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**Preliminary Investigation of the Effects
of Coal-Water Slurry Fuels on the
Combustion in GE Coal Fueled Diesel Engine
(Task 1.1.2.2.1 - Fuels)**

Topical Report

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By
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Erie, Pennsylvania

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1.0 INTRODUCTION

In prior work with the coal fired diesel research engine, a necessity to determine the sensitivity of the engine to a wider range of fuels was resolved and included in the R&D Test Plan submitted on 2/9/89. In general, the economic viability and universal acceptance of the commercial engine will be a factor of its ability to tolerate the widest range of source fuels with minimal fuel beneficiation.

As detailed in the R&D Test Plan, a preliminary investigation on the effects of coal-water slurry (CWS) fuels on the combustion in a GE single cylinder test engine was conducted.

The variables in the selected CWS fuels include mean particle sizes of coal, slurry additive packages (producing rheological change), raw coal sources, coal ranks (heat value), ash levels, and cleaning processes. Thirteen test fuels were prepared by three slurry manufacturers. They were OTISCA Industries Ltd. of Syracuse, NY, Energy & Environmental Research Center (making the UNDERC slurry) of Grand Forks, ND, and AMAX R&D Center of Golden, CO. The AMAX fuels had some problems flowing through our fuel injection systems (FIE) on the first trial but with some work these problems were resolved. Prior to resolving the running problems with the AMAX fuels, AMAX notified us that they will no longer remain in the coal water slurry business. Therefore, only one kind of AMAX fuel was run. OTISCA had problems making the western sub-bituminous coal "COLOWYO" into one kind of CWS in time for the present test. Therefore, only the results of 9 types of fuels were reported here.

For each kind of CWS fuel, a maximum of 100 gallons were bought which was only enough to run the engine for four full load hours. No wear data of engine parts were expected from the tests. It was also not possible to optimize engine performance for each fuel within the supply limit. Therefore, only a preliminary investigation of the combustion of these fuels in the GE engine was possible.

Each fuel manufacturers supplied the specifications of the CWS and its raw coal. The Pennsylvania State University Combustion Laboratory and the Adelphi University Center For Energy Studies were contracted to perform independent conformation test as well as additional rheology and settling property tests. Their full reports are attached in the Appendix.

A test matrix of fuels, given in table 1.1, was established to provide a sampling of the intrinsic fuel parameters that influence system performance in relation to fuel character. In particular, these parameters are particle size distribution, volatility/fixed carbon, ash content, heat content, and slurry rheology.

FUEL NO.	FUEL VENDOR	COAL STATE ORIGIN	SEAM NAME	COAL TYPE	CLEANING PROCESS	MEAN MICRON SIZE	REMARK
1	OTISCA	KENTUCKY	BLUE GEM	BITUMINOUS	PHYSICAL	4.6	LIGNOSOL
2	OTISCA	KENTUCKY	BLUE GEM	BITUMINOUS	PHYSICAL	4.8	MCG 32A
3	OTISCA	KENTUCKY	BLUE GEM	BITUMINOUS	PHYSICAL	3.1	LIGNOSOL
4	OTISCA	KENTUCKY	BLUE GEM	BITUMINOUS	PHYSICAL	3.2	MCG 32A
5	OTISCA	PENN.	MARIANA	BITUMINOUS	PHYSICAL	2.5	MCG 32A
6	UNDERC	WYOMING	KEMMER	SUB-BIT.	CHEMICAL	12	
7	UNDERC	WYOMING	SPRG CRK	SUB-BIT.	PHYS+CHEM	12	
8	UNDERC	WYOMING	SPRG CRK	SUB-BIT.	CHEMICAL	12	
9	AMAX	KENTUCKY	SPLINT	BITUMINOUS	PHYSICAL	8.2	

Table 1.1 Test Fuels

The raw coal analysis, below, shows a definite distinction between the bituminous and sub-bituminous coals. A slightly lower ash content should also be noted between the physically cleaned bituminous fuels and the chemically cleaned sub-bituminous fuels. Other than these differences, the chemical characteristics of the fuels were basically indistinguishable within the coal type.

Coal Type	Fuel No.	Prox. Analysis			Ultimate Analysis				
		Vol. Mat.	Fix. Carb.	Ash	H	C	N	S	O Diff.
KY B-G	1,3	39.5	59.8	0.7	5.3	84.0	2.1	0.8	7.8
KY B-G	2	38.8	60.4	0.8	5.3	84.0	2.1	0.8	7.8
KY B-G	4	39.3	60.0	0.7	5.3	84.0	2.1	0.8	7.8
PA MARI.	5	36.9	61.4	1.7	5.5	83.6	1.7	1.0	8.2
WY KEMM.	6	40.7	56.5	2.8	4.7	74.2	1.5	0.4	19.2
WY SP-CR	7	40.5	57.4	2.1	4.5	75.0	1.4	0.4	18.7
WY SP-CR	8	40.7	56.5	2.8	4.6	73.3	1.4	0.4	20.3
KY SPLINT	9	37.3	60.2	2.5	5.3	82.2	1.9	0.9	9.7

Table 1.2 Raw Coal Analysis (Moisture free, weight %)

The rheology of the fuel was further characterized by examining the macroscopic properties of the slurry. The vendor's analysis is based on fuel samples of as-delivered slurry whereas fuel samples for Penn State and Adelphi were from post engine run samples.

Several differences in the analysis between the laboratories were observed in particle size and viscosity. For particle size, this difference may be associated with the method of particle measurement. Adelphi and Penn State both use a Malvern Particle Size Analyzer where the particle size distribution is based upon the Fraunhofer Diffraction which occurs as the laser light passes through the suspension. Whereas, Otisca uses Micromeritics 5000L or Horiba CAPA 500 equipment and the results differ from those of Adelphi and Penn State. It should also be noted here that as the particle size of the slurry increased, the difference in the Adelphi analysis and the Penn State analysis increased with the vendor analysis falling between the two. The moderate shear rheology shown in table 1.3B also varies between the different analysis laboratories. This may be due, once again, to the differences in equipment used or the length of time between the measurement and the mixing of the slurry sample.

FUEL No.	COAL TYPE	SULFUR		D(50) Microns			ASH	
		VEND.	PSU	VEND.	ADEL.	PSU	VEND.	PSU
1	KY B-G	0.79	0.73	4.8	7.8	7.6	0.89	0.73
2	KY B-G	0.85	0.76	4.8	7.6	7.7	0.81	0.78
3	KY B-G	0.79	-	3.1	-	-	0.70	-
4	KY B-G	1.05	0.85	3.2	-	4.9	0.72	0.76
5	PA MARI.	1.08	1.03	2.5	3.4	3.6	1.71	1.73
6	WY KEMM.	0.37	0.43	13.9	12.6	14.8	2.80	2.69
7	WY SP-CR	0.40	0.47	14.7	11.4	18.8	2.10	1.85
8	WY SP-CR	0.37	0.43	14.9	12.2	17.8	2.76	2.54
9	KY SPLINT	-	0.94	-	8.2	10.6	-	2.53

Table 1.3A Coal water slurry macroscopic properties

FUEL No.	COAL TYPE	SOLIDS			VISCOSITY 100 s ⁻¹		
		VEND.	ADEL.	PSU	VEND.	ADEL.	PSU
1	KY B-G	50.4	48.9	50.5	230	150	149
2	KY B-G	50.1	50.0	49.7	93	75	43
3	KY B-G	-	-	-	-	-	-
4	KY B-G	48.9	-	48.7	136	-	39
5	PA MARI.	50.9	50.8	50.2	32	50	55
6	WY KEMM.	50.1	50.6	50.2	290	195	75
7	WY SP-CR	52.2	53.4	52.0	384	410	82
8	WY SP-CR	50.3	53.4	52.7	297	420	91
9	KY SPLINT	-	51.0	50.2	-	35	25

Table 1.3B Coal water slurry macroscopic properties

FUEL No.	COAL TYPE	HHV		LHV	
		VEND.	PSU	VEND.	PSU
1	KY B-G	14387	14491	3.348	3.258
2	KY B-G	14387	14979	3.348	3.371
3	KY B-G	-	-	-	-
4	KY B-G	14387	15017	3.348	3.380
5	PA MARI.	14916	15143	3.352	3.405
6	WY KEMM.	12667	12734	2.846	2.862
7	WY SP-CR	12757	12874	2.871	2.899
8	WY SP-CR	12746	12833	2.868	2.887
9	KY SPLINT	-	14588	-	3.280

Table 1.3C Coal water slurry macroscopic properties

An extrusion rheometer and pendulum settling apparatus, designed and developed by Adelphi University, were used in the evaluation of the coal-water slurry samples sent to them. The extrusion rheometer is comprised of a testing chamber approximately two feet in length and two inches in diameter, followed by an automated valve. The extrusion orifice has a diameter of 0.21 cm and a length of 6.4 cm. The sample is placed in the testing chamber and the extrusion pressure adjusted in 10 psi increments until a maximum of 100 psi is achieved. At each of the pressure increments, an

electromagnetic valve is actuated simultaneously with a timer, producing a sample which is then weighed. A characteristic pressure versus shear rate curve is then extracted from this information. In conjunction with this work, Adelphi also notes a time function dependence of viscosity in their report given in the appendix.

Adelphi also used a sophisticated method to determine the static stability of their CWS fuel samples based on a design from the Bureau of Mines. This method uses a CWS sample contained in a test tube which is inserted in a pendulum apparatus. (A detailed description is given in the appendix.) The pendulum swings on two pins, breaking a collimated light beam as it passes through the midpoint of its swing. Using a frequency counter, the period for 10 oscillations is determined. The center of mass and moment of inertia is then calculated over a two week period at ambient temperature. A shift in the center of mass of approximately 0.1 cm is indicative of CWS settling. The table below gives a relative comparison of the various samples of coal slurry.

FUEL NO.	FUEL VENDOR	COAL STATE ORIGIN	STABILITY DAYS
1	OTISCA	KENTUCKY	< 1
2	OTISCA	KENTUCKY	2
3	OTISCA	KENTUCKY	-
4	OTISCA	KENTUCKY	-
5	OTISCA	PENN.	14
6	UNDERC	WYOMING	1 Hour
7	UNDERC	WYOMING	< 1
8	UNDERC	WYOMING	< 1
9	AMAX	KENTUCKY	2

Table 1.4 Adelphi Stability Report

In summary, fuels which could be mechanically injected into the combustion chamber could be burned. However, for each type of fuel the operating parameters of the engine (i.e. timing and injection pressure) required changing to optimize engine performance.

2.0 TEST ENGINE SET UP, INSTRUMENTATION AND DATA REDUCTION

2.1 - Two Cylinder Coal Research Engine Description and Set Up

Testing was conducted on a two-cylinder version of the GE-7FDL series locomotive engine (Figures 2.1.1). The left side cylinder was run on coal water slurry (CWS), the right cylinder was run on regular diesel fuel. The right cylinder was used to bring the engine up to speed and operating temperature. The left cylinder was then brought on line and fuel to the right cylinder was shut off. The entire engine load was then carried by the coal fueled cylinder.

The combustion chamber, shown in figure 2.1.2, incorporated direct fuel injection along with a bowl shaped piston crown. The engine's compression ratio was 11.5 and the engine has a bore and stroke of 9 inches and 10.5 inches respectively. Under test load conditions the engine produced 180 KW (over 90% full power) at 1050 rpm. Under normal test conditions the full load inlet air pressure was 65 inches of mercury and 185 F.

Load was provided by a conventional locomotive alternator whose output was dissipated through resistor grids. A large flywheel was mounted to the engine crankshaft and drove the two-bearing alternator through a torsionally flexible coupling to reduce torsional pulsations.

A dry sump lubrication system was used for lubrication on the research engine. The lube oil system included a 5-hp scavenge pump and a 7-hp supply pump. An external holding tank was used, and filtering was provided by both a filter and centrifugal oil separator. A 40-kW circulation heater was used to accelerate engine warm-up, and a standard locomotive shell and tube heat exchanger was used to maintain preset oil temperature once the engine had reached operating temperature.

The engine was cooled by circulating treated water through a closed system using a 7.5-hp pump. The coolant was cooled to a preset temperature by passing it through a shell-and-tube heat exchanger using city water as the cold side liquid.

The research engine has no turbocharger. Shop air, which had been filtered, heated using a 200-kW heater, and throttled to the proper pressure was used as a source of inlet air. A receiver tank (18 in. dia by 72 in. long) was used to reduce fluctuations in the intake manifolds. Exhaust pressure pulses were smoothed by an expansion chamber (30 in. dia by 72 in. long) and by throttling the exhaust with a regulated valve. The throttling also provided the required back pressure on the engine to simulate the operation of a turbocharger.

FIGURE 2.1.1
2 CYLINDER COAL RESEARCH ENGINE
SECTION VIEW

FIGURE 2.1.2

COAL CYLINDER COMBUSTION CHAMBER LAYOUT

Containers for all fluids consumed by the engine, such as the CWS, pilot fuel and lubricating fluid were placed on electronic scales in order to accurately measure fluid consumption. A block diagram of the CWS accumulator injection system is shown in Figure 2.1.3. A conventional jerk pump was used to pump diesel oil into the backside of a piston isolator pump located between thick metal heads. The CWS on the opposite side of the piston was thus pressurized and pushed into the accumulator injector. A check valve was included in the injector inlet line to trap the high pressure CWS in the injector on the refill cycle of the piston. A check valve was also included in the CWS fill line to keep the CWS from reverse flow on the pressurization cycle of the piston pump. A normal jerk pump plunger with a standard relief helix was used as a drive pump for the piston isolator pump. It was therefore possible to use the jerk pump for metering the fuel as well as for pressurization.

A cross sectional sketch of the accumulator injector is shown in Figure 2.1.4. The accumulator volume of this injector was approximately 235 cm³. The system was sized to inject 3 grams of CWS per injection, with the pressure in the injector falling from approximately 83 MPa (12,000 psi) to 48 MPa (7,000 psi) as injection occurred. The lower injection pressure limit of 48 MPa was found to yield good combustion efficiency from prior tests.

In Figure 2.1.3, the injection cycle proceeded as follows: The jerk pump was stroked mechanically from the engine driven camshaft, pushing diesel oil into the oil side of the piston pump. The piston in turn pushed the captive volume of CWS held between the accumulator injector and the piston pump inlet check valve into the accumulator injector. The injector shut-off needle was kept from opening by high pressure nitrogen gas (3200 psi) on top of the needle assembly. At the appropriate injection time, a Moog Series 31 valve, mounted on the injector, opened and 27.5 MPa servo oil flowed under the needle lift piston. This oil lifted the needle allowing the high pressure CWS to flow into the nozzle sack region of the injector and into the engine. At the injection shut-off time specified by the electronic control, the servo valve was toggled and the oil pressure under the needle lift piston was relieved. The needle was then shut by the high pressure gas spring on the top of the needle piston. The pressure on the oil side of the piston pump is then lowered due to the return stroke of the jerk pump. The pressure in the accumulator injector was then held by the check valve on the outlet side of the piston pump and the piston pump was filled from the low pressure CWS supply system.

The electronic control system for the CWS injector was developed using Hewlett-Packard's 3852 programmable controller with appropriate A/D converter, counter, and waveform generator cards. A crankshaft encoder which provided one pulse per degree of crankangle,

**LOW PRESSURE CWS
SUPPLY SYSTEM**

FIGURE 2.1.3

FIGURE 2.1.4
ACCUMULATOR INJECTOR

a TDC pulse and a cylinder pressure signal were used for input to the control system. The controller then provides a pulse signal to the Moog valve on the CWS injector to lift the needle and inject the CWS fuel into the cylinder. Two methods of controlling injection were provided for in the control electronic. First, in manual mode, the start of injection is determined by setting the delay from TDC. Once this point is set, the injection duration is adjusted manually to maintain a 12,000 psi injection pressure with about a 5000 psi pressure drop. A second method, which is more automatic, measures the injection pressure and provides feedback to the controller to automatically maintain the set injection pressure. This second method was not used during fuels testing because it became unstable and caused engine hunting. A better algorithm for providing feed back will be pursued for future testing.

The pilot fuel injection system was a Servojet electronic unit injector from BKM, Inc. A Servojet electronic unit injector consists of four elements:

1. Solenoid valve
2. Pressure intensifier
3. Accumulator
4. Nozzle tip

The solenoid valve was the interface from the injector to the electronic controller. When energized, the injector intensifier was actuated displacing the required amount of fuel into the accumulator. This created a pressure rise of up to 16 times the rail pressure in the nozzle body.

When the solenoid was de-energized, the intensifier retracts, creating a pressure imbalance on the needle valve, lifting the needle and opening the nozzle tip orifice to the fuel stored in the accumulator.

Injection takes place until the pressure in the accumulator drops to the needle valve closing pressure which was preset by spring force. An electronically controlled pressure regulator was mounted to a fuel manifold which includes a safety relief valve, accumulator and return line check valve. Engine power or injection delivery was controlled by the regulation of the rail pressure.

2.2 - Engine Instrumentation

The engine instrumentation was segregated into two classifications; low speed and high speed. The low speed instrumentation included those parameters which were relatively stable and could be sampled by an integrating volt meter. This data was

collected via an HP 3457/3497 DVM/scanner combination under the control of the test management software (TMGR) running on a HP 1000-A900 computer. The reduced data is given in the appendix. This data is a result of approximately one half hour of engine run time scanned every seven seconds and analyzed by the TMGR statistics package.

The so called high speed data includes those parameters which are transient by nature and require a high speed voltage measuring device. An example of these parameters would be the engine firing pressure and the needle lift on the CWS injector. This data was collected on a Norland 3001 Digital/DMX oscilloscope and transferred to a Tektronix 4052 personal computer where the data was reduced to the form shown in the analysis section.

The emissions cart, shown in Figure 2.2.1 and fitted with the instrumentation noted below, was used for sampling gas emissions from the engine during testing. An analog output was taken from the emissions cart and sampled by the low speed data acquisition system. This in turn was reported as part of the low speed data.

Compound	Instrument
NO/NOx	Beckman 955 Chemiluminescent
HC	Beckman 404
CO	Beckman 868, Non-Dispersive Infrared
CO ₂	Beckman 868, Non-Dispersive Infrared
O ₂	SensorMedics, OM-11 EA
SO ₂	DuPont, 400 Photometric Analyzer

A secondary exhaust sampling port was fitted with an absolute filter thimble to gather particulates for post run analysis. The thimbles were sent to the chemistry laboratory at GE Transportation Systems where the percent violates, percent fixed carbon and percent ash in each sample were determined.

2.3 - Data Reduction

Three digital scales were used to determine the consumptions of CWS fuel, diesel pilot fuel, and the purge oil of the injector. The scale outputs were fed into a digital oscilloscope and recorded for a period of about 9 minutes at 0.5 second interval. Linear regression was done to each recorded trace to obtain the average mass flow rate of each type of fluid consumed.

FIGURE 2.2.1 - EMISSIONS EQUIPMENT

The CWS burnout rate of each run was calculated by the ash balance method. Exhaust particulate sample was collected for each run by the absolute filter over a period of 20 minutes after engine had stabilize on the test load. The ash of the sample is determined according to ASTM test method D3174 with a Fischer Model 90 instrument. The ash level of the collected particulates was compared with the ash level in the original coal to obtain the burnout rate for the test run.

The high speed cylinder pressure, injection pressure and needle lift data were all collected on a crankangle basis. Fifty cycles were averaged in the digital oscilloscope for further processing. The power generated by the coal-fired cylinder was determined by the indicated kW calculated with the recorded cylinder pressure trace. Thermodynamic first law calculations were done using cylinder pressure versus volume data to obtain average cylinder temperature and heat release. The water in the CWS was considered to evaporate instantaneously at the time of entrance into the engine cylinder at the corresponding pressure. In the heat release calculation, heat losses to the combustion chamber walls were estimated using the basic methods used in the past [1]. However, the heat transfer coefficients were modified in such a way that the total heat loss conforms with the fuel heat input rate and the burnout rate as determined from the previous explanations. The "Relative Cycle Efficiency" [1] was used to evaluate the effect of the calculated heat release shape on cycle efficiency quantitatively.

Ignition point is arbitrarily defined at the starting point of significant net positive heat release. All pressures quoted are absolute.

3.0 TEST RESULTS

For each test run, a combustion heat release analysis was done. They are compiled in the Appendix. The main engine performance and emission indicators are summarized in table 3.0.

Fuel No.	Run No.	PERFORMANCE			EMISSIONS (ppm)				REMARKS		
		Cyl. Pmax (MPa)	SFC (kJ/IkWh)	Burn-out (%)	NOx	SO2	HC	CO	Test Load (IkW)	Fuel Solid (%)	Other
1	25	16.9	8448	99.2	660	252	205	195	195	50.4	*1
3	75	17.1	8707	98.7	717	323	221	183	190	49.3	
4	20	16.7	8342	99.2	-	-	-	-	191	48.9	
5	21	16.2	8362	98.7	-	-	-	-	190	51.1	
5	23	17.2	8026	98.4	740	191	193	201	191	50.7	
6	28	16.1	8470	99.5	522	194	223	280	191	47.8	
6	29	17.2	8658	99.2	682	215	259	264	192	50.1	
1	31	16.9	8631	98.6	708	243	215	218	189	48.7	*2
2	30	15.7	8812	98.8	672	236	218	302	191	50.2	*3
7	33	13.4	9177	98.8	-	-	-	-	176	51.9	
7	34	16.0	8952	99.0	583	208	193	403	194	52.7	
1	36	16.5	8119	98.7	715	197	184	218	188	47.9	*4
8	37	14.9	8156	99.3	525	182	215	291	180	50.7	*3
8	38	16.0	8407	99.2	574	163	203	243	182	50.0	*3
9	45	15.5	8769	97.7	721	301	277	330	185	49.3	

- *1 Data taken from another test (Emissions Evaluation Test) conducted last year.
- *2 Compared with earlier run #25 using the same no. 1 fuel, the piston ring and cylinder liner have worn considerably. This run serves as baseline for run # 30, 33 & 34.
- *3 The charge pump could only provide 75.5 MPa injection pressure (other runs were 82.3 MPa).
- *4 Replaced piston ring and cylinder liner. Serves as baseline for run # 37 & 38.

Table 3.0 Engine test results (1050 rpm, approximate 95% full load)

The table is broken into three sections to accommodate different engine wear situations. Before the start of engine test, a new set of piston rings and a new cylinder liner, both of standard diesel fuel engine material, were installed. Due to the continuous high engine test load, significant ring and liner wear were detected after about 20 hours operating with coal. A repeat run of the abundant OTISCA fuel (#1 in Table 1.1) was done to serve as baseline for the later runs (run #30 through #34). The results are separated in the above table for clarity. It can be noted that the specific fuel consumption (SFC) values in the second section are generally much higher than those in the first section due to the worn engine parts. At the end of run #34, it was decided that

the cylinder gas blow by in the engine crankcase was excessive and parts needed to be replaced. Special coal fuel engine test material piston rings and liner were available then and they were installed into the test engine. Another #1 fuel baseline run was made (run #36) and it was used for the rest of the tests as shown in the last section. Again, it can be noted that better engine conditions were reflected by the improved SFC values.

As seen in table 3.0, all 9 fuels were able to be run on the engine and to generate over 180 kW (over 90% full power). The test engine combustion system had the capability to provide close to 99% burnout for all fuels. The SFC's are generally within approximately 5% of each other. Since there was not enough fuel to optimize the combustion in each case, they do not represent the best value achievable. These figures, together with the emission results provide general ranges that could be expected from the coal fuel engine. However, upon closer scrutiny of the combustion analyses, the following discussions can be made.

3.1 Bituminous Coal Source Effect

The combustion of OTISCA fuels made from Kentucky Blue Gem (#4) and Pennsylvania Mariana (#5) are compared in figure 3.1.1. They use the same type of additive (MCG-32A). Since the environment in the reciprocating internal combustion engine changes as the piston is moving, combustion can only be compared with the runs that are under similar test conditions. In the upper right side of the figure, the test conditions of the two runs are shown to be very close.

The combustion results are compared in the right side lower table. From the latter table, the maximum cylinder firing pressure is seen to be slightly lower with the #5 fuel (0.5 MPa). It is evidently the result of lower heat release rate between 10 degrees crank angle before top dead center (BTDC) and 10 degrees after TDC as shown on the left side of the figure. The fact that the volatile content of the #5 PA Mariana coal was less than the #4 KY Blue Gem coal, as shown in Table 1.2, was probably the determining factor for slower initial burning. However, the most important combustion results of "Burnout" and "SFC" seem to be all within measuring error range. In fact, it is highly desirable to lower the peak firing pressure (to 15 MPa, if possible, on the GE engine) while maintaining high burnout and low SFC. When the injection timing for the #5 fuel was advanced, higher cylinder firing pressure was obtained (run #23 in Table 3.0) and lower SFC was achieved. But the 17.2 MPa Pmax was not acceptable, and some compromise has to be made.

Generally speaking, not much difference on combustion was seen with the two types of bituminous coal. Minor injection timing adjustment needs to be made to obtain optimum engine performance results.

