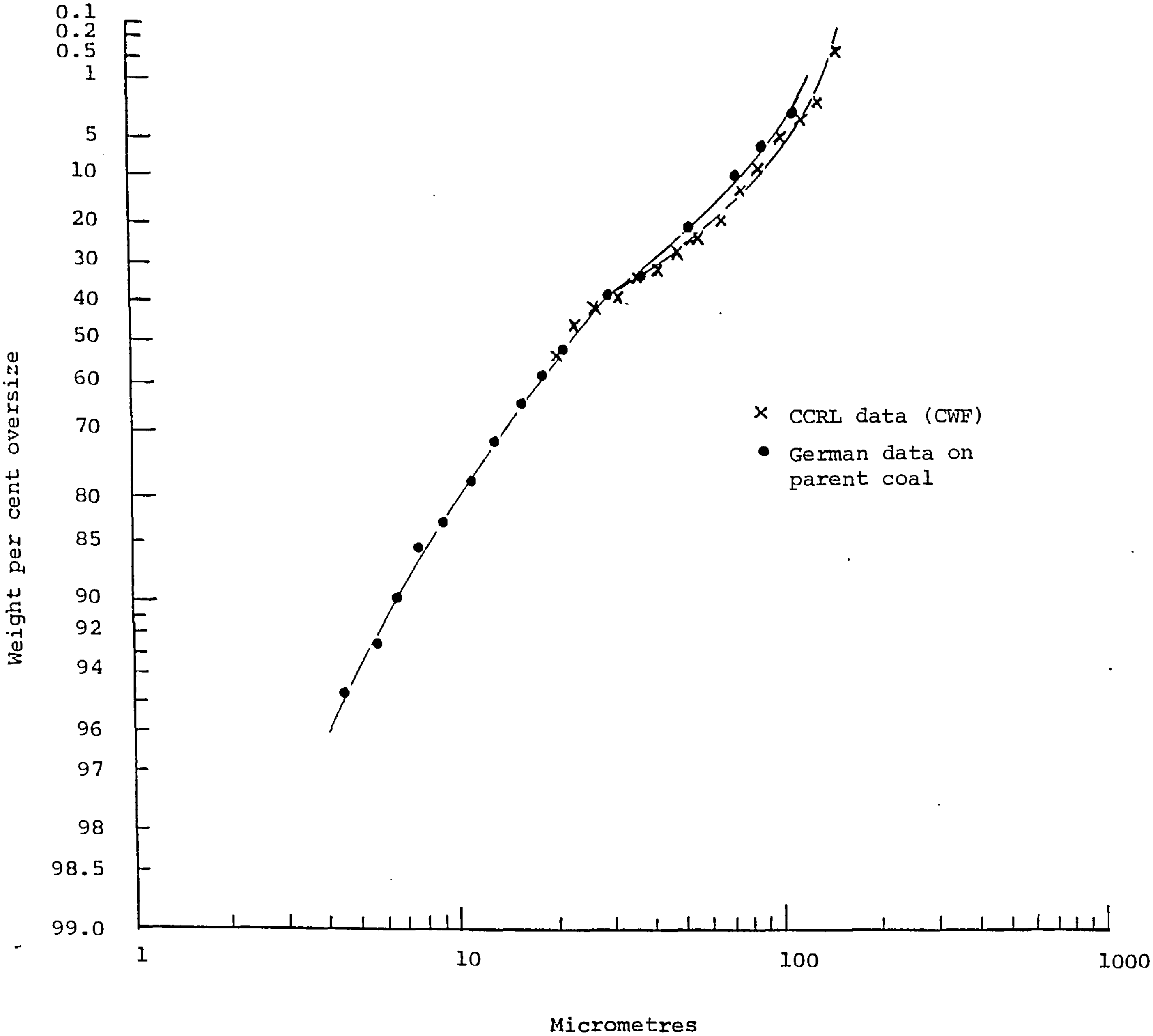


Fig. 1 - Particle size distribution of slurry "S"

