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FE-2437-6

FOSSIL ENERGY

FEASIBILITY STUDY OF USING A COAL/WATER/OIL EMULSION AS A CLEAN LIQUID FUEL

PHASE 2, SECOND YEAR

Interim Report, December 1977—February 1978

By
John P. Dooher

March 1978
Date Published

Work Performed Under Contract No. EX-76-S-01-2437

Adelphi University
Adelphi Research Center, Inc.
Garden City, New York

U. S. DEPARTMENT OF ENERGY

NOTICE

FE-2437-6
Distribution Category UC-90e

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PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY
Under Contract No. E7-77-S-01-2437

FOREWORD

This report summarizes technical progress accomplished during the second quarter of a one year study being conducted for the Department of Energy under Contract No. E7-77-S-01-2437. The work period was December 1, 1977 through February 28, 1978, and was accomplished under the direction of Dr. John P. Dooher, Principal Investigator. Mr. Henry Jacobson is the technical representative for DOE.

Dr. Sung Moon has contributed to the emulsion studies and Dr. Richard W. Genberg has contributed to the instrumentation and fabrication designs. Donald Wright, Research Scientist, has worked with burner design and combustion chamber modification. Technical support has been given by Steven Jakatt, Research Assistant and graduate students, Barbara Gilmartin and Joseph Skura. Undergraduates Nancy Cava and Diane Tabarini have helped us also. Technical services have been provided by Michael Lopez and Paul Matson.

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ABSTRACT

This report represents work accomplished during the second quarter of our second year of our project to determine the feasibility of using coal/water/oil emulsions as a clean liquid fuel.

The main emphasis this quarter was the integration of our major pieces of equipment with a Wang 720 C Calculator. Coal ground with the new ball mill was tested for rheological and combustion properties.

OBJECTIVES

The proposed program of research is a continuation of our first year studies on the feasibility of coal/water/oil emulsions as a clean liquid fuel. These studies have so far demonstrated that select emulsions can be burned in a conventional oil-fired furnace. However, the behavior of the emulsions under pumping and atomization, and their ultimate value as fuels, has been shown to be strongly dependent on the coal used in the emulsion. In our continuation studies, we propose to correlate coal properties with emulsion properties, especially those parameters relevant to practical coal utilization for emulsion fuels.

The technical objectives of our second year research program are:

1. To correlate coal properties (Maceral content, percent sulfur, percent ash, rank, and particle size) with emulsion viscosity and stability.

2. To relate viscosity data obtained from the Rotovisco to the behavior of emulsions during pumping.

3. To correlate coal properties and emulsion composition with combustion properties for a selection of emulsions whose rheological characteristics are deemed satisfactory.

4. To compare combustion characteristics (i.e., thermal efficiency, flame radiation, particulate emissions, air/fuel, and NO_x) of coal/oil slurries vs. coal/water/oil emulsions.

5. To systematically analyze the effect of fuel additives on SO_2 removal and on particulate emissions and furnace chamber deposition.

SUMMARY OF PROGRESS TO DATE

This year we will again comment on the progress of each task.

Task I: Coal Preparation

We have ordered a ball and jar mill to facilitate the grinding of the coal. New coal has been ordered from the Penn. State Data Bank for use in our work in correlating coal properties with viscosity, stability, and thermal efficiency.

Tests have been conducted with the ball mill in order to determine the most efficient combination of grinding media, weight of coal, and grinding time. Large amounts of very finely ground coal were produced.

Task II: Flow Properties

After repairs were made on the Rotovisco, the instrument's calibration was checked. Pumping tests on several emulsions were conducted to determine the visocsity. Rotovisco tests were conducted at the same shear rates as were present in the pipe. The design and manufacture of the pendulum to measure the stability of the emulsions was completed.

Aging tests were conducted on the emulsions made with the finely ground coal.

Task III: Burner Design:

The burner design was modified so that the flame remained stable when an increase in flame width was attempted.

Task IV: Combustion Instrumentation

A detector has been purchased to monitor the NO_x levels in the stack gases.

The Wang 720 C has been integrated with the Paar Oxygen Bomb Calorimeter, the platinum resistance thermometers in the furnace, the water turbine meter, the NO_x detector and the Rotovisco. Programs were written to calculate the heat content of the fuel tested in the calorimeter, to determine the thermal efficiencies of a fuel in two ways, and to calculate and plot shear rates and viscosities from the Rotovisco. A new stainless steel stack has been installed on the furnace and a more consistent draft has been obtained.

Task V: Combustion Tests

After the modification of the burner was accomplished, a new baseline test on #2 oil was conducted. An emulsion made with Kentucky coal which previously had been difficult to burn was tested and had better combustion characteristics with the new nozzle.

Combustion tests were conducted with emulsions made from the finely ground coal. Soda ash and limestone were added to reduce the SO_2 concentration the stack.

DETAILED DESCRIPTION OF TECHNICAL PROGRESS

TASK I: Coal Preparation

The lab size ball mill has been installed, and during this quarter, experiments have been conducted to determine the most efficient method of use. A particle size distribution with the mean particle size in the 60 micron range is our goal. This is what is commonly used in industry and power plants for making coal/#6 oil slurries.

Originally, three-eighth (3/8") inch and half-inch diameter steel balls were used as the grinding media. On the average, the mill was run for eight (8) hours. Large quantities of very finely ground coal, 90% through 325 mesh (45 microns) were obtained. The grind was probably so small due to the tight packing that can result with spheres. Even when the grinding time was reduced, the mixture was very fine. The coal did not sieve successfully in our sieve shaker. When analyzed under a microscope, it was found that the small particles were adhering to the larger ones and thus not going through the mesh.

