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# DEVELOPMENTAL RESEARCH PROGRAM FOR CLEAN INDUSTRIAL AND TRANSPORTATION FUELS FROM COAL

Milestone Report on Process Variable Studies
Period - July, 1978 - February, 1979



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Under Contract No. EX-76-C-01-2514

## OBJECTIVE AND SCOPE OF WORK

### TASK 1

The purpose of this development program is to establish conditions of optimum and reliable operability for the Lummus Clean Fuel From Coal (LCFFC) Process. This catalytic, expanded-bed hydroliquefaction process employs no internal recycle stream in the hydroliquefaction section, and utilizes an anti-solvent deashing technique for solids removal.

The specific objectives of this task are to establish recycle slurry oil self-sufficiency, catalyst life, and process operability for coal liquefaction. Comparative hydroliquefaction performance will be demonstrated using a proprietary Lummus catalyst (or mutually acceptable alternative) versus a standard cobalt/molybdate catalyst.

The scope of work covers the following:

1. Modification of the existing bench-scale expanded bed coal liquefaction test unit to permit continuous operation of the hydroliquefaction reactors, the anti-solvent deashing module, the continuous distillation unit, and the vacuum flashing units. During the modification period, the proprietary catalyst will be prepared and its activity tested. The initial inventory of slurry oil will be topped and hydrogenated.

2. Operation of the integrated facilities to shake down the equipment modifications and to establish conditions for the next sub-task.

3. Operation of the bench-scale unit to demonstrate paste solvent self-sufficiency.

4. To conduct a catalyst life study targeting sulfur of 0.3 and 0.7 wt.%, nitrogen of 0.5 and 0.8 wt.%, and ash of <0.1 wt.% in the +400°F boiler fuel products at, respectively, catalyst ages of 1200 and 2500 pounds of coal per pound of catalyst.

5. Conduct a process variable study to establish the effects of temperature, coal space velocity, and hydrogen partial pressure on process operability, yield structure, and product characterization. Two levels of each of the three variables will be tested, and catalyst decay will be monitored by three replicate runs in the test sequence. Conduct a process variable study to establish the effects of high viscosity on catalyst bed expansion in the first reactor.

6. Operate the bench-scale unit with a standard cobalt-molybdate reference catalyst to obtain comparative catalyst activity and selectivity performance data.

7. Produce feedstock for use in a fixed-bed hydrotreating/hydrocracking study.

## TABLE OF CONTENTS



## TABLES AND FIGURES

TABLES AND FIGURES (Continued)

TABLES AND FIGURES (Continued)

# 1.0 ABSTRACT

The objectives of the subtasks under this program to date are as follow:

A) Establishment of integrated operation.

B) Demonstration of solvent self-sufficiency on equilibrium solvent.

C) Life testing of catalyst.

D) Conduct process variable studies.

The extent of attainment of the above objectives may be summarized as follows:

A) Integrated operation was achieved.

B) Solvent self-sufficiency was demonstrated.

C) Catalyst life test data were obtained.

D) Process variable studies--the subject of this Mileston report--were completed.

This subtask investigated two levels of each of the process variables of temperature, pressure, and coal space rates, together with the effects of high viscosity on catalyst bed expansion in the first reactor. One additional run at a higher temperature, but conforming levels of pressure and coal space rate, together with three catalyst deactivation runs were performed in conjunction with the above process variable parametric study. An 8/12 mesh spherical nickel/molybdenum catalyst was employed in this work.

The chemical hydrogen consumption was less than 3.7 weight percent on coal for the highest severity (840$^{o}$F, 2700 psig, 1.5 lbs of coal/hr/lb catalyst) conditions. Ash in the +400$^{o}$F boiling fuel product was less than 0.05 weight percent. Since the +850$^{o}$F fraction of the recycle

solvent pool varied as the severity levels were changed, the levels of nitrogen in the +400°F boiler fuel product ranged from 0.5 to 0.79 weight percent, and the sulfur from 0.15 to 0.31 weight percent. Over the range of process variables investigated, very little effect on product quality (N and S) was evident in the 400/850°F product fraction; quality differences were essentially dependent on the amount of +850°F material in the product.

The limiting coal space rate in the first hydroliquefaction reactor was established at 3.8 to 3.9 lbs coal/hr/lb catalyst when the 8/12 mesh spherical catalyst was used with a volumetric liquid recycle/fresh feed ratio of 0.20. Holding this coal space rate and increasing the recycle initiated bed overexpansion at a recycle ratio of 0.8. Using a 1/16" extrudate cobalt molybdate catalyst a limiting coal space rate of 3.6 lbs coal/hr/lb catalyst was established at a volumetric liquid recycle/fresh feed ratio of 0.16.

## 2.0 INTRODUCTION

This Milestone Report under Contract No. EX-76-C-01-2514 presents the information generated in the subtask covering the process variable study to:

1) Establish the effects of temperature, coal space velocity, and hydrogen partial pressure on process operability, yield structure, and product characterization, and
2) To establish the effects of high viscosity on catalyst bed expansion in the first reactor.

Following the two subtasks on solvent self-sufficiency with equilibrium solvent, and the catalyst life study covered in the previous Milestone Report, FE-2514-M2, the process variable study was initiated in July, 1978. A total of twelve run periods were included in the investigation of the effects of temperature, coal space velocity, hydrogen partial pressure, and catalyst age. Each run was of sufficient duration to ensure steady state operations at the desired conditions. This generally resulted in the recycle paste solvent inventory being turned over at least once for each set of conditions in the parametric study.

The balance of the work on this subtask was dedicated to establishing the effect of high viscosity on the throughput attainable in the first reactor. The PDU operations on this subtask were completed in March of this year.

The following sections of this report present the data obtained for this subtask together with certain correlated results generated to date based on these data.

## 3.0 SUMMARY

In this subtask covering a study of process variables, a series of eight runs were made at two levels each of temperature (820/840$^{o}$F), pressure (2100/2700 psig), and coal space rate (1.6/2.5 lbs coal/hr/lb catalyst), using a 35 weight percent coal paste feed. A ninth run on this feed was performed at a temperature of 850$^{o}$F, 2700 psig, and a coal space rate of 2.5 lbs/hr/lb catalyst. Three "standard condition" runs using a 30 weight percent coal feed at 830$^{o}$F, 2100 psig, and a coal space rate of 1.6 lb/lb-hr were interspersed to monitor catalyst deactivation, completing the group of twelve runs which covered the effects of the three variables indicated. Nalco Spherocat 502 8/12 mesh spherical nickel/molybdenum catalyst was used.

The balance of the subtask effort pertained to establishing the effect of the high viscosity feed in the first reactor on bed expansion in terms of establishing a limiting throughput. The hydroliquefaction conditions were 830$^{o}$F and 2100 psig, with a 30 weight percent coal paste as feed.

A severity factor was developed to correlate hydrogen consumption as a function of reaction pressure, temperature, and coal space rate which provides a good correlation for most of the results. The chemical hydrogen consumptions for the highest severity hydroliquefaction conditions during this subtask did not exceed 3.7 weight percent on coal. The ash in the product for the overall period was generally less than 0.05 weight percent.

The mix of run conditions which interspersed low severity conditions resulted in varying levels of +850°F material together with the corollary variations in nitrogen and sulfur levels in the recycle solvent pool. As a result, the levels of nitrogen and sulfur in the +400°F boiler fuel product averaged higher than in the catalyst life study (which was operated under esentially uniform conditions) with the nitrogen ranging from 0.5 to 0.79 weight percent, and the sulfur from 0.15 to 0.31 weight percent.

The results over the range of the process variables investigated indicate very little effect on product quality at the same catalyst age, for the -850°F product fraction is the prime determinant on product quality for the +400°F boiler fuel product.

The maximum limitation on coal space rate was determined to be 3.8 to 3.9 lbs coal/hr/lb catalyst for the Nalco Spherocat 502 8/12 mesh spherical catalyst with a volumetric liquid recycle/fresh feed ratio of 0.20. Efforts to hold the same 3.8/3.9 coal space rate while increasing the recycle ratio to 1.0 resulted in initiating unstable bed conditions when the recycle ratio reached the 0.75/0.80 range.

Investigation of the limiting coal space rate on American Cyanamid 1442A, a 1/16" extrudate cobalt molybdate catalyst, indicated that the operations were stable at 3.6 lbs coal/hr/lb catalyst with a liquid recycle/fresh feed ratio of 0.16. The 8/12 mesh spherical catalyst permits a slightly higher throughput.

# 4.0 PROCESS VARIABLE STUDY

## 4.1 General

This subtask covered a parametric study of temperature, pressure, and space velocity at two levels for each, together with a brief investigation of the effects of high viscosity on limiting throughput in the first reactor.

The parametric study on the process variables of temperature, hydrogen partial pressure, and coal space rate at a fixed coal to slurry ratio was conducted to establish the effects on process operability, yield structures, and product characterization. The experimental matrix involved two levels of each of the three variables as follows:

| Temperature, $^{o}F$ | System Pressure, psig | Coal Space Rate lb coal/hr/lb catalyst |
|---|---|---|
| 820 | 2100 | 1.6 |
| 840 | 2700 | 2.5 |

The coal content of the paste feed was 35 weight percent for the eight runs included in the above group.

An additional group of four runs were performed during the course of the parametric study. Using a 35 weight percent coal paste feed concentration, a ninth run was made at conditions of 850$^{o}$F, 2700 psig, and a coal space rate of 2.5 lbs coal/hr/lb of catalyst. The remaining three runs were distributed over the course of the variable study to monitor catalyst deactivation. These standard condition runs were made at 830$^{o}$F, 2100 psig, and 1.6 lbs of coal/hr/lb of catalyst using a 30 weight percent coal paste, conditions corresponding to those employed during the previous catalyst life study subtask of this program. The first twelve runs were made on a single charge of Nalco Spherocat 502 8/12 mesh nickel/molybdate spherical catalyst. The properties of this catalyst are defined in Table 2.

The balance of this subtask covered a study to establish the effects of high viscosity on catalyst bed expansion in the first reactor. The maximum space velocity limitations were determined under the same conditions of temperature (830°F), pressure (2100 psig), and coal paste concentration (30 wt.% coal) utilized in the catalyst life study. Both Nalco Spherocat 502 8/12 mesh nickel/molybdate catalyst and American Cyanamid 1442A 1/16" extrudate cobalt/molybdate catalyst (Table 3) were used.

The limiting throughput conditions on the first reactor were those at which the coal space rate was at the maximum level at which the differential pressure across the first reactor indicated stable performance of the expanded bed. This maximum level was established by gradually increasing the throughput until the differential pressure for the first reactor showed an increase, and then holding conditions to determine if the indication was transitory, stable, or was slowly increasing. If the differential pressure continued to increase over a two-to-four hour period, the feed rate was gradually reduced in one or more increments until the differential pressure returned to its normal pattern, indicating a stable bed. The space velocity so established was the limiting throughput.

4.2 Operations

The operating conditions for the hydroliquefaction unit are reported in Table 4 which also provides the sequence in which the first twelve runs were performed. During this series of runs the hydroliquefaction unit experienced no significant problems other than those of a normal maintenance nature. The deashing unit encountered some intermittent plugging of the small diameter process lines associated with the settler underflow and let-down system due to viscometric effects arising from the low severity operations early in the variable study. Replacement of the steam tracing on these lines with electric tracing corrected this problem. Conditions and data obtained from the deashing operations in this period are included in Table 5.

The runs performed to establish limiting throughputs encountered some difficulty on both Runs (HDS-85 and 86) using the 1442 (1/16") extrudates. Operating conditions for these runs are contained in Table 4.

Run HDS-85 was the first run performed in this program using a 1/16" extrudate cobalt molybdate catalyst (American Cyanamid 1442A) in the hydroliquefaction unit. In both Runs (HDS-85 and 86) the feed rate was increased more slowly toward the limiting condition than for the runs performed on the spherical catalyst.

In the case of Run HDS-85, the indicated coal space velocity of 2.66 lbs of coal/hr/lb of catalyst does not represent a limiting space velocity. When the feed rate reached this level, the third reactor showed a significant increase in differential pressure whereas both the first and second reactors were smooth and normal. Attempts to correct this problem while on stream were unsuccessful. Since the operation remained stable as long as the throughput was not exceeded, the operations were continued to collect data. Following shutdown, foreign material in the nature of fine scale particles was found, primarily partially blocking the bottom screen and, to a lesser extent, the top screen of the third reactor. The first and second reactors and their screens were all clear. All screens were new at the beginning of this run.