HEAT RELEASE AND COMBUSTION ANALYSIS EFFECT OF BITUMINUS COAL ORIGIN, KY BLUE GEM (#4) VS. PA MARIANA (#5)

TEST CONDITIONS					
INJ ST	CWS INJ P	PILOT	TEST		
PILOT CWS	ST END	AMT	LOAD		
(% BTDC)	(MPa)	(mm3)	(kW)		
25	31	82.8	48.1	94	191
25	31	81.8	47.3	93	190

COMBUSTION RESULTS				
CYL	BURN-OUT	REL. EFF	SFC	RUN
P _{max}	(%)	(%)	(kJ/kWh)	†
(MPa)				
16.7	99.2	96.8	8342	20
16.2	98.7	96.2	8362	21

FIGURE 3.1.1 - Bituminous Coal Source Effect

3.2 Fuel Additive Effect

The bulk of the CWS fuel supplied by OTISCA uses mainly Ammonium Lignosulphonate (LIGNOSUL) as dispersent additive. In order to lower slurry viscosity to improve transport property in the fuel supply system, OTISCA recommended to try another additive, Ammonium Condensed Naphtalene Sulphonate (MCG-32A), which is more expensive. According to OTISCA, for the 5 microns mean particle size Kentucky Blue Gem CWS, the viscosity at 112s-1 can be reduced from about 250 cp to 100 cp. For the 3 micron size CWS, it is reduced from 300 to 140 cp.

Combustion of the 5 microns OTISCA fuel using the two types of additives is compared in figure 3.2.1. From the heat release diagram comparison, it is clearly seen that the solid line MCG-32A additive #2 fuel burned much slower than the LIGNOSUL #1 fuel. As expected, the slower burning fuel showed lower cylinder firing pressure as listed in the lower right combustion results table. In this case SFC is seen to have deteriorated by 2%. However, it is interesting to note that the burnout rate was not effected.

The change in fuel additive did change the fuel injection rate somewhat. For the MCG-32A #2 fuel, the average fuel rate through the injector hole was about 51 mm³/degree crankangle (deg ca), whereas for the LIGNOSUL, it was 48 mm³/deg ca. The instantaneous heat input rate and the cumulative heat input are shown in figure 3.2.2. The slower combustion of the MCG-32A fuel happened despite of the higher heat input rate.

It seems that, additive does impact the combustion character of fuel. LIGNOSUL comparatively promoted faster burning over MCG-32A.

3.3 Coal Mean Particle Size Effect

OTISCA fuels with 4.8 and 3.2 micron mean particle sizes (#2 & #4 in Table 1) are compared in figure 3.3.1. The dash line 3.2 micron size coal evidently burned faster than the larger size 4.8 ones.

The first part of the observed instantaneous heat release happens at the same time as the fuel is being injected into the engine cylinder. In figure 3.3.1, this is seen by the CWS needle lift duration extending well after the start of the heat release. The amount of fuel that is available to be burned in the engine cylinder can be represented by the cumulative heat input curve in figure 3.2.2. If at each instance, the actual amount of heat that has been released (cumulative heat release) is compared to the fuel then existing in cylinder, a curve showing the percentage of available fuel burned can be generated as in figure 3.3.2. From this curve, the engine combustion process can be distinctly separated into three periods, i.e. "Ignition delay", "Controlled Combustion", and "After Combustion". It is interesting to note that in

HEAT RELEASE AND COMBUSTION ANALYSIS
EFFECT OF OTISCA CWS FUEL ADDITIVE, MCG 32A VS. LIGNOSUL

Figure 3.2.1 OTISCA Fuel Additive Effect

FUEL INJECTION AND COMBUSTION EFFICIENCY ANALYSIS
EFFECT OF OTISCA CWS FUEL ADDITIVE, LIGNOSUL VS. MCG 32A

Figure 3.2.2 Fuel Additive effect on Injection Rate

HEAT RELEASE AND COMBUSTION ANALYSIS
EFFECT OF CWS FUEL MEAN PARTICLE SIZE, 4.8 VS. 3.2 MICRONS (OTISCA FUEL)

Figure 3.3.1 CWS Fuel Mean Particle Size Effect

Figure 3.3.2 Fuel Injection and Combustion Efficiency Analysis

the "Controlled Combustion" phase, the "% of Fuel Burnt" initially increases rapidly and gradually slows down as if asymptotically approaching a fixed percent number before further increases to about 100% in the "After Combustion" period. This seems to suggest that the air entrainment of the fuel jet limits the percent of fuel that could be burned during the fuel injection period. Such analysis is useful to compare combustion characters of fuels since it can separate the ability of the fuel to flow into the engine cylinder and the ability of the fuel to burn after being injected into the cylinder.

The runs in figure 3.3.1 are compared in this new format in figure 3.3.3. It is seen from the "Cumulative Heat Input" curves that the 3 micron fuel (#4) does not have the ability to flow through the injector as fast as the 5 micron fuel (#2). However, the "% of Fuel Burnt" curves indicate that once the fuel is being injected into the engine cylinder, the 3 micron fuel burned faster than the 5 micron fuel. In the past, we have reported the smaller particle size (3.41 microns) CWS burned worse than larger size (4.63) ones [2]. It was shown that the pressure loss of the higher viscosity smaller particle size CWS had reduced the injection pressure at the nozzle of the conventional pump-line system FIE significantly. With the present accumulator FIE, the injection pressure maintains the same high level at the injector regardless of fuel type. In the previously reported case [2], the actual injection pressure for the finer coal was 41.0 MPa and the coarser coal was 52.2 MPa. In the present case, it was between 83 and 85 MPa for both cases (figure 3.3.1). It is probably due to the much higher injection pressure, even the smaller coal size CWS was able to be finely atomized and burned efficiently. Besides the close to 99% burnout rate as calculated by the ash balance method, the particle size distribution of the particulates collected in the exhaust also indicate sufficient fuel atomization.

A study of particulate size and distributions made by GE Environmental Systems, given in the appendix, shows that each of the samples have a bi-modal distribution of particles. The first peak being ash and the second peak being coal. We have reported that our engine exhaust particulate has a typical size distribution comprising of two log-normal components attributable to a smaller nearly completely burned ash component and a larger incompletely burned carbonaceous component [3].

For fuel selection purpose, if higher burning rate is necessary, other than the measure of reducing particle size can be taken. For instance, in figure 3.3.4, the run with 4.8 micron fuel using LIGNOSUL additive is compared with the previous two runs (both with MCG-32A additive). Clearly, the heat release traces show that the 4.8 micron LIGNOSUL fuel (center line) burns faster than the same coal size MCG-32A fuel and has almost the same burn rate as the 3.2 micron MCG-32A fuel. In the "Combustion Results" table, the last two fuels also have almost the same engine performance results.

FUEL INJECTION AND COMBUSTION EFFICIENCY ANALYSIS
EFFECT OF CWS FUEL MEAN PARTICLE SIZE, 4.8 VS. 3.2 MICRONS (OTISCA FUEL)

Figure 3.3.3 Fuel Mean Particle Size Comparison

HEAT RELEASE AND COMBUSTION ANALYSIS
EFFECT OF CWS FUEL MEAN PARTICLE SIZE, 4.8 VS. 3.2 MICRONS (OTISCA FUEL)

Figure 3.3.4 Effect of Particle Size and Additive

3.4 Bituminous Verses Sub-Bituminous Coal

Two types of Sub-Bituminous coal, the Kemmer and the Spring Creek coal, were tested. They were both prepared by Energy & Environmental Research Center using the Hot-Water-Dried process with close to 15 microns mean particle sizes and labeled as UNDERC in Table 1.1 (fuel #6, #7 & #8). By using two types of ash removal process, i.e. chemical and physical plus chemical, two distinct ash level fuels were intended to be obtained. However, this was not very successful. The ash levels were all very close as seen in Table 1.2 to be from 2.1% to 2.8%.

The #6 Kemmer CWS was shipped with approximately 50% solid loading and the other two were 54 to 55% loading. The higher loading CWS fuels could not flow through our low pressure supply system and had to be diluted down to about 50%, which was the same level as the Bituminous coal CWS. Since the Sub-Bituminous coal has much lower heating value than the Bituminous coal (over 15% lower as shown in Table 1.2), in order to develop the same power on the engine with the same level of SFC, more volume has to be handled by the fuel injection system. Using the same fuel injector, the injection duration is increased and SFC is generally higher. When the needed amount of fuel exceeded the capability of the present FIE, test load had to be reduced. However, the burnout rates of Sub-Bituminous coal were all very high. In fact, in Table 3.0, they seem to have higher average burnout rate than the Bituminous CWS.

During tests, the Spring Creek CWS (#7 & #8 fuels) somehow always plugged up the pressure transducer lead tube. The fuel injection pressure could only be estimated. Therefore, it is difficult to examine the details of combustion with this coal. The general impression was Kemmer (#6) coal burned faster than the Spring Creek coal and the chemically cleaned coal (#6 & #8) burned faster and had slightly higher burnout rate than the coal with additional physical cleaning process (#7).

It is possible to compare the combustion of the #1 Bituminous coal fuel run #25 with the #6 Sub-Bituminous Coal fuel run #28. This is shown in figure 3.4.1. On the CWS needle lift traces, it is clearly seen that the dash line Sub-Bituminous fuel run #28 had much longer injection duration. In the "combustion Results" table in the figure, the burnout rate of run #28 seems to be slightly higher. On the heat release traces, the #28 Sub-Bituminous coal run is distinctly lower in peak value. Yet, this is somewhat expected due to the Sub-Bituminous coal has less heat. However, the low heat release is also the effect of less heat available in engine cylinder during fuel injection period. The Fuel Injection And Combustion Efficiency Analysis in figure 3.4.2 help elucidate some basic combustion character. On the Cumulative Heat Input curves, the slope (rate) with the Sub-Bituminous coal is seen lower as the result of less heating value. Therefore, during the fuel injection period, at any time, there was less fuel heat available in the engine cylinder. However, during this "Controlled Combustion" period, more percentage of the

HEAT RELEASE AND COMBUSTION ANALYSIS
EFFECT OF COAL TYPE, BITUMINUS (#1) VS. SUB-BITUMINUS (#6) COAL

Figure 3.4.1 Effect of Coal Rank

FUEL INJECTION AND COMBUSTION EFFICIENCY ANALYSIS
EFFECT OF COAL TYPE, BITUMINUS VS. SUB-BITUMINUS COAL

Figure 3.4.2 Coal Rank Comparison

available fuel is burned as indicated by the "% of Fuel Burned" traces. Besides, the limit of the percentage of fuel that could be burned for the Kemmer Sub-Bituminous coal seems to be higher. It is conceivable that this might be the result of lower combustible contents (Hydrogen and Carbon as Shown in Table 1.2) in the Sub-Bituminous fuel. If the air entrainment of the fuel injection jet is the same, than the local equivalence ratio of the Sub-Bituminous coal fuel would be lower. This might help to increase the instantaneous % of fuel burned and the limit attainable during this period. It is thus clear that the overall lower heat release rate shown in the previous figure 3.4.1 is actually the result of slower fuel heat being fed into the engine cylinder rather than slower burning rate. Therefore, in order to use lower heating value coal, the design parameters of the fuel injection equipment have to be changed so as to inject fuel faster.

4.0 CONCLUSIONS

The following conclusions are obtained from this investigation.

- o All the test CWS fuels were successfully burned in the GE engine combustion system. They include:
 - o 3 to 15 microns mean particle size;
 - o 0.7 to 2.8% ash level;
 - o KY Blue Gem & PA Mariana Bituminous coal, WY Kemmer and Spring Creek Sub-Bituminous coal;
 - o Coal beneficiated with physical & chemical processes;
 - o Two kinds of additives for OTISCA CWS;
 - o Burnout is not effected by ash or particle size within the test range.
- o For each kind of CWS fuel, the detail design parameters of the FIE has to be compatible.
- o With sufficiently high fuel injection pressure, the 3 micron mean particle size OTISCA fuel burns faster than the 5 micron ones.
- o For OTISCA fuel, the burn rate using Ammonium Lignosulphonate as additive is faster than using Ammonium Condensed Naphtalene Sulphonate.

REFERENCES

- [1] Coal-Fueled Diesel: Technology Development Final Report to US DOE, GE Research and Development Center, March 1989.
- [2] Hsu B. D., "Progress on the Investigation of Coal-Water Slurry Fuel in a Medium Speed Diesel Engine: Part 2 - Preliminary Full Load Test," ASME Transactions, Journal of Engineering for Gas Turbine and Power, Vol. 110, No. 3, pp. 423-430.
- [3] Slaughter D. M., et al., "Control of Emissions in The Coal-Fueled Locomotive," ASME Publications, Coal Fueled Diesel Engines, Vol. 11, 1990.

APPENDIX I
HEAT RELEASE RECORDS

10.130.1030
 ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)
 17.45, 187.5
 ENTER IDC CORR. (+/- DEG), INJ ST (DEG BTDC) & INJ DURATION (DEG)
 -0.4, 31.52

ENTER COAL FRACTION & DENSITY OF CWS USED: 0.4894, 1.097

ENTER "1" FOR UKOH OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: 0.025

ENTER CONSUMPTION (LB/SEC), TEMP (DEG F) OF CONSTITUENTS

CWS: 5.4487E-2, 95

PILOT DIESEL: 1.5339E-3, 80

PURGE OIL: 4.1419E-4, 85

WT % OF COAL, PILOT DIESEL, PURGE OIL, TRITON & H2O IN FUEL

46.8 % 2.7 % 0.6 % 1.2 % 48.8 %

ENERGY % OF COAL, PILOT DIESEL, PURGE OIL, TRITON OF RUN

90.6 % 6.7 % 1.4 % 1.3 %

INJECTION PER STROKE OF CWS, PILOT DIESEL, PURGE OIL & TRITON

2549 mm3/str 94 mm3/str 19 mm3/str 33 mm3/str

TOTAL ENERGY INP RATE: 1592408 KJ/HR 1509392 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS TR 4741, L20, #2 FUEL, 1050 RPM 95% LOAD

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN

21,137,1050

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)

46.76,187.8

ENTER TDC CORR.(+/- DEG), INJ ST(DEG BTDC) & INJ DURATION(DEG)

-0.4,31.53

ENTER COAL FRACTION & DENSITY OF CWS USED: 0.5113,1.081

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: 0.025

ENTER CONSUMPTION (LB/SEC),TEMP(DEG F) OF CONSTITUENTS

CWS: 5.1819E-2,85

PILOT DIESEL: 1.5238E-3,80

PURGE OIL: 5.7392E-4,85

WT % OF COAL,PILOT DIESEL,PURGE OIL,TRITON & H2O IN FUEL

48.6 % 2.8 % 0.8 % 1.2 % 46.5 %

ENERGY % OF COAL,PILOT DIESEL,PURGE OIL,TRITON OF RUN

90.2 % 6.7 % 1.9 % 1.3 %

INJECTION PER STROKE OF CWS,PILOT DIESEL,PURGE OIL & TRITON

2459 mm3/str 93 mm3/str 26 mm3/str 32 mm3/str

TOTAL ENERGY IHP RATE: 1591458 KJ/HR 1508491 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L21, FUEL #3, 1050 RPM, 95% LOAD

INJ ST: 31.4 DEG BTDC

IGN ST: 17.0 DEG BTDC

IGN LAG: 14.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN
 23,145,1051
 ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)
 46.72,187.7
 ENTER TDC CORR.(+/- DEG), INJ ST(DEG BTDC) & INJ DURATION(DEG)
 -0.4,36.51
 ENTER COAL FRACTION & DENSITY OF CWS USED: 0.5068,1.102
 ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2
 ENTER COAL WT FRACTION OF TRITON USED IN CWS: 0.025
 ENTER CONSUMPTION (LB/SEC),TEMP(DEG F) OF CONSTITUENTS
 CWS: 4.9513E-3,85
 PILOT DIESEL: 1.7557E-3,80
 PURGE OIL: 6.3839E-4,85
 WT % OF COAL,PILOT DIESEL,PURGE OIL,TRITON & H2O IN FUEL
 47.9 % 3.4 % 0.9 % 1.2 % 46.6 %
 ENERGY % OF COAL,PILOT DIESEL,PURGE OIL,TRITON OF RUN
 98.6 % 8.0 % 2.2 % 1.2 %
 INJECTION PER STROKE OF CWS,PILOT DIESEL,PURGE OIL & TRITON
 2303 mm3/str 107 mm3/str 29 mm3/str 31 mm3/str
 TOTAL ENERGY INP RATE: 1534239 KJ/HR 1454255 BTU/HR
 ** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L23, FUEL #3, 1050 RPM, 95% LOAD, Pmax OPTIMIZED

INJ ST: 36.4 DEG BTDC IGN ST: 17.0 DEG BTDC IGN LAG: 19.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN

25.153.1051

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)

46.68.187.8

ENTER TDC CORR. (+/- DEG), INJ ST (DEG BTDC) & INJ DURATION (DEG)

-0.4.32.53

ENTER COAL FRACTION & DENSITY OF CWS USED: 0.5037.1.104

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: 0.025

ENTER CONSUMPTION (LB/SEC), TEMP (DEG F) OF CONSTITUENTS

CWS: 5.4042E-2.85

PILOT DIESEL: 1.8484E-3.80

PURGE OIL: 4.0912E-4.85

WT % OF COAL, PILOT DIESEL, PURGE OIL, TRITON & H2O IN FUEL

47.8 % 3.3 % 0.5 % 1.2 % 47.1 %

ENERGY % OF COAL, PILOT DIESEL, PURGE OIL, TRITON OF RUN

89.6 % 7.9 % 1.3 % 1.3 %

INJECTION PER STROKE OF CWS, PILOT DIESEL, PURGE OIL & TRITON

2509 mm3/str 113 mm3/str 19 mm3/str 33 mm3/str

TOTAL ENERGY IHP RATE: 1644070 KJ/HR 1558360 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L25, FUEL #1, 1050 RPM, 95% LOAD

INJ ST: 32.4 DEG BTDC

IGN ST: 17.0 DEG BTDC

IGN LAG: 15.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN

28,165,1052

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)

46.43,188

ENTER TDC CORR.(+/- DEG), INJ ST(DEG BTDC) & INJ DURATION(DEG)

-0.4,30,63

ENTER COAL FRACTION & DENSITY OF CWS USED: 0.4776,1.132

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: .00001

ENTER CONSUMPTION (LB/SEC),TEMP(DEG F) OF CONSTITUENTS

CWS: 6.5725E-2,85

PILOT DIESEL: 2.0152E-3,80

PURGE OIL: 3.4424E-4,85

WT % OF COAL,PILOT DIESEL,PURGE OIL,TRITON & H2O IN FUEL

46.2 % 3.0 % 0.4 % 0.0 % 50.5 %

ENERGY % OF COAL,PILOT DIESEL,PURGE OIL,TRITON OF RUN

90.2 % 8.7 % 1.1 % 0.0 %

INJECTION PER STROKE OF CWS,PILOT DIESEL,PURGE OIL & TRITON

3010 mm3/str 123 mm3/str 16 mm3/str 0 mm3/str

TOTAL ENERGY INP RATE: 1621029 KJ/HR 1536521 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L28, UNDERC SUB-BITUMINUS KEMMER COAL, 1050 RPM, 95% LOAD

INJ ST: 30.4 DEG BTDC

IGN ST: 18.0 DEG BTDC

IGN LAG: 12.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN
 29,169,1052
 ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)
 16.16,187.9
 ENTER TDC CORR. (+/- DEG), INJ ST(DEG BTDC) & INJ DURATION(DEG)
 -0.4,38,62
 ENTER COAL FRACTION & DENSITY OF CWS USED: 0.5009,1.148
 ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2
 ENTER COAL WT FRACTION OF TRITON USED IN CWS: .00001
 ENTER CONSUMPTION (LB/SEC), TEMP(DEG F) OF CONSTITUENTS
 CWS: 6.4286E-2,85
 PILOT DIESEL: 1.9693E-3,80
 PURGE OIL: 4.4303E-4,85
 WT % OF COAL,PILOT DIESEL,PURGE OIL,TRITON & H2O IN FUEL
 48.4 % 3.0 % 0.5 % 0.0 % 48.2 %
 ENERGY % OF COAL,PILOT DIESEL,PURGE OIL,TRITON OF RUN
 90.3 % 8.3 % 1.4 % 0.0 %
 INJECTION PER STROKE OF CWS,PILOT DIESEL,PURGE OIL & TRITON
 2903 mm3/str 120 mm3/str 20 mm3/str 0 mm3/str
 TOTAL ENERGY INP RATE: 1660755 KJ/HR 1574176 BTU/HR
 ** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L29, UNDERC SUB-BITUMINUS KEMMER COAL, 95% LOAD, HIGH Pmax

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN
30,173,1053

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)
46.23,187.6

ENTER TDC CORR. (+/- DEG), INJ ST (DEG BTDC) & INJ DURATION (DEG)
-0.4,30.49

ENTER COAL FRACTION & DENSITY OF CWS USED: 0.5015,1.096

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: 0.025

ENTER CONSUMPTION (LB/SEC), TEMP (DEG F) OF CONSTITUENTS

CWS: 5.4580E-2,85

PILOT DIESEL: 1.8276E-3,80

PURGE OIL: 9.6822E-4,85

WT % OF COAL, PILOT DIESEL, PURGE OIL, TRITON & H2O IN FUEL

47.3 % 3.2 % 1.3 % 1.2 % 47.0 %

ENERGY % OF COAL, PILOT DIESEL, PURGE OIL, TRITON OF RUN

88.1 % 7.6 % 3.0 % 1.2 %

INJECTION PER STROKE OF CWS, PILOT DIESEL, PURGE OIL & TRITON

2548 mm3/str 111 mm3/str 44 mm3/str 33 mm3/str

TOTAL ENERGY INP RATE: 1680303 KJ/HR 1592705 BTU/HR

± 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS TR 4741, L30, FUEL #10, 1050 RPM, 95% LOAD

INJ ST: 30.4 DEG BTDC

IGN ST: 17.0 DEG BTDC

IGN LAG: 13.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN

31,177,1052

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)

46.20,187.9

ENTER TDC CORR. (+/- DEG), INJ ST (DEG BTDC) & INJ DURATION (DEG)

-0.4,31.52

ENTER COAL FRACTION & DENSITY OF CWS USED: 0.4874,1.106

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: 0.025

ENTER CONSUMPTION (LB/SEC), TEMP (DEG F) OF CONSTITUENTS

CWS: 5.4212E-2,85

PILOT DIESEL: 2.0507E-3,90

PURGE OIL: 7.6054E-4,95

WT % OF COAL, PILOT DIESEL, PURGE OIL, TRITON & H2O IN FUEL

45.9 % 3.6 % 1.0 % 1.1 % 48.3 %

ENERGY % OF COAL, PILOT DIESEL, PURGE OIL, TRITON OF RUN

97.6 % 2.9 % 2.4 % 1.2 %

INJECTION PER STROKE OF CWS, PILOT DIESEL, PURGE OIL & TRITON

2511 mm3/str 125 mm3/str 35 mm3/str 32 mm3/str

TOTAL ENERGY INP RATE: 1633456 KJ/HR 1548300 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L31, FUEL #1, 1050 RPM, 95% LOAD

INJ ST: 31.4 DEG BTDC

IGN ST: 17.0 DEG BTDC

IGN LAG: 14.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN

33,5,1053

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)

46.04,187.5

ENTER TDC CORR.(+/- DEG), INJ ST(DEG BTDC) & INJ DURATION(DEG)

-0.4,31,64

ENTER COAL FRACTION & DENSITY OF CWS USED: 0.5187,1.155

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: 0.00001

ENTER CONSUMPTION (LB/SEC),TEMP(DEG F) OF CONSTITUENTS

CWS: 5.9864E-2,85

PILOT DIESEL: 1.8259E-3,80

PURGE OIL: 5.5181E-4,85

WT % OF COAL,PILOT DIESEL,PURGE OIL,TRITON & H2O IN FUEL

50.0 % 2.9 % 0.7 % 0.0 % 46.4 %

ENERGY % OF COAL,PILOT DIESEL,PURGE OIL,TRITON OF RUN

90.3 % 7.9 % 1.8 % 0.0 %

INJECTION PER STROKE OF CWS,PILOT DIESEL,PURGE OIL & TRITON

2685 mm3/str 111 mm3/str 25 mm3/str 0 mm3/str

TOTAL ENERGY IHP RATE: 1615549 KJ/HR 1531326 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L33, UNDERC SPR-CRK 2.1% ASH FUEL, 90% LOAD, 1050 RPM

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN

34,9,1054

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)

46.02,197.9

ENTER TDC CORR.(+/- DEG), INJ ST(DEG BTDC) & INJ DURATION(DEG)