In order to solve the grinding problem, tests are being conducted with cylindrical grinding media. These have more pore space between them when rotated in the mill. This approach is proving successful and producing more large particles. After the coal has been sieved in the shaker, each sieve is placed above a gentle suction and the coal slightly agitated. This removes any fine particles which may not have gone through the sieve.

TASK II: Flow Properties

The finely ground coal was not suitable for our correlation work on coal properties and viscosity because of its small average particle size. We decided, however, that since we had such a large quantity of coal, it should be used for combustion tests. The main rheological tests sought to find a suitable emulsion for combustion studies.

A large bath of emulsion, approximately 300 grams, was prepared and then divided among four beakers. The emulsions were tested fifteen minutes, one hour, one day, and one week after preparation. Shear rate was increased from 0 to 2340 sec^{-1} at the rate 936 sec^{-1}/minute and then brought back to zero. All tests were conducted at 25^{o}C. The breakdown of data follows:

EMULSION PSOC 102 COAL	SHEAR RATE (Sec^{-1})	VISCOSITY (CP)	COMMENTS
40-20-40	187.2	315	separation
15 min.	468	183	in Rotovisco at
	2340	54.2	1853 sec^{-1} (Fig.#1)
	468*	75.6	all liquid not
			in emulsion
40-20=40	187.2	330.8	separation in
1 hour	468	189	Rotovisco at 1844sec^{-1}
	2340	87.6	all liquid not
	468*	80.3	in emulsion
40-20-40	187.2	303	sharp initial
1 day	468	167	rise-all liquid
	2340	49.1	not in emulsion
	468*	69.3	
40-20-40	187.2	417	separation in
1 week	468	227	Rotovisco at 1628
	2340	111	sec^{-1} - all liquid
	468*	126	not in emulsion

* Decreasing shear rate

EMULSION PSOC 102 COAL	SHEAR RATE (Sec^{-1})	VISCOSITY (CP)	COMMENTS
40-15-40 15 min.	187.2	276	separation in
	468	173	Rotovisco at 1844
	2340	77.5	sec^{-1} - all liquid
	468*	107	not in emulsion
40-15-40 1 hour	187.2	327	separation in
	468	197	Rotovisco at 1825
	2340	91.4	sec^{-1} - all liquid
	468*	110	not in emulsion
40-15-40 1 day	187.2	354	separation in
	468	208	Rotovisco at 1310
	2340	57.3	sec^{-1} - all liquid
	468*	66.2	not in emulsion
40-15-40 1 week	187.2	402	very sharp initial
	468	230	rise - all liquid
	2340	102	not in emulsion
	468*	115	

* Decreasing shear rate

EMULSION PSOC 102 COAL	SHEAR RATE (Sec^{-1})	VISCOSITY (CP)	COMMENTS
40-10-40 15 min.	187.2	331	smooth flow curve
	468	170	
	2340	88.2	
	468*	123	
40-10-40 1 hour	187.2	236	smooth flow curve
	468	153	
	2340	69.3	
	468*	107	
40-10-40 1 day	187.2	260	some separation in beaker - none in Rotovisco
	468	151	
	2340	63.6	
	468*	85.1	
40-10-40 1 week	187.2	331	some separation beaker - none in Rotovisco - sharp initial rise
	468	189	
	2340	72.5	
	468*	88.2	

* Decreasing shear rate

EMULSION PSOC 102 COAL	SHEAR RATE (Sec^{-1})	VISCOSITY (CP)	COMMENTS
45-15-40	72	981	separated in
15 min.	180	642	Rotovisco -
	180*	297	started breaking
			at 371 sec^{-1}
45-10-40	72	311	smooth flow
15 min.	180	201	curve
	900	119	
	180*	230	
50-10-40	72	1963	separated in
15 min	180	1015	beaker - separ-
	360	536	ated in Rotovisco
	180*	555	at 418 sec^{-1}

*Decreasing shear rate

Because of its good rheological properties and the equal proportions of coal and oil, the 40-10-40 emulsion was chosen for the combustion studies. It pumped extremely well and there were no clogging problems in either the pump or the feed line.

TASK IV: Combustion Instrumentation

We had several problems with our stove pipe stack. It would become very hot during efficiency tests and thus hazardous. The combustion gases would rapidly cool, diminishing the draft. The pipe was vented out a side wall of the laboratory and the draft was dependent on the wind direction. A new stainless steel stack with asbestos insulation was installed through the roof and this has given us an excellent draft. It has an adjustable damper control and provisions for the insertion of a precipitator. Ports contain a platinum resistance thermometer for monitoring stack temperature, a stack pressure line connected to a pressure transducer, and sampling lines to the gas chromatograph, the NO_x analyzer, and the soot measuring device. See Figure #2.

The Center for Energy Studies has been given the use of the Wang 720 C advanced programming calculator which was used in our efficiency studies at NASA. The printer is a Wang 702. In order to feed data into the Wang, a sixteen channel Scientek Sl-800A scanner in conjunction with a Keithley 171 digital voltmeter is used. Frequencies from the turbine meter can also be fed into the Wang. These instruments have made it possible to do calculations that previously were done laboriously with hand held calculators.

The first piece of equipment that was integrated with the Wang was the Paar oxygen bomb calorimeter. Previously, the temperature was monitored using a mercury thermometer with a magnifying eye piece attached. The operator would check that the temperature was in equilibrium, ignite the bomb, record the temperatures every fifteen seconds for four minutes and then every minute for five minutes, determine the maximum temperature obtained, and calculate the heat content of the fuel. Instead of using the mercury thermometer, a thermistor, which was calibrated against the mercury thermometer, was placed in the bomb and the potential difference across it was monitored by the Wang. Using a known resistor in series with the thermistor, the resistance of the thermistor, and thus the temperature of the water can be calculated. The program written for the Wang calculates the weight of the sample, determines when the temperature is in equilibrium, tells the operator when to ignite the bomb, determines the maximum temperature reached, and calculates the heat content of the fuel.