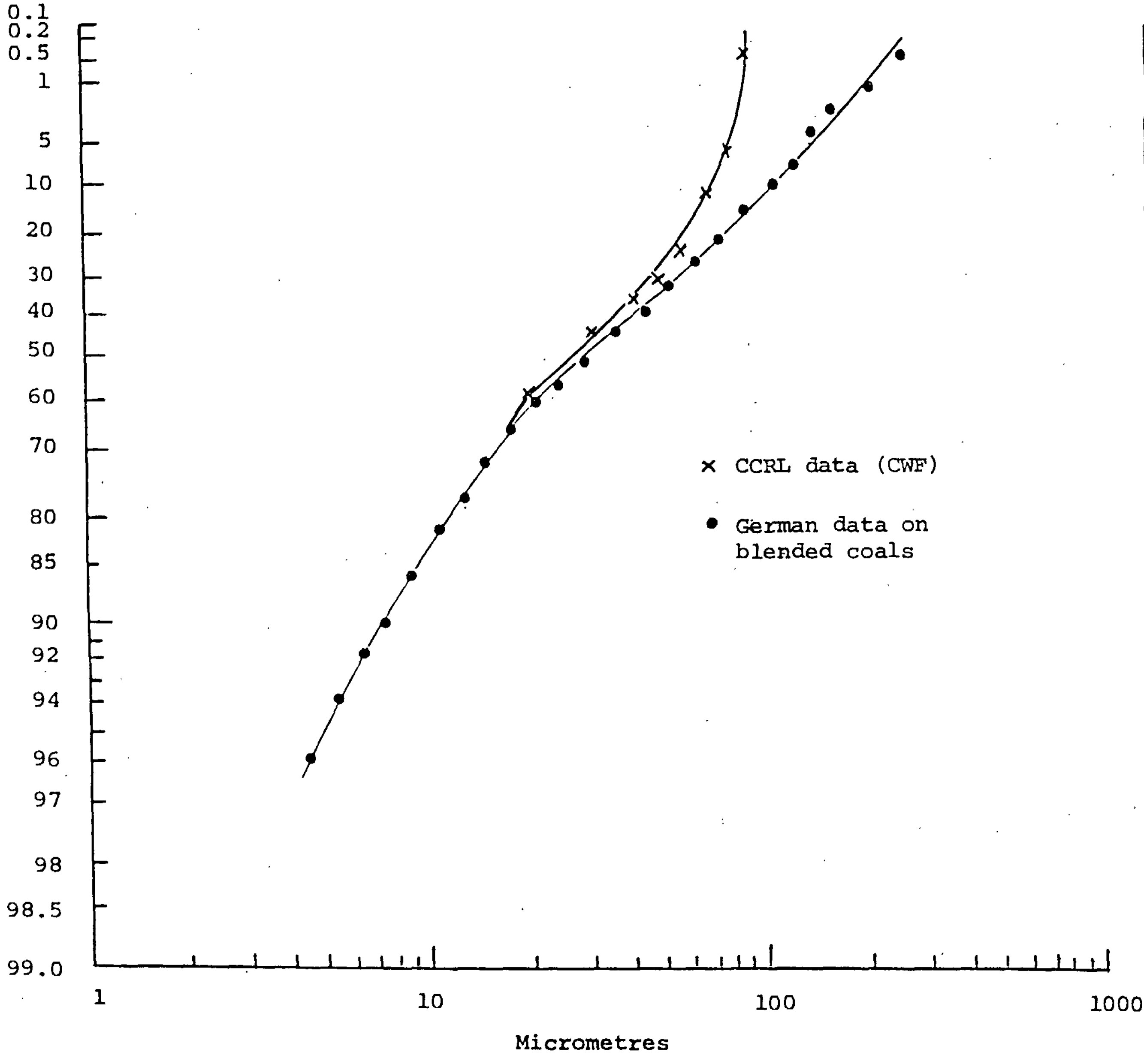


Fig. 2 - Particle size distribution of slurry "B"