-0.4,37,68

ENTER COAL FRACTION & DENSITY OF CWS USED: 0.527,1.155

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: .00001

ENTER CONSUMPTION (LB/SEC),TEMP(DEG F) OF CONSTITUENTS

CWS: 6.4339E-2,85

PILOT DIESEL: 1.9467E-3,90

PURGE OIL: 3.0196E-4,85

WT % OF COAL,PILOT DIESEL,PURGE OIL,TRITON & H2O IN FUEL

51.1 % 2.8 % 0.3 % 0.0 % 45.8 %

ENERGY % OF COAL,PILOT DIESEL,PURGE OIL,TRITON OF RUN

91.7 % 7.4 % 0.9 % 0.0 %

INJECTION PER STROKE OF CWS,PILOT DIESEL,PURGE OIL & TRITON

2883 mm3/str 112 mm3/str 14 mm3/str 0 mm3/str

TOTAL ENERGY INP RATE: 1739045 KJ/HR 1647436 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L34, UNDERC SPR-CRK 2.1% ASH FUEL, 95% LOAD, 1050 RPM

INJ ST: 37.4 DEG BTDC

IGN ST: 23.0 DEG BTDC

IGN LAG: 14.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN
L36.17.1052

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)
45.25.187.5

ENTER TDC CORR. (+/- DEG), INJ ST(DEG BTDC) & INJ DURATION(DEG)
-.4.31.52

ENTER COAL FRACTION & DENSITY OF CWS USED: .4792, 1.064

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: .015

ENTER CONSUMPTION (LB/SEC), TEMP(DEG F) OF CONSTITUENTS

CWS: 5.2656E-2, 85

PILOT DIESEL: 1.8311E-3, 80

PURGE OIL: 3.4134E-4, 85

WT % OF COAL, PILOT DIESEL, PURGE OIL, TRITON & H2O IN FUEL

45.8 % 3.3 % 0.5 % 0.7 % 49.7 %

ENERGY % OF COAL, PILOT DIESEL, PURGE OIL, TRITON OF RUN

89.7 % 8.4 % 1.2 % 0.9 %

INJECTION PER STROKE OF CWS, PILOT DIESEL, PURGE OIL & TRITON

2548 mm3/str 112 mm3/str 16 mm3/str 19 mm3/str

TOTAL ENERGY IHP RATE: 1529977 KJ/HR 1450216 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741. L36, OTISCA 5 MICRON KY BLUE GEM FUEL, 1050 RPM, 95% LOAD

INJ ST: 31.4 DEG BTDC

IGN ST: 18.0 DEG BTDC

IGN LAG: 13.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN

L37, 21, 1055

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)

45.57, 187.1

ENTER TDC CORR. (+/- DEG), INJ ST (DEG BTDC) & INJ DURATION (DEG)

-.4, 31, 56

ENTER COAL FRACTION & DENSITY OF CWS USED: .507, 1.111

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: .015

ENTER CONSUMPTION (LB/SEC), TEMP (DEG F) OF CONSTITUENTS

CWS: 5.5292E-2, 85

PILOT DIESEL: 1.9275E-3, 80

PURGE OIL: 4.1670E-4, 85

WT % OF COAL, PILOT DIESEL, PURGE OIL, TRITON & H2O IN FUEL

48.4 % 3.2 % 0.5 % 0.7 % 47.1 %

ENERGY % OF COAL, PILOT DIESEL, PURGE OIL, TRITON OF RUN

88.9 % 8.7 % 1.5 % 0.9 %

INJECTION PER STROKE OF CWS, PILOT DIESEL, PURGE OIL & TRITON

2554 mm3/str 111 mm3/str 19 mm3/str 21 mm3/str

TOTAL ENERGY INP RATE: 1468294 KJ/HR 1391748 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L37, UNDERC SPRG CRK CHEM CLEAN, 1050 RPM, 90% LOAD

INJ ST: 31.4 DEG BTDC

IGN ST: 18.0 DEG BTDC

IGN LAG: 13.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN

L38,25,1055

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)

45.23,187.1

ENTER TDC CORR. (+/- DEG), INJ ST(DEG BTDC) & INJ DURATION(DEG)

-4.35,58

ENTER COAL FRACTION & DENSITY OF CWS USED: .500,1.099

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: .015

ENTER CONSUMPTION (LB/SEC),TEMP(DEG F) OF CONSTITUENTS

CWS: 5.8942E-2,85

PILOT DIESEL: 1.9248E-3,90

PURGE OIL: 3.4633E-4,85

WT % OF COAL,PILOT DIESEL,PURGE OIL,TRITON & H2O IN FUEL

47.9 % 3.0 % 0.4 % 0.7 % 47.9 %

ENERGY % OF COAL,PILOT DIESEL,PURGE OIL,TRITON OF RUN

89.6 % 8.3 % 1.2 % 0.9 %

INJECTION PER STROKE OF CWS,PILOT DIESEL,PURGE OIL & TRITON

2752 mm3/str 111 mm3/str 16 mm3/str 22 mm3/str

TOTAL ENERGY IHP RATE: 1532197 KJ/HR 1452320 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L38, UNDERC SPRG CRK CHEM CLEAN, 1050 RPM, 90% LOAD, TIM ADV

INJ ST: 35.4 DEG BTDC

IGN ST: 20.0 DEG BTDC

IGN LAG: 15.4 DEG CA

HEAT RELEASE CALCULATION FOR CWS TESTS

ENTER: LOG NO., FILE NO. OF PRESSURE DATA, & RPM OF RUN

43.53.1034

ENTER THE MANIFOLD AIR PRESSURE (PSIA) & TEMPERATURE (DEG F)

47.4, 188.8

ENTER TDC CORR. (+/- DEG), INJ ST (DEG BTDC) & INJ DURATION (DEG)

-0.4, 34.49

ENTER COAL FRACTION & DENSITY OF CWS USED: 0.493, 1.093

ENTER "1" FOR UKON OR "2" FOR TRITON USED IN CWS: 2

ENTER COAL WT FRACTION OF TRITON USED IN CWS: 0.015

ENTER CONSUMPTION (LB/SEC), TEMP (DEG F) OF CONSTITUENTS

CWS: 5.5005E-2, 85

PILOT DIESEL: 2.1054E-3, 80

PURGE OIL: 2.6400E-4, 85

WT % OF COAL, PILOT DIESEL, PURGE OIL, TRITON & H2O IN FUEL

47.8 % 3.7 % 0.3 % 0.7 % 48.3 %

ENERGY % OF COAL, PILOT DIESEL, PURGE OIL, TRITON OF RUN

89.3 % 9.1 % 0.9 % 0.8 %

INJECTION PER STROKE OF CWS, PILOT DIESEL, PURGE OIL & TRITON

2529 mm3/str 128 mm3/str 12 mm3/str 20 mm3/str

TOTAL ENERGY INP RATE: 1620253 KJ/HR 1535785 BTU/HR

** 20% PURGE OIL RETURNED TO FUEL TANK

HEAT RELEASE AND COMBUSTION ANALYSIS

TR 4741, L45, AMAX 8 MIC, SPLINT FUEL, ROUND ENTR NOZZLE

APPENDIX II

FUEL CHARACTERIZATION TESTS REPORT

PENNSYLVANIA STATE UNIVERSITY COMBUSTION LABORATORY

**GENERAL ELECTRIC TRANSPORTATION SYSTEMS COAL-WATER
SLURRY FUEL ANALYSIS REPORT**

By:
Bruce G. Miller
John Elston
Alan W. Scaroni

February 27, 1990

For:
Bertrand D. Hsu
Diesel Engine Engineering
Transportation Systems Engineering Department
2901 East Lake Road
Erie, Pennsylvania 16531

By:
The Combustion Laboratory
The Pennsylvania State University
University Park, Pennsylvania 16802

February 27, 1990

Dr. Bertrand D. Hsu
Diesel Engine Engineering
Transportation Systems Engineering Department
2901 East Lake Road
Erie, Pennsylvania 16531

Dear Bert:

Enclosed please find the results for the characterization of eight coal-water slurry fuel (CWSF) samples. The analyses conducted include proximate (and hence solids loading), ultimate, ash composition (major oxides such as CaO, MgO, SiO₂, Al₂O₃, TiO₂, Fe₂O₃, MnO, K₂O, and SO₃), calorific value, particle size distribution, and CWSF rheology using the following techniques:

• Proximate analysis	Leco MAC-400
• Ultimate analysis	Leco Model CHN-600; Leco SC-132
• Ash composition	Atomic Absorption Spectrophotometry (AAS) using ASTM Method D 3682
• Calorific value	Parr Adiabatic Calorimeter
• Particle size distribution	Malvern 2600C Laser Diffraction Particle and Droplet Sizer
• Viscosity	Bohlin Visco 88 BV Viscometer

All analyses were conducted at The Combustion Laboratory with the exception of the ash composition. The ash composition was to be determined by direct-coupled plasma spectroscopy by a laboratory on campus; however, their instrument broke down in early January and they were not sure when it would be operational. As a result, the ash samples were sent to the Department of Chemistry at Western Kentucky University in order to meet General Electric's deadline of the end of February. As-received CWSF samples were analyzed for the proximate analysis and dried samples were used for the ultimate analysis and calorific determination. The D(v, 0.9), D(v, 0.5), and D(v, 0.1) values are the particle sizes where, respectively, 90%, 50%, and 10% of the particles, by volume, are less than the indicated particle size.

Table 1 is a summary of the results for the eight CWSF samples. The analysis of the second sample that Penn State received labeled #1 is reported as #1A. Western

University can not determine TiO_2 with AAS. They use indirectly-coupled plasma spectroscopy (ICP); however, their instrument broke down and TiO_2 was not determined. When the ICP is repaired they will complete the analyses and send the values to Penn State at which time Penn State will send the results to General Electric.

Rheograms for each of the samples have been enclosed. The viscosity was determined by placing a well mixed sample of the CWSF in a cup and bob assembly with dimensions of 33 mm and 30 mm, respectively, so as to completely immerse the bob and contact the thermocouple. The sample temperature was maintained at $25^\circ \pm 1^\circ \text{C}$ by a constant temperature water jacket. The viscosity was measured at 50 different shear rates with increasing and decreasing shear rate sweeps, producing viscosity versus shear rate curves. The shear rate was increased from 19 to 1,005/s, then decreased to 19. Each measurement was made at a strain delay time (period the bob spins at a particular shear rate before measurement) of 5 seconds and a measurement integration time (period that the instrument is measuring viscosity, after the strain delay time, with the results integrated over this period) of 5 seconds. The viscosities reported in Table 1 are those from the increasing shear rate curve.

Enclosed please find an invoice for the samples that were analyzed. Please call me if you have any questions.

Sincerely,

Bruce G. Miller

TABLE 1. GENERAL ELECTRIC COAL-WATER FUEL ANALYSIS

Fuel No:	1		2		3	
	A.R. ^a	Dry	A.R.	Dry	A.R.	Dry
Proximate Analysis, %wt.						
Moisture	49.47	---	51.29	---	49.82	---
Volatile Matter	20.03	39.64	18.92	38.84	18.25	36.36
Fixed Carbon	30.15	59.66	29.40	60.77	31.03	61.83
Ash	0.35	0.70	0.37	0.75	0.91	1.81
Ultimate Analysis, %wt.						
Moisture	49.47	---	51.29	---	49.82	---
Carbon	42.78	84.66	41.05	84.28	42.82	85.33
Hydrogen	2.85	5.65	2.69	5.53	2.71	5.40
Nitrogen	1.01	1.99	1.01	2.07	0.85	1.70
Sulfur	0.37	0.73	0.41	0.85	0.52	1.03
Oxygen	3.17	6.27	3.18	6.52	2.37	4.73
Ash	0.35	0.70	0.37	0.75	0.91	1.81
Higher Heating Value, Btu/lb	7,322	14,491	7,315	15,017	7,599	15,143
Particle Size Distribution, μm						
D (v, 0.9)	19.4		12.7		8.6	
D (v, 0.5)	7.6		4.9		3.6	
D (v, 0.1)	3.0		2.6		2.4	
Viscosity, cp @ 25°C ^b						
50/s	85		32		40	
100/s	149		39		55	
500/s	326 (@ 464/s)		133		142	
1,000/s	---		203 (@ 669/s)		194	
					(@ 779/s)	
Ash Composition, %wt.						
SiO ₂	23.0		17.6		40.1	
Al ₂ O ₃	24.3		22.3		22.2	
TiO ₂						
Fe ₂ O ₃	20.1		34.4		21.5	
MgO	1.3		1.2		0.5	
CaO	6.3		5.9		2.3	
MnO	0.02		0.03		0.01	
Na ₂ O	3.1		1.1		0.8	
K ₂ O	1.6		5.6		1.5	
SO ₃	11.1		14.8		1.67	
Total	90.8		102.9		90.6	

^aAs-received samples^bViscosity is reported at 50, 100, 500, and 1,000/s. In several cases, the maximum shear rate attainable was less than 1,000/s because the shear stress of the sample exceeded the instrument's maximum torque. The maximum shear rate actually obtained is contained in the paranthesis.

TABLE 1. GENERAL ELECTRIC COAL-WATER FUEL ANALYSIS (Cont.)

Fuel No:	5		6		7	
	A.R.	Dry	A.R.	Dry	A.R.	Dry
Proximate Analysis, %wt.						
Moisture	48.03	---	47.26	---	49.82	---
Volatile Matter	20.86	40.14	21.26	40.31	20.02	39.90
Fixed Carbon	30.15	58.01	30.14	57.15	29.02	57.84
Ash	0.96	1.85	1.34	2.54	1.37	2.74
Ultimate Analysis, %wt.						
Moisture	48.03	---	47.26	---	49.82	---
Carbon	39.80	76.59	39.50	74.90	38.15	76.03
Hydrogen	2.49	4.80	2.44	4.63	2.36	4.71
Nitrogen	0.71	1.37	0.69	1.31	0.87	1.73
Sulfur	0.21	0.40	0.23	0.43	0.24	0.47
Oxygen	7.79	14.99	8.53	16.18	7.19	14.32
Ash	0.96	1.85	1.34	2.54	1.37	2.74
Higher Heating Value, Btu/lb	6,691	12,874	6,678	12,833	6,390	12,734
Particle Size Distribution, μm						
D (v, 0.9)	50.6		47.4		36.4	
D (v, 0.5)	18.8		17.8		14.8	
D (v, 0.1)	4.3		4.2		4.0	
Viscosity, cp @ 25°C						
50/s	68		69		66	
100/s	82		91		75	
500/s	103		131		92	
1,000/s	101		137		9	
Ash Composition, %wt.						
SiO ₂	25.9		54.0		47.1	
Al ₂ O ₃	23.6		17.9		17.0	
TiO ₂						
Fe ₂ O ₃	11.6		8.5		13.1	
MgO	1.7		0.6		1.1	
CaO	10.5		3.6		5.3	
MnO	0.02		0.01		0.07	
Na ₂ O	1.0		0.6		0.8	
K ₂ O	0.1		0.2		0.2	
SO ₃	31.1		12.9		15.9	
Total	105.5		98.3		100.6	

TABLE 1. GENERAL ELECTRIC COAL-WATER FUEL ANALYSIS (Cont.)

Fuel No:	10		1A	
	A.R.	Dry	A.R.	Dry
Proximate Analysis, %wt.				
Moisture	50.31	---	50.89	---
Volatile Matter	19.49	39.22	19.46	39.63
Fixed Carbon	29.81	60.00	29.30	59.66
Ash	0.39	0.78	0.35	0.71
Ultimate Analysis, %wt.				
Moisture	50.31	---	50.89	---
Carbon	42.36	85.24	41.55	84.60
Hydrogen	2.81	5.65	2.76	5.62
Nitrogen	0.98	1.98	0.97	1.97
Sulfur	0.38	0.76	0.38	0.77
Oxygen	2.78	5.59	3.10	6.32
Ash	0.39	0.78	0.35	0.72
Higher Heating Value, Btu/lb	7,443	14,979	7,353	14,974
Particle Size Distribution, μm				
D (v, 0.9)	19.2		23.0	
D (v, 0.5)	7.7		10.3	
D (v, 0.1)	2.9		3.2	
Viscosity, cp @ 25°C				
50/s	31		50	
100/s	43		82	
500/s	105		201	
1,000/s	150 (@ 970/s)		221 (@ 666/s)	
Ash Composition, %wt.				
SiO ₂	58.5		25.7	
Al ₂ O ₃	11.7		23.5	
TiO ₂				
Fe ₂ O ₃	8.6		24.1	
MgO	0.6		1.3	
CaO	3.1		5.9	
MnO	0.04		0.02	
Na ₂ O	0.6		3.4	
K ₂ O	0.1		1.5	
SO ₃	8.8		10.4	
Total	92.0		95.8	

Fuel

Bohlin Visco 88-Viscometry # 1

Viscosity in Pas

0.0 0.2 0.4 0.6 0.8 1.0 1.2
F6 Set scales F7%Plot F9,10 Tab Esc 1/5

F6

Bahlin Viscon 88-Viscometry # 1

Viscosity in Pas

Shear stress

F6 Set scales F7,8 Plot

1.2 8 ml/s

1.0 1.2 8 ml/s

Bohlin Visco 88-Viscometry # 1

Viscosity in Pas

350

300

250

200

150

100

50

0

shear rates

100

200

300

400

500

600

700

800

0.0 0.2 0.4 0.6 0.8 1.0 1.2 ml/s

F6 Set scales F7/F8/F9/F10/F11/F12/F13/F14/F15/F16/F17/F18/F19/F20/F21/F22/F23/F24/F25/F26/F27/F28/F29/F30/F31/F32/F33/F34/F35/F36/F37/F38/F39/F40/F41/F42/F43/F44/F45/F46/F47/F48/F49/F50/F51/F52/F53/F54/F55/F56/F57/F58/F59/F60/F61/F62/F63/F64/F65/F66/F67/F68/F69/F70/F71/F72/F73/F74/F75/F76/F77/F78/F79/F80/F81/F82/F83/F84/F85/F86/F87/F88/F89/F90/F91/F92/F93/F94/F95/F96/F97/F98/F99/F100

Fuel #

Bohlin Visco 88-Viscometry # 1

Viscosity in Pas

Shear rates

0.0 0.2 0.4 0.6 0.8 1.0 1.2 x 10⁴ 1/s

F6 Set scales F7,8 Plot F9,10 Tab Esc Page 1

[illegible][illegible]

Fuel #6

Bohlin Wiscor 88-Wisconetry # 1

Viscosity in Pas

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
F6 Set scales F7,8 Plot F9,10 Tab E50 Page 1

Fuel #7

Rollin Visco 88-Viscometry # 1

Viscosity mPas

Shear rates

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1/3
F6 Set scales F7, Plot F9, Tab Esc Page 1

Fuel #10

Bohlin Visco 99-Viscometry # 1

Viscosity in Pas

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

F6 Set scales F78 Plot F9,10 Tab Esc Page 1

PENNSTATE

Combustion Laboratory
Fuel Science Program

(814) 865-4802
865-2126

405 Academic Activities Building
The Pennsylvania State University
University Park, PA 16802

May 25, 1990

Dr. Bertrand D. Hsu
Diesel Engine Engineering
Transportation Systems Engineering Department
2901 East Lake Road
Erie, Pennsylvania 16531

Dear Bert:

Enclosed find the results for the characterization of the coal-water slurry fuel sample labeled AM01. All analyses were conducted by the techniques described in the previous report to GE (dated February 27, 1990) with the exception of the ash composition. The ash composition for sample AM01 was conducted at Penn State using direct-coupled plasma spectroscopy.

The invoice for conducting the analysis is also enclosed. Please call me if you have any questions.

Sincerely,

Bruce G. Miller
Senior Research Assistant

TABLE 1. GENERAL ELECTRIC COAL-WATER FUEL ANALYSIS

Fuel No:	AM01	
	<u>A.R.*</u>	<u>Dry</u>
Proximate Analysis, %wt.		
Moisture	49.84	---
Volatile Matter	18.90	37.26
Fixed Carbon	30.20	60.21
Ash	1.27	2.53
Ultimate Analysis, %wt.		
Moisture	49.84	---
Carbon	41.25	82.24
Hydrogen	2.67	5.33
Nitrogen	0.93	1.86
Sulfur	0.47	0.94
Oxygen	3.57	7.10
Ash	1.27	2.53
Higher Heating Value, Btu/lb	7,317	14,588
Particle Size Distribution, μm		
D (v, 0.9)	33.4	
D (v, 0.5)	10.6	
D (v, 0.1)	3.6	
Viscosity, cp @ 25°C		
50/s	23	
100/s	25	
500/s	29	
1,000/s	32	
Ash Composition, %wt.		
SiO ₂	44.8	
Al ₂ O ₃	27.1	
TiO ₂	1.83	
Fe ₂ O ₃	12.0	
MgO	1.55	
CaO	5.52	
MnO	0.07	
Na ₂ O	0.75	
K ₂ O	1.06	
P ₂ O ₅	0.67	
SO ₃	4.8	
Total	100.2	

*As-received samples

APPENDIX III

FUEL CHARACTERIZATION TESTS REPORT

ADELPHI UNIVERSITY CENTER FOR ENERGY STUDIES

EVALUATION OF SELECTED COAL WATER SLURRY SAMPLES

FINAL REPORT FOR
GENERAL ELECTRIC COMPANY
TRANSPORTATION SYSTEMS

PREPARED BY

JOHN DOOHER AND ASSOCIATES

MARCH 1990

INTRODUCTION

The Adelphi group has been active in the field of coal slurry fuels since the late seventies. A specialized testing laboratory has been developed to specifically evaluate and characterize coal water slurry fuels. Substantial programs have been conducted by the Adelphi group for EPRI, DOE, ESEERCO, Florida Power and Light Company, ARCO, LILCO, Stone and Webster, Florida Power Corporation, NYSERDA, NEPSCO, NYPA, Occidental Petroleum, EPA, and several other industrial clients.

Through this work, the Adelphi group has formulated a unique expertise in the analysis of coal water slurry fuels including rheological properties, stability, atomization and combustion.

TEST PROGRAM

Seven samples, fuels 1, 1A, 3, 5, 6, 7 and 10 were received for evaluation in our laboratory. Additionally, fuels 1A and 6 were evaluated for the effect of shearing. The samples were sheared in an industrial blender with a 3000 1/s shear rate at the blade tip for 30 seconds. Testing included: Moderate shear testing ($\sim 50 - 500$ 1/s) at three temperatures using a Haake viscometer; High shear testing ($\sim 1500 - 15,000$) using a high shear rheometer; Static stability as a function of time (2 weeks) using the Pendulum Settling Apparatus. The particle size distribution and the maximum theoretical packing density of coal for each

slurry were determined. In the following section, the results are presented on a comparative basis. Appendix A provides the results on an individual basis.

RESULTS

RHEOLOGICAL EVALUATION

Moderate Shear Rheology

The rheology was determined at moderate shear using a Haake concentric cylinder viscometer as a function of temperature, Table 1. Usually, the viscosity is quoted from the third flow curve, i.e. the equilibrium flow curve. However, due to the large discrepancy between curves 1 and 3, both are quoted in Table 1. A description of the instrumentation and test procedures are provided in Appendix B.

All samples exhibited extremely dilatant behavior at all test temperatures, i.e. viscosity increasing with increasing shear rate. In addition, the viscosity increased from curve 1 to curve 3 indicating rheopexy for fuels 5, 6, and 7, i.e. the viscosity is increasing as a function of time as well as shear. As expected, the viscosity decreased with an increase in temperature.

Table 1
Moderate Shear Rheology

Sample	Curve 1		Curve 3	
	η_{100} (mPa-s)	PLI (n)	η_{100} (mPa-s)	PLI (n)
20°C				
1	160	1.6	150	1.8
1A	210	1.8	190	2.0
1A (sheared)	165	1.7	140	2.0
3	60	1.6	50	1.7
5	280	1.4	410	1.8
6	275	1.4	420	1.8
6 (sheared)	255	1.4	375	1.9
7	160	1.4	195	1.6
10	95	1.7	75	1.9
30°C				
1	110	1.7	90	2.0
1A	145	1.7	115	2.0
1A (sheared)	110	1.7	75	2.0
3	40	1.4	25	1.7
5	250	1.3	260	1.7
6	210	1.5	250	1.8
6 (sheared)	200	1.5	250	1.8
7	115	1.4	125	1.6
10	70	1.6	55	1.8
50°C				
1	70	1.4	50	1.7
1A	90	1.6	60	1.9
1A (sheared)	60	1.6	50	1.8
3	25	1.3	10	1.7
5	120	1.3	130	1.7
6	120	1.7	90	1.9
6 (sheared)	135	1.6	100	1.8
7	65	1.4	50	1.6
10	40	1.6	25	2.0

η_{100} = viscosity at 100 1/s
PLI = power law index

High Shear Rheology

The rheological behavior at high shear was determined using the Adelphi Extrusion Rheometer. Little difference in behavior was seen for the nine fuels in the shear rate range tested, Table 2.

Table 2
High Shear Rheology

Sample	Shear Rate Range (1/s)	Power Law Index (n)
1	3,600 - 23,000	1.0
1A	2,300 - 18,850	1.0
1A (sheared)	3,000 - 24,000	1.0
3	3,000 - 13,000	1.3
5	4,100 - 24,800	1.1
6	4,000 - 30,000	1.0
6 (sheared)	4,000 - 28,000	1.0
7	5,500 - 32,000	1.1
10	2,800 - 17,000	1.1

STABILITY DETERMINATION

The fuels were evaluated for stability using the Pendulum Settling Apparatus. The center of mass was determined initially, one hour, and 1, 3, 7, 10, and 14 days. Figure 1 provides a summary of the nine samples tested. The line drawn at 0.10 cm is

indicative of the point at which the sample is settled. Fuel 3 was the only sample received which exhibited stability over the two week test period. Fuel 10 was stable for 3 days. The remaining samples 1, 1A, 5, 6, and 7 were stable for less than 1 day. All samples were hardpacked upon receipt. Extreme measures were taken for resuspension, i.e. chisel and hammer.