So far, the most important application of the Wang has been the calculation of thermal efficiency. The inlet and outlet temperature of the water, the stack temperature, the NO_x level and the totalizer, which measures water flow from a turbine meter, are scanned and printed every minute. The heat content of the fuel is entered manually and stored. After each batch of fuel is used, the weight of fuel is entered and the thermal efficiency calculated and printed. The efficiency is determined in two ways. The first adds up the total water flow during the interval when the fuel was used, averages the inlet and outlet water temperatures and multiplies the difference in temperature by the total water flow to determine the total number of kilocalories. This is then divided by the product of the weight of the fuel and its heat content per kilogram, and the result is designated efficiency "A". In the second method, the energy stored in the heat exchanger is added to the ΔT-water flow product. This stored energy is calculated by assuming a linear temperature gradient in the exchanger. When the furnace is warming up, efficiency "B" is much higher than efficiency "A" due to the increase in the temperature of the water in the heat exchanger. When equilibrium is reached, the outlet temperature remains constant and efficiencies "A" and "B" are the same. Graphs of efficiency vs. time will be discussed in the next section.

We have also integrated the Rotovisco and the Wang. The program scans the X&Y output of the Rotovisco every five seconds, calculates the shear rate and viscosity at each point, and stores these two values. Because of memory limitations, only sixty points can be scanned, but these include points for increasing and decreasing shear rate. The results are printed and a graph of viscosity vs. shear rate is automatically generated. Figure #3 shows the results for an emulsion made with southern Illinois coal. A new program is being written for constant shear tests. It will plot viscosity vs. time at a given shear rate.

TASK V: Combustion Tests

After the Wang efficiency program was perfected, tests were conducted on #2 oil and 40-10-40 emulsions using PSOC 102, a Pennyslvania coal. This coal has a heat content of 7.75 kcal./gm., an ash content of 7.07% and a sulfur content of 1.36%.

Efficiencies were monitored from the beginning in the #2 oil test to determine the time needed to reach the average efficiency. It was achieved after one & a half hours of burning. As seen from Figure #4, the efficiencies calculated from each of the two previously mentioned methods are extremely close. The average efficiency was a little over 72%. A smoke number of 1 was obtained using a Dwyer Smoke Gauge. The average excess air level of 38% was a little high due to too low a fuel rate. Average hydrocarbon concentration was 0.0008% or 8 ppm.

The PSOC 102 emulsions burned very well with average efficiencies about five percent lower than that obtained with #2 oil alone. The flames were stable with no flame outs and little sooting of the viewing ports. The soot and ash deposited in the furnace were heaviest when limestone was added to the emulsion, but in all cases was easily cleaned and no fusion was present.

In the combustion test with a straight 40-10-40 PSOC 102 emulsion, average efficiencies of 67.2% and 67.4% were obtained. See Figure #5. The smoke numbers rose to 6 because of the addition of coal. The lowest hydrocarbon concentration, 9 ppm, was obtained at an excess air level of 34%. The averages for the test were excess air, 26.7% and HC level, 18 ppm. An SO_2 reading of 490 ppm was taken at the 34% excess air level.

When 12.2g of Na_2CO_3 were added to 100g of water to remove 50% stoichiometrics of the sulfur, the thermal efficiency of the emulsion was not degraded. See Figure #6. The average concentration of SO_2 was 320 ppm, which is the corrected reading for the 34% excess air level used. This amounts to a 35% reduction in the previous test. During the soda ash test, the average excess air was 20%, the HC level 10 ppm, and the smoke number 3.