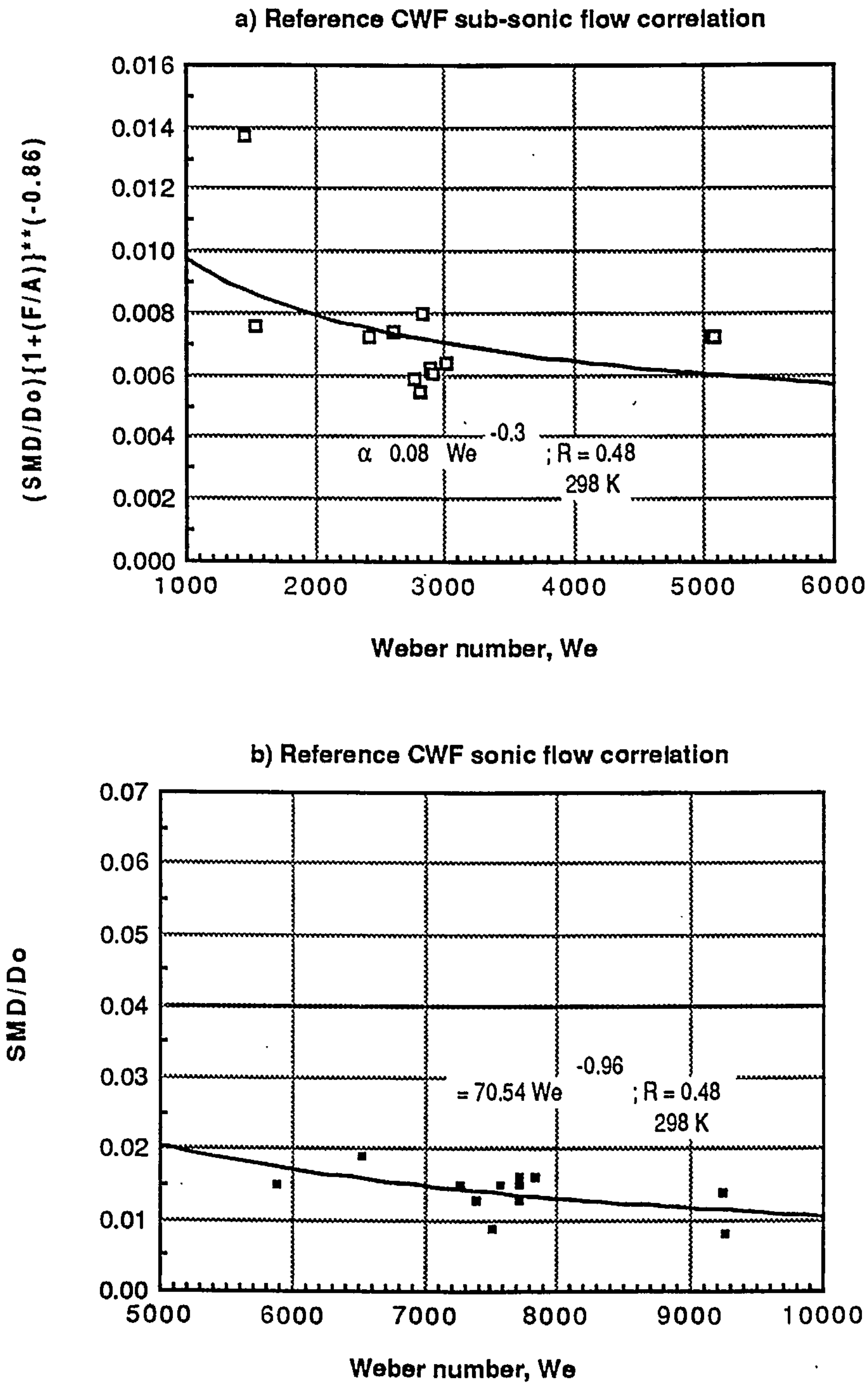
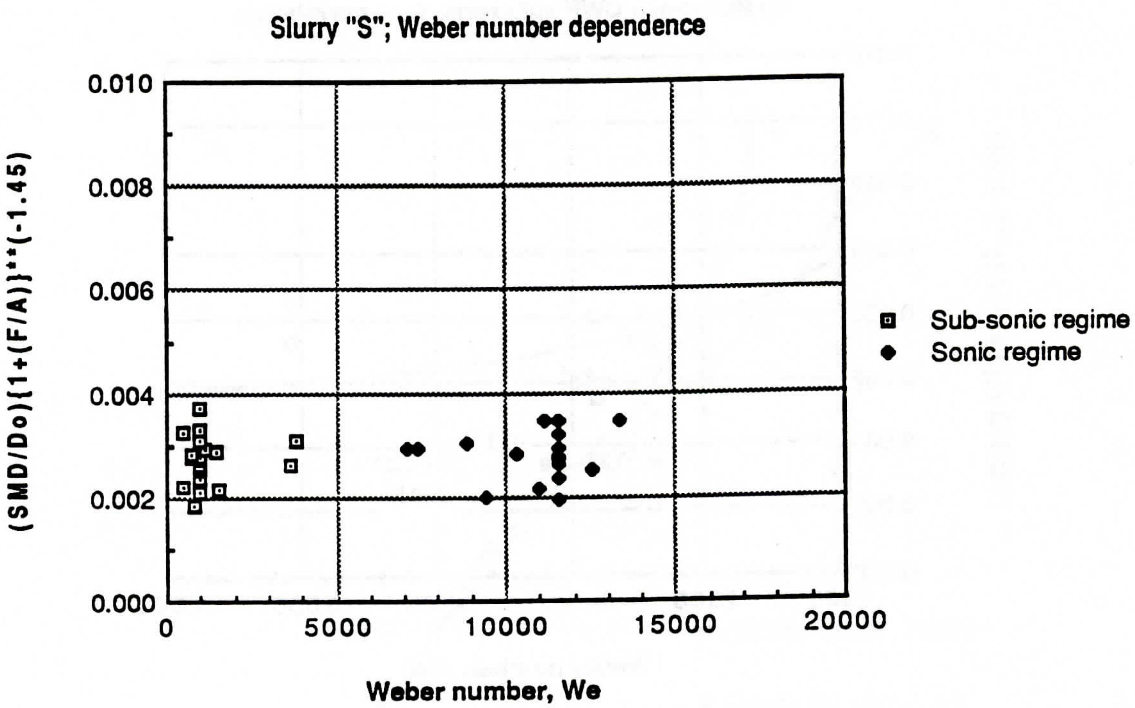