As a result of shearing, the stability of fuel 1A improved, while fuel 6 became less stable, Figure 2.

Figure 1. Stability Results

Figure 2. Effect of Shearing on Stability

PARTICLE SIZE DISTRIBUTION

The particle size distribution was determined using a Malvern Particle Size Analyzer. The PSD analysis is based on the Fraunhofer Diffraction which occurs as the laser light passes through the suspension.

The maximum packing, ϕ_m , for the particle size distribution of each sample was calculated using a computer program developed by Adelphi which breaks the particle size distribution into discrete

bands. A geometric construction is developed whereby successive bands of particles are packed in the available volume. ϕ_m is the theoretical maximum amount of coal which can be contained in a CWS without loss of fluidity. Table 3 provides the particle size distributions for the samples tested. The average particle size varied from 3.4 to 12.6 microns.

Table 3
Particle Size Distributions

Sample Size (microns)	1	1A	3	5	6	7	10
	% Retained						
54.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33.7	0.0	0.0	0.0	0.2	2.1	4.5	0.0
23.7	1.7	0.0	0.0	14.0	23.1	18.3	1.0
17.7	6.4	0.4	0.0	13.7	7.9	11.7	5.2
13.6	11.1	10.1	0.0	12.7	10.7	11.8	10.9
10.5	16.6	16.8	0.1	13.2	13.8	11.2	13.1
8.2	14.2	14.3	3.3	9.9	8.3	8.0	13.9
6.4	17.3	14.3	20.0	7.2	6.5	10.4	17.0
5.0	11.6	14.3	8.7	6.9	7.6	5.4	12.4
3.9	7.1	12.0	4.6	7.6	7.2	2.7	7.6
3.0	8.2	7.5	22.1	5.3	4.5	6.8	8.0
2.4	5.4	5.6	16.0	3.3	3.0	4.2	5.6
1.9	1.8	3.2	3.5	2.4	2.4	1.0	2.1
1.5	0.8	1.0	3.0	1.6	1.5	0.8	0.9
1.2	0.5	0.2	5.0	0.6	0.5	1.0	0.6
<1.2	0.8	0.2	13.6	1.2	0.9	2.1	1.7
D(50)	7.8	7.1	3.4	11.4	12.2	12.6	7.6
VMD	9.2	7.9	4.0	13.1	14.8	15.2	8.7
SMD	5.9	5.7	2.2	6.6	7.2	6.6	5.4
ϕ_m	69.3	68.3	71.9	71.9	72.4	73.3	69.9

VMD = Volume Mean Diameter (microns)

SMD = Sauter Mean Diameter (microns)

ϕ_m = Theoretical Maximum Packing (vol%)

DISCUSSIONS AND CONCLUSIONS

In reviewing this study, it is important to delineate the properties of slurry fuels with respect to the two major aspects of their use: handling properties, and atomization/combustion.

Handling Properties of Coal Water Slurry Fuels

In terms of handling, the most important properties are pumpability and sedimentation stability. Over the past decade, certain criteria have been developed for boiler furnace applications based on extensive rheological, flow testing, and sedimentation studies of CWS. Since storage and handling are critical for diesel applications as well, these criteria may be applied.

Pumpability

The rheological characterization of CWS is represented by the equation

$$\eta = k \dot{\gamma}^n$$

where:

- η = viscosity
- k = consistency index
- $\dot{\gamma}$ = shear rate
- n = power law index
($n=1$ for Newtonian fluids)

The basic criteria for handling are: reasonable apparent viscosity at $\dot{\gamma} = 100$ 1/s, e.g. < 1000 mPa-s, a power law index $n < 1.2$ for $10 < \dot{\gamma} < 100$ 1/s, and a viscosity which remains constant or decreases with time under shear. If these criteria are

violated, the following problems can occur:

- A thickening of the slurry under shear with time.
- A thickening of the slurry in the high shear regions of the handling system.
- Dynamic instabilities causing clogging of handling systems.

The potential consequences include: problems with the pump(s) and valve(s), i.e. clogging or failure. Usually slurries do not satisfy the criteria can be adjusted by water addition to fall within the acceptable range.

As can be seen from the results of Table 1, none of the slurries tested met the criteria for the power law index. i.e. they were all extremely dilatant. However, since all the slurries had viscosities under the 1000 mPa-s it is possible that short term handling, especially for those slurries with viscosities under 200 mPa-s, would not present a problem. Three of these CWS exhibited rheopectic behavior, i.e. an increase in viscosity with time and shear. Such behavior can lead to additional handling problems under system start-up or sudden accelerated flow conditions.

Stability

Stability against sedimentation of coal particles is an important consideration in the handling of slurries. Depending on the application, a criteria must be established for sedimentation rate as well as the nature of the settled material. If the coal

settles into a hard pack it may not be possible to reagitate the slurry into a usable form with the handling system components. Continuous agitation may not be feasible due to practical considerations or because of a degradation of the slurry under prolonged periods of shear.

As can be seen in Figure 1, only sample 3 met a minimal settling criteria. The remaining slurries settled rapidly into a hardpack. Continuous agitation or recirculation would be required with the attendant potential long term pumping problems induced by continued shearing of dilatant, rheopectic systems.

Atomization and Combustion

The criteria for handling may not be sufficient to insure good atomization and combustion properties. These properties are inherently specific to the atomizer-combustion system, operating conditions, and physio-chemical properties of the coals used in CWS preparation. For a high pressure atomizer used in a diesel engine, it is desirable to have as low a viscosity as possible, and as small a coal particle size as is feasible. In addition, because of the large shear rates experienced by the slurry passing through the atomizer orifice, it is necessary to insure that there is no anomalous behavior at high shear such as dilatancy. The results of the high shear testing indicated that the extreme dilatancy of the slurries essentially disappeared at shear rates above 3000 1/s indicating that this factor may not be relevant to atomization quality. This decrease in dilatancy with

increasing shear rates is a general trend of slurries with coal concentrations significantly less than the maximum possible volumetric packing. However, since the injector system feeds slurry from an accumulator system, all slurries undergo rapid accelerated flow. In this case, the magnitude of the apparent viscosity and the degree of rheopexy can play an important role. In addition, because of the small atomizer orifice, the slurries with a smaller average particle size might atomize and burn better.

SUMMARY

In conclusion, the following inferences from the test program can be drawn.

- All the slurries tested showed extreme dilatancy at moderate shear rates indicating potential pumping problems for the most viscous ones (>200 mPa-s). Additionally, rheoplectic behavior was exhibited by three of the CWS.
- All but one of the slurries were unstable under static storage conditions and would require continuous agitation.

Appendix A

Summary of the data for the following fuels:

- Fuel 1
- Fuel 1A
- Fuel 1A (sheared)
- Fuel 3
- Fuel 5
- Fuel 6
- Fuel 6 (sheared)
- Fuel 7
- Fuel 10

DATA SUMMARY SHEET

Sample Description: Fuel #1

Solids Concentration (wt%): 48.9

pH: 5.6

Density (g/ml): 1.11

Particle Size Distribution:

D(50) (microns) 7.8

ϕ_m (vol%) 69.3

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20 ⁰ C	150	1.9
30 ⁰ C	90	2.0
50 ⁰ C	50	1.7

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
3,600 - 23,000	1.0

Stability: 1 day

* Viscosity @ 100 1/s

PARTICLE SIZE DISTRIBUTION

Size (microns)	% Retained
54.9	0.0
33.7	0.0
23.7	1.7
17.7	6.4
13.6	11.1
10.5	16.6
8.2	14.2
6.4	17.3
5.0	11.6
3.9	7.1
3.0	8.2
2.4	5.4
1.9	1.8
1.5	0.8
1.2	0.5
< 1.2	0.8

D(50) 7.8 microns

VMD 9.2 microns

SMD 5.9 microns

ϕ_m 69.3 vol %

DATA SUMMARY SHEET

Sample Description: Fuel #1A

Solids Concentration (wt%): 49.5

pH: 6.5

Density (g/ml): 1.12

Particle Size Distribution:

D(50) (microns) 7.1

ϕ_m (vol%) 68.3

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20 °C	190	2.0
30 °C	115	2.0
50 °C	60	1.9

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
2,300 - 18,850	1.0

Stability: < 1 day

* Viscosity @ 100 1/s

PARTICLE SIZE DISTRIBUTION

SAMPLE 1A

Size (microns)	% Retained
54.9	0.0
33.7	0.0
23.7	0.0
17.7	0.4
13.6	10.1
10.5	16.8
8.2	14.3
6.4	14.3
5.0	14.3
3.9	12.0
3.0	7.5
2.4	5.6
1.9	3.2
1.5	1.0
1.2	0.2
< 1.2	0.2

D(50) 7.1 microns

VMD 7.9 microns

SMD 5.7 microns

ϕm 68.3 vol %

DATA SUMMARY SHEET

Sample Description: Fuel #1A (Sheared)

Solids Concentration (wt%): 49.5

pH: 6.3

Density (g/ml): 1.12

Particle Size Distribution:

D(50) (microns) 7.1

ϕ_m (vol%) 68.3

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20 °C	140	2.0
30 °C	75	2.0
50 °C	50	1.8

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
3,000 - 24,000	1.0

Stability: 3 days

* Viscosity @ 100 1/s

DATA SUMMARY SHEET

Sample Description: Fuel #3

Solids Concentration (wt%): 50.8

pH: 6.3

Density (g/ml): 1.12

Particle Size Distribution:

D(50) (microns) 3.4

ϕ_m (vol%) 71.9

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20°C	50	1.7
30°C	25	1.7
50°C	10	1.7

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
3,000 - 13,000	1.3

Stability: 14 days (stable for entire test period)

* Viscosity @ 100 1/s

PARTICLE SIZE DISTRIBUTION

Size (microns)	% Retained
54.9	0.0
33.7	0.0
23.7	0.0
17.7	0.0
13.6	0.0
10.5	0.1
8.2	3.3
6.4	20.0
5.0	8.7
3.9	4.6
3.0	22.1
2.4	16.0
1.9	3.5
1.5	3.0
1.2	5.0
< 1.2	13.6

D(50) 3.4 microns

VHD 4.0 microns

SMD 2.2 microns

ϕ_m 71.9 vol %

DATA SUMMARY SHEET

Sample Description: Fuel #5

Solids Concentration (wt%): 53.4

pH: 6.4

Density (g/ml): 1.19

Particle Size Distribution:

D(50) (microns) 11.4

ϕ_m (vol%) 71.9

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20 °C	410	1.8
30 °C	260	1.7
50 °C	130	1.7

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
4,100 - 24,800	1.1

Stability: < 1 day

* Viscosity @ 100 1/s

PARTICLE SIZE DISTRIBUTION

SAMPLE 5

Size (microns)	% Retained
54.9	0.0
33.7	0.2
23.7	14.0
17.7	13.7
13.6	12.7
10.5	13.2
8.2	9.9
6.4	7.2
5.0	6.9
3.9	7.6
3.0	5.3
2.4	3.3
1.9	2.4
1.5	1.6
1.2	0.6
< 1.2	1.2

D(50) 11.4 microns

VMD 13.1 microns

SMD 6.6 microns

ϕ_m 71.9 vol %

DATA SUMMARY SHEET

Sample Description: Fuel #6

Solids Concentration (wt%): 53.4

pH: 6.3

Density (g/ml): 1.18

Particle Size Distribution:

D(50) (microns) 12.2

ϕ_m (vol%) 72.4

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20 °C	420	1.8
30 °C	250	1.8
50 °C	90	1.9

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
4,000 - 30,000	1.0

Stability: < 1 day

* Viscosity @ 100 1/s

PARTICLE SIZE DISTRIBUTION

SAMPLE 6

Size (microns)	% Retained
54.9	0.0
33.7	2.1
23.7	23.1
17.7	7.9
13.6	10.7
10.5	13.8
8.2	8.3
6.4	6.5
5.0	7.6
3.9	7.2
3.0	4.5
2.4	3.0
1.9	2.4
1.5	1.5
1.2	0.5
< 1.2	0.9

D(50) 12.2 microns

VMD 14.8 microns

SMD 7.2 microns

ϕ_m 72.4 vol %

DATA SUMMARY SHEET

Sample Description: Fuel #6 (Sheared)

Solids Concentration (wt%): 53.4
pH: 6.3
Density (g/ml): 1.18

Particle Size Distribution:

D(50) (microns) 12.2

ϕ_m (vol%) 72.4

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20°C	375	1.9
30°C	250	1.8
50°C	100	1.8

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
4,000 - 28,000	1.0

Stability: <1 day

* Viscosity @ 100 1/s

DATA SUMMARY SHEET

Sample Description: Fuel #7

Solids Concentration (wt%): 50.6

pH: 7.2

Density (g/ml): 1.17

Particle Size Distribution:

D(50) (microns) 12.6

ϕ_m (vol%) 73.3

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20 ⁰ C	195	1.6
30 ⁰ C	125	1.6
50 ⁰ C	55	1.6

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
5,500 - 32,000	1.1

Stability: 1 hour

* Viscosity @ 100 1/s

PARTICLE SIZE DISTRIBUTION

Size (microns)	% Retained
54.9	0.0
33.7	4.5
23.7	18.3
17.7	11.7
13.6	11.8
10.5	11.2
8.2	8.0
6.4	10.4
5.0	5.4
3.9	2.7
3.0	6.8
2.4	4.2
1.9	1.0
1.5	0.8
1.2	1.0
< 1.2	2.1

D(50) 12.6 microns

VMD 15.2 microns

SMD 6.6 microns

ϕ_m 73.3 vol %

DATA SUMMARY SHEET

Sample Description: Fuel #10

Solids Concentration (wt%): 50.0

pH: 7.9

Density (g/ml): 1.12

Particle Size Distribution:

D(50) (microns) 7.6

ϕ_m (vol%) 69.9

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20°C	75	1.9
30°C	55	1.8
50°C	25	2.0

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
2,800 - 17,000	1.1

Stability: 2 days

* Viscosity @ 100 1/s

PARTICLE SIZE DISTRIBUTION

Size (microns)	% Retained
54.9	0.0
33.7	0.0
23.7	1.0
17.7	5.2
13.6	10.9
10.5	13.1
8.2	13.9
6.4	17.0
5.0	12.4
3.9	7.6
3.0	8.0
2.4	5.6
1.9	2.1
1.5	0.9
1.2	0.6
< 1.2	1.7

D(50) 7.6 microns

VMD 8.7 microns

SMD 5.4 microns

ϕ_m 69.9 vol %

Appendix B

Haake Concentric Cylinder Viscometer

This instrument was used to determine the rheological properties of the coal water slurries (CWS) at moderate shear. The CWS is sheared in the annular space between the rotating cylinder and the stationary cup. The torque necessary to rotate the cylinder at a given speed is measured by a torsion spring. The stator is surrounded by a tempering vessel. The temperature can be controlled to $\pm 0.01^{\circ}\text{C}$. The overall viscosity measurement is accurate to $\pm 5\%$ and the yield point has an accuracy of $\pm 10\%$. When calibrated with a Newtonian fluid the viscometer is accurate to $\pm 1\%$. The viscometer is integrated with a Hewlett-Packard data acquisition and analysis system. The signals from the viscometer are monitored twice per second and converted to torque and rotational speed values. Viscosity as a function of shear rate was computed using the appropriate flow model, the modified power law flow model described below:

$$\tau - \tau_0 = k \dot{\gamma}^n$$

where:

- τ_0 = yield stress
- τ = shear stress
- k = consistency index
- $\dot{\gamma}$ = shear rate
- n = power law index

When $n=1$, the sample is Newtonian (viscosity does not change with shear rate); when $n<1$, the sample is pseudoplastic (viscosity

decreasing with increasing shear rate); when $n > 1$, the sample is dilatant (viscosity increasing with shear rate).

The sensor appropriate for the CWS was the MVIII system. In this system, the rotor radius measures 1.511 cm and the stator, 2.097 cm. The annular gap is 0.586 cm or 5860 microns, thus providing adequate clearance for the larger coal particles as well as a large sample size to minimize the effect of any evaporation which might occur. Since the rotor length is large, 6.007 cm, the end effect with this system is negligible. When using higher test temperatures, i.e. $> 30^{\circ}\text{C}$, a humidity chamber was used to prevent water evaporation of the sample.

Figure B-1 shows representative flow curves from a variable shear test. The rotor speed is proportional to the shear rate and shear stress is computed from the torque of the rotating bob and the geometry of the system. The shear rate to which the sample is subjected is continuously increased from zero to a maximum determined by the viscosity of the CWS, curve 1; decreased to zero, curve 2; increased to maximum shear as in curve 1; decreased to zero, curve 4. The shear rate range is determined by the viscosity of the CWS tested.

Adelphi Extrusion Rheometer

This rheometer is comprised of a testing chamber approximately two feet in length and two inches in diameter, followed by an automated valve. The extrusion orifice has a diameter of 0.21 cm and a length of 6.4 cm. The sample is placed in a testing

chamber, the cover fastened to the chamber wall and the extrusion pressure adjusted to an initial pressure of 10 psi. The electromagnetic valve is actuated simultaneously with a timer. At set time intervals, samples were extruded and weighed. The pressure is increased to 100 psi in increments of 10 psi or a maximum determined by the viscosity. Characteristic pressure vs. shear rate curves, (Figure B-2) were drawn and evaluated based on these tests. From the curve, the power law index, n , was determined. Shear rates up to 15,000 1/s have been achieved with this device.

01/03/80

TEST #: GE-8

FUEL: FUEL #3

TEMPERATURE: 30C

MEASURING SYSTEM: MV1150

INSTRUMENT CONSTANTS:

R1= 1.843 R2= 2.087

L1= 6.007

ACCELERATION: 200 rpm/min

CURVE #1 _____

CURVE #2 _____

CURVE #3 _____

CURVE #4 _____

Figure B-1. Typical Moderate Shear Test Curves

Figure B-2. High Shear Testing

Pendulum Settling Apparatus (PSA)

Based on a design from the Bureau of Mines, Adelphi developed a sophisticated method to determine the static stability of coal-containing fuels. Figure B-3 shows a block diagram of the PSA. The fuel is contained in a test tube, which is inserted in the pendulum apparatus. The pendulum swings on two pins, breaking a collimated light beam as it passes through the midpoint of its swing. Using a frequency counter, the period for ten oscillations is determined. Because the PSA is a physical pendulum, two sets of measurements must be taken so that the center of mass and moment of inertia can be determined. The frequency counter is integrated with a data acquisition system

and computer. To insure the system's accuracy, on each day of testing, the center of mass of a standard metal tube is determined. The CWS were tested for two weeks at ambient temperature. The center of mass was determined initially, and after one hour, 1, 2, 3, 7, 10, and 14 days. When not being tested, the CWS samples are stored in constant temperature baths. By convention, shifts in the center of mass are said to be positive when the coal settles; however, due to bacterial growth or possibly structural rearrangement of the CWS, rises in the center of mass is sometimes seen. These numbers are quoted as negative shifts. A shift of approximately 0.1 cm is indicative of a settled CWS which would require reagitation.

Figure B-3. Pendulum Settling Apparatus (PSA).

Adelphi University

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PARTICLE SIZE DISTRIBUTION

SAMPLE AM01

Size (microns)	% Retained
54.9	0.0
33.7	0.0
23.7	4.6
17.7	11.4
13.6	11.6
10.5	10.3
8.2	11.8
6.4	13.5
5.0	9.2
3.9	6.4
3.0	6.8
2.4	4.9
1.9	3.4
1.5	2.4
1.2	1.0
< 1.2	2.6

D(50) 8.2 microns

VMD 10.2 microns

SMD 5.0 microns

ϕ_m 72.3 vol %

DATA SUMMARY SHEET

Sample Description: Fuel AMO1

Solids Concentration (wt%): 51.0

pH: 7.9

Density (g/ml): 1.13

Particle Size Distribution:

D(50) (microns) 8.2

ϕ_m (vol%) 72.3

Moderate Shear Rheology:

	Apparent Viscosity* (mPa-s)	Power Law Index (n)
20°C	35	1.1
30°C	27	1.1
50°C	16	1.1

High Shear Rheology:

Shear Rate Range (1/s)	Power Law Index (n)
3,000 - 8,500	1.2

Stability: 2 days

* Viscosity @ 100 1/s

APPENDIX IV
GENERAL ENGINE DATA

TEST REQUEST NUMBER : 4741

CWS FUELS

TEST RUN NUMBER : 20

Otisca Kentucky Blue Gem - 3.2 Micron

12:48 PM WED., 8 NOV., 1989

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
P19 RACK (MM)	30.52	31.45	31.05	.2779
T9 R.B. AIR MANIFOLD (F)	183.3	188.0	185.9	1.760
T8 L.B. AIR MANIFOLD (F)	185.1	189.7	187.5	1.646
T7 AIR ORIFICE INLET (F)	164.4	165.3	164.9	.2795
T1 WATER INLET (F)	177.4	179.5	178.6	.6424
T5 FUEL #1 (F) (CWS)	86.94	88.65	87.89	.4088
T6 FUEL #2 (F) (PILOT)	100.5	103.0	101.4	.6186
T11 R. CYLINDER EXHAUST (F)	186.4	187.8	187.1	.4899
T10 L. CYLINDER EXHAUST (F)	673.0	677.1	674.8	1.205
T3 OIL INLET (F)	180.9	182.6	181.9	.4958
T4 OIL OUTLET (F)	191.9	192.9	192.4	.3196
T12 EXHAUST RECREIVER (F)	810.2	815.7	813.3	1.561
P7 AIR METER INLET (IN-H2O)	64.33	68.30	66.27	1.526
P5 OIL HEADER (PSI)	43.31	68.93	54.27	8.903
P6 SERVO OIL (PSI)	3658.	3699.	3683.	11.83
P3 WATER INLET (PSI)	73.93	76.19	75.01	.7516
P4 WATER OUTLET (PSI)	70.86	72.27	71.56	.3955
P9 L.B. AIR INLET MAN.(IN-HG)	63.13	67.69	65.71	1.431
P10 PILOT RAIL PRESSURE (PSI)	489.1	490.8	490.4	.4356
P1 CWS HEADER (PSI)	307.6	435.7	375.9	52.80
P12 FUEL #1 HEADER (PSI)	39.45	39.85	39.64	.1516
P13 PILOT HEADER (PSI)	21.17	30.05	23.43	2.970
P2 PURGE SYSTEM (PSI)	.1210E+05	.1297E+05	.1262E+05	269.3
P17 BAROMETRIC (IN-HG)	28.94	28.95	28.94	0.000
T2 WATER OUTLET (F)	180.8	182.4	181.7	.4792

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	12.77	12.81	12.79	.9454E-02
VOLTS CONVERTED FROM BCD VALUE	207.0	207.0	207.0	0.000
AMPS CONVERTED FROM BCD VALUE	628.0	629.0	628.5	.6547
ENGINE RPM FROM BCD VALUE	1049.	1051.	1050.	.2315
MOYNO RPM FROM BCD VALUE	475.0	480.0	476.8	1.307
KILLOWATTS	130.0	130.2	130.1	.8183E-01

TEST REQUEST NUMBER : 4741

CWS FUELS

TEST RUN NUMBER : 21

Otisca - Pennsylvania Mariana - 2.5 Micron & MCG-32A - Drum 1149

1:05 PM THU., 9 NOV., 1989

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
P19 RACK (MM)	29.01	34.61	31.11	.9364
T9 R.B. AIR MANIFOLD (F)	183.3	189.1	186.2	1.542
T8 L.B. AIR MANIFOLD (F)	185.0	190.4	187.8	1.560
T7 AIR ORIFICE INLET (F)	158.1	162.0	160.3	.6591
T1 WATER INLET (F)	177.0	179.9	178.4	.5962
T5 FUEL #1 (F) (CWS)	86.41	91.42	88.27	.6067
T6 FUEL #2 (F) (PILOT)	96.27	108.7	102.1	2.993
T11 R. CYLINDER EXHAUST (F)	185.7	190.2	187.7	.8651
T10 L. CYLINDER EXHAUST (F)	683.0	697.8	689.6	3.059
T3 OIL INLET (F)	181.1	183.7	182.5	.5287
T4 OIL OUTLET (F)	192.0	193.4	192.6	.2319
T12 EXHAUST RECIEVER (F)	822.5	838.6	829.4	3.382
P7 AIR METER INLET (IN-H2O)	63.21	68.37	66.18	1.510
P5 OIL HEADER (PSI)	42.10	72.68	56.14	9.134
P6 SERVO OIL (PSI)	3693.	3734.	3721.	5.313
P3 WATER INLET (PSI)	63.73	67.39	65.62	.8204
P4 WATER OUTLET (PSI)	60.79	62.21	61.53	.2859
P9 L.B. AIR INLET MAN.(IN-HG)	62.59	67.83	65.42	1.303
P10 PILOT RAIL PRESSURE (PSI)	489.2	1832.	878.3	542.3
P1 CWS HEADER (PSI)	346.2	393.8	370.9	7.825
P12 FUEL #1 HEADER (PSI)	38.96	40.52	39.90	.4197
P13 PILOT HEADER (PSI)	17.74	30.63	23.03	3.125
P2 PURGE SYSTEM (PSI)	.1175E+05	.1361E+05	.1262E+05	422.6
P17 BAROMETRIC (IN-HG)	28.80	28.81	28.80	.2196E-01
T2 WATER OUTLET (F)	179.4	182.6	181.1	.5891