The difficulty encountered in Run HDS-86 was due to a capacity limitation in the coal paste system. (This problem evidenced itself with the 30 weight percent coal paste used; it would not have been a factor for a 35/40 weight percent coal paste). The existing paste system has a capacity approximately 40 percent greater than the nominal 30 pound per hour design coal capacity of the hydroliquefaction unit. When combined with the slow increase in throughput to establish limiting conditions mentioned previously, it was found that, in the time required to reach the unstable space rate of 4.42 lb coal/hr/lb of catalyst level indicated in Table 4, and then decrease the feed to locate a stable operating level at 3.6 lb/hr/lb catalyst, the coal paste had been so depleted that no material balance over a significant time period was possible. (The current capability of the coal paste system will sustain a coal space velocity of approximately 4 lb coal/hr/lb catalyst).

Based on previous experience with the spherical catalyst, Run HDS-87A was started up and the space velocity relatively quickly brought up to exceed limiting throughput at a space velocity of 4.83 lbs coal/hr/lb catalyst. The throughput was gradually reduced until the stable level of 3.85 lbs coal/hr/lb catalyst was reached in 87B. The external volumetric liquid recycle/fresh feed ratio for 87 A&B was in the 0.16/0.20 range as shown in Table 4. The recycle ratio was then gradually increased to unity for HDS-87C. At a volumetric liquid recycle/fresh feed ratio of 0.77 with a coal space velocity of 3.85 lbs/hr/lb catalyst, the bed was stable as evidenced by the differential pressure across the first reactor, and at 0.8 the first perturbation occurred. At a recycle to fresh feed ratio of 1.03, and a coal space velocity of 3.85 lbs/hr/lb catalyst (87C conditions), the throughput limit was exceeded.

### 4.3 Parametric Study

The results obtained on the parametric study and the catalyst reference runs are contained in Tables 4 through 15 and Figures 1 through 6.

#### 4.3.1 Severity Factor

A severity factor was developed to correlate hydrogen consumption as a function of reaction pressure, temperature, and coal space rate. The hydrogen consumption is termed the "net hydrogen" which is the total chemical hydrogen consumed minus the hydrogen in ammonia, water and hydrogen sulfide or pounds of hydrogen that go into hydrocarbon products per 100 pounds of moisture, ash-free coal.

The results of the variable study were fit to a number of models. In the model shown in Figure 1, a $T^2$ dependence has been used with a base temperature of 700°F. All but two points fit the correlation. These runs, HDS 76 and 79, were made at 840°F and a space rate of 1.51-1.54. The net hydrogen consumptions were about the same as for Runs HDS 67 and 77, which were made at the same space rate but at a lower temperature, 820°F. A different severity factor, one that uses a lower base temperature and a different exponent on temperature would have brought these two points closer in line, but at the sacrifice of more scatter of the other points. Runs 85A and 87B, of the high-throughput tests have been included to show that hydrogen consumptions in runs of coal space rates as high as 3.9 are predicted by this severity factor. Figure 2 shows gas make correlated by the severity factor.

The severity factor is a first attempt to correlate the effects of operating parameters on reaction results. Models based on plug flow, first and second-order kinetics are currently being fitted to the data and will be discussed in the Final Report.

4.3.2 Catalyst Age

Based on the nitrogen in the 400-850$^{o}$F fraction of the products from the "standard condition" runs, HDS-68, 78 and 83, the catalyst replacement rate was calculated to be one pound per 1947 pounds of coal to maintain 0.5 weight percent nitrogen. This is lower than the replacement rate calculated from the catalyst aging study subtask. The catalyst replacement rate to make a 0.5% nitrogen product was expected to be higher than in the catalyst aging study because the catalyst had experienced higher temperatures of up to 850$^{o}$F. Additionally, the nitrogen content in the solvent started relatively high compared to the solvent nitrogen in the catalyst aging runs because this solvent was derived from products accumulated during the end of the catalyst aging tests when denitrogenation (and desulfurization) activity had declined. Figure 3 shows that solvent nitrogen was over 0.65% at the start of the variable study and only near the end of the study did it dip lower than for solvent of the catalyst aging runs. The following Figure 4 shows that the 400-850°F nitrogens of Runs 68, 78 and 83 agree well with nitrogens of the variable study, when measured at the same catalyst age.

The upper plot in Figure 4 is the variation of TLP nitrogen with catalyst age. The total liquid products contained more nitrogen because of the greater quantities of 850°F+ in the TLP as compared to Runs 52-65. Variations in reaction conditions and the amount of 850°F+ in the recycle solvent accounted for the greater quantities of 850°F+ material.

Figure 5 shows the relationship between sulfur and recycle solvent and total liquid product (TLP) for the catalyst age runs and the standard condition Runs HDS-68, 78, and 83. The sulfur content for the standard reference runs was generally at a higher level than for the catalyst aging runs. The reasons for this are similar to those commented on with respect to nitrogen.

Figure 6 shows the 850°F+ fraction in TLP and recycle solvent versus catalyst age. Again the corresponding TLP and recycle solvent data for the standard condition Runs HDS-68, 78, and 83 are superimposed.

Within the ranges of the variables studied for the twelve runs, wherein the variations of temperature were 20/30°F, (820/850°F) pressure 600 psig (2100/2700 psig), and coal space rate of 0.9 (1.6/2.5), the variables investigated had essentially no effect on the N content of the 400/850°F boiling range product fraction when compared to the catalyst age runs as shown in Figure 4. Restated, changing the severity factor by more than twofold did not significantly affect the quality of the 400/850°F product fraction, again in comparison with the catalyst age runs. The variations in quantity of +850°F material in the product exercises by far the most significant effects on product quality.

The three runs made at standard conditions were compared to earlier runs at the same reaction conditions and catalyst age to determine the effect of increased external recycle rate for the hydroliquefaction reactors. Table 10 indicates that distillate yields are relatively independent of the twofold increase in recycle ratio. (In this Table Runs 68, 78, and 83 of the current series are compared with the comparable catalyst age runs 52, 60, and 62). Further, the nitrogen and sulfur contents of the 500/850$^{o}$F distillate for Run 78 were 0.41 and 0.12 weight percent respectively, versus nitrogen of 0.45 and sulfur 0.14 weight percent for Run 60, indicating little effect of recycle ratio on product quality.

Runs 87B and 87C were made at the same high coal space rate, but the recycle rate in 87C was five times greater than in 87B. The TLP distillation data of these two runs are virtually the same, again indicating no effect of recycle rate on product yields.

### 4.3.3 Viscometric Effect on Throughput - First Reactor

Tables 11 through 14 present Brookfield viscosity data for 30 and 35 weight percent coal paste, representative recycle solvent, and total liquid products from the hydroliquefaction unit. Table 15 contains the viscosities determined on blends of the fresh coal paste and liquid recycle entering the first reactor for the high throughput runs 87A, 87B, and 87C. Figures 12 through 16 present plots of viscosity versus shear rate.

In Figures 14, 15, and 16, the viscosity versus shear rate plots of 87A, 87B, and 87C indicate a higher apparent viscosity for 87C. This reflects the effects of the higher volumetric recycle to fresh feed ratio of 1.03 for this run in combination with 8.3 weight percent of unconverted coal in the recycle stream. Reference to Table 13 for Run 81 in which the unconverted coal was 7.22 weight percent with a recycle ratio of 0.63 indicates a similar effect, in that the apparent viscosity of the Run 81 blend exceeds the 30 weight percent coal paste viscosity (Table 11) at the lower shear rates.

As determined in Run HDS-86 for the 1/16" extrudate catalyst, and in HDS-87B using the 8/12 mesh spherical catalyst, the bed in the first reactor was stable at the following maximum coal space rates:

| Catalyst | American Cyanamid 1442A 1/16" Extrudates | Nalco Spherocat 502 8/12 Mesh Spheres |
|---|---|---|
| Maximum Coal Space Rate, lb/lb hr | 3.6 | 3.85 |
| Volumetric Recycle/ Fresh Feed Ratio | 0.16 | 0.20 |

From the above it can be seen that the spherical catalyst permitted a slightly higher (5-6 percent) limiting throughput.

TABLE 1

Feed Coal (Illinois No. 6) Inspection Data

Proximate Analysis

| | |
|---|---|
| Moisture Content, wt.% | 4.29 |
| Volatile Matter (Dry Basis), wt.% | 40.01 |
| Ash Content (Dry Basis), wt.% | 10.79 |
| Fixed Carbon (Dry Basis), wt.% | 49.20 |

Ultimate Analysis (DAF Basis)

| | |
|---|---|
| Carbon Content, wt.% | 80.18 |
| Hydrogen Content, wt.% | 5.55 |
| Sulfur Content, wt.% | 3.53 |
| Nitrogen Content, wt.% | 1.34 |
| Oxygen Content (Via Diff.), wt.% | 9.40 |

Sieve Analysis

| | |
|---|---|
| +60 Mesh, wt.% | 0.2 |
| -60/+80 Mesh, wt.% | 1.1 |
| -80/+100 Mesh, wt.% | 0.1 |
| -100/+200 Mesh, wt.% | 54.8 |
| -200/+325 Mesh, wt.% | 41.2 |
| -325 Mesh, wt.% | 2.6 |

# TABLE 2

## SPHERICAL CATALYST PHYSICAL PROPERTIES

| | |
|---|---|
| Catalyst Manufacturer | Nalco |
| Catalyst Identification | Spherocat 502 |
| Catalyst Description | Nickel Molybdate on Alumina/8-12 Mesh Spheres |
| Pellet Diameter, inches | 0.05-0.09 |
| Pellet Length/Diameter Ratio | 1.0 |
| Bulk Density, lbs/ft.$^3$ | 34.9 |
| Surface Area, $m^2$/gm | 202 |
| Pore Volume, cc/gm | 0.063 |
| Median Pore Diameter, Å | 132 |

## PORE SIZE DISTRIBUTION

| Average Pore Diameter | Cumulative Pore Volume (1) |
|---|---|
| > 40 A | 0.60 |
| > 60 A | 0.56 |
| > 120 A | |
| > 250 A | |
| > 500 A | 0.11 |
| > 1500 A | 0.04 |
| > 4000 A | ----- |

## CHEMICAL ANALYSIS

| | |
|---|---|
| NiO, wt.% | 4.1 |
| MoO, wt.% | 14.3 |
| FeO, wt.% | 0.4 (nominal) |

(1) Supplier's numbers

TABLE 3

Extrudate Catalyst Physical Properties

| | |
|---|---|
| Catalyst Manufacturer | American Cyanamid |
| Catalyst Identification | MTG-S-02-03 (1442A) |
| Catalyst Type | Cobalt Molybdate on Aluminum |
| Pellet Shape | Extrudate |
| Pellet Diameter, ins. | 0.62 |
| Pellet Length, ins. | .22 |
| Crush Strength, lbs/in. | 79 |
| Promoters, wt.% | |
| $Na_2O$ | .007 |
| CoO | 3.2 |
| $MoO_3$ | 16.0 |
| $SO_4$ | .3 |
| $SiO_2$ | .2 |
| Surface Area, $m^2/gm$ | 300 |
| Pore Volume, cc/gm | .80 |
| Apparent Bulk Density, $lb/ft^3$ | 33 |
| Compacted Bulk Density, $lb/ft^3$ | 38 |
| Loss on Ignition, wt.% | 2.9 |
| Loss on Abrasion, wt.% | >.1 |