Fig. 3 - Correlations of spray quality data, reference CWF



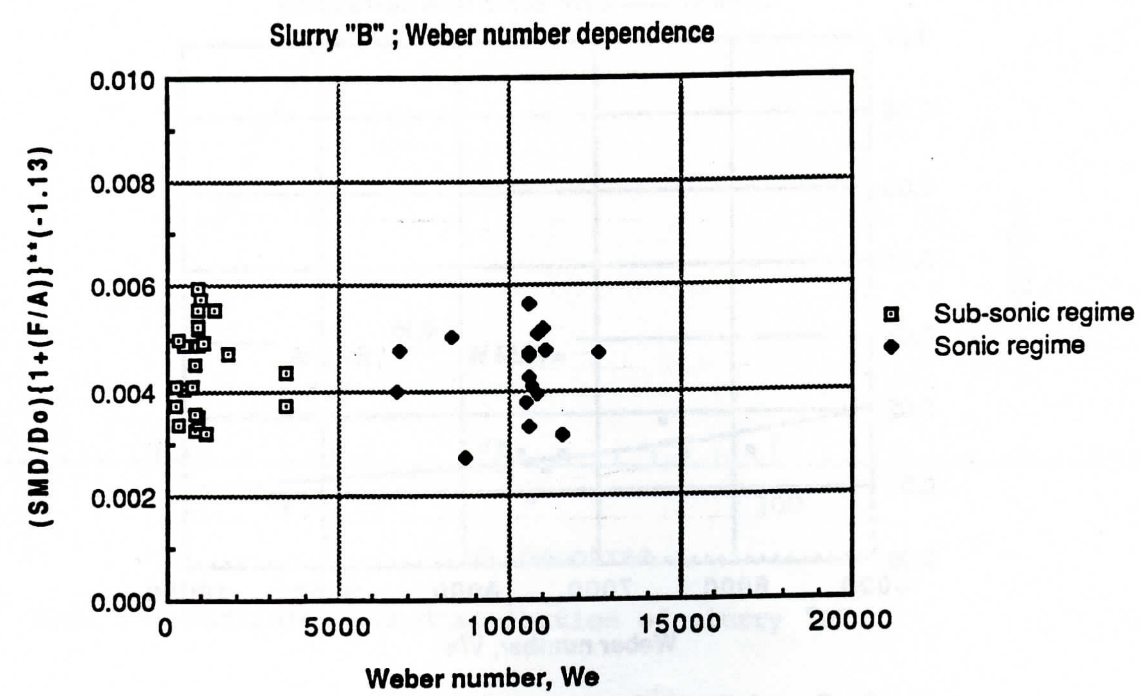


Fig. 4 - Correlations of spray