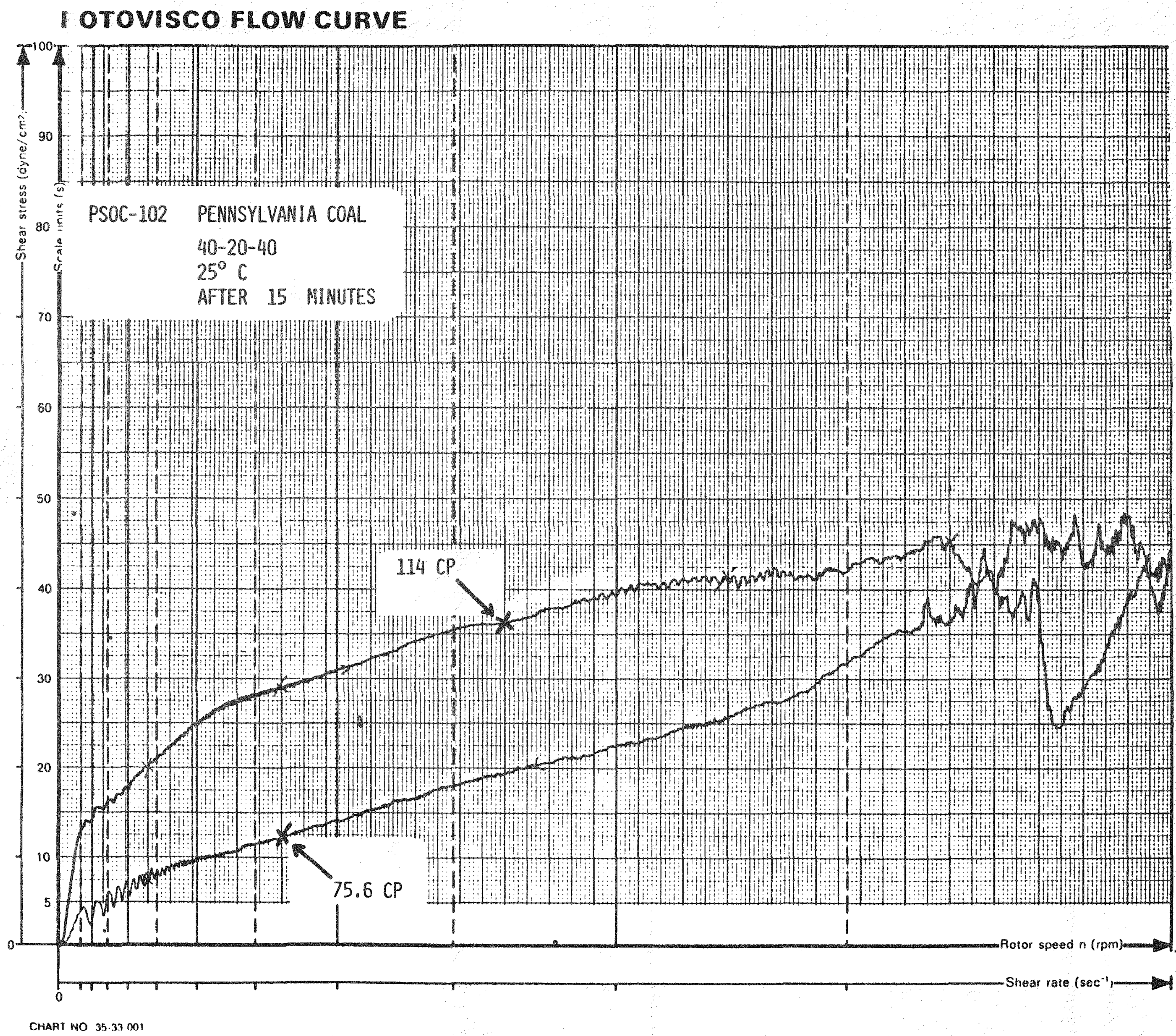
In the final test, 2.25g of limestone was added to every 40g of coal. Figure #7 shows low initial efficiencies. This was due to the low temperature, 55^{o}C, at which the outlet water was stabilized before starting to burn the emulsion. After two hours, efficiencies "A" and "B" became close, indicating that equilibrium had been re-established. The decline of efficiency in the last half hour was possibly due to ash and soot deposition on the heat exchanger tubes. For this test the newly arrived NO_x detector was used, and the average level of NO_x was 134 ppm. The Dwyer smoke number was 6, the average excess air 32%, and the HC level 9 ppm. There was difficulty with the gas chromatograph during this test and the data on SO_2 concentration is still being analyzed.

Measuring the radiation levels from the flame in open air has proved to be inefficient, because there is no control on the excess air level and no measurement possible on the combustion gases. We have designed an enclosed radiation combustion chamber with continuous viewing down the length of the flame. Construction will start shortly and more information will be included in the next report.