TABLE 4

HYDROLIQUEFACTION PROCESS DATA

| | HDS-67 | HDS-68 | HDS-71 | HDS-72 | HDS-74 | HDS-76 | HDS-77 | HDS-78 |
|---|---|---|---|---|---|---|---|---|
| **Hydroliquefaction Process Conditions** | | | | | | | | |
| Temperature, °F | 820 | 830 | 850 | 820 | 840 | 840 | 820 | 830 |
| Pressure, psig | 2700 | 2100 | 2700 | 2700 | 2700 | 2100 | 2100 | 2100 |
| Coal Space Rate, lbs coal/hr/lb catalyst | 1.65 | 1.48 | 2.42 | 2.42 | 2.65 | 1.54 | 1.56 | 1.60 |
| Volumetric Liquid Recycle/Feed Ratio | 1.0 | .71 | .57 | .57 | .53 | 1.6 | 1.6 | 1.17 |
| Coal Content of Paste, wt.% | 35 | 30 | 35 | 35 | 35 | 35 | 35 | 30 |
| Inlet Hydrogen Flow Rate, MSCF/TDC (as is) | 28.2 | 33.4 | 25.1 | 24.8 | 21.9 | 39.1 | 38.5 | 37.6 |
| Inlet Hydrogen Purity, vol.% | 92.73 | 93.21 | 91.05 | 93.34 | 94.12 | 95.60 | 97.28 | 96.54 |
| **Total Liquid Product Inspection Data *** | | | | | | | | |
| Carbon, wt.% | 87.47 | 87.00 | 85.75 | 86.13 | 87.25 | 85.91 | 85.83 | 86.34 |
| Hydrogen, wt.% | 7.36 | 7.21 | 7.08 | 6.99 | 7.05 | 6.93 | 6.95 | 6.90 |
| Nitrogen wt.% | .68 | .70 | .71 | .70 | .72 | .83 | .84 | .82 |
| Sulfur wt.% | .46 | .38 | .48 | .70 | .50 | .60 | .67 | .49 |
| Ash, wt.% | 3.66 | 3.46 | 3.72 | 3.27 | 3.90 | 4.04 | 4.11 | 3.46 |
| Oxygen, Ψ wt.% | 4.01 | 4.00 | 3.67 | 3.81 | 3.69 | 3.72 | 4.16 | 3.36 |
| Quinoline Insolubles, wt.% | 5.30 | 4.79 | 5.96 | 5.97 | 5.28 | 6.54 | 6.11 | 4.98 |
| S. G. at 60°F | 1.1169 | 1.1195 | 1.1349 | 1.1545 | 1.1133 | 1.1547 | 1.1572 | 1.1452 |
| **Total Liquid Product Distillation Data** | | | | | | | | |
| Cuts IBP-400°F, wt.% | 7.36 | 6.10 | 4.19 | 4.27 | 5.96 | 3.38 | 3.16 | 2.67 |
| 400-500°F, wt.% | 9.36 | 11.55 | 10.40 | 8.34 | 9.05 | 6.50 | 6.81 | 4.97 |
| 500-850°F, wt.% | 46.97 | 48.08 | 50.20 | 43.09 | 49.14 | 49.74 | 47.97 | 49.21 |
| +850°F, wt.% | 36.31 | 34.27 | 35.21 | 44.30 | 35.85 | 40.38 | 42.06 | 43.15 |
| **Light Oil Product Distillation Data** | | | | | | | | |
| Cuts IBP-400°F, wt.% | 42.49 | 43.13 | 31.03 | 42.59 | 41.94 | 22.76 | 20.18 | 24.05 |
| 400-500°F, wt.% | 28.32 | 31.87 | 36.10 | 30.46 | 27.25 | 27.83 | 25.75 | 24.64 |
| 500-850°F, wt.% | 29.19 | 25.00 | 32.87 | 26.95 | 30.81 | 49.41 | 54.07 | 51.31 |
| S. G. at 60°F | .9106 | ----- | ----- | .9047 | .9071 | .9665 | .9718 | .9574 |

* On TLP blend not on cuts

Ψ Outside analysis

TABLE 4 Continued

HYDROLIQUEFACTION PROCESS DATA

| | HDS-67-68 | HDS-71 | HDS-72 | HDS-74 | HDS-76-77 | HDS-78 |
|---|---|---|---|---|---|---|
| **Recycle Solvent Inspection Data** | | | | | | |
| Nitrogen, wt.% | .66 | .70 | .49 | .68 | .73 | .69 |
| Carbon, wt.% | 90.61 | 89.17 | 90.56 | 90.19 | 90.72 | 89.91 |
| Hydrogen, wt.% | 7.29 | 7.11 | 7.27 | 7.07 | 7.05 | 6.93 |
| Sulfur, wt.% | .18 | .16 | .15 | .32 | .34 | .31 |
| Ash, wt.% | .03 | .01 | .01 | .10 | .24 | .25 |
| Oxygen, wt.% | 1.88 | 1.50 | 1.52 | 1.64 | 1.88 | 1.91 |
| S.G. at 60°F | 1.1042 | 1.1100 | 1.0748 | 1.1246 | 1.1323 | 1.1363 |
| **Recycle Solvent Distillation Data** | | | | | | |
| Cuts IBP-400°F, wt.% | 3.80 | 4.32 | 6.34 | .43 | -0- | -0- |
| 400-500°F, wt.% | 9.58 | 8.35 | 14.15 | 5.77 | 4.15 | 1.79 |
| 500-850°F, wt.% | 52.30 | 55.06 | 62.56 | 62.93 | 62.60 | 65.44 |
| 850-900°F, wt.% | 5.46 | 4.04 | {16.95 | 1.73 | 4.87 | 2.10 |
| +900°F | 28.86 | 28.23 | { | 29.14 | 28.38 | 30.67 |

TABLE 4 Continued

HYDROLIQUEFACTION PROCESS DATA

| | HDS-79 | HDS-81 | HDS-82 | HDS-83 | HDS-85 | HDS-86 | HDS-87A | HDS-87B | HDS-87C |
|---|---|---|---|---|---|---|---|---|---|
| **Hydroliquefaction Process Conditions** | | | | | | | | | |
| Temperature, $^{o}F$ | 840 | 820 | 840 | 830 | 830 | 830 | 830 | 830 | 830 |
| Pressure, psig | 2700 | 2100 | 2100 | 2100 | 2100 | 2100 | 2100 | 2100 | 2100 |
| Coal Space Rate, lbs coal/hr/lb catalyst | 1.51 | 2.57 | 2.57 | 1.58 | 2.66 | 4.42 | 4.83 | 3.85 | 3.85 |
| Volumetric Liquid Recycle/Feed Ratio | 1.6 | .63 | .63 | 1.17 | .45 | .16 | .16 | .20 | 1.03 |
| Coal Content of Paste, wt.% | 35 | 35 | 35 | 30 | 30 | 30 | 30 | 30 | 30 |
| Inlet Hydrogen Flow Rate, MSCF/TDC (as is) | 43.0 | 25.4 | 25.4 | 41.2 | 22.9 | 13.8 | 13.8 | 17.3 | 17.3 |
| Inlet Hydrogen Purity, vol.% | 93.38 | 93.66 | 88.93 | 92.93 | 90.52 | 92.38 | 94.11 | 94.57 | 93.52 |
| **Total Liquid Product Inspection Data** | | | | | | | | | |
| Carbon, wt.% | 86.33 | 84.96 | 84.06 | 86.86 | 85.15 | 87.12 | 87.54 | 87.26 | 87.39 |
| Hydrogen, wt.% | 7.03 | 6.83 | 6.84 | 7.03 | 6.72 | 6.90 | 6.82 | 6.75 | 6.82 |
| Nitrogen, wt.% | .85 | .86 | .85 | .90 | .78 | .79 | .65 | .66 | .66 |
| Sulfur, wt.% | .43 | .62 | .57 | .56 | .51 | .73 | .54 | .57 | .57 |
| Ash, wt.% | 4.06 | 4.03 | 3.87 | 3.35 | 3.50 | ---- | | 3.34 | ---- |
| Oxygen, wt.% | 3.70 | 4.11 | 3.81 | 3.43 | 3.71 | 4.42 | 2.99 | 3.28 | 3.36 |
| Quinoline Insolubles, wt.% | 4.92 | 6.71 | 5.56 | 5.23 | 5.08 | ---- | 4.51 | 6.68 | 6.49 |
| S. G. at $60^{o}F$ | 1.1263 | 1.1733 | 1.1601 | 1.1363 | 1.1279 | 1.1319 | 1.1406 | 1.1444 | 1.1726 |
| **Total Liquid Product Distillation Data** | | | | | | | | | |
| Cuts IBP-$400^{o}F$, wt.% | 6.76 | 3.61 | 3.71 | 4.03 | 4.92 | 6.54 | 3.70 | 4.36 | 3.54* |
| 400-$500^{o}F$, wt.% | 6.77 | 5.18 | 7.87 | 6.77 | 5.51 | 7.56 | 8.17 | 9.22 | 8.82 |
| 500-$850^{o}F$, wt.% | 44.16 | 45.61 | 46.13 | 52.45 | 44.76 | 46.65 | 52.50 | 51.48 | 52.76 |
| +$850^{o}F$, wt.% | 42.31 | 45.60 | 42.29 | 36.75 | 44.81 | 39.25 | 35.63 | 34.94 | 34.87 |
| **Light Oil Product Distillation Data** | | | | | | | | | |
| Cuts IBP-$400^{o}F$, wt.% | 35.17 | 37.85 | 33.33 | 27.37 | 49.43 | ----- | ----- | 39.53 | ----- |
| 400-$500^{o}F$, wt.% | 27.20 | 24.92 | 28.14 | 25.34 | 22.31 | ----- | ----- | 32.01 | ----- |
| 500-$850^{o}F$, wt.% | 37.63 | 37.23 | 38.53 | 47.29 | 28.26 | ----- | ----- | 28.46 | ----- |
| S. G. at $60^{o}F$ | .9212 | .9242 | .9358 | .9440 | .8984 | ----- | ----- | .9188 | ----- |

* Data as reported in the monthly report required correction for an error in the laboratory distillation

TABLE 4 Continued

HYDROLIQUEFACTION PROCESS DATA

| | HDS-79 | HDS-81-82 | HDS-83 | HDS-85 | HDS-87 A,B,C |
|---|---|---|---|---|---|
| **Recycle Solvent Inspection Data** | | | | | |
| Nitrogen, wt.% | .78 | .68 | .56 | .75 | .47 |
| Carbon, wt.% | 89.86 | 90.63 | 90.10 | 89.27 | 90.83 |
| Hydrogen, wt.% | 7.04 | 7.14 | 6.88 | 6.98 | 7.03 |
| Sulfur, wt.% | .29 | .22 | .23 | .29 | .24 |
| Ash, wt.% | .12 | .09 | .08 | .15 | .04 |
| Oxygen, wt.% | 1.91 | 1.50 | 1.67 | 2.18 | 1.13 |
| S.G. at 60 F | 1.1314 | 1.1067 | 1.1170 | 1.1279 | 1.1075 |
| **Recycle Solvent Distillation Data** | | | | | |
| Cuts IBP-400°F, wt.% | 2.15 | 1.35 | .92 | 4.79 | 2.52 |
| 400-500°F, wt.% | 4.74 | 5.77 | 7.63 | 5.66 | 9.93 |
| 500-850°F, wt.% | 52.06 | 65.46 | 60.27 | 50.24 | 67.99 |
| 850-900°F, wt.% | 6.21 | 7.07 | { 31.18 | { 39.31 | 19.56 |
| +900°F, wt.% | 34.84 | 20.35 | { | { | |

TABLE 5

DEASHING AND DISTILLATION PROCESS DATA

| | HDS-67-71 | HDS-72-74 | HDS-76-77 | HDS-78-79 | HDS-81-83 | HDS-85 | HDS-86-87 |
|---|---|---|---|---|---|---|---|
| **Deashing Process Conditions** | | | | | | | |
| Temperature, °F | 530 | 530 | 530 | 530 | 530 | 530 | 530 |
| Relative Underflow Rate, wt.% | 39.9 | 30.4 | 26.8 | 26.1 | 26.2 | 29.6 | 29.2 |
| Antisolvent Feed Ratio | .78 R | .62 R | .56 R | .54 R | .50 R | .56 R | .56 R |
| Upflow Velocity, ft/hr | .51 Vu | .36 Vu | .69 Vu | .71 Vu | .60 Vu | .60 Vu | .59 Vu |
| **Deashing Inspection Data** | | | | | | | |
| Average Ash Content of Stripped Overflow Product, wt.% | .03 | .05 | .04 | .03 | .05 | .03 | .05 |
| **Deashing Stripped Overflow Data** | | | | | | | |
| Cuts IBP-400°F, wt.% | 2.15 | 1.19 | 1.62 | { 4.48 | 3.75 | 5.15 | { 4.99 |
| 400-500°F, wt.% | 4.12 | 4.20 | 4.66 | { | 3.57 | 5.63 | { |
| 500-850°F, wt.% | 55.39 | 54.49 | 55.92 | 52.27 | 53.16 | 56.11 | 49 85 |
| +850°F, wt.% | 38.3[illegible] | 40.12 | 37.80 | 43.25 | 39.52 | 33.11 | 45.16 |
| **Deashing Underflow Data** | | | | | | | |
| Cuts IBP-500°F, wt.% | 29.59 | 28.92 | 29.41 | 41.19 | 36.33 | 31.05 | 17.02 |
| 500-850°F, wt.% | 36.80 | 42.78 | 40.78 | 23.66 | 22.58 | 36.16 | 41.01 |
| +850°F, wt.% | 33.61 | 28.31 | 29.81 | 35.15 | 41.08 | 32.79 | 41.97 |
| **Dirty Vacuum Flash Overhead Data** | | | | | | | |
| Cuts IBP-400°F, wt.% | 30.42 | 11.42 | 14.90 | { 25.47 | | 10.79 | 9.05 |
| 400-500°F, wt.% | 13.62 | 13.16 | 10.88 | { | | 9.52 | 8.86 |
| 500-850°F, wt.% | 55.96 | { 75.42 | 68.97 | 71.64 | | 37.07 * | 38.62 * |
| +850°F, wt.% | -0- | { | 5.25 | 2.89 | | 42.62 † | 43.47 † |
| **Dirty Vacuum Flash Bottoms Data** | | | | | | | |
| Quinoline Insolubles, wt.% | 41.32 | 39.71 | 42.89 | 45.46 | 42.19 | 41.95 | 43.85 |