quality data, CWF slurry

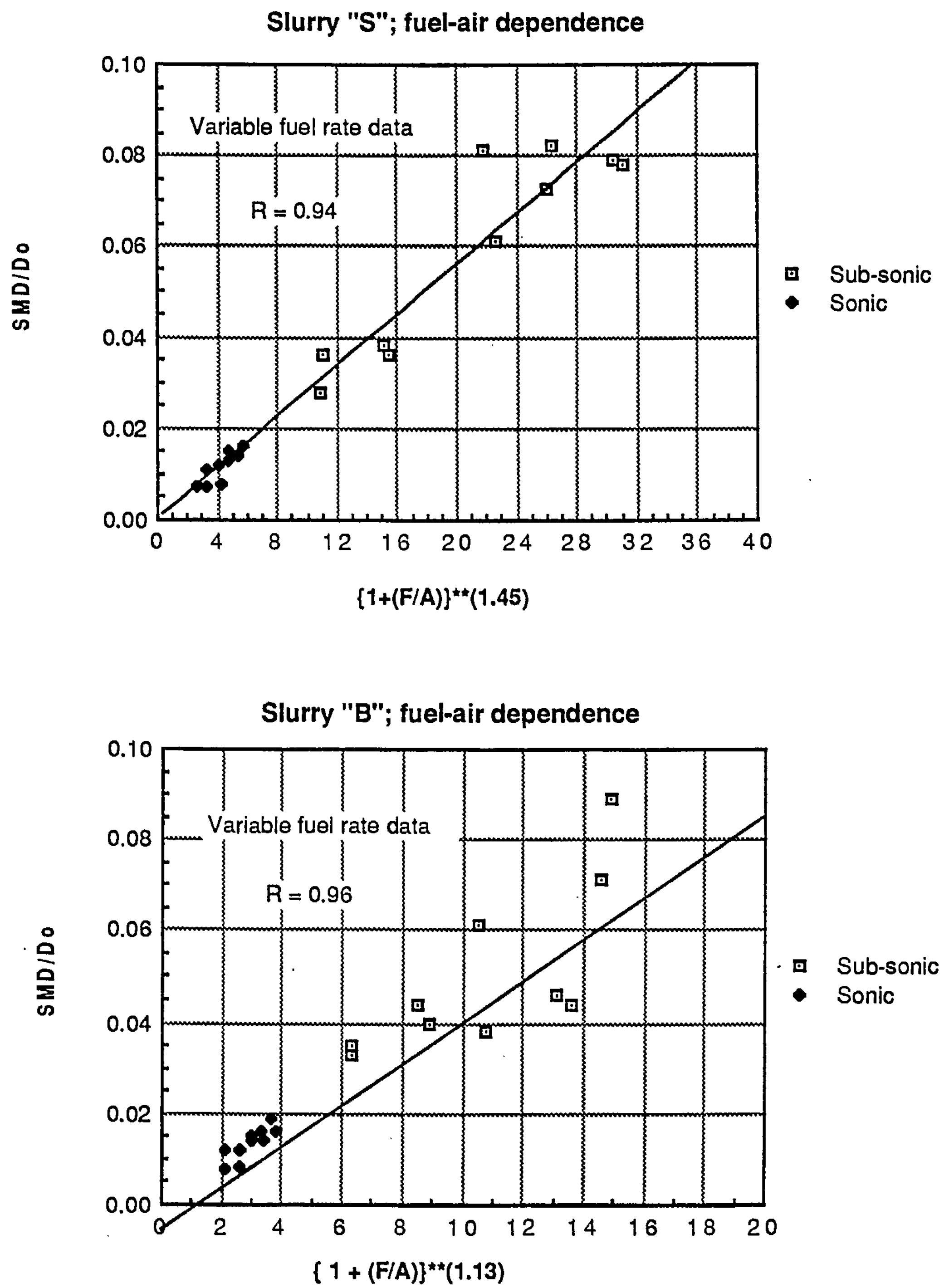


Fig. 5 - Spray data, fuel-air dependence, CWF slurry