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	12.15	13.09	12.62	.2756
VOLTS CONVERTED FROM BCD VALUE	207.0	208.0	207.1	.3588
AMPS CONVERTED FROM BCD VALUE	628.0	639.0	629.5	.8577
ENGINE RPM FROM BCD VALUE	1048.	1053.	1050.	2.227
MOYNO RPM FROM BCD VALUE	455.0	546.0	491.4	15.45
KILLOWATTS	130.0	132.3	130.3	.3221

TEST REQUEST NUMBER : 4741

CWS FUELS

TEST RUN NUMBER : 23

Otisca - Pennsylvania Mariana - 2.5 Micron & MCG-32A

11:13 AM TUE., 14 NOV., 1989

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
P19 RACK (MM)	30.27	33.18	31.82	.6658
T9 R.B. AIR MANIFOLD (F)	183.3	188.3	186.1	1.509
T8 L.B. AIR MANIFOLD (F)	184.9	190.0	187.7	1.572
T7 AIR ORIFICE INLET (F)	153.8	156.0	154.8	.4585
T1 WATER INLET (F)	177.4	179.5	178.3	.6132
T5 FUEL #1 (F) (CWS)	87.62	89.58	88.46	.5124
T6 FUEL #2 (F) (PILOT)	100.1	104.7	102.4	1.021
T11 R. CYLINDER EXHAUST (F)	187.8	189.5	188.7	.4121
T10 L. CYLINDER EXHAUST (F)	667.5	672.9	670.2	1.361
T3 OIL INLET (F)	179.3	182.3	181.1	.6835
T4 OIL OUTLET (F)	191.2	192.5	191.8	.3509
T12 EXHAUST RECREIVER (F)	805.1	814.1	809.4	2.004
P7 AIR METER INLET (IN-H2O)	63.59	68.21	66.19	1.596
P5 OIL HEADER (PSI)	42.47	72.84	58.47	8.914
P6 SERVO OIL (PSI)	3700.	3726.	3715.	7.779
P3 WATER INLET (PSI)	65.49	68.62	67.17	.7943
P4 WATER OUTLET (PSI)	62.78	63.99	63.38	.2603
P9 L.B. AIR INLET MAN.(IN-HG)	62.87	67.59	65.34	1.456
P10 PILOT RAIL PRESSURE (PSI)	242.7	284.0	264.5	9.867
P1 CWS HEADER (PSI)	344.3	413.8	381.1	22.29
P12 FUEL #1 HEADER (PSI)	38.83	39.63	39.32	.2121
P13 PILOT HEADER (PSI)	20.71	29.96	23.54	3.358
P2 PURGE SYSTEM (PSI)	.1215E+05	.1313E+05	.1268E+05	293.6
P17 BAROMETRIC (IN-HG)	29.15	29.15	29.15	.5413E-02
T2 WATER OUTLET (F)	179.7	182.1	181.2	.5268

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	11.08	11.21	11.15	.4105E-01
VOLTS CONVERTED FROM BCD VALUE	207.0	208.0	207.1	.1936
AMPS CONVERTED FROM BCD VALUE	627.0	629.0	628.4	.6010
ENGINE RPM FROM BCD VALUE	1049.	1052.	1051.	.6708
MOYNO RPM FROM BCD VALUE	451.0	461.0	454.2	2.178
KILLOWATTS	129.8	130.8	130.1	.1759

TEST REQUEST NUMBER : 4741
 CWS FUELS
 TEST RUN NUMBER : 25
 OTISCA - KENTUCKY BLUE GEM 4.6 MICRON - BASE LINE W/BKM INJ.

12:04 PM FRI., 17 NOV., 1989

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
P19 RACK (MM)	29.57	32.50	30.43	.3788
T9 R.B. AIR MANIFOLD (F)	182.8	188.6	186.0	1.582
T8 L.B. AIR MANIFOLD (F)	184.9	190.4	187.8	1.619
T7 AIR ORIFICE INLET (F)	158.4	162.0	160.0	.6954
T1 WATER INLET (F)	179.2	181.1	180.2	.3296
T5 FUEL #1 (F) (CWS)	81.66	85.60	83.75	.8110
T6 FUEL #2 (F) (PILOT)	84.21	96.62	90.75	2.764
T11 R. CYLINDER EXHAUST (F)	186.1	189.2	187.5	.5228
T10 L. CYLINDER EXHAUST (F)	674.4	688.2	681.3	3.367
T3 OIL INLET (F)	183.0	185.5	184.7	.3348
T4 OIL OUTLET (F)	193.8	195.5	194.7	.3316
T12 EXHAUST RECREIVER (F)	811.0	827.2	820.1	3.256
P7 AIR METER INLET (IN-H2O)	63.27	68.54	66.16	1.610
P5 OIL HEADER (PSI)	43.28	70.48	56.20	8.320
P6 SERVO OIL (PSI)	3714.	3762.	3737.	13.59
P3 WATER INLET (PSI)	63.98	67.64	65.88	.8227
P4 WATER OUTLET (PSI)	61.33	63.08	62.11	.3046
P9 L.B. AIR INLET MAN.(IN-HG)	62.88	67.02	65.26	1.287
P10 PILOT RAIL PRESSURE (PSI)	1644.	1851.	1745.	47.82
P1 CWS HEADER (PSI)	334.8	411.6	375.9	15.93
P12 FUEL #1 HEADER (PSI)	39.46	40.59	39.94	.2528
P13 PILOT HEADER (PSI)	19.32	32.63	23.55	3.968
P2 PURGE SYSTEM (PSI)	.1295E+05	.1417E+05	.1360E+05	272.6
P17 BAROMETRIC (IN-HG)	29.14	29.18	29.15	.1955E-01
T2 WATER OUTLET (F)	181.5	183.8	183.0	.3320
M1 OXYGEN (%)	10.77	11.42	11.22	.1503
M2 CARBON DIOXIDE (%)	3.199	6.519	5.646	1.088

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	11.29	12.07	11.68	.2250
VOLTS CONVERTED FROM BCD VALUE	206.0	208.0	207.1	.2936
AMPS CONVERTED FROM BCD VALUE	627.0	632.0	629.6	.9201
ENGINE RPM FROM BCD VALUE	1048.	1054.	1051.	.7928
MOYNO RPM FROM BCD VALUE	473.0	523.0	490.6	8.840
KILLOWATTS	129.4	131.5	130.4	.3248

TEST REQUEST NUMBER : 4741
 Coal Slurry Fuels Testing
 TEST RUN NUMBER : 28
 UNDERC - WYOMING KEMMER - 12 MICRON WITH ANIONIC DISPERSANT

11:02 AM WED., 6 DEC., 1989

LATA DESCRIPTOR	MIN	MAX	MEAN	STD

P19 RACK (MM)	35.76	40.22	38.13	1.415
T9 R.B. AIR MANIFOLD (F)	183.2	188.7	186.2	1.525
T8 L.B. AIR MANIFOLD (F)	185.2	190.2	188.0	1.547
T7 AIR ORIFICE INLET (F)	155.5	157.5	156.6	.3761
T1 WATER INLET (F)	179.6	181.7	180.7	.3966
T5 FUEL #1 (F) (CWS)	72.45	77.57	74.93	1.095
T6 FUEL #2 (F) (PILOT)	72.84	88.58	83.78	2.508
T11 R. CYLINDER EXHAUST (F)	184.4	186.4	185.4	.4396
T10 L. CYLINDER EXHAUST (F)	699.9	710.6	706.2	2.075
T3 OIL INLET (F)	182.5	185.1	184.0	.4972
T4 OIL OUTLET (F)	193.9	195.6	194.9	.2839
T12 EXHAUST RECREIVER (F)	832.2	845.1	839.4	2.617
P7 AIR METER INLET (IN-H2O)	62.80	67.69	65.60	1.541
P5 OIL HEADER (PSI)	44.50	68.50	55.77	7.313
P6 SERVO OIL (PSI)	3694.	3730.	3710.	8.841
P3 WATER INLET (PSI)	70.15	73.80	71.97	.8523
P4 WATER OUTLET (PSI)	67.76	69.13	68.24	.2909
P9 L.B. AIR INLET MAN.(IN-HG)	61.92	66.91	64.75	1.245
P10 PILOT RAIL PRESSURE (PSI)	1422.	1622.	1507.	43.21
P1 CWS HEADER (PSI)	263.1	512.7	363.8	66.29
P12 FUEL #1 HEADER (PSI)	39.72	42.14	41.09	.4366
P13 PILOT HEADER (PSI)	18.86	31.65	22.70	3.707
P2 PURGE SYSTEM (PSI)	.1327E+05	.1422E+05	.1389E+05	229.1
P17 BAROMETRIC (IN-HG)	28.84	28.88	28.85	.1195E-01
T2 WATER OUTLET (F)	182.5	184.7	183.8	.4108
M1 OXYGEN (%)	12.45	12.65	12.53	.4327E-01
M2 CARBON DIOXIDE (%)	7.016	7.184	7.114	.3531E-01
M3 NOX (PPM)	510.7	531.9	522.1	5.019
M4 CARBON MONOXIDE (PPM)	269.3	306.5	285.9	7.060
M5 HYDROCARBONS (PPM)	196.3	228.9	218.2	6.430
M6 SULFUR DIOXIDE (PPM)	180.4	198.0	193.2	4.242

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD

DECIMAL TIME FOR REPORT	10.58	11.04	10.81	.1325
VOLTS CONVERTED FROM BCD VALUE	207.0	208.0	207.1	.3121
AMPS CONVERTED FROM BCD VALUE	628.0	631.0	629.4	.5385
ENGINE RPM FROM BCD VALUE	1048.	1054.	1052.	1.210
MOYNO RPM FROM BCD VALUE	509.0	519.0	514.4	2.164
KILLOWATTS	130.0	131.2	130.3	.2603

TEST REQUEST NUMBER : 4741
 Coal Slurry Fuels Testing
 TEST RUN NUMBER : 29
 UNDERC - WYOMING KEMMER - 12 MICRON WITH ANIONIC DISPERSANT

11:39 AM FRI., 8 DEC., 1989

DATA DESCRIPTOR	MIN	MAX	MEAN	STD

P19 RACK (MM)	33.67	37.86	35.71	.9074
T9 R.B. AIR MANIFOLD (F)	182.5	188.7	186.0	1.620
T8 L.B. AIR MANIFOLD (F)	185.0	190.5	187.9	1.612
T7 AIR ORIFICE INLET (F)	159.2	163.7	161.2	.9357
T1 WATER INLET (F)	179.6	182.2	180.8	.4841
T5 FUEL #1 (F) (CWS)	72.09	78.11	75.18	1.214
T6 FUEL #2 (F) (PILOT)	83.45	93.85	89.03	2.346
T11 R. CYLINDER EXHAUST (F)	183.8	187.9	186.2	.9828
T10 L. CYLINDER EXHAUST (F)	674.5	697.8	686.9	4.810
T3 OIL INLET (F)	183.5	186.0	184.9	.5376
T4 OIL OUTLET (F)	195.1	196.8	196.1	.5921E-01
T12 EXHAUST RECREIVER (F)	803.8	832.3	816.5	5.473
P7 AIR METER INLET (IN-H2O)	62.32	67.59	65.09	1.556
P5 OIL HEADER (PSI)	44.57	68.49	54.91	7.261
P6 SERVO OIL (PSI)	3716.	3750.	3733.	7.146
P3 WATER INLET (PSI)	67.97	72.55	70.41	.8765
P4 WATER OUTLET (PSI)	65.71	67.65	66.54	.3561
P9 L.B. AIR INLET MAN.(IN-HG)	61.58	66.87	64.21	1.300
P10 PILOT RAIL PRESSURE (PSI)	1423.	1622.	1508.	44.44
P1 CWS HEADER (PSI)	307.8	441.1	390.6	32.54
P12 FUEL #1 HEADER (PSI)	39.78	42.03	40.93	.4837
P13 PILOT HEADER (PSI)	18.53	31.69	22.24	3.677
P2 PURGE SYSTEM (PSI)	.1270E+05	.1378E+05	.1336E+05	271.6
P17 BAROMETRIC (IN-HG)	29.59	29.61	29.60	.2641E-01
T2 WATER OUTLET (F)	182.4	185.1	183.9	.5442
M1 OXYGEN (%)	12.38	12.87	12.62	.9053E-01
M2 CARBON DIOXIDE (%)	6.774	7.180	6.983	.7608E-01
M3 NOX (PPM)	652.0	709.5	683.1	10.83
M4 CARBON MONOXIDE (PPM)	205.4	389.2	266.9	46.68
M5 HYDROCARBONS (PPM)	221.6	289.6	250.8	15.87
M6 SULFUR DIOXIDE (PPM)	185.9	227.1	215.0	7.453

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD

DECIMAL TIME FOR REPORT	10.87	11.65	11.26	.2274
VOLTS CONVERTED FROM BCD VALUE	207.0	208.0	207.0	.2907
AMPS CONVERTED FROM BCD VALUE	629.0	631.0	630.2	.7127
ENGINE RPM FROM BCD VALUE	1050.	1055.	1052.	2.153
MOYNO RPM FROM BCD VALUE	509.0	535.0	518.9	5.006
KILLOWATTS	130.2	131.2	130.5	.1332

TEST REQUEST NUMBER : 4741
 Coal Slurry Fuels Testing
 TEST RUN NUMBER : 30
 OTISCA - KENTUCKY BLUE GEM - 4.8 MICRON FUEL W/ MCG 32A & TRITON - BARREL 1151
 11:42 AM THU., 14 DEC., 1980

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
P19 RACK (MM)	32.98	37.42	34.83	.8068
T9 R.B. AIR MANIFOLD (F)	182.5	188.9	186.0	1.658
T8 L.B. AIR MANIFOLD (F)	184.4	190.3	187.6	1.663
T7 AIR ORIFICE INLET (F)	161.3	164.5	163.1	.6152
T1 WATER INLET (F)	179.9	181.8	180.9	.3212
T5 FUEL #1 (F) (CWS)	71.30	78.14	74.97	1.725
T6 FUEL #2 (F) (PILOT)	77.93	90.25	84.66	3.067
T11 R. CYLINDER EXHAUST (F)	184.0	187.4	185.7	.6967
T10 L. CYLINDER EXHAUST (F)	688.8	703.9	697.7	2.937
T3 OIL INLET (F)	182.5	185.1	183.9	.4424
T4 OIL OUTLET (F)	193.6	195.1	194.4	.2347
T12 EXHAUST RECEIVER (F)	819.7	839.9	830.3	4.331
P7 AIR METER INLET (IN-H2O)	62.31	67.37	65.13	1.637
P5 OIL HEADER (PSI)	44.62	68.23	56.10	7.367
P6 SERVO OIL (PSI)	3700.	3768.	3732.	15.07
P3 WATER INLET (PSI)	69.34	73.50	71.32	.9811
P4 WATER OUTLET (PSI)	71.33	73.18	72.17	.3789
P9 L.B. AIR INLET MAN.(IN-HG)	61.80	66.77	64.34	1.210
P10 PILOT RAIL PRESSURE (PSI)	490.1	490.3	490.2	.5515
P1 CWS HEADER (PSI)	337.7	405.5	370.3	18.86
P12 FUEL #1 HEADER (PSI)	40.53	41.41	40.95	.2096
P13 PILOT HEADER (PSI)	19.87	32.16	22.52	3.207
P2 PURGE SYSTEM (PSI)	.1001E+05	.1137E+05	.1069E+05	336.6
P17 BAROMETRIC (IN-HG)	29.18	29.20	29.19	0.000
T2 WATER OUTLET (F)	182.5	184.6	183.8	.4281
M1 OXYGEN (%)	12.70	20.73	13.09	1.134
M2 CARBON DIOXIDE (%)	.1818	6.746	6.427	.8925
M3 NOX (PPM)	31.46	701.6	654.1	88.41
M4 CARBON MONOXIDE (PPM)	18.38	376.8	278.4	51.68
M5 HYDROCARBONS (PPM)	90.54	236.8	221.0	19.19
M6 SULFUR DIOXIDE (PPM)	41.33	266.1	247.8	30.17

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	10.96	11.70	11.33	.2148
VOLTS CONVERTED FROM BCD VALUE	207.0	208.0	207.1	.3640
AMPS CONVERTED FROM BCD VALUE	628.0	632.0	629.8	1.186
ENGINE RPM FROM BCD VALUE	1050.	1056.	1053.	.6993
MOYNO RPM FROM BCD VALUE	486.0	510.0	497.0	5.129
KILLOWATTS	130.0	131.5	130.4	.3478

TEST REQUEST NUMBER : 4741

Coal Slurry Fuels Testing

TEST RUN NUMBER : 31

OTISCA KENTUCKY BLUE GEM - 4.6 MICRON FUEL W/ LIGNOSOL - DRUM 1157

9:33 AM FRI., 15 DEC., 1989

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
RACK (MM)	31.23	33.93	32.50	.4703
T9 R.B. AIR MANIFOLD (F)	183.1	189.5	186.4	1.650
T8 L.B. AIR MANIFOLD (F)	184.7	190.9	187.9	1.678
T7 AIR ORIFICE INLET (F)	164.1	167.4	165.7	.6618
T1 WATER INLET (F)	179.0	181.8	180.5	.6093
T5 FUEL #1 (F) (CWS)	70.42	75.63	73.59	1.073
T6 FUEL #2 (F) (PILOT)	77.32	90.96	84.74	3.370
T11 R. CYLINDER EXHAUST (F)	183.9	188.0	185.8	.7993
T10 L. CYLINDER EXHAUST (F)	680.7	695.5	688.5	3.492
T3 OIL INLET (F)	186.1	189.1	187.7	.5514
T4 OIL OUTLET (F)	196.9	199.0	198.0	.3816
T12 EXHAUST RECEIVER (F)	814.7	832.3	823.9	3.763
P7 AIR METER INLET (IN-H2O)	62.32	67.40	65.27	1.517
P5 OIL HEADER (PSI)	44.14	66.94	54.09	6.622
P6 SERVO OIL (PSI)	3695.	3742.	3710.	7.984
P3 WATER INLET (PSI)	70.05	74.41	72.36	.9689
P4 WATER OUTLET (PSI)	72.04	74.30	73.06	.4986
P9 L.B. AIR INLET MAN.(IN-HG)	61.53	66.74	64.29	1.320
P10 PILOT RAIL PRESSURE (PSI)	489.2	490.2	490.1	.3161
P1 CWS HEADER (PSI)	299.3	445.1	374.1	42.91
P12 FUEL #1 HEADER (PSI)	40.05	41.67	40.80	.3497
P13 PILOT HEADER (PSI)	19.84	30.43	22.39	3.178
P2 PURGE SYSTEM (PSI)	.1064E+05	.1183E+05	.1125E+05	323.6
P17 BAROMETRIC (IN-HG)	29.21	29.23	29.22	.3353E-01
T2 WATER OUTLET (F)	181.6	184.8	183.3	.5640
M1 OXYGEN (%)	12.60	20.34	12.85	.6074
M2 CARBON DIOXIDE (%)	.3179	6.744	6.558	.5168
M3 NOX (PPM)	128.6	744.9	704.3	46.48
M4 CARBON MONOXIDE (PPM)	21.65	279.8	233.1	23.51
M5 HYDROCARBONS (PPM)	111.0	243.5	224.1	13.02
M6 SULFUR DIOXIDE (PPM)	128.3	262.1	250.5	11.84

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	8.644	9.556	9.100	.2643
VOLTS CONVERTED FROM BCD VALUE	206.0	208.0	207.0	.2870
AMPS CONVERTED FROM BCD VALUE	629.0	631.0	630.0	.9050
ENGINE RPM FROM BCD VALUE	1050.	1054.	1052.	.6283
MOYNO RPM FROM BCD VALUE	432.0	522.0	503.3	8.876
KILLOWATTS	129.6	131.2	130.4	.3118

TEST REQUEST NUMBER : 4741
 Coal Slurry Fuels Testing
 TEST RUN NUMBER : 33
 UNDERC Wyoming Spring Creek Sub-bituminous Coal - 12 Micron

10:51 AM THU., 11 JAN., 1990

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
P19 RACK (MM)	26.83	28.99	28.03	.3656
T9 R.B. AIR MANIFOLD (F)	183.8	188.3	186.0	1.270
T8 L.B. AIR MANIFOLD (F)	185.1	189.7	187.5	1.354
T7 AIR ORIFICE INLET (F)	153.4	155.3	154.4	.4411
T1 WATER INLET (F)	178.7	180.9	180.1	.5225
T5 FUEL #1 (F) (CWS)	67.64	75.48	71.30	1.0
T6 FUEL #2 (F) (PILOT)	93.13	97.02	95.26	1.0
T11 R. CYLINDER EXHAUST (F)	183.5	187.8	186.1	1.337
T10 L. CYLINDER EXHAUST (F)	694.5	707.8	702.6	4.127
T3 OIL INLET (F)	183.8	185.7	184.8	.4503
T4 OIL OUTLET (F)	194.7	196.0	195.3	.3010
T12 EXHAUST RECEIVER (F)	831.4	847.5	841.4	5.588
P7 AIR METER INLET (IN-H2O)	62.26	66.67	64.86	1.522
P5 OIL HEADER (PSI)	44.18	71.06	56.02	7.718
P6 SERVO OIL (PSI)	3679.	3699.	3688.	5.801
P3 WATER INLET (PSI)	71.31	74.31	72.85	.8293
P4 WATER OUTLET (PSI)	75.65	77.13	76.50	.3782
P9 L.B. AIR INLET MAN.(IN-HG)	61.63	66.05	63.96	1.163
P10 PILOT RAIL PRESSURE (PSI)	1411.	1859.	1609.	140.2
P1 CWS HEADER (PSI)	342.3	384.5	365.4	12.35
P12 FUEL #1 HEADER (PSI)	40.24	40.98	40.59	.1854
P13 PILOT HEADER (PSI)	19.63	28.68	22.33	2.663
P2 PURGE SYSTEM (PSI)	.1244E+05	.1338E+05	.1301E+05	277.7
P17 BAROMETRIC (IN-HG)	28.57	28.58	28.58	0.000
T2 WATER OUTLET (F)	181.6	183.9	182.8	.5627

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	10.74	10.85	10.79	.3378E-01
VOLTS CONVERTED FROM BCD VALUE	198.0	199.0	198.5	.5039
AMPS CONVERTED FROM BCD VALUE	603.0	605.0	604.0	.4694
ENGINE RPM FROM BCD VALUE	1051.	1055.	1053.	.8979
MOYNO RPM FROM BCD VALUE	518.0	623.0	571.0	35.95
KILLOWATTS	119.6	120.4	119.9	.3012

TEST REQUEST NUMBER : 4741
 Coal Slurry Fuels Testing
 TEST RUN NUMBER : 34
 UNDERC Wyoming Spring Creek Sub-bituminous Coal - 12 Micron

11:48 AM FRI., 12 JAN., 1990

DATA DESCRIPTOR	MIN	MAX	MEAN	STD

P19 RACK (MM)	28.79	34.75	30.48	1.046
T9 R.B. AIR MANIFOLD (F)	184.1	188.1	186.0	.9586
T8 L.B. AIR MANIFOLD (F)	185.4	190.4	187.8	1.239
T7 AIR ORIFICE INLET (F)	163.2	165.4	164.2	.5042
T1 WATER INLET (F)	180.9	183.1	182.1	.4271
T5 FUEL #1 (F) (CWS)	67.27	74.75	70.77	1.409
T6 FUEL #2 (F) (PILOT)	83.24	88.64	86.25	1.189
T11 R. CYLINDER EXHAUST (F)	187.0	188.7	187.8	.3132
T10 L. CYLINDER EXHAUST (F)	734.3	743.0	738.8	2.083
T3 OIL INLET (F)	184.7	186.4	185.6	.3458
T4 OIL OUTLET (F)	196.6	197.5	197.1	.1103
T12 EXHAUST RECEIVER (F)	870.6	886.1	876.6	2.677
P7 AIR METER INLET (IN-H2O)	62.14	66.89	64.73	1.610
P5 OIL HEADER (PSI)	45.65	69.50	57.45	7.852
P6 SERVO OIL (PSI)	3692.	3750.	3730.	13.06
P3 WATER INLET (PSI)	71.29	75.05	72.92	.7339
P4 WATER OUTLET (PSI)	76.73	78.47	77.70	.4243
P9 L.B. AIR INLET MAN.(IN-HG)	61.48	65.96	63.91	1.151
P10 PILOT RAIL PRESSURE (PSI)	1390.	1859.	1627.	117.0
P1 CWS HEADER (PSI)	354.6	381.0	367.5	5.076
P12 FUEL #1 HEADER (PSI)	40.03	41.15	40.50	.2806
P13 PILOT HEADER (PSI)	19.40	31.95	22.96	3.386
P2 PURGE SYSTEM (PSI)	.1263E+05	.1386E+05	.1332E+05	331.8
P17 BAROMETRIC (IN-HG)	28.81	28.82	28.81	.2353E-01
T2 WATER OUTLET (F)	184.1	186.1	185.1	.5117
M1 OXYGEN (%)	11.95	12.56	12.25	.8331E-01
M2 CARBON DIOXIDE (%)	7.179	7.636	7.407	.6759E-01
M3 NOX (PPM)	564.6	610.4	583.6	7.677
M4 CARBON MONOXIDE (PPM)	364.4	509.0	403.3	31.62
M5 HYDROCARBONS (PPM)	184.5	215.1	193.4	6.117
M6 SULFUR DIOXIDE (PPM)	203.4	214.9	208.2	2.439