* 500-650°F    † +650°F

TABLE 6

ELEMENTAL ANALYSIS OF TOTAL LIQUID PRODUCT DISTILLATION FRACTIONS DATA

| | HDS-67 | HDS-68 | HDS-71 | HDS-72 | HDS-74 | HDS-76 | HDS-77 | HDS-78 |
|---|---|---|---|---|---|---|---|---|
| IBP-400°F | | | | | | | | |
| Hydrogen, wt.% | 11.74 | 11.80 | 11.53 | 11.94 | 11.80 | 11.52 | 11.58 | 11.58 |
| Carbon, wt.% | 85.12 | 87.57 | 85.52 | 85.83 | 85.28 | 85.56 | 84.66 | 85.40 |
| Nitrogen, wt.% | .21 | .15 | .19 | .11 | .19 | .21 | .21 | .19 |
| Sulfur, wt.% | TR | <.06 | TR | TR | TR | <.06 | .06 | .06 |
| 400-500°F | | | | | | | | |
| Hydrogen, wt.% | 9.57 | 9.37 | 9.44 | 9.28 | 9.32 | 9.59 | 9.52 | 9.40 |
| Carbon, wt.% | 89.48 | 89.28 | 88.62 | 87.36 | 89.12 | 88.18 | 88.62 | 88.37 |
| Nitrogen, wt.% | .26 | .19 | .24 | .13 | .27 | .35 | .34 | .36 |
| Sulfur, wt.% | <.06 | <.06 | TR | TR | TR | .11 | .06 | .06 |
| 500-850°F | | | | | | | | |
| Hydrogen, wt.% | 7.45 | 7.39 | 7.39 | 7.59 | 7.29 | 7.55 | 7.64 | 7.55 |
| Carbon, wt.% | 91.43 | 90.62 | 88.86 | 90.94 | 91.04 | 90.41 | 90.79 | 90.50 |
| Nitrogen, wt.% | .39 | .42 | .46 | .35 | .41 | .44 | .44 | .41 |
| Sulfur, wt.% | <.06 | .06 | .06 | .11 | .06 | .06 | .09 | .12 |
| +850°F | | | | | | | | |
| Hydrogen, wt.% | 5.80 | 5.42 | 5.42 | 5.50 | 5.38 | 5.35 | 5.40 | 5.58 |
| Carbon, wt.% | 82.30 | 81.06 | 80.50 | 81.25 | 81.92 | 80.03 | 79.81 | 81.42 |
| Nitrogen, wt.% | 1.26 | 1.37 | 1.25 | 1.22 | 1.38 | 1.43 | 1.42 | 1.37 |
| Sulfur, wt.% | .74 | .98 | 1.01 | 1.07 | 1.01 | 1.04 | 1.06 | .99 |

TABLE 6 Continued

ELEMENTAL ANALYSIS OF TOTAL LIQUID PRODUCT DISTILLATION FRACTIONS DATA

| | HDS-79 | HDS-81 | HDS-82 | HDS-83 | HDS-85 | HDS-86 | HDS-87A | HDS-87B | HDS-87C |
|---|---|---|---|---|---|---|---|---|---|
| IBP-400°F | | | | | | | | | |
| Hydrogen, wt.% | 11.80 | 11.66 | 11.33 | 11.76 | 11.85 | 11.98 | 11.36 | 11.46 | 11.47 |
| Carbon, wt.% | 84.57 | 84.23 | 84.33 | 85.18 | 84.88 | 85.89 | 85.21 | 85.74 | 85.83 |
| Nitrogen, wt.% | .22 | .20 | .16 | .26 | .20 | .21 | .12 | .11 | .14 |
| Sulfur, wt.% | TR | .09 | <.06 | .12 | <.06 | ----- | ----- | TR | ----- |
| 400-500°F | | | | | | | | | |
| Hydrogen, wt.% | 9.66 | 9.36 | 8.92 | 9.49 | 9.34 | 9.12 | 9.05 | 9.12 | 9.46 |
| Carbon, wt.% | 87.89 | 88.19 | 88.44 | 90.03 | 89.10 | 89.17 | 89.87 | 90.26 | 89.96 |
| Nitrogen, wt.% | .29 | .30 | .29 | .27 | .26 | .19 | .20 | .15 | .17 |
| Sulfur, wt.% | TR | .06 | .07 | <.06 | .07 | ----- | ----- | TR | ----- |
| 500-850°F | | | | | | | | | |
| Hydrogen, wt.% | 7.57 | 7.56 | 7.33 | 7.54 | 7.29 | 7.15 | 7.02 | 7.03 | 7.10 |
| Carbon, wt.% | 91.28 | 90.21 | 88.97 | 90.36 | 90.74 | 91.23 | 90.91 | 92.00 | 91.99 |
| Nitrogen, wt.% | .55 | .44 | .45 | .54 | .44 | .41 | .33 | .40 | .33 |
| Sulfur, wt.% | .10 | .12 | .12 | .14 | .14 | ----- | ----- | .17 | ----- |
| +850°F | | | | | | | | | |
| Hydrogen, wt.% | 5.29 | 5.43 | 5.29 | 5.33 | 5.26 | 5.34 | 5.55 | 5.15 | 5.23 |
| Carbon, wt.% | 81.19 | 79.40 | 78.24 | 81.46 | 79.11 | 82.06 | 82.29 | 79.69 | 79.81 |
| Nitrogen, wt.% | 1.35 | 1.40 | 1.46 | 1.59 | 1.26 | 1.47 | 1.28 | 1.23 | 1.34 |
| Sulfur, wt.% | .88 | 1.13 | 1.18 | 1.06 | .99 | ----- | ----- | 1.38 | ----- |

TABLE 7

HYDROLIQUEFACTION RUN YIELD SUMMARY

| Run | Hydrogen Consumption lbs/100 lbs coal (as is) | $C_1$-$C_4$ Gas Make lbs/100 lbs coal (as is) | Net +500°F Paste Oil Make lbs/100 lbs coal (as is) | Unconverted Coal lbs/100 lbs coal (as is) |
|---|---|---|---|---|
| HDS-67 | 3.17 | 6.73 | 28.58 | 4.45 |
| HDS-68 | 3.18 | 6.91 | 20.06 | 4.23 |
| HDS-71 | 3.32 | 8.53 | 27.56 | 5.66 |
| HDS-72 | 2.13 | 4.28 | 24.69 | 5.88 |
| HDS-74 | 2.93 | 5.72 | 23.66 | 4.24 |
| HDS-76 | 2.98 | 7.22 | 20.52 | 6.62 |
| HDS-77 | 2.82 | 5.94 | 20.22 | 4.84 |
| HDS-78 | 3.12 | 6.95 | 25.03 | 4.55 |
| HDS-79 | 3.69 | 9.17 | 21.88 | 3.16 |
| HDS-81 | 1.95 | 4.19 | 24.52 | 7.22 |
| HDS-82 | 2.47 | 5.58 | 22.85 | 4.55 |
| HDS-83 | 3.21 | 6.47 | 22.67 | 5.92 |
| HDS-85 | 2.08 | 4.81 | 24.06 | 4.94 |
| HDS-87B | 1.62 | 4.28 | 26.16 | 8.30 |

## TABLE 8

### YIELD STRUCTURES *

| | HDS-67 | HDS-68 | HDS-71 | HDS-72 | HDS-74 | HDS-76 |
|---|---|---|---|---|---|---|
| **Coal Feed, wt.%** | | | | | | |
| Carbon | 68.474 | Same | Same | Same | Same | Same |
| Hydrogen | 4.740 | | | | | |
| Nitrogen | 1.144 | | | | | |
| Sulfur (Total) | 3.015 | | | | | |
| Mineral Matter (Sulfur Free) | 10.299 | | | | | |
| Water | 4.300 | | | | | |
| Organic Oxygen | 8.028 | | | | | |
| Total | 100.000 | | | | | |
| Hydrogen Added | 3.166 | 3.175 | 3.323 | 2.130 | 2.926 | 2.978 |
| Total | 103.166 | 103.175 | 103.323 | 102.130 | 102.926 | 102.978 |
| **Net Products, wt.%** | | | | | | |
| Ammonia | .712 | .560 | .735 | .210 | .616 | .386 |
| Water | 9.181 | 9.757 | 10.038 | 8.992 | 11.611 | 9.266 |
| Carbon Monoxide | .075 | .140 | .019 | .018 | .043 | .221 |
| Carbon Dioxide | .222 | .280 | .344 | .157 | .077 | .187 |
| $C_1$'s | 2.061 | 2.428 | 2.929 | 1.666 | 2.067 | 2.339 |
| $C_2$'s | 2.133 | 1.821 | 2.375 | 1.232 | 1.857 | 1.655 |
| $C_3$'s | 1.512 | 1.634 | 1.901 | .868 | .804 | 1.815 |
| $C_4$'s | 1.025 | 1.027 | 1.327 | .514 | .992 | 1.412 |
| Hydrogen Sulfide | 2.256 | 2.381 | 2.204 | 1.505 | 1.771 | 2.096 |
| $C_5$-400°F Naphtha | 10.974 | 11.299 | 7.915 | 8.984 | 10.951 | 9.093 |
| 400-500°F Distillate | 9.424 | 10.477 | 11.054 | 8.372 | 9.316 | 9.612 |
| 500-850°F Distillate | 28.069 | 20.929 | 27.441 | 24.536 | 25.695 | 23.201 |
| Residual Product in Overflow | .492 | .348 | .441 | .801 | .425 | .407 |
| Residual Product in Stripped Underflow | 19.080 | 24.650 | 17.871 | 27.377 | 21.402 | 23.811 |
| Unconverted Coal (MAF) | 4.453 | 4.231 | 5.657 | 5.883 | 4.245 | 6.621 |
| Ash & Inorganic Sulfur | 11.497 | 11.213 | 11.072 | 11.015 | 11.054 | 10.856 |
| Total | 103.166 | 103.175 | 103.323 | 102.130 | 102.926 | 102.978 |

* Refinements in $H_2$ consumption based on additional analytical work are reflected herein.

## TABLE 8 Continued

## YIELD STRUCTURES

| | HDS-77 | HDS-78 | HDS-79 | HDS-81 | HDS-82 | HDS-83 |
|---|---|---|---|---|---|---|
| **Coal Feed, wt.%** | | | | | | |
| Carbon | 68.474 | Same | Same | Same | Same | Same |
| Hydrogen | 4.740 | | | | | |
| Nitrogen | 1.444 | | | | | |
| Sulfur (Total) | 3.015 | | | | | |
| Mineral Matter (Sulfur Free) | 10.299 | | | | | |
| Water | 4.300 | | | | | |
| Organic Oxygen | 8.028 | | | | | |
| Total | 100.000 | | | | | |
| Hydrogen Added | 2.823 | 3.123 | 3.691 | 1.945 | 2.474 | 3.209 |
| Total | 102.823 | 103.123 | 103.691 | 101.945 | 102.474 | 103.209 |
| **Net Products, wt.%** | | | | | | |
| Ammonia | 0.380 | .265 | .559 | .165 | .165 | .053 |
| Water | 9.989 | 11.329 | 12.136 | 10.218 | 9.828 | 11.393 |
| Carbon Monoxide | 0.240 | .217 | .218 | .493 | .729 | .607 |
| Carbon Dioxide | 0.228 | .291 | .156 | .405 | .520 | .319 |
| $C_1$'s | 1.949 | 2.324 | 2.975 | 1.504 | 2.112 | 2.317 |
| $C_2$'s | 1.466 | 1.720 | 2.304 | 1.118 | 1.510 | 1.691 |
| $C_3$'s | 1.460 | 1.694 | 2.220 | .988 | 1.258 | 1.549 |
| $C_4$'s | 1.064 | 1.212 | 1.667 | .578 | .695 | .910 |
| Hydrogen Sulfide | 1.954 | 2.435 | 2.573 | 1.879 | 2.045 | 1.926 |
| $C_5$-400°F Naphtha | 8.561 | 8.624 | 16.392 | 8.423 | 8.982 | 11.249 |
| 400-500°F Distillate | 9.490 | 8.616 | 10.602 | 7.163 | 9.582 | 10.959 |
| 500-850°F Distillate | 22.571 | 28.819 | 23.650 | 31.413 | 24.774 | 25.535 |
| Residual Product in Overflow | .422 | .595 | .532 | .680 | .494 | .440 |
| Residual Product in Stripped Underflow | 27.295 | 19.303 | 13.523 | 18.483 | 24.198 | 17.230 |
| Unconverted Coal (MAF) | 4.842 | 4.547 | 3.163 | 7.218 | 4.547 | 5.917 |
| Ash & Inorganic Sulfur | 10.912 | 11.132 | 11.021 | 11.217 | 11.035 | 11.114 |
| Total | 102.823 | 103.123 | 103.691 | 101.945 | 102.474 | 103.209 |