CONCLUSIONS:

In our second report on the first year's grant, we reported that the particle size distribution has a major effect on the rheological properties of the emulsion. This was again confirmed in our work with small coal particles this quarter. When the average particle size of the PSOC 102 coal was around 65 microns, there was no trouble in making a stable 40-20-40 emulsion with a smooth flow curve. In comparison, when this emulsion is made with the fine coal, there is a layer of clear liquid immediately formed on top of the emulsion. The flow curve in Figure #1 with its anomalous behavior at high shear rates was repeated for a majority of the emulsions in which all the liquid was not incorporated into the emulsions. It was more difficult to find an emulsion with good kinetic and static stability using the finely ground coal.

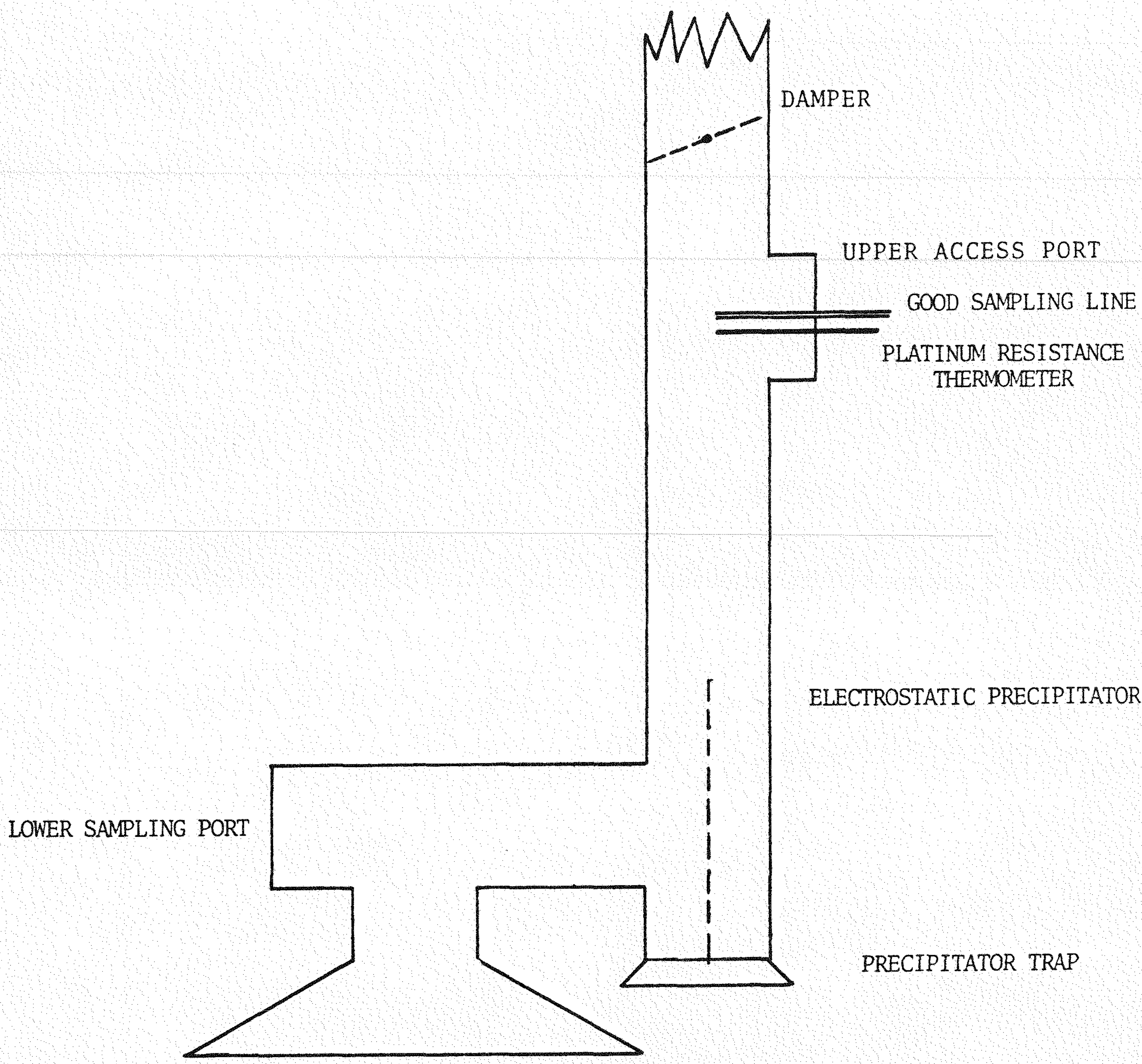
The test with soda ash, which showed a reduced SO_2 level but no reduction in thermal efficiency, was a major accomplishment. This quarter combustion tests will be run on other coals with coarser grinds in the hope of duplicating these results.