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD

DECIMAL TIME FOR REPORT	11.57	11.81	11.69	.6897E-01
VOLTS CONVERTED FROM BCD VALUE	207.0	208.0	207.1	.2155
AMPS CONVERTED FROM BCD VALUE	628.0	631.0	629.6	.9014
ENGINE RPM FROM BCD VALUE	1048.	1057.	1054.	1.051
MOYNO RPM FROM BCD VALUE	540.0	595.0	565.1	11.62
KILLOWATTS	130.0	131.2	130.4	.2777

TEST REQUEST NUMBER : 4741
 Coal Slurry Fuels Testing
 TEST RUN NUMBER : 36
 OTISCA KENTUCKY BLUE GEM - 4.6 MICRON FUEL W/ LIGNOSOL - DRUM 1155

11:55 AM MON., 29 JAN., 1990

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
P19 RACK (MM)	31.18	34.86	32.66	.7087
T9 R.B. AIR MANIFOLD (F)	184.5	186.8	185.6	.5354
T8 L.B. AIR MANIFOLD (F)	185.8	189.6	187.5	.7002
T7 AIR ORIFICE INLET (F)	160.7	163.2	161.7	.4146
T1 WATER INLET (F)	180.7	182.4	181.7	.3120
T5 FUEL #1 (F) (CWS)	71.17	74.78	73.34	.8228
T6 FUEL #2 (F) (PILOT)	79.48	87.48	83.69	1.878
T11 R. CYLINDER EXHAUST (F)	182.9	188.5	186.8	1.258
T10 L. CYLINDER EXHAUST (F)	690.8	703.8	697.6	2.780
T3 OIL INLET (F)	184.5	185.9	185.2	.3207
T4 OIL OUTLET (F)	194.9	195.9	195.4	.1627
T12 EXHAUST RECREIVER (F)	819.5	840.6	833.3	4.610
P7 AIR METER INLET (IN-H2O)	60.83	66.48	63.19	1.744
P5 OIL HEADER (PSI)	46.02	69.54	57.26	7.179
P6 SERVO OIL (PSI)	3730.	3763.	3746.	9.395
P3 WATER INLET (PSI)	71.51	75.28	73.60	.8443
P4 WATER OUTLET (PSI)	67.55	69.66	68.43	.4374
P9 L.B. AIR INLET MAN.(IN-HG)	60.36	65.84	62.35	1.441
P10 PILOT RAIL PRESSURE (PSI)	1439.	1882.	1665.	103.9
P1 CWS HEADER (PSI)	345.8	424.1	381.2	16.68
P12 FUEL #1 HEADER (PSI)	41.09	42.47	41.68	.3223
P13 PILOT HEADER (PSI)	19.50	31.55	22.60	3.054
P2 PURGE SYSTEM (PSI)	.1308E+05	.1406E+05	.1367E+05	266.2
P17 BAROMETRIC (IN-HG)	29.07	29.10	29.09	.9442E-02
T2 WATER OUTLET (F)	183.4	185.4	184.6	.3884
M1 OXYGEN (%)	12.53	12.81	12.66	.5680E-01
M2 CARBON DIOXIDE (%)	6.511	6.756	6.649	.5038E-01
M3 NOX (PPM)	698.8	731.5	714.5	6.953
M4 CARBON MONOXIDE (PPM)	196.9	260.2	217.8	11.17
M5 HYDROCARBONS (PPM)	128.6	204.8	183.9	19.54
M6 SULFUR DIOXIDE (PPM)	171.3	212.0	196.6	11.62

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	11.50	11.92	11.71	.1227
VOLTS CONVERTED FROM BCD VALUE	206.0	208.0	207.0	.3184
AMPS CONVERTED FROM BCD VALUE	628.0	631.0	628.7	.5884
ENGINE RPM FROM BCD VALUE	1053.	1057.	1055.	1.662
MOYNO RPM FROM BCD VALUE	486.0	620.0	552.3	32.28
KILLOWATTS	129.4	131.0	130.1	.2614

TEST REQUEST NUMBER : 4741
 Coal Slurry Fuels Testing
 TEST RUN NUMBER : 37
 UNDERC - WYOMING SPRING CREEK SUB. BIT. - BARREL # U05/U06

10:51 AM TUE., 30 JAN., 1990

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
P19 RACK (MM)	30.23	35.04	32.80	.7950
T9 R.B. AIR MANIFOLD (F)	184.2	185.9	185.2	.3428
T8 L.B. AIR MANIFOLD (F)	185.8	188.6	187.1	.6824
T7 AIR ORIFICE INLET (F)	154.4	156.7	155.7	.5290
T1 WATER INLET (F)	180.0	181.5	180.7	.3055
T5 FUEL #1 (F) (CWS)	71.52	73.99	72.87	.5603
T6 FUEL #2 (F) (PILOT)	85.26	90.88	88.32	1.196
T11 R. CYLINDER EXHAUST (F)	183.1	185.6	184.7	.7768
T10 L. CYLINDER EXHAUST (F)	684.2	693.8	689.8	2.790
T3 OIL INLET (F)	184.7	186.3	185.5	.4154
T4 OIL OUTLET (F)	194.7	195.7	195.3	.2455
T12 EXHAUST RECREIVER (F)	803.8	816.0	810.2	3.160
P7 AIR METER INLET (IN-H2O)	61.52	66.20	63.69	1.719
P5 OIL HEADER (PSI)	45.42	69.94	56.86	8.093
P6 SERVO OIL (PSI)	3707.	3728.	3716.	5.316
P3 WATER INLET (PSI)	70.87	74.10	72.24	.7351
P4 WATER OUTLET (PSI)	66.30	67.91	67.18	.4760
P9 L.B. AIR INLET MAN.(IN-HG)	60.97	65.49	62.87	1.360
P10 PILOT RAIL PRESSURE (PSI)	1455.	1863.	1657.	92.80
P1 CWS HEADER (PSI)	371.0	388.8	380.5	4.000
P12 FUEL #1 HEADER (PSI)	41.15	41.86	41.50	.2156
P13 PILOT HEADER (PSI)	19.34	31.30	22.72	3.055
P2 PURGE SYSTEM (PSI)	.1294E+05	.1381E+05	.1347E+05	248.8
P17 BAROMETRIC (IN-HG)	29.28	29.29	29.28	0.000
T2 WATER OUTLET (F)	181.8	183.7	183.0	.3958
M1 OXYGEN (%)	13.11	13.32	13.21	.4336E-01
M2 CARBON DIOXIDE (%)	6.491	6.656	6.578	.4001E-01
M3 NOX (PPM)	517.2	534.4	525.1	4.336
M4 CARBON MONOXIDE (PPM)	279.8	345.5	290.7	8.295
M5 HYDROCARBONS (PPM)	194.2	244.0	214.7	8.560
M6 SULFUR DIOXIDE (PPM)	170.1	191.2	182.2	5.006

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	10.66	10.86	10.76	.5484E-01
VOLTS CONVERTED FROM BCD VALUE	200.0	201.0	200.4	.4826
AMPS CONVERTED FROM BCD VALUE	609.0	611.0	610.0	.6246
ENGINE RPM FROM BCD VALUE	1050.	1058.	1055.	.4226
NOYNO RPM FROM BCD VALUE	514.0	570.0	537.3	7.931
KILLOWATTS	121.8	122.8	122.2	.3478

TEST REQUEST NUMBER : 4741
 Coal Slurry Fuels Testing
 TEST RUN NUMBER : 38
 UNDERC - WYOMING SPRING CREEK SUB. BIT.

12:12 PM WED., 31 JAN., 1990

DATA DESCRIPTOR	MIN	MAX	MEAN	STD

P19 RACK (MM)	30.80	35.16	32.89	.7814
T9 R.B. AIR MANIFOLD (F)	184.4	186.2	185.2	.3769
T8 L.B. AIR MANIFOLD (F)	185.7	188.2	187.1	.5414
Y7 AIR ORIFICE INLET (F)	161.6	164.0	162.6	.4515
T1 WATER INLET (F)	179.8	182.0	181.0	.5259
T5 FUEL #1 (F) (CWS)	69.77	75.56	73.36	1.039
T6 FUEL #2 (F) (PILOT)	80.39	88.25	85.20	1.655
T11 R. CYLINDER EXHAUST (F)	187.2	188.7	188.0	.3439
T10 L. CYLINDER EXHAUST (F)	672.1	680.8	676.0	2.293
T3 OIL INLET (F)	183.4	186.0	184.8	.6039
T4 OIL OUTLET (F)	194.9	196.0	195.4	.2684
T12 EXHAUST RECREIVER (F)	804.6	813.3	809.0	1.761
P7 AIR METER INLET (IN-H2O)	61.32	66.14	63.36	1.613
P5 OIL HEADER (PSI)	45.28	69.95	57.33	7.437
P6 SERVO OIL (PSI)	3654.	3740.	3704.	19.19
P3 WATER INLET (PSI)	69.89	73.69	71.85	.8293
P4 WATER OUTLET (PSI)	65.30	67.25	66.31	.4318
P9 L.B. AIR INLET MAN.(IN-HG)	60.62	65.28	62.31	1.266
P10 PILOT RAIL PRESSURE (PSI)	1463.	1880.	1683.	93.82
P1 CWS HEADER (PSI)	364.5	394.9	383.6	5.552
P12 FUEL #1 HEADER (PSI)	40.78	41.68	41.20	.2301
P13 PILOT HEADER (PSI)	19.21	35.11	22.62	3.416
P2 PURGE SYSTEM (PSI)	.1316E+05	.1405E+05	.1371E+05	256.1
P17 BAROMETRIC (IN-HG)	29.50	29.51	29.51	.5382E-02
T2 WATER OUTLET (F)	182.0	184.8	183.8	.5354
M1 OXYGEN (%)	12.86	13.31	12.97	.5477E-01
M2 CARBON DIOXIDE (%)	6.490	6.803	6.733	.3556E-01
M3 NOX (PPM)	550.3	583.9	573.7	4.542
M4 CARBON MONOXIDE (PPM)	230.0	493.7	243.1	23.56
M5 HYDROCARBONS (PPM)	154.7	233.2	203.1	17.22
M6 SULFUR DIOXIDE (PPM)	139.8	171.8	163.0	7.847

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD

DECIMAL TIME FOR REPORT	11.88	12.21	12.04	.9628E-01
VOLTS CONVERTED FROM BCD VALUE	201.0	201.0	201.0	0.000
AMPS CONVERTED FROM BCD VALUE	610.0	612.0	610.6	.8393
ENGINE RPM FROM BCD VALUE	1044.	1057.	1055.	1.381
MOYNO RPM FROM BCD VALUE	513.0	563.0	532.6	6.320
KILLOWATTS	122.6	123.0	122.7	.5032E-01

TEST REQUEST NUMBER : 4741

Coal Slurry Fuels Testing

TEST RUN NUMBER : 45

Amax Coal Water Slurry Fuel

11:19 AM THU., 19 APR., 1990

DATA DESCRIPTOR	MIN	MAX	MEAN	STD
P19 RACK (MM)	24.86	25.90	25.45	.2226
T9 R.B. AIR MANIFOLD (F)	183.4	188.6	186.2	1.584
T8 L.B. AIR MANIFOLD (F)	185.6	190.7	188.6	1.556
T7 AIR ORIFICE INLET (F)	150.9	152.0	151.4	.2642
T1 WATER INLET (F)	179.2	181.2	180.3	.5603
T5 FUEL #1 (F) (CWS)	73.87	75.90	74.76	.4314
T6 FUEL #2 (F) (PILOT)	81.82	83.22	82.48	.3773
T11 R. CYLINDER EXHAUST (F)	187.5	189.3	188.5	.5051
T10 L. CYLINDER EXHAUST (F)	681.2	685.4	683.6	1.221
T3 OIL INLET (F)	182.2	183.9	183.2	.5152
T4 OIL OUTLET (F)	193.3	194.1	193.6	.2416
T12 EXHAUST RECEIVER (F)	812.7	821.4	817.3	1.907
P7 AIR METER INLET (IN-H2O)	64.97	69.40	66.77	1.464
P5 OIL HEADER (PSI)	47.37	71.94	60.04	7.681
P6 SERVO OIL (PSI)	3686.	3730.	3709.	12.13
P3 WATER INLET (PSI)	103.2	104.0	103.7	.1727
P4 WATER OUTLET (PSI)	117.4	118.2	117.9	.1517
P9 L.B. AIR INLET MAN.(IN-HG)	64.77	68.44	66.74	.9636
P10 PILOT RAIL PRESSURE (PSI)	1553.	2005.	1856.	133.1
P11 EXHAUST TO INLET D.P.(PSI)	50.40	50.81	50.61	.1126
P1 CWS HEADER (PSI)	291.9	448.4	351.0	46.21
P12 FUEL #1 HEADER (PSI)	22.52	25.50	23.73	.7824
P13 PILOT HEADER (PSI)	24.54	30.29	26.46	1.751
P2 PURGE SYSTEM (PSI)	.1368E+05	.1442E+05	.1414E+05	225.5
P17 BAROMETRIC (IN-HG)	29.73	29.73	29.73	.1119E-01
P20 CRANKCASE PRESSURE	.5662	.9582	.7047	.1327
T2 WATER OUTLET (F)	181.6	184.2	183.1	.7307
M1 OXYGEN (%)	12.84	13.03	12.94	.4537E-01
M2 CARBON DIOXIDE (%)	6.933	7.069	7.000	.3745E-01
M3 NOX (PPM)	694.8	750.3	723.4	12.44
M4 CARBON MONOXIDE (PPM)	315.8	368.0	346.2	12.33
M5 HYDROCARBONS (PPM)	253.6	260.8	256.7	1.715
M6 SULFUR DIOXIDE (PPM)	296.3	302.0	299.3	1.272

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD
DECIMAL TIME FOR REPORT	11.22	11.32	11.27	.2902E-01
VOLTS CONVERTED FROM BCD VALUE	207.0	208.0	207.2	.4050
AMPS CONVERTED FROM BCD VALUE	627.0	630.0	629.1	.6810
ENGINE RPM FROM BCD VALUE	1053.	1056.	1054.	.5620
MOYNO RPM FROM BCD VALUE	519.0	523.0	521.5	.9087
KILLOWATTS	129.8	131.0	130.4	.3720

TEST REQUEST NUMBER : 4731
 SYSTEM III F.I.E. EMISSIONS TESTS
 TEST RUN NUMBER : 75
 Otisca Kentucky Blue Gem 4.8 micron Fuel

11:48 AM TUE., 18 JULY, 1989

DATA DESCRIPTOR	MIN	MAX	MEAN	STD

P19 RACK (MM)	34.24	37.45	35.81	.8859
T9 R.B. AIR MANIFOLD (F)	3.917	10.04	6.724	1.608
T2 L.B. AIR MANIFOLD (F)	189.0	191.0	190.1	.4984
T7 AIR ORIFICE INLET (F)	163.0	164.9	163.9	.3995
T1 WATER INLET (F)	176.8	179.0	178.0	.5627
T5 FUEL #1 (F) (CWS)	101.9	103.5	102.7	.4050
T6 FUEL #2 (F) (PILOT)	99.26	102.9	101.1	.8871
T11 R. CYLINDER EXHAUST (F)	207.6	209.4	208.8	.4270
T10 L. CYLINDER EXHAUST (F)	741.2	747.2	744.3	1.733
T3 OIL INLET (F)	184.7	186.6	185.7	.5603
T4 OIL OUTLET (F)	195.7	197.4	196.5	.4310
T12 EXHAUST RECEIVER (F)	881.6	893.7	888.8	3.293
P5 OIL HEADER (PSI)	42.74	66.79	56.22	9.199
P3 WATER INLET (PSI)	67.93	73.91	70.93	1.898
P4 WATER OUTLET (PSI)	65.94	68.17	67.15	.6853
P9 L.B. AIR INLET MAN.(IN-HG)	63.51	68.15	65.83	1.362
P1 CWS HEADER (PSI)	350.9	411.9	375.8	11.56
P12 FUEL #1 HEADER (PSI)	40.68	41.15	40.92	.1549
T2 WATER OUTLET (F)	179.8	182.0	180.8	.6276

Engineering Calculations

CALC DESCRIPTOR	MIN	MAX	MEAN	STD

VOLTS CONVERTED FROM BCD VALUE	207.0	208.0	207.0	.2290
AMPS CONVERTED FROM BCD VALUE	628.0	630.0	628.7	.4249
ENGINE RPM FROM BCD VALUE	1050.	1059.	1054.	1.494
MOYNO RPM FROM BCD VALUE	461.0	579.0	499.4	23.44
KILLOWATTS	130.0	131.0	130.2	.1870

APPENDIX V.
PARTICULATE SIZE DISTRIBUTION STUDY

General Electric Environmental Services, Inc.
20 North Seventh St. Lebanon, PA 17042
610 274 7000

February 27, 1990

Mr. Bert Hsu
GE Transportation Systems
Building 14-3
2301 East Lake Road
Erie, Pennsylvania 16531

Subject: DOE/GETS CWM Fuel Diesel Project
GEESI Ref: S9513/PA1

Dear Bert:

Enclosed are results of particle size distribution and loss on ignition determinations performed for six samples of single cylinder engine exhaust particulate, identified as per the attached.

Sincerely,

W. VanKleunen

cc: E. Gal
M. Mengel
E. Samuel

Date

February 14, 1990

Our Reference

JG.021490.1

Mr. William VanKlevnen
GE ENVIRONMENTAL SYSTEMS
200 North Seventh Street
Labanon, PA 17042

Dear Mr. VanKlevnen:

Enclosed is the particle size data on the six samples you submitted to Shimadzu for analysis on our SALD-1100. This data is presented in three forms. The first is the original run sheets. These are divided into three sections. The first section shows the fixed distribution results on the cumulative and differential data. The next section relates cumulative and differential data for user specified diameters and percentiles. The last section shows the corresponding cumulative curve and differential histogram.

The second data presentation is the sample summary sheet. This sheet is also divided into three sections. The top section contains customer and sample information. The middle section shows the cumulative distribution data, their average and standard deviation for the three analysis runs. The bottom section shows statistical data on the cumulative distribution. Listed are the Median, D10, D90, 10/90 Ratio, D84.1, D15.9, and Width for each run along with average and standard deviation values.

The Median is your Average Particle Size (APS). It denotes where the cumulative curve passes the 50th percentile. This means 50% of the sample volume is greater and 50% of the volume is smaller than this value.

The 10/90 Ratio is calculated by dividing the 90th percentile by the 10th percentile. This value allows you to quantitatively show how well the "tails" of your distribution is repeating. If this value is steady the outer edges of your distribution are stable.

The Width indicates both width, and along with the 10/90 Ratio, stability of your distribution. If this value is small (< 1) the distribution is relatively narrow. On the other hand, if it is large (> 1) than you have a wide distribution. If this value remains steady over several runs, your distribution is repeating well. To calculate the Width, divide the 84.1 percentile by the 15.9 percentile, take the square root and subtract 1. The 84.1 and 15.9 percentiles are used because they approximate one standard deviation from the center of the distribution.

SHIMADZU SCIENTIFIC INSTRUMENTS, INC.

7102 RIVERWOOD DRIVE, COLUMBIA, MARYLAND 21046

Phone No. (301) 381-1227 Fax No. (301) 381-1222

The final data presentation is a graphic overlay of the cumulative curves. These graphs were generated from the sample summary sheets using GRAPHER software. Sample graphs show how well the distributions repeated. The comparison graph overlays all samples on one graph.

Your samples were each carefully prepared by suspending each one in methanol. Then each sample was dispersed for thirty seconds using a twenty-five watt sonic probe.

Each sample showed a bi-modal distribution. The first peak being ash and the second peak being coal.

Thank you for considering Shimadzu and our SALD-1100 for your particle sizing needs. If we can be of further assistance, please do not hesitate to contact us at (301)-381-1227.

SINCERELY,

SHIMADZU SCIENTIFIC INSTRUMENTS, INC.

Joseph F. Greenbeck Jr.
Product Specialist

CC: C. Munday - Product Manager

SHIMADZU SCIENTIFIC INSTRUMENTS, INC

February 12, 1990

Mr. Joe Greenbeck
Shimadzu Scientific Instruments, Inc.
7102 Riverwood Drive
Columbia, Maryland 21046

Subject: SALD-1100 Laser Diffraction Analysis
GE PO No.: BV4-J59513-004

Dear Mr. Greenbeck:

Please perform particle size distribution analyses on six samples of particulate identified as follows:

<u>RUN #</u>	<u>DATE/THIMBLE #</u>	<u>APPROXIMATE SAMPLE WEIGHT, GRAMS</u>
28	12-7-89	2.0
29	12-11-89	2.0
30	12-15-89	2.0
31	12-15-89	1.0
33	A5	1.2
34	C6	2.0

These samples are a combination of coal ash and carbonaceous products of combustion.

The samples will be sent under separate cover via United Parcel Service. GE will issue a Purchase Order extension to the subject Purchase Order for six analyses at \$100 per analysis. It will be appreciated if the analyses can be performed on this authorization before receipt of the extension.

Very truly yours,

William VanKleunen

cc: E. Gal

February 12, 1990

Mr. Joe Greenbeck
Shimadzu Scientific Instruments, Inc.
7102 Riverwood Drive
Columbia, Maryland 21046

Subject: SALD-1100 Laser Diffraction Analysis
GE PO No.: BV4-J59513-004

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33	A5	1.2
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The samples will be sent under separate cover via United Parcel Service. GE will issue a Purchase Order extension to the subject Purchase Order for six analyses at \$100 per analysis. It will be appreciated if the analyses can be performed on this authorization before receipt of the extension.