## TABLE 8 Continued

## YIELD STRUCTURES

| | HDS-85 | HDS-87B |
|---|---|---|
| **Coal Feed, wt.%** | | |
| Carbon | 68.474 | Same |
| Hydrogen | 4.740 | |
| Nitrogen | 1.144 | |
| Sulfur (Total) | 3.015 | |
| Mineral Matter (Sulfur Free) | 10.299 | |
| Water | 4.300 | |
| Organic Oxygen | 8.028 | |
| Total | 100.000 | |
| Hydrogen Added | 2.082 | 1.619 |
| Total | 102.082 | 101.619 |
| **Net Products, wt.%** | | |
| Ammonia | .506 | .202 |
| Water | 9.548 | 10.389 |
| Carbon Monoxide | .577 | .587 |
| Carbon Dioxide | .592 | .614 |
| $C_1$'s | 1.910 | 1.504 |
| $C_2$'s | 1.297 | 1.246 |
| $C_3$'s | 1.035 | .969 |
| $C_4$'s | .568 | .558 |
| Hydrogen Sulfide | 3.000 | 1.889 |
| $C_5$-400$^{\circ}$F Naphtha | 12.682 | 9.420 |
| 400-500$^{\circ}$F Distillate | 7.391 | 10.147 |
| 500-850$^{\circ}$F Distillate | 26.385 | 27.302 |
| Residual Product in Overflow | .605 | .459 |
| Residual Product in Stripped Underflow | 19.924 | 17.078 |
| Unconverted Coal (MAF) | 4.937 | 8.298 |
| Ash & Inorganic Sulfur | 11.125 | 10.957 |
| Total | 102.082 | 101.619 |

TABLE 9

ELEMENTAL ANALYSIS OF +400°F
BOILER FUEL PRODUCT

| Catalyst Life lbs coal/lb catalyst | S, wt.% | N, wt.% | C, wt.% | H, wt.% |
|---|---|---|---|---|
| 460.5 | .16 | .57 | 89.87 | 7.23 |
| 811.8 | .15 | .50 | 90.56 | 7.15 |
| 977.6 | .29 | .68 | 90.49 | 7.00 |
| 1019.3 | .25 | .69 | 88.37 | 6.97 |
| 1136.3 | .31 | .69 | 89.91 | 6.94 |
| 1175.9 | .28 | .79 | 89.93 | 6.93 |
| 1242.5 | .24 | .69 | 90.69 | 7.09 |
| 1318.9 | .23 | .69 | 90.76 | 7.03 |
| 1393.6 | .21 | .56 | 90.14 | 6.84 |

FIGURE 1

SEVERITY FACTOR FOR NET HYDROGEN CONSUMPTION

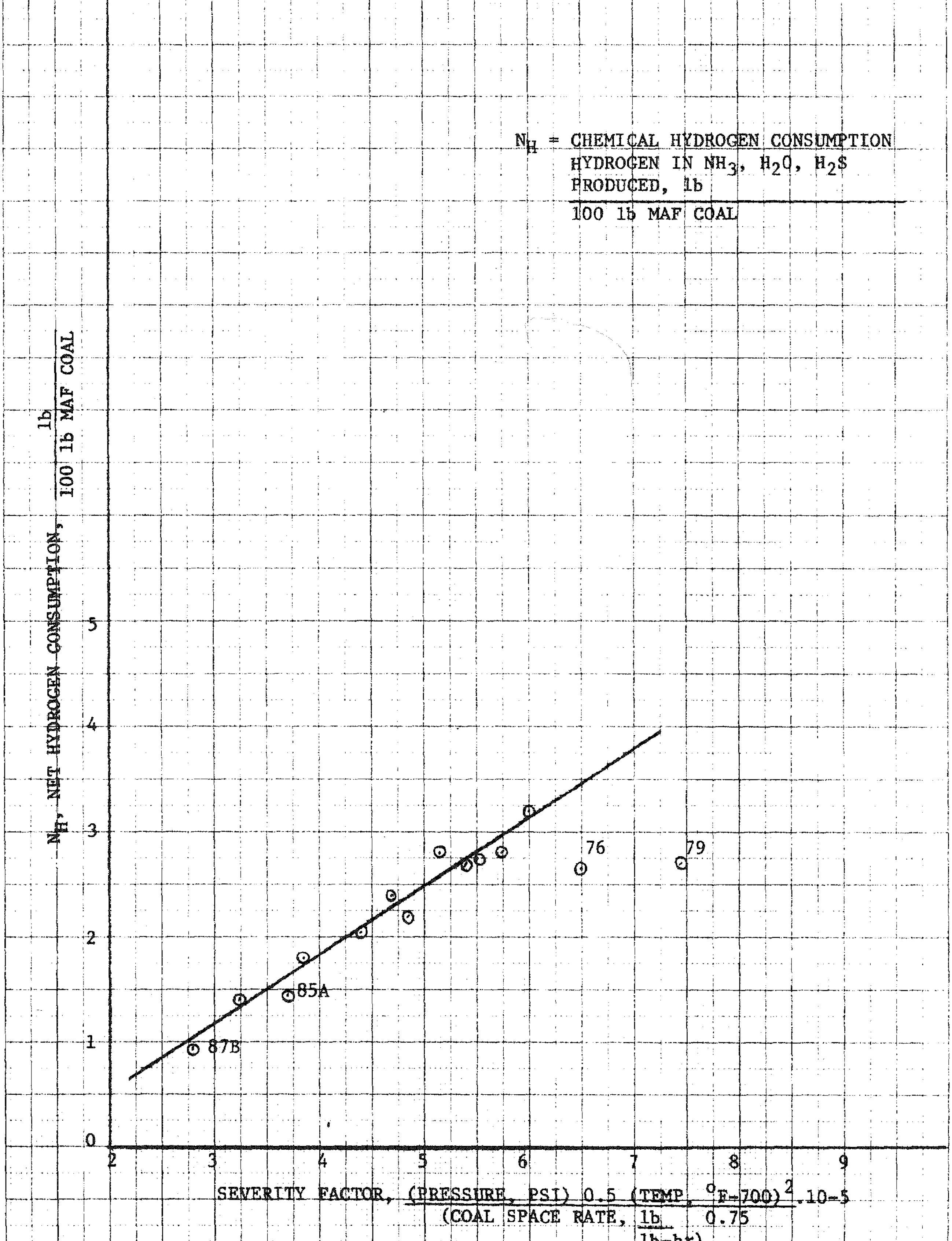


FIGURE 2

GAS MAKE VS. SEVERITY FACTOR

VARIABLE STUDY

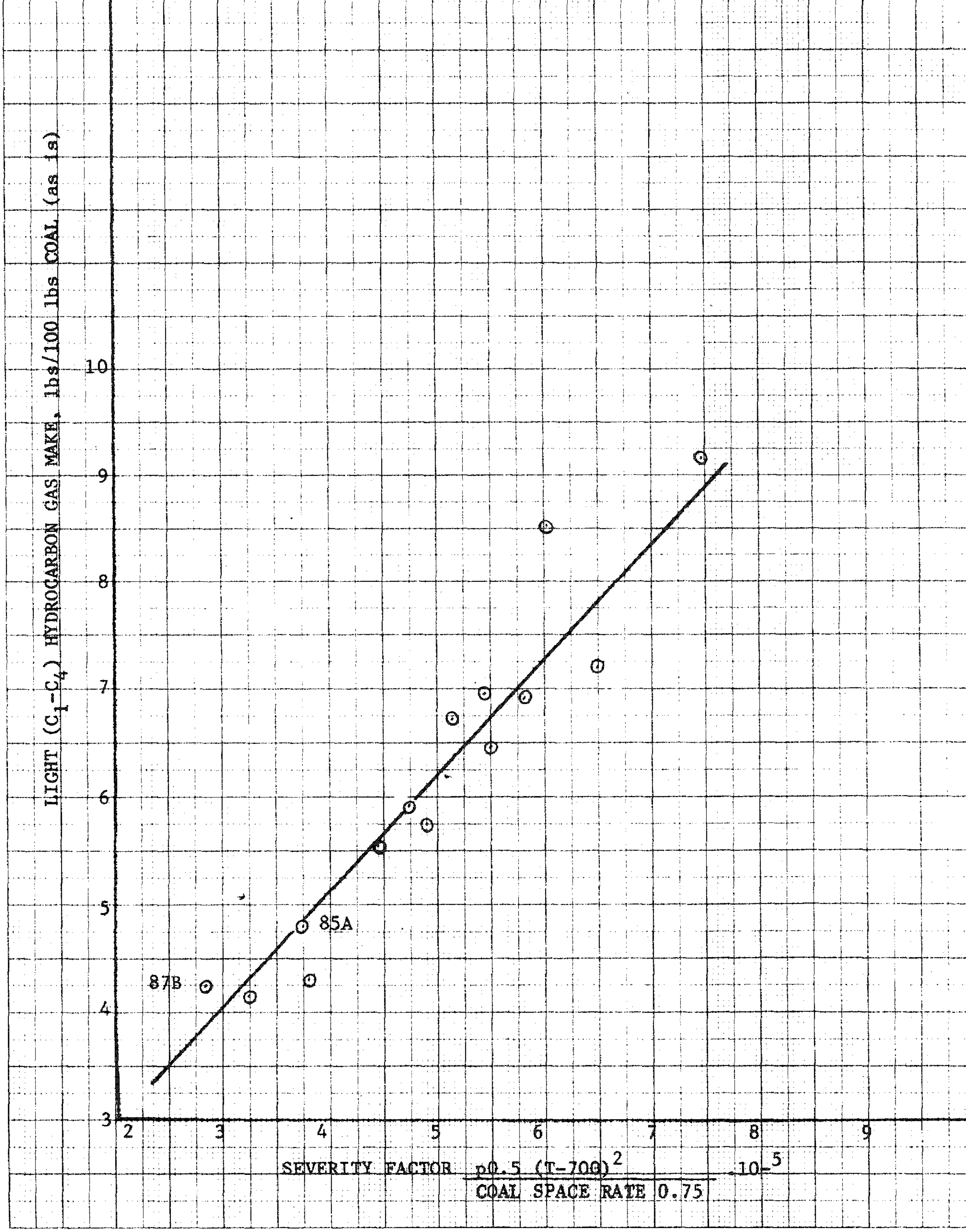
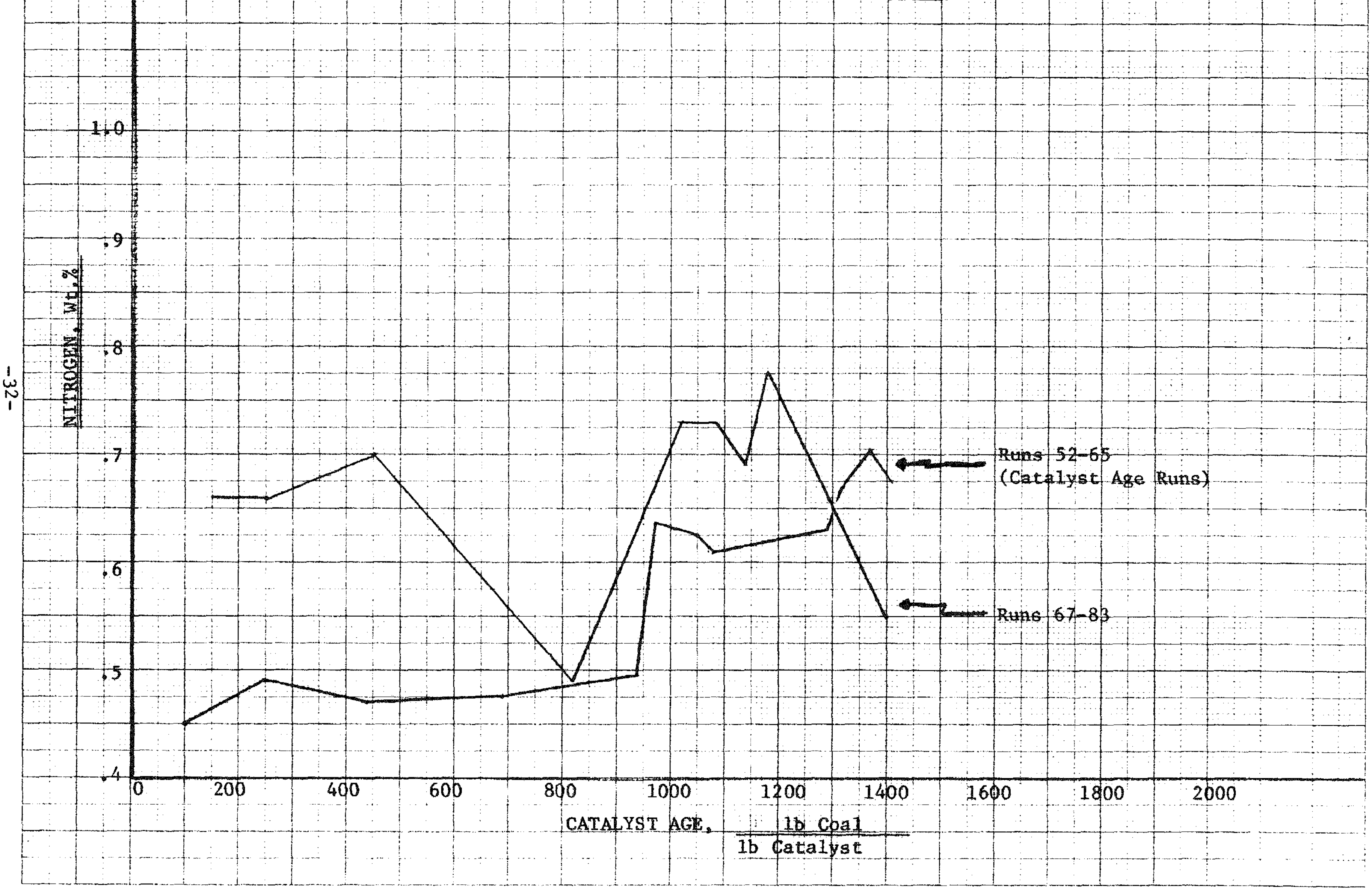