I OTOVISCO FLOW CURVE
Shear stress (dyne/cm²)
Scale units (s)
100
90
80
70
60
50
40
30
20
10
5
0
PSOC-102 PENNSYLVANIA COAL
40-20-40
25° C
AFTER 15 MINUTES
114 CP
75.6 CP
Rotor speed n (rpm)
Shear rate (sec⁻¹)
CHART NO 35-33 001

FIGURE #1

FIGURE #2



NEW STACK ARRANGEMENT
USING INSULATED PIPE

FIGURE #3

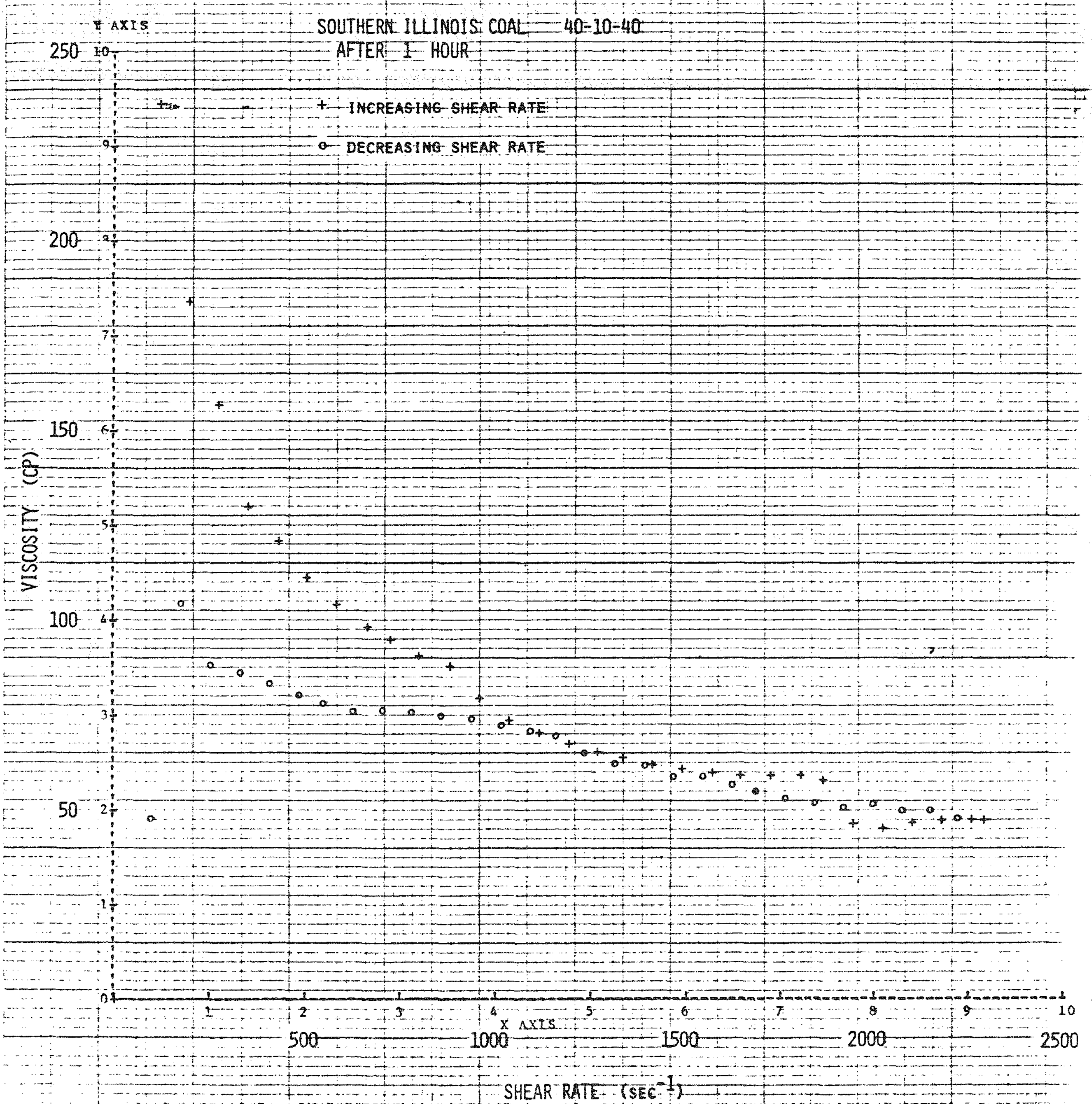
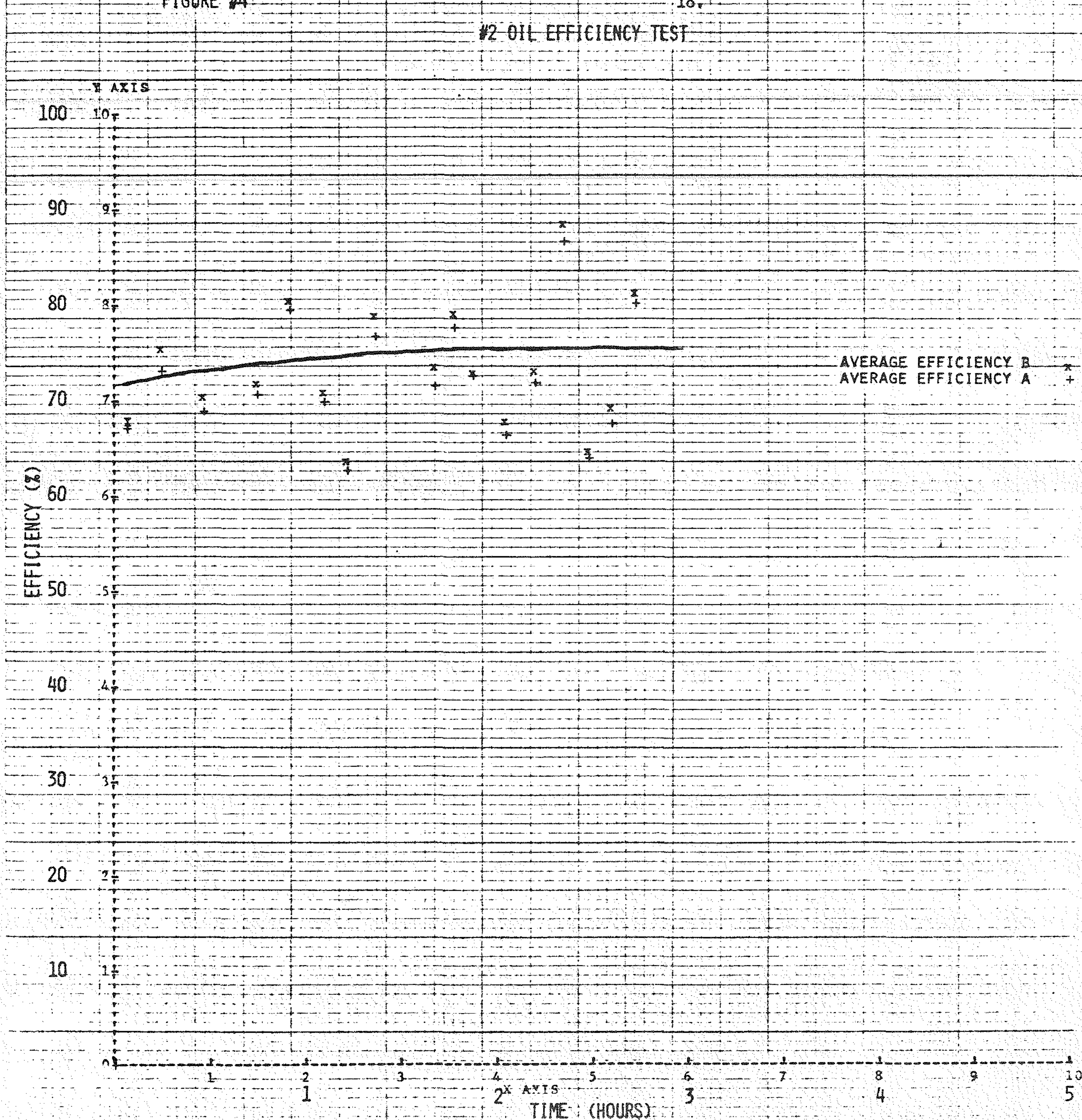

SOUTHERN ILLINOIS COAL 40-10-40
AFTER 1 HOUR
Y AXIS
+ INCREASING SHEAR RATE
o DECREASING SHEAR RATE
VISCOSITY (CP)
250
200
150
100
50
X AXIS
500
1000
1500
2000
2500
SHEAR RATE (SEC^{-1})

FIGURE #4


18.
#2 OIL EFFICIENCY TEST
Y AXIS
100
90
80
70
60
50
40
30
20
10
EFFICIENCY (%)
AVERAGE EFFICIENCY B
AVERAGE EFFICIENCY A
X AXIS
1
2
3
4
5
TIME (HOURS)