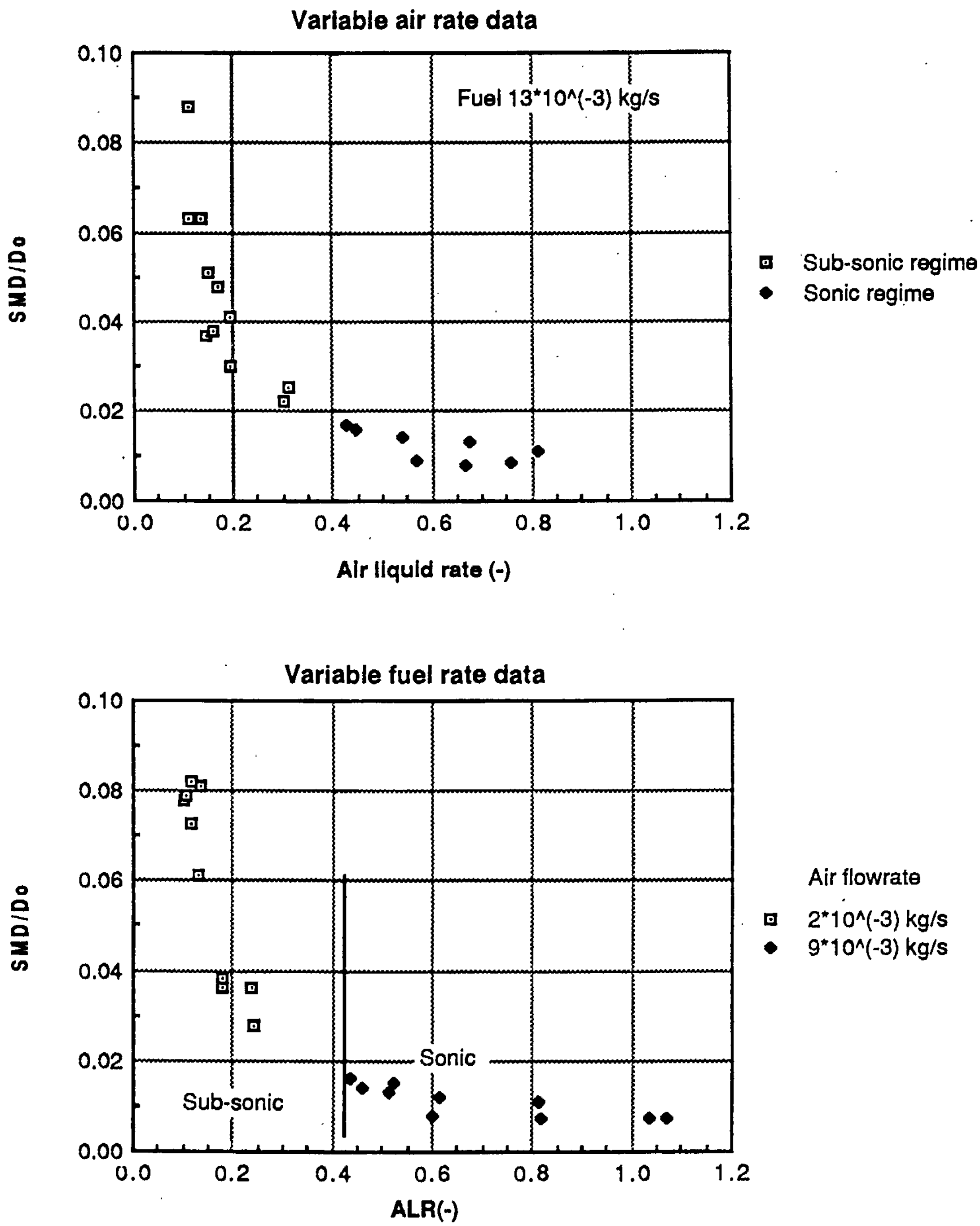
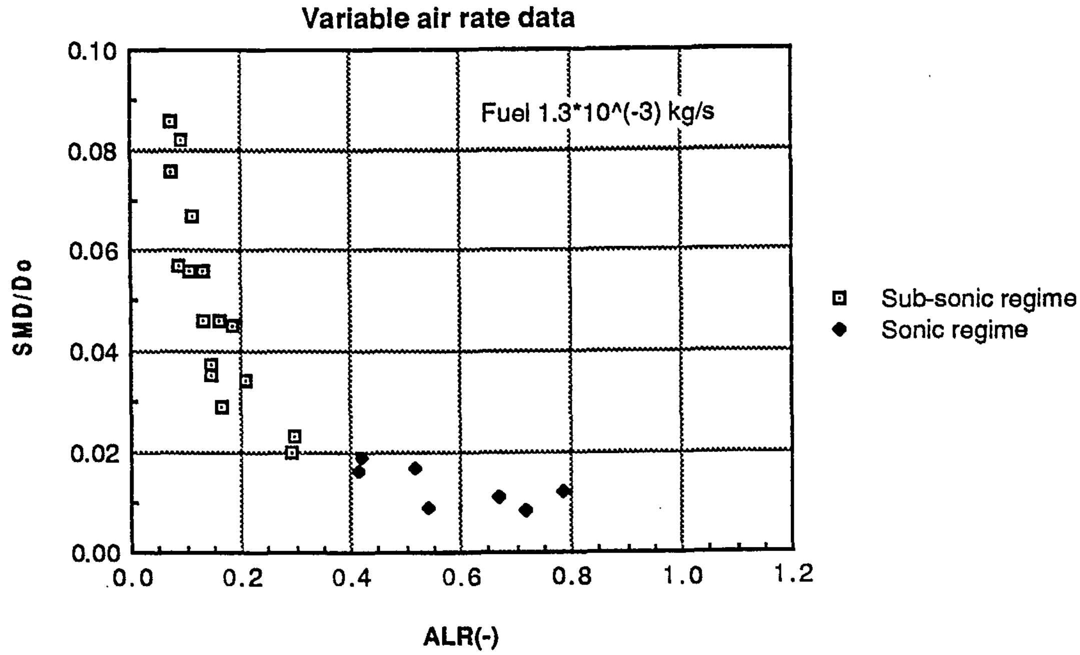


Fig. 6 - Spray data, variable air and fuel rate correlations, slurry "S"