FIGURE 3

NITROGEN IN RECYCLE SOLVENT VS. CATALYST AGE



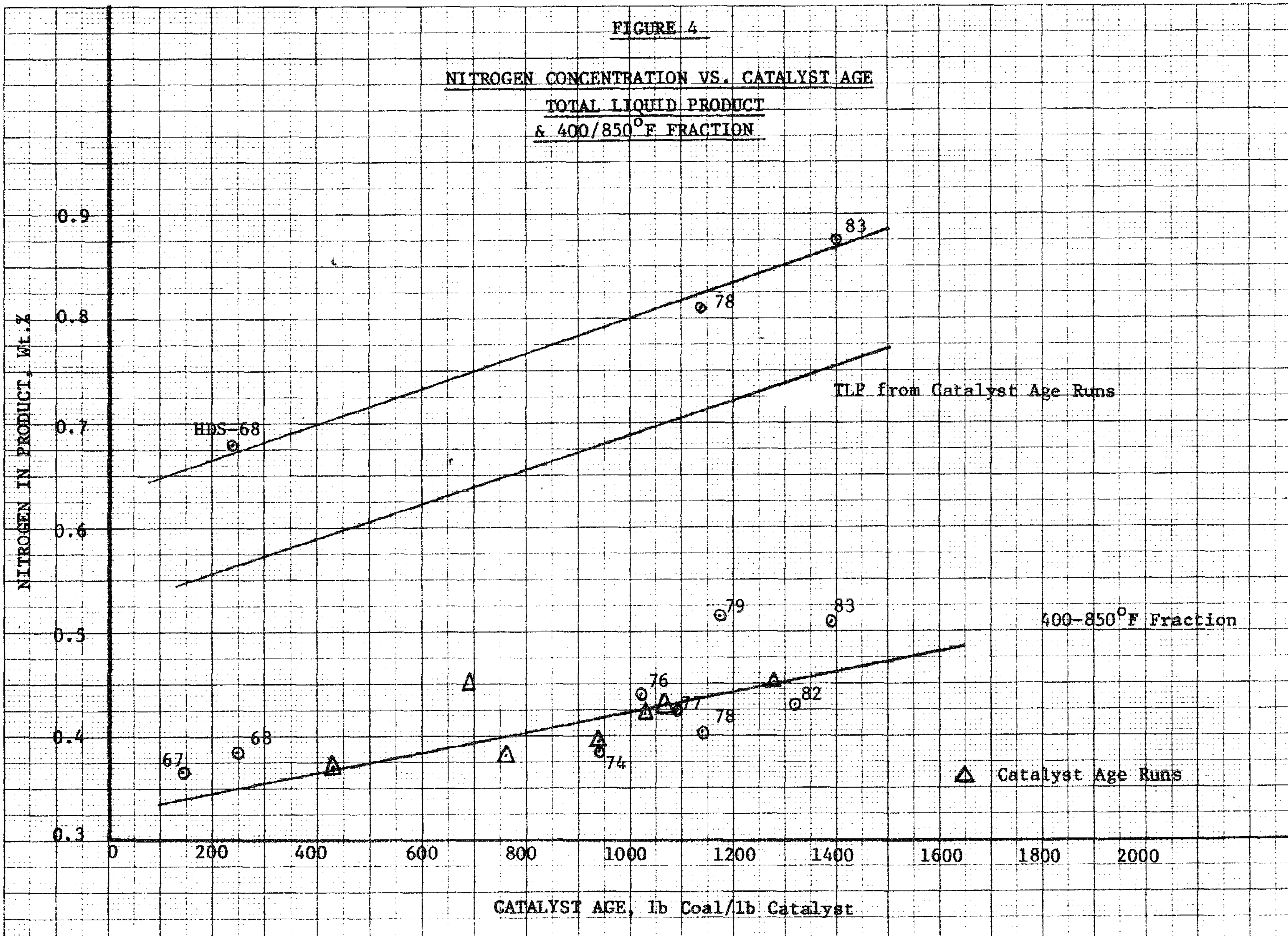



FIGURE 4

NITROGEN CONCENTRATION VS. CATALYST AGE
TOTAL LIQUID PRODUCT
& 400/850°F FRACTION

FIGURE 5

SULFUR IN RECYCLE SOLVENT AND TLP VS. CATALYST AGE

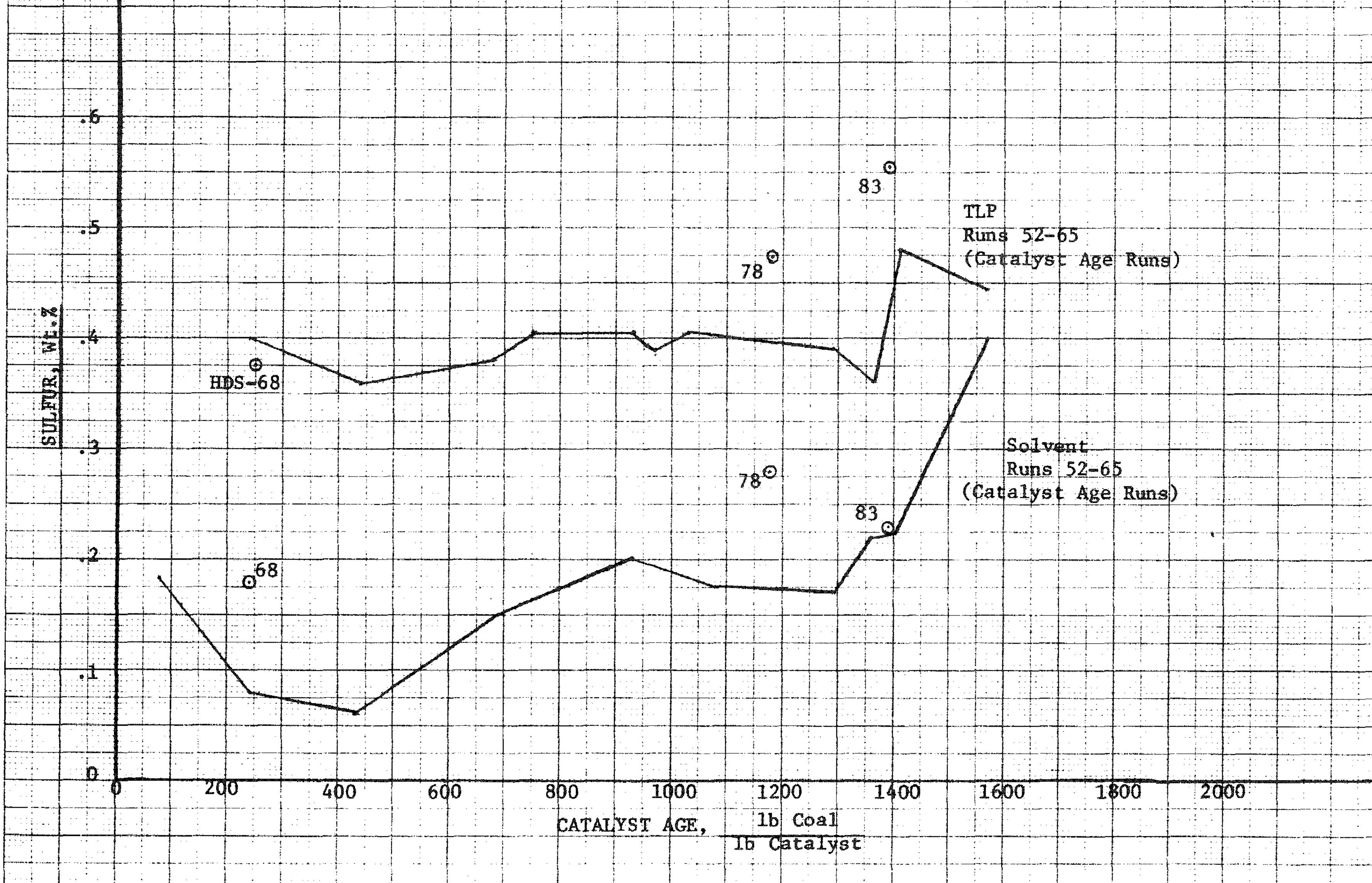


FIGURE 6

850°F+ FRACTION IN TOTAL LIQUID PRODUCT AND RECYCLE SOLVENT VS. CATALYST AGE

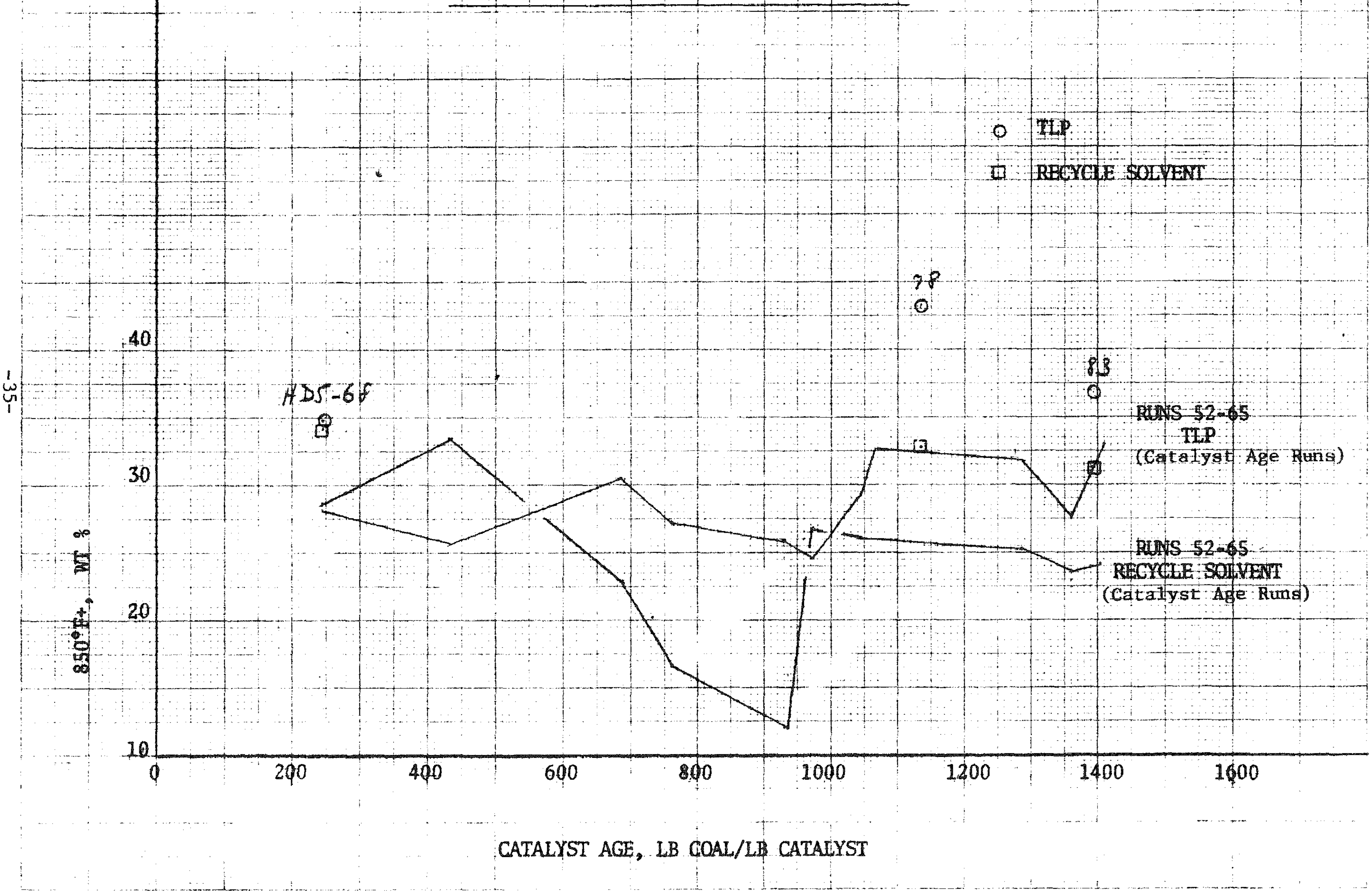


TABLE 10

EFFECT OF RECYCLE ON PRODUCT QUALITY AND YIELD

| RUN NO. | 68 | 52 | 78 | 60 | 83 | 62 |
|---|---|---|---|---|---|---|
| Temp, °F | 830 | ⟶ | | | | |
| Pressure, psig | 2100 | ⟶ | | | | |