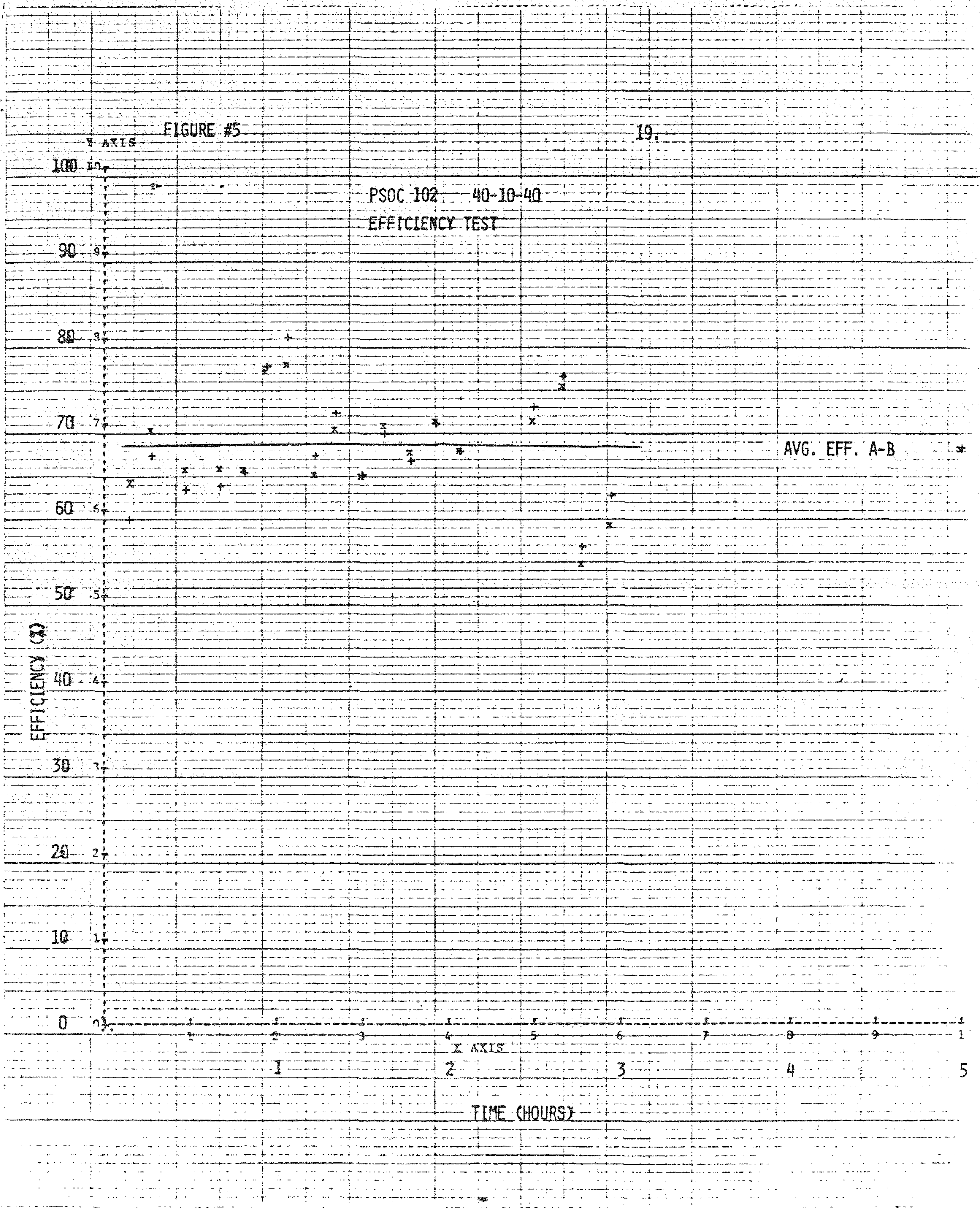


FIGURE #5
19.
Y AXIS
PSOC 102 40-10-40
EFFICIENCY TEST
EFFICIENCY (%)
100
90
80
70
60
50
40
30
20
10
0
AVG. EFF. A-B
X AXIS
1
2
3
4
5
TIME (HOURS)