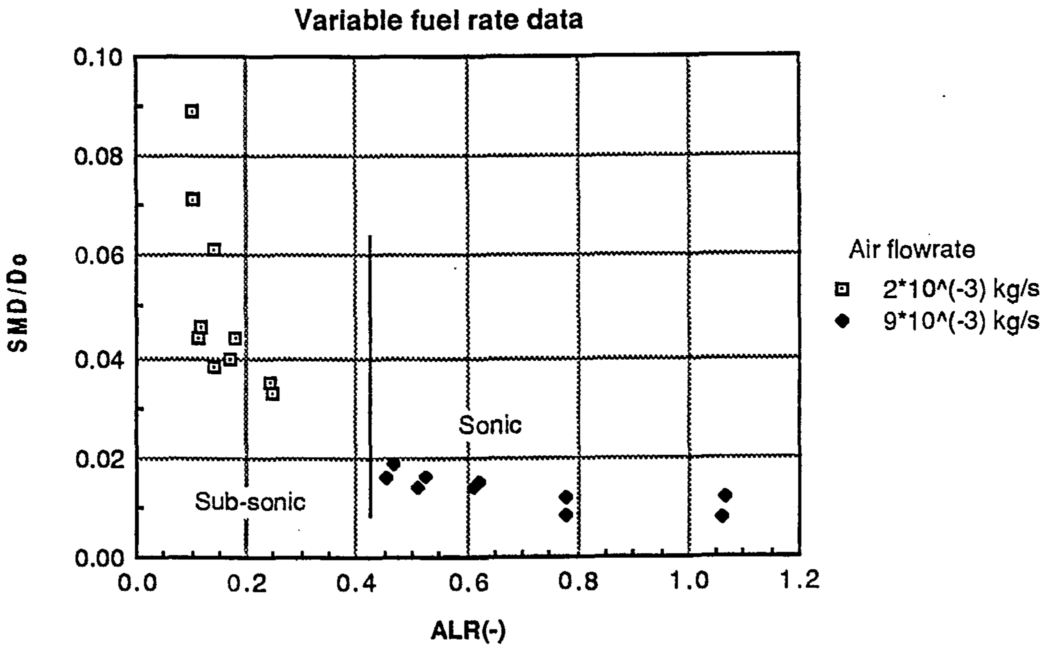


Fig. 7 - Spray data, variable air and fuel rate correlations, slurry "B"