| Space Rate, lb/lb-hr | 1.48 | 1.55 | 1.60 | 1.32 | 1.58 | 1.53 |
| Catalyst Age, lb/lb | 245.7 | 247.6 | 1136.3 | 1284.4 | 1393.6 | 1408.7 |
| Recycle Ratio, v/v | 0.71 | 0.64 | 1.17 | 0.61 | 1.17 | 0.57 |
| Yield | | | | | | |
| IBP-500°F | 17.7 | 12.4 | 7.6 | 12.9 | 10.8 | 12.8 |
| 500-850°F | 48.1 | 59.3 | 49.2 | 55.5 | 52.5 | 54.2 |
| 850°F+ | 34.3 | 28.3 | 43.2 | 31.7 | 36.8 | 32.9 |
| Nitrogen (500-850 | | | 0.41 | 0.45 | | |
| Sulfur (500-850) | | | 0.12 | 0.14 | | |

FIGURE 7

RECYCLE SOLVENT CARBON AND HYDROGEN VS. PROCESSING TIME

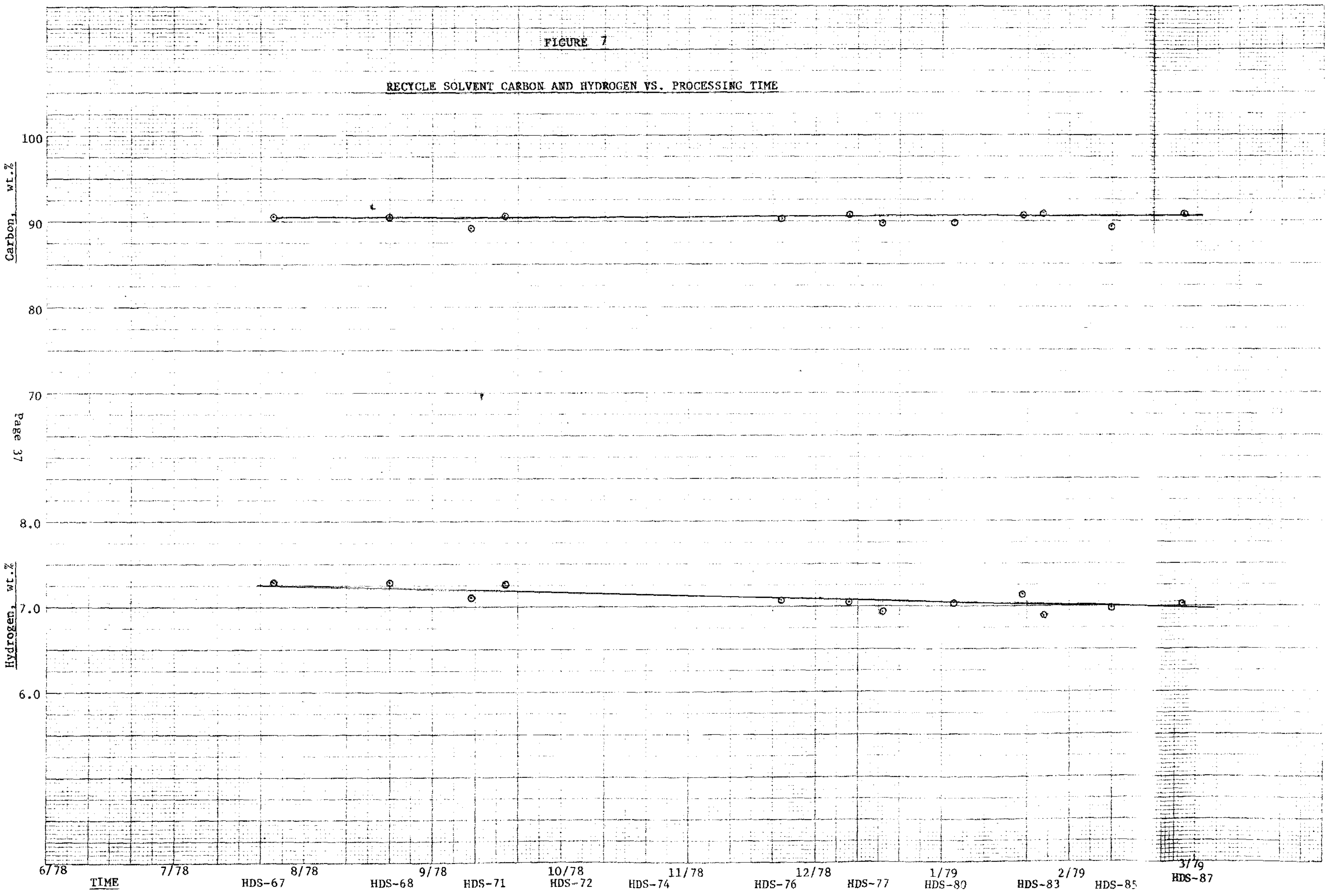
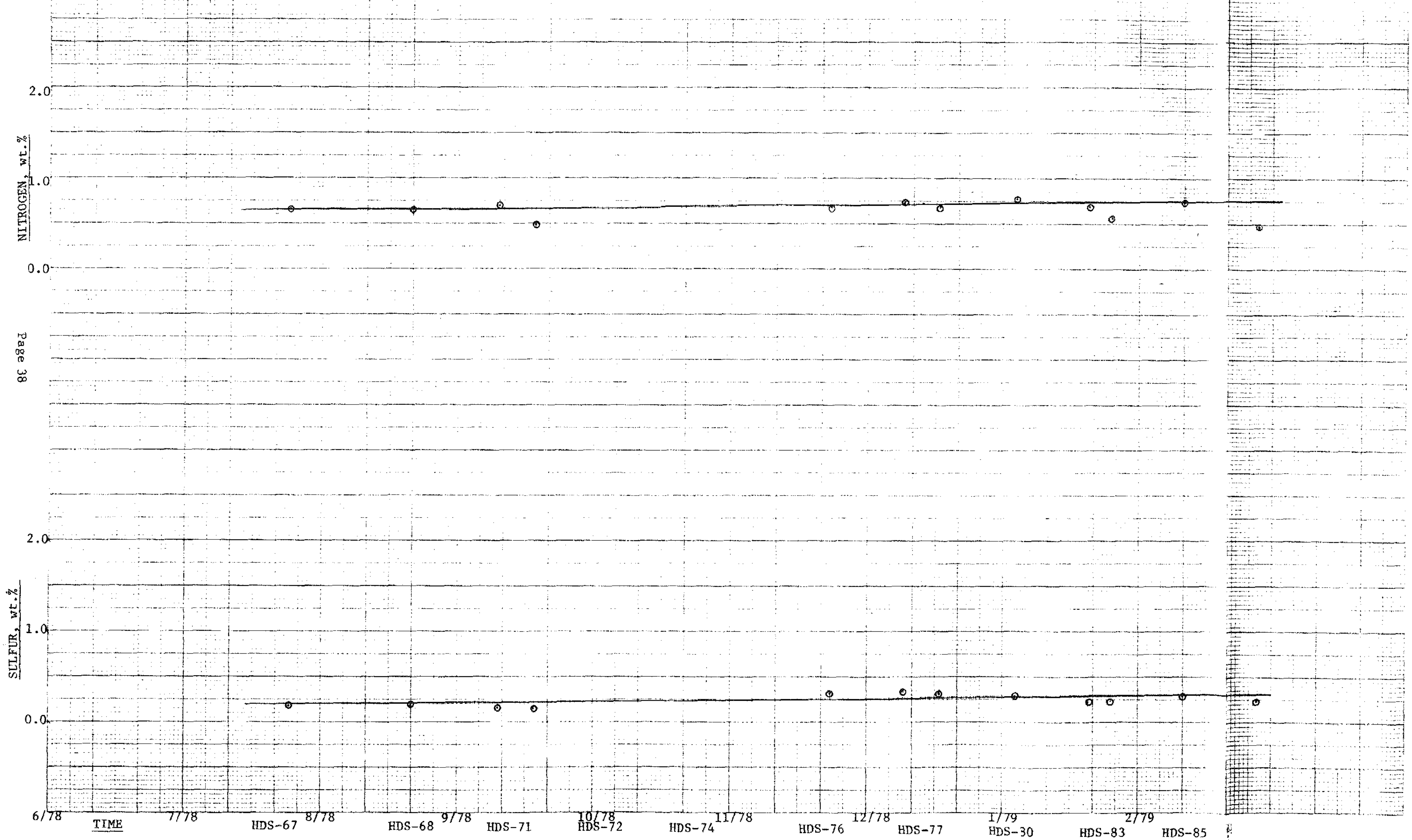