Very truly yours,

William VanKleunen

cc: E. Gal

PARTICLE SIZE DATA SUMMARY SHEET

INSTRUMENT SALD-1100

DATE: February 13, 1990

SAMPLE INFORMATION

CUSTOMER NAME G.E.E.S.
 SAMPLE TYPE Coke-Ash
 SAMPLE NUMBER Run 28 12-7-89
 RANGE/MODE A-3
 SUSPENSION MEDIA Methanol

	RUN #1	RUN #2	RUN #3		
DIAMETER	VOLUME PERCENT	VOLUME PERCENT	VOLUME PERCENT	AVERAGE	STD.DEV
45.00	100.0	100.0	100.0	100.0	0.0
31.00	100.0	100.0	100.0	100.0	0.0
22.00	100.0	100.0	100.0	100.0	0.0
16.00	100.0	100.0	100.0	100.0	0.0
11.00	96.6	96.1	95.8	96.2	0.4
7.50	82.9	80.5	78.8	80.7	2.1
5.30	79.4	76.6	74.5	76.8	2.5
3.70	67.8	65.2	63.4	65.5	2.2
2.60	21.1	19.9	19.0	20.0	1.1
1.80	8.1	7.4	6.8	7.4	0.7
1.30	3.0	2.7	2.4	2.7	0.3
0.88	1.4	1.2	1.1	1.2	0.2
0.60	0.3	0.2	0.2	0.2	0.1
0.43	0.0	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0	0.0
0.17	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0

	μm	μm	μm	Average	Std.Dev
MEDIAN DIA	3.24	3.29	3.33	3.29	0.05
D 84.1	7.77	8.20	8.46	8.14	0.35
D 15.9	2.25	2.31	2.37	2.31	0.06
WIDTH	0.86	0.88	0.89	0.88	0.02
D 10	1.90	1.94	1.98	1.94	0.04
D 90	9.16	9.47	9.66	9.43	0.25
RATIO	4.82	4.88	4.88	4.86	0.03

PARTICLE SIZE DATA SUMMARY SHEET

INSTRUMENT SALD-1100

DATE: February 13, 1990

SAMPLE INFORMATION

CUSTOMER NAME G.E.E.S.
 SAMPLE TYPE Coke-Ash
 SAMPLE NUMBER Run 29 12-11-89
 RANGE/MODE A-3
 SUSPENSION MEDIA Methanol

	RUN #1	RUN #2	RUN #3		
	VOLUME	VOLUME	VOLUME		
DIAMETER	PERCENT	PERCENT	PERCENT	AVERAGE	STD.DEV
45.00	100.0	100.0	100.0	100.0	0.0
31.00	100.0	100.0	100.0	100.0	0.0
22.00	100.0	100.0	100.0	100.0	0.0
16.00	100.0	100.0	100.0	100.0	0.0
11.00	97.0	97.5	97.2	97.2	0.3
7.50	84.8	87.7	86.0	86.2	1.5
5.30	81.7	85.2	83.3	83.4	1.8
3.70	69.6	72.6	70.9	71.0	1.5
2.60	21.0	22.2	21.6	21.6	0.6
1.80	7.6	8.3	7.9	7.9	0.4
1.30	2.6	2.8	2.7	2.7	0.1
0.88	1.1	1.2	1.1	1.1	0.1
0.60	0.2	0.2	0.2	0.2	0.0
0.43	0.0	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0	0.0
0.17	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0

	μm	μm	μm	Average	Std.Dev
MEDIAN DIA	3.21	3.16	3.19	3.19	0.03
D 84.1	6.95	5.14	5.89	5.99	0.91
D 15.9	2.26	2.20	2.37	2.28	0.09
WIDTH	0.75	0.53	2.23	1.17	0.92
D 10	1.92	1.88	1.90	1.90	0.02
D 90	8.84	8.22	8.59	8.55	0.31
RATIO	4.60	4.37	4.52	4.50	0.12

PARTICLE SIZE DATA SUMMARY SHEET

INSTRUMENT SALD-1100

DATE: February 13, 1990

SAMPLE INFORMATION

CUSTOMER NAME G.E.E.S.
 SAMPLE TYPE Coke-Ash
 SAMPLE NUMBER Run 30 12-15-89
 RANGE/MODE A-3
 SUSPENSION MEDIA Methanol

	RUN #1	RUN #2	RUN #3		
DIAMETER	VOLUME PERCENT	VOLUME PERCENT	VOLUME PERCENT	AVERAGE	STD.DEV
45.00	100.0	100.0	100.0	100.0	0.0
31.00	100.0	100.0	100.0	100.0	0.0
22.00	100.0	100.0	100.0	100.0	0.0
16.00	100.0	100.0	100.0	100.0	0.0
11.00	94.2	94.1	94.0	94.1	0.1
7.50	71.2	70.4	69.9	70.5	0.7
5.30	65.0	63.9	63.2	64.0	0.9
3.70	53.2	52.0	51.2	52.1	1.0
2.60	13.6	13.1	12.7	13.1	0.5
1.80	3.2	2.9	2.7	2.9	0.3
1.30	0.6	0.6	0.5	0.6	0.1
0.88	0.0	0.0	0.0	0.0	0.0
0.60	0.0	0.0	0.0	0.0	0.0
0.43	0.0	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0	0.0
0.17	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0

	μm	μm	μm	Average	Std.Dev
MEDIAN DIA	3.60	3.63	3.66	3.63	0.03
D 84.1	9.29	9.36	9.40	9.35	0.06
D 15.9	2.65	2.67	2.68	2.67	0.02
WIDTH	0.87	0.87	2.23	1.32	0.78
D 10	2.29	2.32	2.35	2.32	0.03
D 90	10.25	10.30	10.33	10.29	0.04
RATIO	4.48	4.44	4.40	4.44	0.04

PARTICLE SIZE DATA SUMMARY SHEET

INSTRUMENT SALD-1100

DATE: February 13, 1990

SAMPLE INFORMATION

CUSTOMER NAME G.E.E.S.
 SAMPLE TYPE Coke-Ash
 SAMPLE NUMBER Run 31 12-15-89
 RANGE/MODE A-3
 SUSPENSION MEDIA Methanol

	RUN #1	RUN #2	RUN #3		
DIAMETER	VOLUME PERCENT	VOLUME PERCENT	VOLUME PERCENT	AVERAGE	STD.DEV
45.00	100.0	100.0	100.0	100.0	0.0
31.00	100.0	100.0	100.0	100.0	0.0
22.00	100.0	100.0	100.0	100.0	0.0
16.00	100.0	100.0	100.0	100.0	0.0
11.00	94.2	94.0	93.8	94.0	0.2
7.50	70.8	69.9	68.8	69.8	1.0
5.30	65.0	63.9	62.3	63.7	1.4
3.70	55.1	54.1	52.1	53.8	1.5
2.60	15.7	15.3	14.5	15.2	0.6
1.80	5.0	4.8	4.4	4.7	0.3
1.30	1.6	1.5	1.3	1.5	0.2
0.88	0.6	0.6	0.5	0.6	0.1
0.60	0.1	0.1	0.1	0.1	0.0
0.43	0.0	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0	0.0
0.17	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0

	μm	μm	μm	Average	Std.Dev
MEDIAN DIA	3.53	3.57	3.63	3.58	0.05
D 84.1	9.32	9.40	9.49	9.40	0.09
D 15.9	2.60	2.61	2.64	2.62	0.02
WIDTH	0.89	0.90	2.23	1.34	0.77
D 10	2.14	2.16	2.21	2.17	0.04
D 90	10.27	10.32	10.39	10.33	0.06
RATIO	4.80	4.78	4.70	4.76	0.05

PARTICLE SIZE DATA SUMMARY SHEET

INSTRUMENT SALD-1100

DATE: February 13, 1990

SAMPLE INFORMATION

CUSTOMER NAME G.E.E.S.
 SAMPLE TYPE Coke-Ash
 SAMPLE NUMBER Run 33 Thimble A5
 RANGE/MODE A-3
 SUSPENSION MEDIA Methanol

	RUN #1	RUN #2	RUN #3		
DIAMETER	VOLUME PERCENT	VOLUME PERCENT	VOLUME PERCENT	AVERAGE	STD.DEV
45.00	100.0	100.0	100.0	100.0	0.0
31.00	100.0	100.0	100.0	100.0	0.0
22.00	100.0	100.0	100.0	100.0	0.0
16.00	100.0	100.0	100.0	100.0	0.0
11.00	95.9	95.7	95.3	95.6	0.3
7.50	79.7	78.4	76.3	78.1	1.7
5.30	75.7	74.0	71.6	73.8	2.1
3.70	64.6	63.2	61.2	63.0	1.7
2.60	20.4	19.8	19.4	19.9	0.5
1.80	8.1	7.2	7.8	7.9	0.2
1.30	3.2	3.0	2.9	3.0	0.2
0.88	1.6	1.5	1.4	1.5	0.1
0.60	0.3	0.3	0.3	0.3	0.0
0.43	0.0	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0	0.0
0.17	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0

	μm	μm	μm	Average	Std.Dev
MEDIAN DIA	3.29	3.32	3.37	3.33	0.04
D 84.1	8.31	8.52	8.78	8.54	0.24
D 15.9	2.27	2.31	2.33	2.30	0.03
WIDTH	0.91	0.92	2.23	1.35	0.76
D 10	1.90	1.93	1.93	1.92	0.02
D 90	9.56	9.70	9.89	9.72	0.17
RATIO	5.03	5.03	5.12	5.06	0.06

PARTICLE SIZE DATA SUMMARY SHEET

INSTRUMENT SALD-1100

DATE: February 13, 1990

SAMPLE INFORMATION

CUSTOMER NAME G.E.E.S.
 SAMPLE TYPE Coke-Ash
 SAMPLE NUMBER Run 34 Thimble C6
 RANGE/MODE A-3
 SUSPENSION MEDIA Methanol

	RUN #1	RUN #2	RUN #3		
DIAMETER	VOLUME PERCENT	VOLUME PERCENT	VOLUME PERCENT	AVERAGE	STD.DEV
45.00	100.0	100.0	100.0	100.0	0.0
31.00	100.0	100.0	100.0	100.0	0.0
22.00	100.0	100.0	100.0	100.0	0.0
16.00	100.0	100.0	100.0	100.0	0.0
11.00	95.0	94.7	94.5	94.7	0.3
7.50	74.9	73.7	72.8	73.8	1.1
5.30	69.9	68.5	67.4	68.6	1.3
3.70	59.6	58.3	57.4	58.4	1.1
2.60	18.3	17.8	17.5	17.9	0.4
1.80	6.9	6.6	6.5	6.7	0.2
1.30	2.5	2.4	2.3	2.4	0.1
0.88	1.2	1.1	1.1	1.1	0.1
0.60	0.2	0.2	0.2	0.2	0.0
0.43	0.0	0.0	0.0	0.0	0.0
0.30	0.0	0.0	0.0	0.0	0.0
0.17	0.0	0.0	0.0	0.0	0.0
0.10	0.0	0.0	0.0	0.0	0.0

	µm	µm	µm	Average	Std.Dev
MEDIAN DIA	3.41	3.44	3.47	3.44	0.03
D 84.1	8.94	9.06	9.15	9.05	0.11
D 15.9	2.40	2.44	2.46	2.43	0.03
WIDTH	0.93	0.93	2.23	1.36	0.75
D 10	1.99	2.01	2.02	2.01	0.02
D 90	10.00	10.09	10.16	10.08	0.08
RATIO	5.03	5.02	5.03	5.02	0.00

G.E. Environmental Systems
SALD-1100 Analysis 2/13/90
Coke/Ash Run 28 12-7-89

G.E. Environmental Systems
SALD-1100 Analysis 2/13/90
Coke/Ash Run 29 12-11-89

G.E. Environmental Systems
SALD-1100 Analysis 2/13/90
Coke/Ash Run 30 12-15-89

G.E. Environmental Systems
SALD-1100 Analysis 2/13/90
Coke/Ash Run 31 12-15-89

G.E. Environmental Systems
SALD-1100 Analysis 2/13/90
Coke/Ash Run 33 Thimble A5

G.E. Environmental Systems
SALD-1100 Analysis 2/13/90
Coke/Ash Run 34 Thimble C6

G.E. Environmental Systems
SALD-1100 Analysis 2/13/90
Coke/Ash Run Comparison

General Electric Environmental Services, Inc.
200 North Seventh Street
Lebanon, Pennsylvania 17042
Telephone 717/272-2001
Telex 842-332

DUSTAN/IS DATA

LOSS ON IGNITION DETERMINATION

Sample Received from: GETS./DOE CORL WALK DIESEL TRU

Date: 2/9/90

Sample Particulars: GEEST No. 59513/PAR2 Lab No. _____

Starting Temp: AMBIENT

Material DIESEL ENGINE EXHAUST/ASH

Final Temp: 800°C

Source GETS TEST RUN #28/GETS THIMBLE

GETS TEST RUN #29/GETS THIMBLE

	TEST DATE 12-7-89 GETS TEST RUN #28		TEST DATE 12-11-89 GETS TEST RUN #29	
	RUN #1 #309	RUN #2 #114	RUN #1 #301	RUN #2 #304
Wt. of crucible and dust (b)	14.2245	13.9354	14.2583	14.1906
Wt. of crucible (a)	13.2281	12.9349	13.0583	13.1906
Wt. of dust (b-a)	1.0008	1.0005	1.0000	1.0000
Wt. of crucible and dust before ignition (b)	14.2295	13.9354	14.0583	14.1906
Wt. of crucible and dust after ignition (c)	13.9982	13.7124	13.8062	13.9412
Wt. of loss (b - c)	0.2313	0.2230	0.2521	0.2494
% L.C.I. = $\frac{\text{wt of loss} \times 100}{\text{wt of dust}}$	23.11%	22.29%	25.21%	24.94%

ASH

2270%

24.93%

Remarks:

Name:

M. H. Conrad

LOSS ON IGNITION DETERMINATION

Sample Received from: GETS/DDE COAL WATER DIESEL PRJT

Date: 2/12/90

Sample Particulars: GEEST No. 59513/PA2 Lab No. -----

Starting Temp: AIRBURN

Material DIESEL ENGINE EXHAUST / ASM

Final Temp: 800°C

Source GETS TEST RUN # 33/GETS THIMBLE

GETS TEST RUN # 34 /GETS THIMBLE

	THIMBLE AS		THIMBLE CG	
	GETS TEST RUN # 33	GETS TEST RUN # 34	GETS TEST RUN # 33	GETS TEST RUN # 34
	RUN #1	RUN #2	RUN #1	RUN #2
Wt. of crucible and dust (b)	13.9972	13.1581	13.4298	13.4316
Wt. of crucible (a)	12.9962	12.1556	12.4298	12.4297
Wt. of dust (b-a=y)	1.0010	1.0025	1.0000	1.0019
Wt. of crucible and dust before ignition (b)	13.9972	13.1581	13.4298	13.4316
Wt. of crucible and dust after ignition (c)	13.6403	12.7990	13.0824	13.0927
Wt. of loss (b - c)	0.3569	0.3591	0.3474	0.3389
% L.O.I. = $\frac{\text{wt of loss} \times 100}{\text{wt of dust}}$	35.65%	35.82%	34.74%	33.83%

Agh

64.27%

65.72%

Remarks:

Name:

M. A. Arnold

DUST AND SIS DATA

LOSS ON IGNITION DETERMINATION

Sample Received from: GETS DOE COAL WATER DIESEL PRJT

Date: 2/12/72

Starting Temp: Ambient

Final Temp: 300°C

Sample Particulars: GEEST No. 59513/PA2 Lab No. _____

Material ~~DIESEL ENGINE EXHAUST~~ / ASH

Source: GETS TEST RUN # 30 / GETS THIMBLE

GETS TEST RUN # 31 / GETS THINBLE

	TEST DATE 12-15-89		TEST DATE 12-15-89	
	GAES TEST RUN #1	GAES TEST RUN #2	GAES TEST RUN #1	GAES TEST RUN #2
Wt. of crucible and dust (b)	RUN #1 #1006	RUN #2 #123	RUN #1 #3028	RUN #2 #307
Wt. of crucible (a)	13.8802	13.4214	14.1362	14.4492
Wt. of dust (b-a)	12.8813	12.4206	13.1359	13.4473
	1.0016	1.0008	1.0003	1.0019
Wt. of crucible and dust before ignition (b)	13.8802	13.4214	14.1362	14.4492
Wt. of crucible and dust after ignition (c)	13.2249	12.7709	13.4883	13.8005
Wt. of loss (b - c)	0.6503	0.6505	0.6479	0.6487
% L.O.I. = $\frac{\text{wt of loss} \times 100}{\text{wt of dust}}$	64.93%	65.00%	64.77%	64.75%

味

Remarks:

Name:

M. H. Fernald

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 34.004
RANGE:A3 METHOD:D
ABS= 0.152 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER		DIF.	CUM.
	X:(μm)	q3:(%)	Q3:(%)	
01	45.00 - 31.00	0	100.0	
02	31.00 - 22.00	0	100.0	
03	22.00 - 16.00	0	100.0	
04	16.00 - 11.00	5.0	100.0	
05	11.00 - 7.50	20.1	95.0	
06	7.50 - 5.30	5.0	74.9	
07	5.30 - 3.70	10.3	69.9	
08	3.70 - 2.60	41.2	59.6	
09	2.60 - 1.80	11.4	18.3	
10	1.80 - 1.30	4.4	6.9	
11	1.30 - 0.88	1.3	2.5	
12	0.88 - 0.60	0.9	1.2	
13	0.60 - 0.43	0.2	0.2	
14	0.43 - 0.30	0	0	
15	0.30 - 0.17	0	0	
16	0.17 - 0.10	0	0	
17	0.10	0	0	

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 34.004
RANGE:A3 METHOD:D
ABS= 0.159 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER		DIF.	CUM.
	X:(μm)	q3:(%)	Q3:(%)	
01	45.00 - 31.00	0	100.0	
02	31.00 - 22.00	0	100.0	
03	22.00 - 16.00	0	100.0	
04	16.00 - 11.00	5.3	100.0	
05	11.00 - 7.50	21.8	94.7	
06	7.50 - 5.30	5.3	73.7	
07	5.30 - 3.70	10.1	68.5	
08	3.70 - 2.60	40.5	58.3	
09	2.60 - 1.80	11.2	17.8	
10	1.80 - 1.30	4.3	6.6	
11	1.30 - 0.88	1.3	2.4	
12	0.88 - 0.60	0.9	1.1	
13	0.60 - 0.43	0.2	0.2	
14	0.43 - 0.30	0	0	
15	0.30 - 0.17	0	0	
16	0.17 - 0.10	0	0	
17	0.10	0	0	

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 34.003
RANGE:A3 METHOD:D
ABS= 0.157 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER		DIF.	CUM.
	X:(μm)	q3:(%)	Q3:(%)	
01	45.00 - 31.00	0	100.0	
02	31.00 - 22.00	0	100.0	
03	22.00 - 16.00	0	100.0	
04	16.00 - 11.00	5.5	100.0	
05	11.00 - 7.50	21.7	94.5	
06	7.50 - 5.30	5.4	72.8	
07	5.30 - 3.70	10.0	67.4	
08	3.70 - 2.60	39.9	57.4	
09	2.60 - 1.80	11.0	17.5	
10	1.80 - 1.30	4.2	6.5	
11	1.30 - 0.88	1.3	2.3	
12	0.88 - 0.60	0.9	1.1	
13	0.60 - 0.43	0.2	0.2	
14	0.43 - 0.30	0	0	
15	0.30 - 0.17	0	0	
16	0.17 - 0.10	0	0	
17	0.10	0	0	

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 34.004
RANGE:A3 METHOD:D
ABS= 0.152 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.		DIF.	CUM.	CUM.	DIAM.
	X:(μm)	q3:(%)	Q3:(%)	Q3:(%)	Q3:(%)	X:(μm)
01	45.00	0	100.0	99.00	14.85	
02	40.00	0	100.0	95.00	11.02	
03	35.00	0	100.0	90.00	10.00	
04	30.00	0	100.0	84.10	8.94	
05	25.00	0	100.0	75.00	7.52	
06	20.00	0	100.0	50.00	3.41	
07	15.00	0.9	99.1	25.00	2.75	
08	10.00	9.2	90.8	15.90	2.40	
09	7.50	15.1	74.9	10.00	1.99	
10	5.00	6.7	68.2	5.00	1.56	
11	2.50	51.1	17.1	1.00	0.82	
12	1.00	15.5	1.6			
13	0.75	0.8	0.8			
14	0.50	0.7	0.1			
15	0.25	0.1	0			
16	0.10	0	0			

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 34.004
RANGE:A3 METHOD:D
ABS= 0.159 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.		DIF.	CUM.	CUM.	DIAM.
	X:(μm)	q3:(%)	Q3:(%)	Q3:(%)	Q3:(%)	X:(μm)
01	45.00	0	100.0	99.00	14.90	
02	40.00	0	100.0	95.00	11.20	
03	35.00	0	100.0	90.00	10.89	
04	30.00	0	100.0	84.10	9.06	
05	25.00	0	100.0	75.00	7.68	
06	20.00	0	100.0	50.00	3.44	
07	15.00	0.9	99.1	25.00	2.77	
08	10.00	9.6	89.5	15.90	2.44	
09	7.50	15.8	73.7	10.00	2.01	
10	5.00	6.9	66.8	5.00	1.59	
11	2.50	50.2	16.6	1.00	0.84	
12	1.00	15.1	1.5			
13	0.75	0.8	0.7			
14	0.50	0.6	0.1			
15	0.25	0.1	0			
16	0.10	0	0			

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 34.003
RANGE:A3 METHOD:D
ABS= 0.157 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.		DIF.	CUM.	CUM.	DIAM.
	X:(μm)	q3:(%)	Q3:(%)	Q3:(%)	Q3:(%)	X:(μm)
01	45.00	0	100.0	99.00	14.97	
02	40.00	0	100.0	95.00	11.39	
03	35.00	0	100.0	90.00	10.16	
04	30.00	0	100.0	84.10	9.15	
05	25.00	0	100.0	75.00	7.79	
06	20.00	0	100.0	50.00	3.47	
07	15.00	1.0	99.0	25.00	2.78	
08	10.00	9.9	89.1	15.90	2.46	
09	7.50	16.3	72.8	10.00	2.02	
10	5.00	7.0	65.8	5.00	1.60	
11	2.50	49.5	16.3	1.00	0.85	
12	1.00	14.8	1.5			
13	0.75	0.8	0.7			
14	0.50	0.6	0.1			
15	0.25	0.1	0			
16	0.10	0	0			

SAMPLE
SAMPLE

SAMPLE
SAMPLE

SAMPLE
SAMPLE

ID G.E.E.S. 2/13/90
 COKE-ASH/RUN 34.001

SAMPLE ID G.E.E.S. 2/13/90
 SAMPLE # COKE-ASH/RUN 34.001

ID G.E.E.S. 2/13/90
 COKE-ASH/RUN 34.002

SAMPLE ID G.E.E.S. 2/13/90
 SAMPLE # COKE-ASH/RUN 34.002

ID G.E.E.S. 2/13/90
 COKE-ASH/RUN 34.003

SAMPLE ID G.E.E.S. 2/13/90
 SAMPLE # COKE-ASH/RUN 34.003

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 33.001
RANGE:A3 METHOD:D
ABS= 0.142 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)
01	45.00 - 31.00	0	100.0
02	31.00 - 22.00	0	100.0
03	22.00 - 16.00	0	100.0
04	16.00 - 11.00	4.1	100.0
05	11.00 - 7.50	16.2	95.9
06	7.50 - 5.30	4.1	79.7
07	5.30 - 3.70	11.1	75.7
08	3.70 - 2.60	44.2	64.6
09	2.60 - 1.80	12.3	20.4
10	1.80 - 1.30	4.9	8.1
11	1.30 - 0.88	1.6	3.2
12	0.88 - 0.60	1.3	1.6
13	0.60 - 0.43	0.3	0.3
14	0.43 - 0.30	0	0
15	0.30 - 0.17	0	0
16	0.17 - 0.10	0	0
17	0.10	0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 33.002
RANGE:A3 METHOD:D
ABS= 0.143 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)
01	45.00 - 31.00	0	100.0
02	31.00 - 22.00	0	100.0
03	22.00 - 16.00	0	100.0
04	16.00 - 11.00	4.3	100.0
05	11.00 - 7.50	17.3	95.7
06	7.50 - 5.30	4.3	78.4
07	5.30 - 3.70	10.8	74.0
08	3.70 - 2.60	43.4	61.2
09	2.60 - 1.80	12.0	19.8
10	1.80 - 1.30	4.7	7.8
11	1.30 - 0.88	1.5	3.0
12	0.88 - 0.60	1.2	1.5
13	0.60 - 0.43	0.3	0.3
14	0.43 - 0.30	0	0
15	0.30 - 0.17	0	0
16	0.17 - 0.10	0	0
17	0.10	0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 33.003
RANGE:A3 METHOD:D
ABS= 0.143 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)
01	45.00 - 31.00	0	100.0
02	31.00 - 22.00	0	100.0
03	22.00 - 16.00	0	100.0
04	16.00 - 11.00	4.7	100.0
05	11.00 - 7.50	18.9	95.3
06	7.50 - 5.30	4.7	76.3
07	5.30 - 3.70	10.4	71.6
08	3.70 - 2.60	41.8	61.2
09	2.60 - 1.80	11.6	19.4
10	1.80 - 1.30	4.8	7.8
11	1.30 - 0.88	1.5	2.9
12	0.88 - 0.60	1.2	1.4
13	0.60 - 0.43	0.3	0.3
14	0.43 - 0.30	0	0
15	0.30 - 0.17	0	0
16	0.17 - 0.10	0	0
17	0.10	0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 33.001
RANGE:A3 METHOD:D
ABS= 0.142 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM. X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)	CUM. Q3:(%)	DIAM. X:(μ m)
01	45.00	0	100.0	99.00	14.59
02	40.00	0	100.0	95.00	10.76
03	35.00	0	100.0	90.00	9.56
04	30.00	0	100.0	84.10	8.31
05	25.00	0	100.0	75.00	5.18
06	20.00	0	100.0	50.00	3.29
07	15.00	0.7	99.3	25.00	2.70
08	10.00	7.4	91.9	15.90	2.27
09	7.50	12.2	79.7	10.00	1.90
10	5.00	5.8	73.9	5.00	1.47
11	2.50	54.8	19.1	1.00	0.73
12	1.00	17.0	2.1		
13	0.75	1.1	1.1		
14	0.50	0.9	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 33.002
RANGE:A3 METHOD:D
ABS= 0.143 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM. X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)	CUM. Q3:(%)	DIAM. X:(μ m)
01	45.00	0	100.0	99.00	14.68
02	40.00	0	100.0	95.00	10.84
03	35.00	0	100.0	90.00	9.70
04	30.00	0	100.0	84.10	8.52
05	25.00	0	100.0	75.00	5.73
06	20.00	0	100.0	50.00	3.32
07	15.00	0.7	99.3	25.00	2.71
08	10.00	7.9	91.4	15.90	2.31
09	7.50	13.0	78.4	10.00	1.93
10	5.00	6.1	72.3	5.00	1.49
11	2.50	53.8	18.5	1.00	0.74
12	1.00	16.5	2.0		
13	0.75	1.0	1.0		
14	0.50	0.9	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 33.003
RANGE:A3 METHOD:D
ABS= 0.143 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM. X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)	CUM. Q3:(%)	DIAM. X:(μ m)
01	45.00	0	100.0	99.00	14.79
02	40.00	0	100.0	95.00	10.94
03	35.00	0	100.0	90.00	9.89
04	30.00	0	100.0	84.10	8.78
05	25.00	0	100.0	75.00	6.79
06	20.00	0	100.0	50.00	3.37
07	15.00	0.8	99.2	25.00	2.73
08	10.00	8.6	90.6	15.90	2.33
09	7.50	14.2	76.3	10.00	1.93
10	5.00	6.4	69.9	5.00	1.49
11	2.50	51.8	18.2	1.00	0.76
12	1.00	16.2	1.9		
13	0.75	1.0	1.0		
14	0.50	0.8	0.1		
15	0.25	0.1	0		
16	0.10	0	0