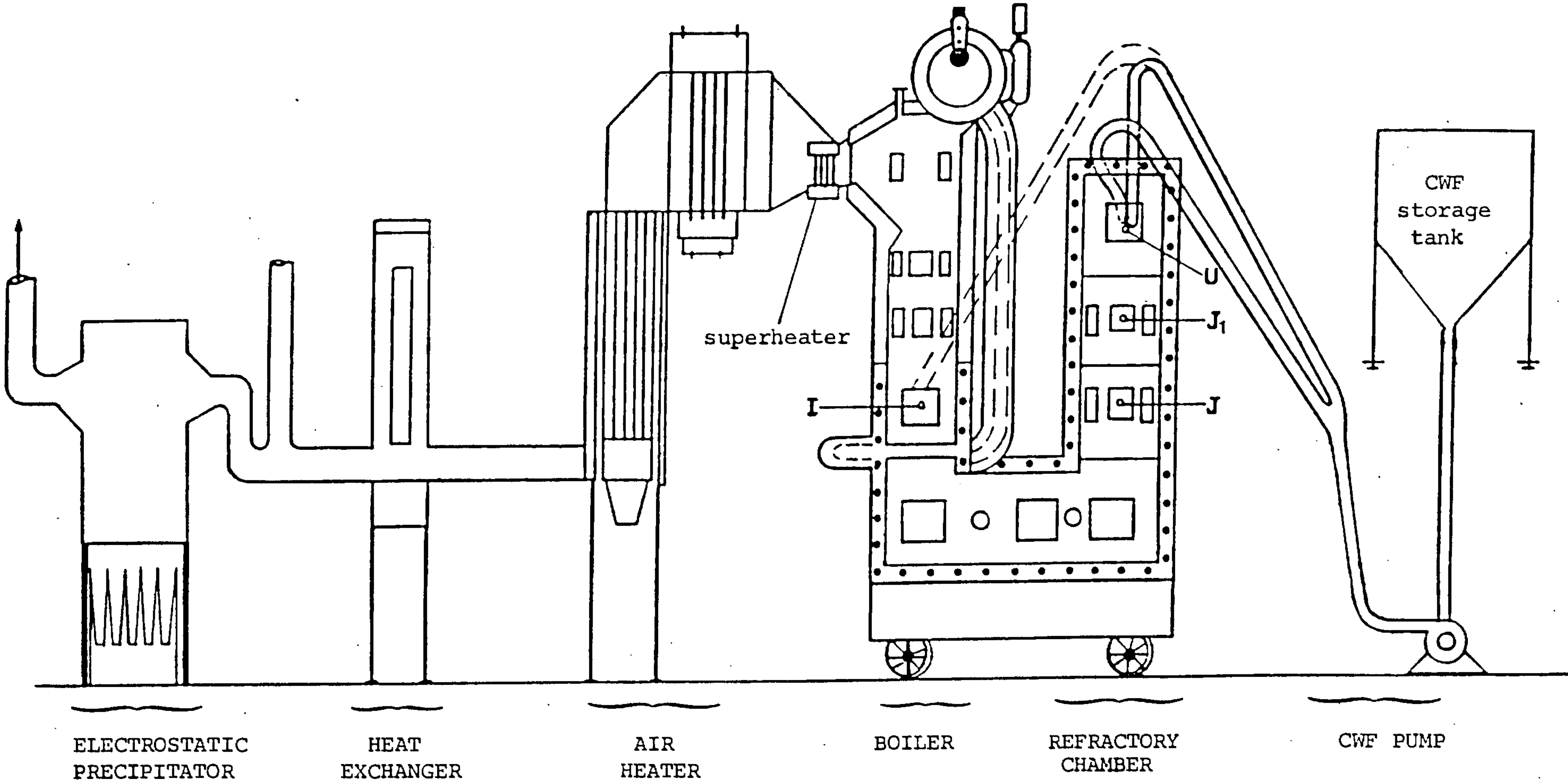


Fig. 8 - Schematic of CCRL pilot-scale boiler with CWF handling system

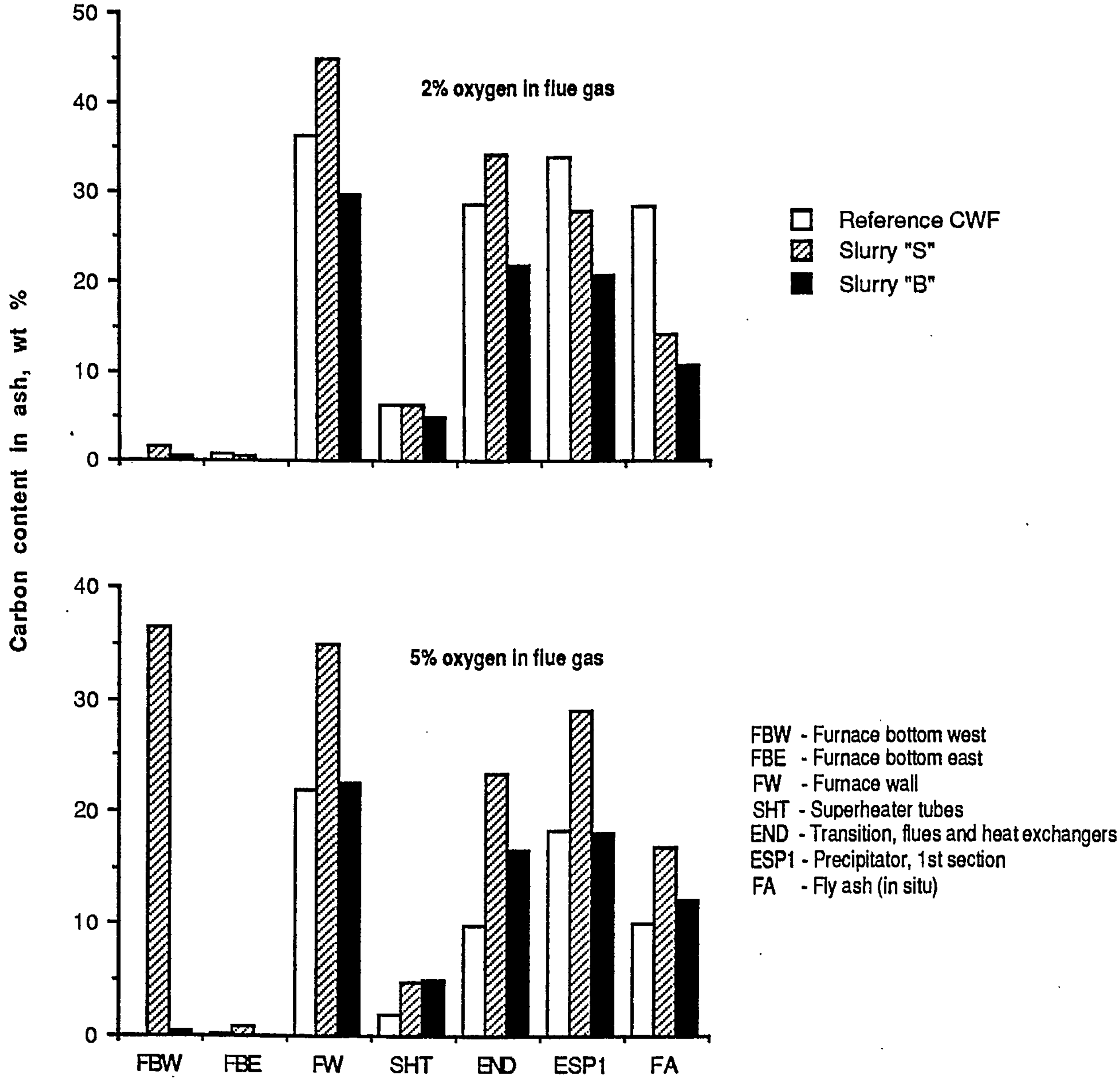


Fig. 9 - Carbon content in ash samples at various locations in pilot-scale boiler