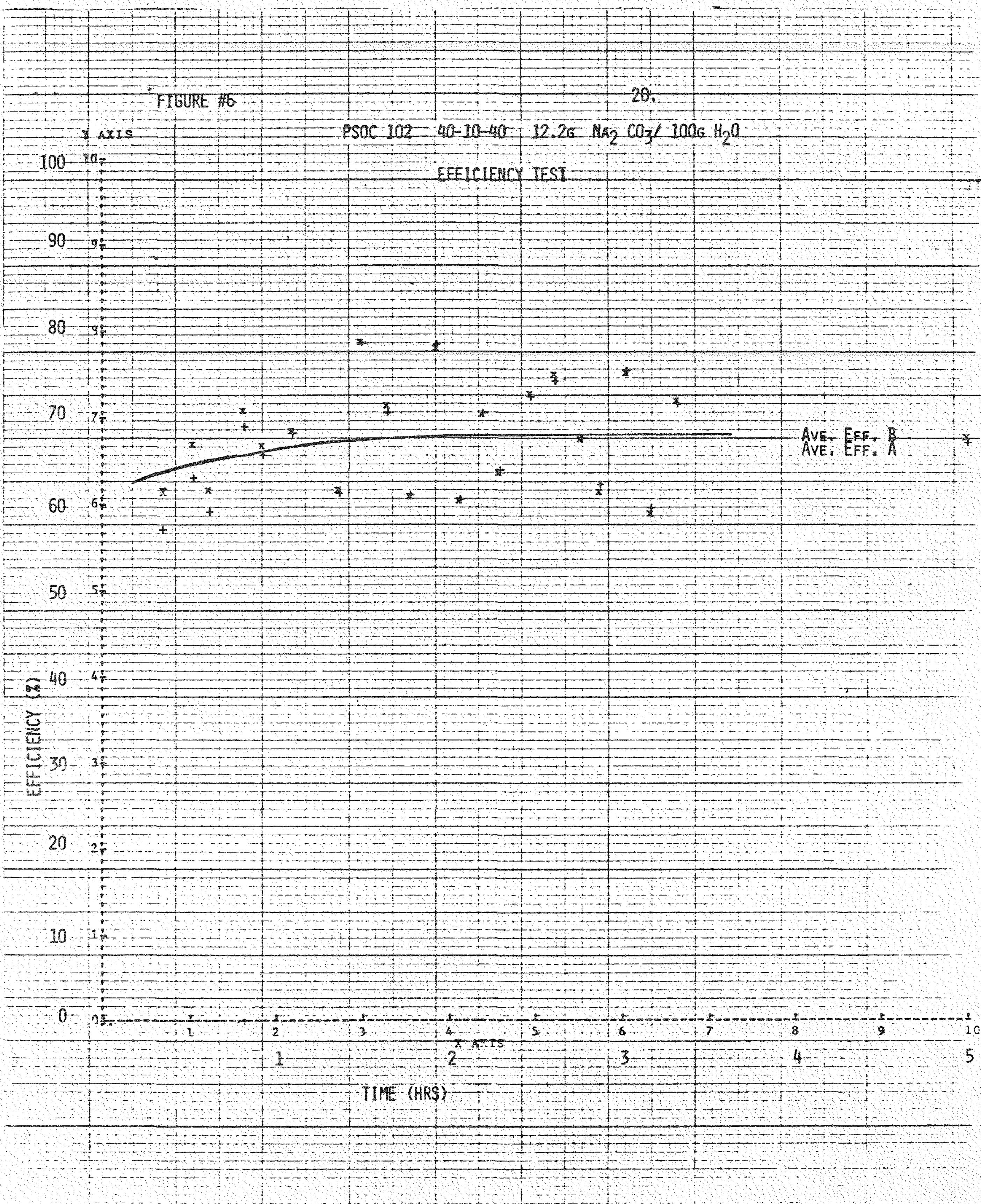
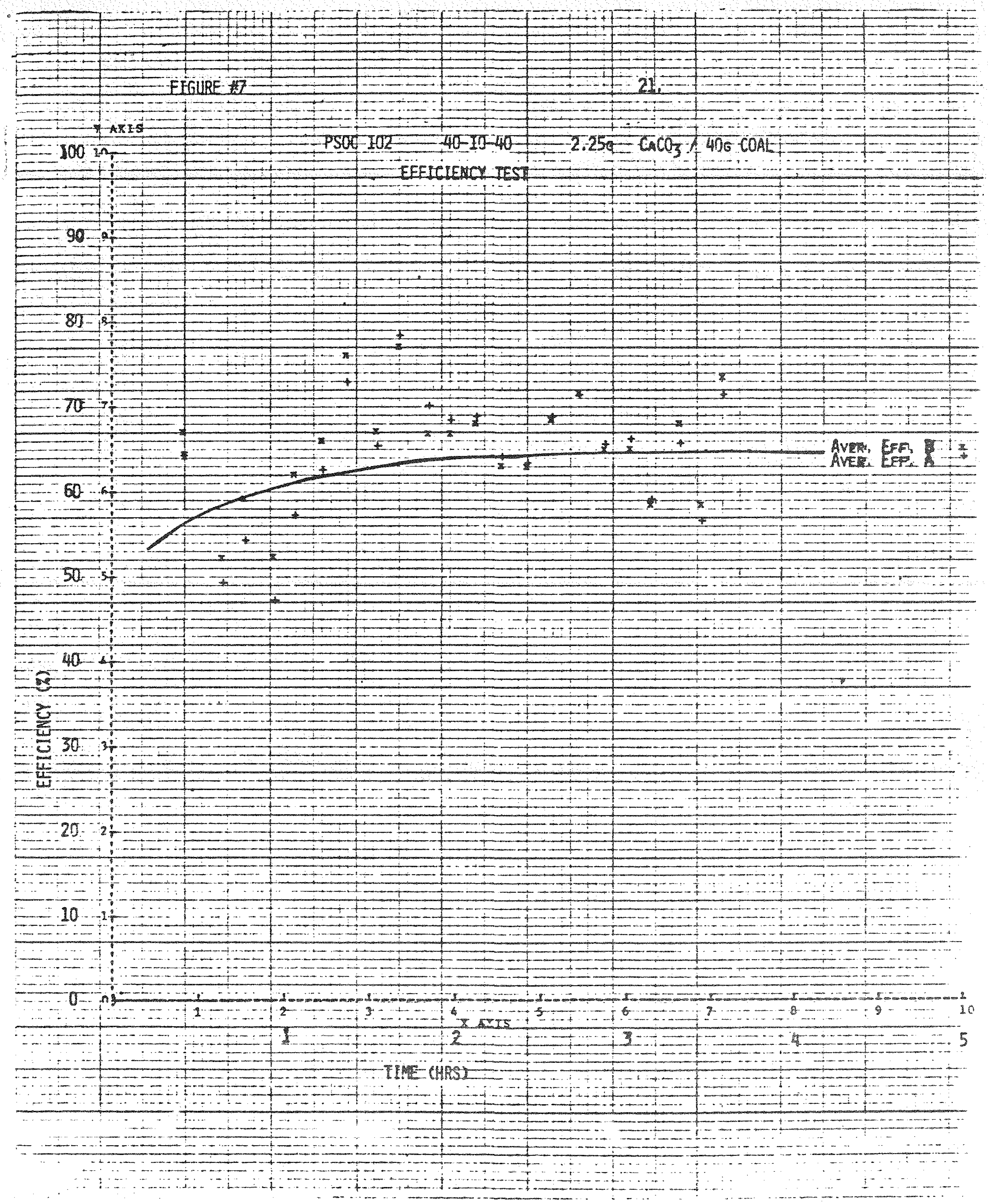


FIGURE #6
20.
PSOC 102 40-10-40 12.2G NA_2CO_3/ 100G H_2O
EFFICIENCY TEST
Y AXIS
EFFICIENCY (%)
100
90
80
70
60
50
40
30
20
10
0
AVE. EFF. B
AVE. EFF. A
X AXIS
1
2
3
4
5
TIME (HRS)



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