E ID G.E.E.S. 2/13/90
E # COKE-ASH/RUN 33.001

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 33.001

ID G.E.E.S. 2/13/90
COKE-ASH/RUN 33.002

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 33.002

ID G.E.E.S. 2/13/90
COKE-ASH/RUN 33.003

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 33.003

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 31.001
RANGE:A3 METHOD:D
ABS= 0.174 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER	DIF.	CUM.
	X:(μ m)	q3:(%)	Q3:(%)
01	45.00 - 31.00	0	100.0
02	31.00 - 22.00	0	100.0
03	22.00 - 16.00	0	100.0
04	16.00 - 11.00	5.8	100.0
05	11.00 - 7.50	23.3	94.2
06	7.50 - 5.30	5.8	70.8
07	5.30 - 3.70	9.9	65.0
08	3.70 - 2.60	39.5	55.1
09	2.60 - 1.80	10.7	15.7
10	1.80 - 1.30	3.4	5.0
11	1.30 - 0.88	1.0	1.6
12	0.88 - 0.60	0.5	0.6
13	0.60 - 0.43	0.1	0.1
14	0.43 - 0.30	0	0
15	0.30 - 0.17	0	0
16	0.17 - 0.10	0	0
17	0.10	0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 31.002
RANGE:A3 METHOD:D
ABS= 0.178 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER	DIF.	CUM.
	X:(μ m)	q3:(%)	Q3:(%)
01	45.00 - 31.00	0	100.0
02	31.00 - 22.00	0	100.0
03	22.00 - 16.00	0	100.0
04	16.00 - 11.00	6.0	100.0
05	11.00 - 7.50	24.1	94.0
06	7.50 - 5.30	6.0	69.9
07	5.30 - 3.70	9.8	63.9
08	3.70 - 2.60	38.8	54.1
09	2.60 - 1.80	10.5	15.3
10	1.80 - 1.30	3.3	4.8
11	1.30 - 0.88	0.9	1.5
12	0.88 - 0.60	0.5	0.6
13	0.60 - 0.43	0.1	0.1
14	0.43 - 0.30	0	0
15	0.30 - 0.17	0	0
16	0.17 - 0.10	0	0
17	0.10	0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 31.003
RANGE:A3 METHOD:D
ABS= 0.175 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER	DIF.	CUM.
	X:(μ m)	q3:(%)	Q3:(%)
01	45.00 - 31.00	0	100.0
02	31.00 - 22.00	0	100.0
03	22.00 - 16.00	0	100.0
04	16.00 - 11.00	6.2	100.0
05	11.00 - 7.50	25.0	93.8
06	7.50 - 5.30	6.5	68.8
07	5.30 - 3.70	10.2	62.3
08	3.70 - 2.60	37.6	52.1
09	2.60 - 1.80	10.1	14.5
10	1.80 - 1.30	3.0	4.4
11	1.30 - 0.88	0.9	1.3
12	0.88 - 0.60	0.4	0.5
13	0.60 - 0.43	0.1	0.1
14	0.43 - 0.30	0	0
15	0.30 - 0.17	0	0
16	0.17 - 0.10	0	0
17	0.10	0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 31.001
RANGE:A3 METHOD:D
ABS= 0.174 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.	DIF.	CUM.	CUM.	DIAM.
	X:(μ m)	q3:(%)	Q3:(%)	Q3:(%)	X:(μ m)
01	45.00	0	100.0	99.00	15.01
02	40.00	0	100.0	95.00	11.60
03	35.00	0	100.0	90.00	10.27
04	30.00	0	100.0	84.10	9.32
05	25.00	0	100.0	75.00	8.03
06	20.00	0	100.0	50.00	3.53
07	15.00	1.0	99.0	25.00	2.83
08	10.00	10.6	88.4	15.90	2.60
09	7.50	17.5	70.8	10.00	2.14
10	5.00	7.4	63.4	5.00	1.80
11	2.50	48.9	14.5	1.00	1.04
12	1.00	13.6	0.9		
13	0.75	0.5	0.4		
14	0.50	0.3	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 31.002
RANGE:A3 METHOD:D
ABS= 0.178 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.	DIF.	CUM.	CUM.	DIAM.
	X:(μ m)	q3:(%)	Q3:(%)	Q3:(%)	X:(μ m)
01	45.00	0	100.0	99.00	15.04
02	40.00	0	100.0	95.00	11.72
03	35.00	0	100.0	90.00	10.32
04	30.00	0	100.0	84.10	9.40
05	25.00	0	100.0	75.00	8.13
06	20.00	0	100.0	50.00	3.57
07	15.00	1.0	99.0	25.00	2.84
08	10.00	11.0	88.0	15.90	2.61
09	7.50	18.1	69.9	10.00	2.16
10	5.00	7.6	62.3	5.00	1.81
11	2.50	48.1	14.2	1.00	1.04
12	1.00	13.3	0.9		
13	0.75	0.5	0.4		
14	0.50	0.3	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 31.003
RANGE:A3 METHOD:D
ABS= 0.175 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.	DIF.	CUM.	CUM.	DIAM.
	X:(μ m)	q3:(%)	Q3:(%)	Q3:(%)	X:(μ m)
01	45.00	0	100.0	99.00	15.07
02	40.00	0	100.0	95.00	11.85
03	35.00	0	100.0	90.00	10.39
04	30.00	0	100.0	84.10	9.49
05	25.00	0	100.0	75.00	8.25
06	20.00	0	100.0	50.00	3.63
07	15.00	1.1	98.9	25.00	2.87
08	10.00	11.4	87.5	15.90	2.64
09	7.50	18.8	68.8	10.00	2.21
10	5.00	8.1	60.7	5.00	1.84
11	2.50	47.3	13.4	1.00	1.12
12	1.00	12.6	0.8		
13	0.75	0.4	0.3		
14	0.50	0.3	0		
15	0.25	0	0		
16	0.10	0	0

G.E.E.S. 2/13/90
COKE-ASH/RUN 31.001

PARTICLE DIAMETER (μm)

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 31.001

→ X PARTICLE DIAMETER (μm)

G.E.E.S. 2/13/90
COKE-ASH/RUN 31.002

PARTICLE DIAMETER (μm)

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 31.002

→ X PARTICLE DIAMETER (μm)

G.E.E.S. 2/13/90
COKE-ASH/RUN 31.003

PARTICLE DIAMETER (μm)

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 31.003

→ X PARTICLE DIAMETER (μm)

SALD-1100 PARTICLE SIZE ANALYSIS
V2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 30.001
RANGE:A3 METHOD:D
ABS= 0.163 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER		DIF.	CUM.	
	X:(μ m)		q3:(%)	Q3:(%)	
01	45.00	31.00	0	100.0	
02	31.00	22.00	0	100.0	
03	22.00	16.00	0	100.0	
04	16.00	11.00	5.8	100.0	
05	11.00	7.50	23.0	94.2	
06	7.50	5.30	6.2	71.2	
07	5.30	3.70	11.7	65.0	
08	3.70	2.60	39.6	53.2	
09	2.60	1.80	10.4	13.6	
10	1.80	1.30	2.5	3.2	
11	1.30	0.88	0.6	0.6	
12	0.88	0.60	0	0	
13	0.60	0.43	0	0	
14	0.43	0.30	0	0	
15	0.30	0.17	0	0	
16	0.17	0.10	0	0	
17	0.10		0	0	

SALD-1100 PARTICLE SIZE ANALYSIS
V2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 30.002
RANGE:A3 METHOD:D
ABS= 0.160 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER		DIF.	CUM.	
	X:(μ m)		q3:(%)	Q3:(%)	
01	45.00	31.00	0	100.0	
02	31.00	22.00	0	100.0	
03	22.00	16.00	0	100.0	
04	16.00	11.00	5.9	100.0	
05	11.00	7.50	23.7	94.1	
06	7.50	5.30	6.5	70.4	
07	5.30	3.70	11.9	63.9	
08	3.70	2.60	38.9	52.0	
09	2.60	1.80	10.2	13.1	
10	1.80	1.30	2.3	2.9	
11	1.30	0.88	0.6	0.6	
12	0.88	0.60	0	0	
13	0.60	0.43	0	0	
14	0.43	0.30	0	0	
15	0.30	0.17	0	0	
16	0.17	0.10	0	0	
17	0.10		0	0	

SALD-1100 PARTICLE SIZE ANALYSIS
V2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 30.003
RANGE:A3 METHOD:D
ABS= 0.152 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER		DIF.	CUM.	
	X:(μ m)		q3:(%)	Q3:(%)	
01	45.00	31.00	0	100.0	
02	31.00	22.00	0	100.0	
03	22.00	16.00	0	100.0	
04	16.00	11.00	6.0	100.0	
05	11.00	7.50	24.1	94.0	
06	7.50	5.30	6.7	69.9	
07	5.30	3.70	12.0	63.2	
08	3.70	2.60	38.4	51.2	
09	2.60	1.80	10.0	12.7	
10	1.80	1.30	2.2	2.7	
11	1.30	0.88	0.5	0.5	
12	0.88	0.60	0	0	
13	0.60	0.43	0	0	
14	0.43	0.30	0	0	
15	0.30	0.17	0	0	
16	0.17	0.10	0	0	
17	0.10		0	0	

SALD-1100 PARTICLE SIZE ANALYSIS
V2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 30.001
RANGE:A3 METHOD:D
ABS= 0.163 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.	DIF.	CUM.	CUM.	DIAM.
	X:(μ m)	q3:(%)	Q3:(%)	Q3:(%)	X:(μ m)
01	45.00	0	100.0	99.00	15.00
02	40.00	0	100.0	95.00	11.56
03	35.00	0	100.0	90.00	10.25
04	30.00	0	100.0	84.10	9.29
05	25.00	0	100.0	75.00	7.99
06	20.00	0	100.0	50.00	3.60
07	15.00	1.0	99.0	25.00	2.88
08	10.00	10.5	88.5	15.90	2.65
09	7.50	17.3	71.2	10.00	2.29
10	5.00	8.1	63.1	5.00	1.92
11	2.50	50.6	12.5	1.00	1.36
12	1.00	12.3	0.2		
13	0.75	0.2	0		
14	0.50	0	0		
15	0.25	0	0		
16	0.10	0	0		

SALD-1100 PARTICLE SIZE ANALYSIS
V2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 30.002
RANGE:A3 METHOD:D
ABS= 0.160 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.	DIF.	CUM.	CUM.	DIAM.
	X:(μ m)	q3:(%)	Q3:(%)	Q3:(%)	X:(μ m)
01	45.00	0	100.0	99.00	15.02
02	40.00	0	100.0	95.00	11.66
03	35.00	0	100.0	90.00	10.30
04	30.00	0	100.0	84.10	9.36
05	25.00	0	100.0	75.00	8.08
06	20.00	0	100.0	50.00	3.63
07	15.00	1.0	99.0	25.00	2.90
08	10.00	10.8	88.2	15.90	2.67
09	7.50	17.8	70.4	10.00	2.32
10	5.00	8.4	62.0	5.00	1.94
11	2.50	50.0	12.0	1.00	1.38
12	1.00	11.8	0.2		
13	0.75	0.2	0		
14	0.50	0	0		
15	0.25	0	0		
16	0.10	0	0		

SALD-1100 PARTICLE SIZE ANALYSIS
V2.11
SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 30.003
RANGE:A3 METHOD:D
ABS= 0.152 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.	DIF.	CUM.	CUM.	DIAM.
	X:(μ m)	q3:(%)	Q3:(%)	Q3:(%)	X:(μ m)
01	45.00	0	100.0	99.00	15.04
02	40.00	0	100.0	95.00	11.72
03	35.00	0	100.0	90.00	10.33
04	30.00	0	100.0	84.10	9.40
05	25.00	0	100.0	75.00	8.14
06	20.00	0	100.0	50.00	3.66
07	15.00	1.0	99.0	25.00	2.91
08	10.00	11.0	88.0	15.90	2.68
09	7.50	18.1	69.9	10.00	2.35
10	5.00	8.6	61.3	5.00	1.96
11	2.50	49.6	11.7	1.00	1.39
12	1.00	11.5	0.2		
13	0.75	0.2	0		
14	0.50	0	0		
15	0.25	0	0		
16	0.10	0	0

D G.E.E.S. 2/13/90
COKE-ASH/RUN 30.001

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 30.001

D G.E.E.S. 2/13/90
COKE-ASH/RUN 30.002

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 30.002

G.E.E.S. 2/13/90
COKE-ASH/RUN 30.003

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 30.003

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE #: COKE-ASH/RUN 29.001
RANGE:A3 METHOD:D
ABS= 0.150 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER		DIF.	CUM.
	X:(μ m)		q3:(%)	Q3:(%)
01	45.00	31.00	0	100.0
02	31.00	22.00	0	100.0
03	22.00	16.00	0	100.0
04	16.00	11.00	3.0	100.0
05	11.00	7.50	12.2	97.0
06	7.50	5.30	3.0	84.8
07	5.30	3.70	12.1	81.7
08	3.70	2.60	48.5	69.6
09	2.60	1.80	13.4	21.0
10	1.80	1.30	5.1	7.6
11	1.30	0.88	1.5	2.6
12	0.88	0.60	0.9	1.1
13	0.60	0.43	0.2	0.2
14	0.43	0.30	0	0
15	0.30	0.17	0	0
16	0.17	0.10	0	0
17	0.10		0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE #: COKE-ASH/RUN 29.001
RANGE:A3 METHOD:D
ABS= 0.150 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.	DIF.	CUM.	CUM.	DIAM.
	X:(μ m)	q3:(%)	Q3:(%)	Q3:(%)	X:(μ m)
01	45.00	0	100.0	99.00	14.15
02	40.00	0	100.0	95.00	10.34
03	35.00	0	100.0	90.00	8.84
04	30.00	0	100.0	84.10	6.95
05	25.00	0	100.0	75.00	4.34
06	20.00	0	100.0	50.00	3.21
07	15.00	0.5	99.5	25.00	2.68
08	10.00	5.6	93.9	15.90	2.26
09	7.50	9.1	84.8	10.00	1.92
10	5.00	5.0	79.8	5.00	1.52
11	2.50	60.1	19.6	1.00	0.84
12	1.00	18.0	1.6		
13	0.75	0.9	0.7		
14	0.50	0.6	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SAMPLE I
SAMPLE II

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE #: COKE-ASH/RUN 29.002
RANGE:A3 METHOD:D
ABS= 0.149 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER		DIF.	CUM.
	X:(μ m)		q3:(%)	Q3:(%)
01	45.00	31.00	0	100.0
02	31.00	22.00	0	100.0
03	22.00	16.00	0	100.0
04	16.00	11.00	2.5	100.0
05	11.00	7.50	9.9	97.5
06	7.50	5.30	2.5	87.7
07	5.30	3.70	12.6	85.2
08	3.70	2.60	50.4	72.6
09	2.60	1.80	14.0	22.2
10	1.80	1.30	5.4	8.3
11	1.30	0.88	1.6	2.8
12	0.88	0.60	1.0	1.2
13	0.60	0.43	0.2	0.2
14	0.43	0.30	0	0
15	0.30	0.17	0	0
16	0.17	0.10	0	0
17	0.10		0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE #: COKE-ASH/RUN 29.002
RANGE:A3 METHOD:D
ABS= 0.149 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.	DIF.	CUM.	CUM.	DIAM.
	X:(μ m)	q3:(%)	Q3:(%)	Q3:(%)	X:(μ m)
01	45.00	0	100.0	99.00	13.75
02	40.00	0	100.0	95.00	9.97
03	35.00	0	100.0	90.00	8.22
04	30.00	0	100.0	84.10	5.14
05	25.00	0	100.0	75.00	3.96
06	20.00	0	100.0	50.00	3.16
07	15.00	0.4	99.6	25.00	2.65
08	10.00	4.5	95.1	15.90	2.20
09	7.50	7.4	87.7	10.00	1.88
10	5.00	4.5	83.1	5.00	1.48
11	2.50	62.4	20.7	1.00	0.81
12	1.00	19.0	1.7		
13	0.75	0.9	0.8		
14	0.50	0.7	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SAMPLE
SAMPLE

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE #: COKE-ASH/RUN 29.003
RANGE:A3 METHOD:D
ABS= 0.147 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER		DIF.	CUM.
	X:(μ m)		q3:(%)	Q3:(%)
01	45.00	31.00	0	100.0
02	31.00	22.00	0	100.0
03	22.00	16.00	0	100.0
04	16.00	11.00	2.8	100.0
05	11.00	7.50	11.2	97.2
06	7.50	5.30	2.8	86.0
07	5.30	3.70	12.3	83.3
08	3.70	2.60	49.4	70.9
09	2.60	1.80	13.7	21.6
10	1.80	1.30	5.3	7.9
11	1.30	0.88	1.5	2.7
12	0.88	0.60	0.9	1.1
13	0.60	0.43	0.2	0.2
14	0.43	0.30	0	0
15	0.30	0.17	0	0
16	0.17	0.10	0	0
17	0.10		0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE #: COKE-ASH/RUN 29.003
RANGE:A3 METHOD:D
ABS= 0.147 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM.	DIF.	CUM.	CUM.	DIAM.
	X:(μ m)	q3:(%)	Q3:(%)	Q3:(%)	X:(μ m)
01	45.00	0	100.0	99.00	13.99
02	40.00	0	100.0	95.00	10.20
03	35.00	0	100.0	90.00	8.59
04	30.00	0	100.0	84.10	5.89
05	25.00	0	100.0	75.00	4.17
06	20.00	0	100.0	50.00	3.19
07	15.00	0.5	99.5	25.00	2.66
08	10.00	5.1	94.4	15.90	2.23
09	7.50	8.4	86.0	10.00	1.90
10	5.00	4.8	81.2	5.00	1.50
11	2.50	61.1	20.1	1.00	0.84
12	1.00	18.5	1.6		
13	0.75	0.9	0.7		
14	0.50	0.6	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SAMPLE
SAMPLE

G.E.E.S. 2/13/90
COKE-ASH/RUN 29.001

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 29.001

G.E.E.S. 2/13/90
COKE-ASH/RUN 29.002

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 29.002

D G.E.E.S. 2/13/90
COKE-ASH/RUN 29.003

SAMPLE ID G.E.E.S. 2/13/90
SAMPLE # COKE-ASH/RUN 29.003

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 28.001
RANGE:A3 METHOD:D
ABS= 0.158 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)
01	45.00 - 31.00	0	100.0
02	31.00 - 22.00	0	100.0
03	22.00 - 16.00	0	100.0
04	16.00 - 11.00	3.4	100.0
05	11.00 - 7.50	13.7	96.6
06	7.50 - 5.30	3.4	82.9
07	5.30 - 3.70	11.7	79.4
08	3.70 - 2.60	46.7	67.8
09	2.60 - 1.80	13.0	21.1
10	1.80 - 1.30	5.1	8.1
11	1.30 - 0.88	1.6	3.0
12	0.88 - 0.60	1.1	1.4
13	0.60 - 0.43	0.3	0.3
14	0.43 - 0.30	0	0
15	0.30 - 0.17	0	0
16	0.17 - 0.10	0	0
17	0.10	0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 28.002
RANGE:A3 METHOD:D
ABS= 0.159 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)
01	45.00 - 31.00	0	100.0
02	31.00 - 22.00	0	100.0
03	22.00 - 16.00	0	100.0
04	16.00 - 11.00	3.9	100.0
05	11.00 - 7.50	15.6	96.1
06	7.50 - 5.30	3.9	80.5
07	5.30 - 3.70	11.3	70.6
08	3.70 - 2.60	45.4	65.2
09	2.60 - 1.80	12.5	19.9
10	1.80 - 1.30	4.7	7.4
11	1.30 - 0.88	1.4	2.7
12	0.88 - 0.60	1.0	1.2
13	0.60 - 0.43	0.2	0.2
14	0.43 - 0.30	0	0
15	0.30 - 0.17	0	0
16	0.17 - 0.10	0	0
17	0.10	0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 28.003
RANGE:A3 METHOD:D
ABS= 0.157 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAMETER X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)
01	45.00 - 31.00	0	100.0
02	31.00 - 22.00	0	100.0
03	22.00 - 16.00	0	100.0
04	16.00 - 11.00	4.2	100.0
05	11.00 - 7.50	17.0	95.8
06	7.50 - 5.30	4.2	78.8
07	5.30 - 3.70	11.1	74.5
08	3.70 - 2.60	44.4	63.4
09	2.60 - 1.80	12.2	19.0
10	1.80 - 1.30	4.4	6.8
11	1.30 - 0.88	1.3	2.4
12	0.88 - 0.60	0.8	1.1
13	0.60 - 0.43	0.2	0.2
14	0.43 - 0.30	0	0
15	0.30 - 0.17	0	0
16	0.17 - 0.10	0	0
17	0.10	0	0

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 28.001
RANGE:A3 METHOD:D
ABS= 0.158 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM. X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)	CUM. Q3:(%)	DIAM. X:(μ m)
01	45.00	0	100.0	99.00	14.35
02	40.00	0	100.0	95.00	10.53
03	35.00	0	100.0	90.00	9.16
04	30.00	0	100.0	84.10	7.77
05	25.00	0	100.0	75.00	4.62
06	20.00	0	100.0	50.00	3.24
07	15.00	0.6	99.4	25.00	2.68
08	10.00	6.2	93.2	15.90	2.25
09	7.50	10.3	82.9	10.00	1.90
10	5.00	5.3	77.5	5.00	1.48
11	2.50	57.9	19.7	1.00	0.76
12	1.00	17.8	1.9		
13	0.75	1.0	0.9		
14	0.50	0.8	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 28.002
RANGE:A3 METHOD:D
ABS= 0.159 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM. X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)	CUM. Q3:(%)	DIAM. X:(μ m)
01	45.00	0	100.0	99.00	14.54
02	40.00	0	100.0	95.00	10.71
03	35.00	0	100.0	90.00	9.47
04	30.00	0	100.0	84.10	8.20
05	25.00	0	100.0	75.00	5.04
06	20.00	0	100.0	50.00	3.29
07	15.00	0.7	99.3	25.00	2.71
08	10.00	7.1	92.2	15.90	2.31
09	7.50	11.7	80.5	10.00	1.94
10	5.00	5.7	74.7	5.00	1.53
11	2.50	56.2	18.6	1.00	0.80
12	1.00	16.9	1.7		
13	0.75	0.9	0.8		
14	0.50	0.7	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SALD-1100 PARTICLE SIZE ANALYSIS
U2.11

SAMPLE ID.:G.E.E.S. 2/13/90
SAMPLE # :COKE-ASH/RUN 28.003
RANGE:A3 METHOD:D
ABS= 0.157 T:5 I: 1(S) U: 0(S)

<PARTICLE SIZE DISTRIBUTION DATA>

	DIAM. X:(μ m)	DIF. q3:(%)	CUM. Q3:(%)	CUM. Q3:(%)	DIAM. X:(μ m)
01	45.00	0	100.0	99.00	14.65
02	40.00	0	100.0	95.00	10.82
03	35.00	0	100.0	90.00	9.66
04	30.00	0	100.0	84.10	8.46
05	25.00	0	100.0	75.00	5.51
06	20.00	0	100.0	50.00	3.33
07	15.00	0.7	99.3	25.00	2.73
08	10.00	7.7	91.5	15.90	2.37
09	7.50	12.8	78.8	10.00	1.98
10	5.00	6.0	72.7	5.00	1.58
11	2.50	55.0	17.7	1.00	0.86
12	1.00	16.2	1.5		
13	0.75	0.8	0.7		
14	0.50	0.6	0.1		
15	0.25	0.1	0		
16	0.10	0	0		

SAMPLE ID G.E
SAMPLE # COKE

SAMPLE ID G.
SAMPLE # CO

SAMPLE ID
SAMPLE #

E.S. 2/13/90
 -ASH/RUN 28.001

SAMPLE ID G.E.E.S. 2/13/90
 SAMPLE # COKE-ASH/RUN 28.001

E.S. 2/13/90
 -ASH/RUN 28.002

SAMPLE ID G.E.E.S. 2/13/90
 SAMPLE # COKE-ASH/RUN 28.002

E.E.S. 2/13/90
 KE-ASH/RUN 28.003

SAMPLE ID G.E.E.S. 2/13/90
 SAMPLE # COKE-ASH/RUN 28.003

END

DATE FILMED

02 / 20 / 91