FIGURE 8

RECYCLE SOLVENT NITROGEN AND SULFUR VS. PROCESSING TIME



## FIGURE 9

### RECYCLE SOLVENT DISTILLATION CUTS VS. PROCESSING TIME

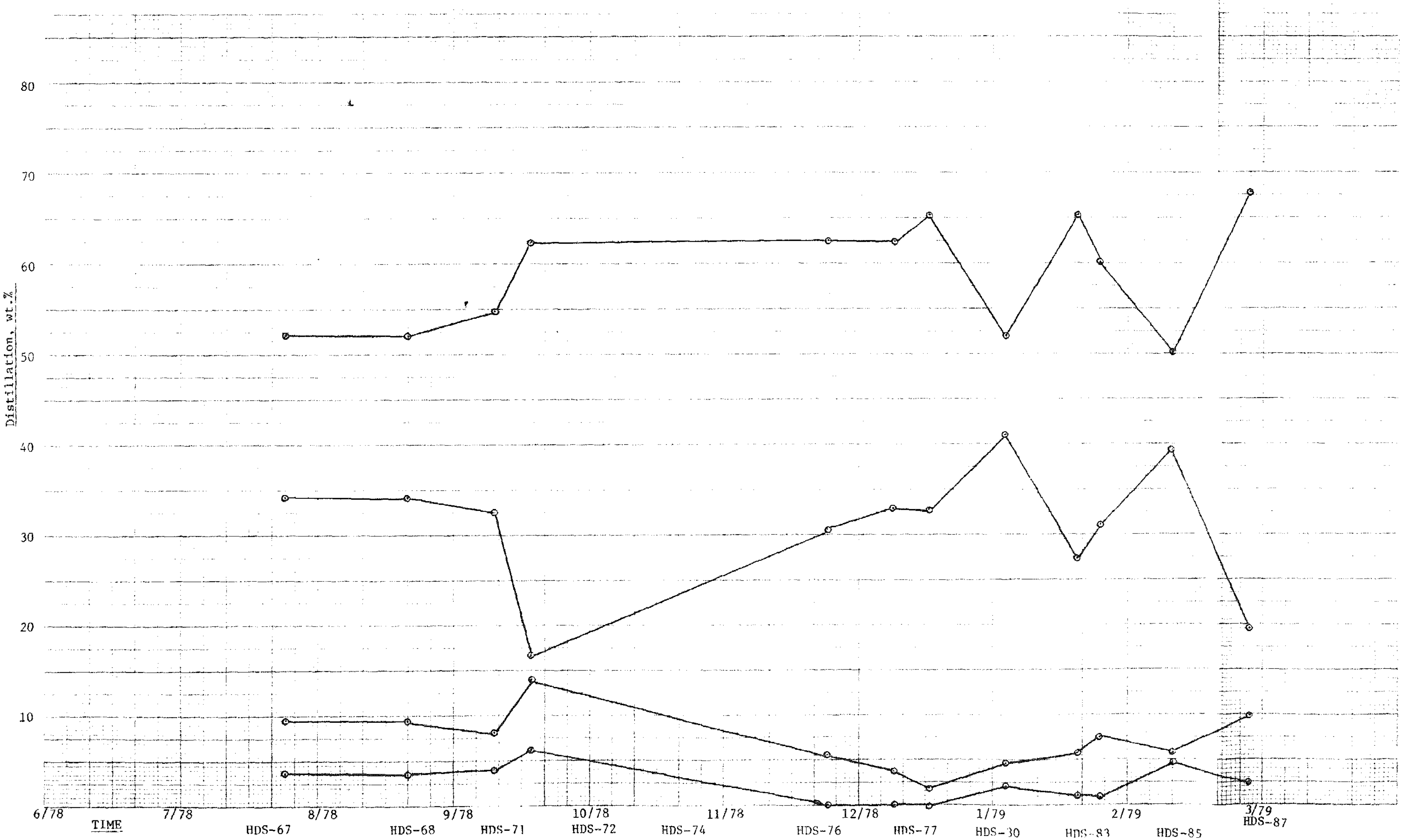


FIGURE 10

+400°F BOILER FUEL PRODUCT HYDROGEN AND CARBON VS. CATALYST LIFE

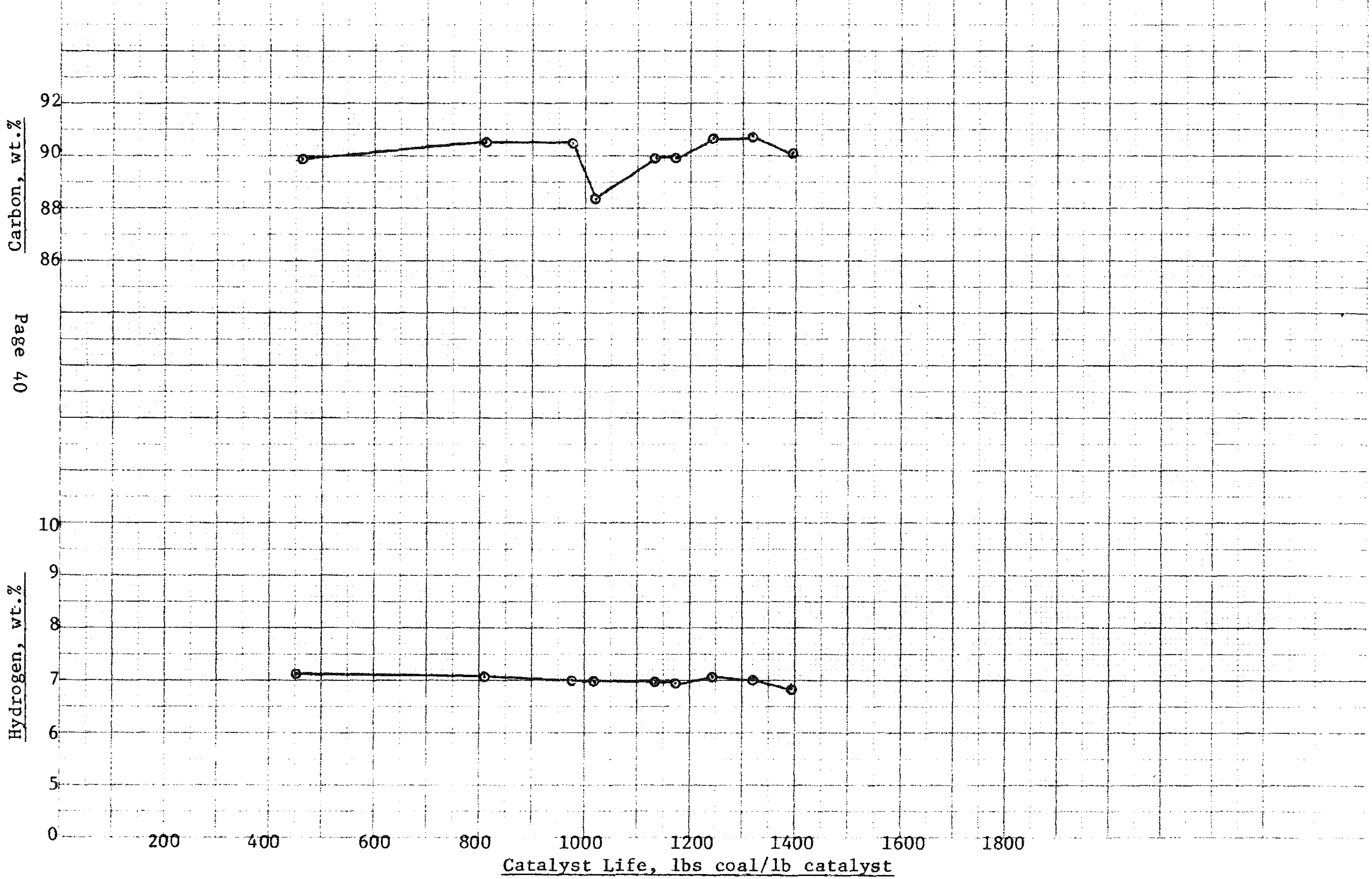


FIGURE 11

+400°F BOILER FUEL PRODUCT SULFUR AND NITROGEN VS. CATALYST LIFE

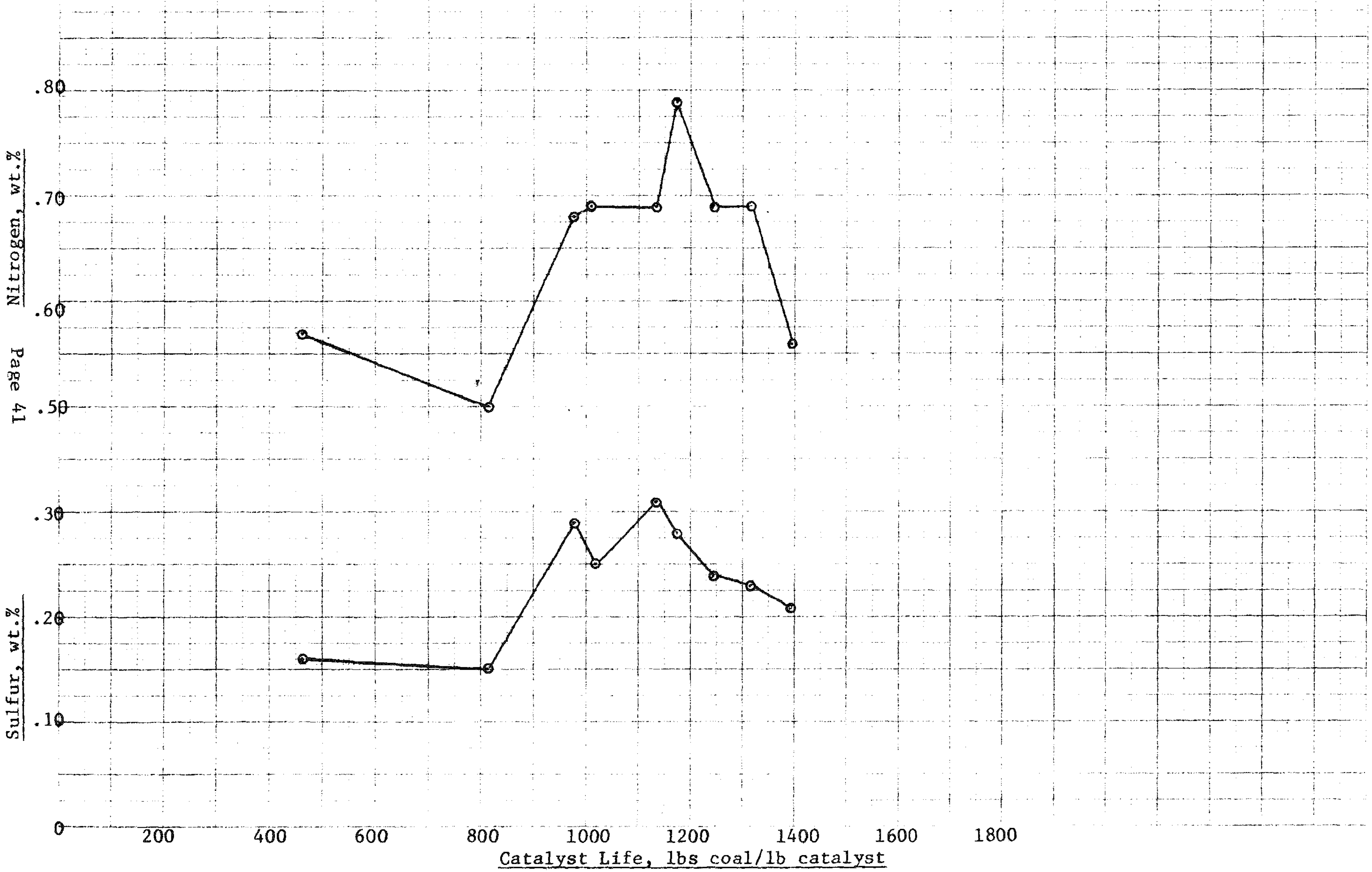


TABLE 11

VISCOSITY DATA

30% Coal Paste

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 200 | 15.84 | 203.5 |
| 200 | 7.92 | 207.0 |
| 200 | 3.96 | 214.0 |
| 200 | 1.98 | 228.0 |
| 200 | 0.792 | 275.0 |
| 200 | 0.396 | 300.0 |
| 250 | 39.60 | 53.4 |
| 250 | 15.84 | 56.25 |
| 250 | 7.92 | 64.5 |
| 250 | 3.96 | 66.0 |
| 250 | 1.98 | 70.0 |
| 300 | 79.20 | 28.15 |
| 300 | 39.60 | 28.8 |
| 300 | 15.84 | 29.75 |
| 300 | 7.92 | 35.5 |
| 300 | 3.96 | 36.0 |
| 300 | 1.98 | 40.0 |
| 300 | 0.792 | 60.0 |
| 300 | 0.396 | 70.0 |
| 400 | 79.20 | 30.7 |
| 400 | 39.60 | 31.1 |
| 400 | 15.84 | 31.75 |
| 400 | 7.92 | 35.5 |
| 400 | 3.96 | 39.0 |
| 400 | 1.98 | 46.0 |

TABLE 12

VISCOSITY DATA

35% Coal Paste

| Temperature, $^{o}F$ | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 200 | 15.84 | 117.0 |
| 200 | 7.92 | 121.5 |
| 200 | 3.96 | 129.0 |
| 200 | 1.98 | 146.0 |
| 200 | 0.792 | 175.0 |
| 200 | 0.396 | 180.0 |
| 250 | 79.20 | 35.6 |
| 250 | 39.60 | 36.9 |
| 250 | 15.84 | 39.0 |
| 250 | 7.92 | 42.0 |
| 250 | 3.96 | 50.0 |
| 250 | 1.98 | 60.0 |
| 250 | 0.792 | 90.0 |
| 250 | 0.396 | 100.0 |
| 300 | 79.20 | 14.0 |
| 300 | 39.60 | 14.4 |
| 300 | 15.84 | 15.25 |
| 300 | 7.92 | 15.5 |
| 300 | 3.96 | 18.0 |
| 300 | 1.98 | 20.0 |
| 300 | 0.792 | 30.0 |
| 400 | 79.20 | 10.3 |
| 400 | 39.60 | 10.8 |
| 400 | 15.84 | 12.75 |
| 400 | 7.92 | 13.0 |
| 400 | 3.96 | 15.0 |
| 400 | 1.98 | 16.0 |
| 400 | 0.792 | 25.0 |

TABLE 13

VISCOSITY DATA

HDS-72 Total Liquid Product

| Temperature, $^{o}F$ | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 150 | 16.80 | 633 |
| 150 | 8.40 | 640 |
| 150 | 3.36 | 660 |
| 150 | 1.68 | 680 |
| 150 | 0.84 | 740 |
| 150 | 0.42 | 800 |
| 150 | 0.168 | 1000 |
| 150 | 0.084 | 1200 |
| 200 | 39.60 | 94.5 |
| 200 | 15.84 | 100.0 |
| 200 | 7.92 | 108.5 |
| 200 | 3.96 | 126.0 |
| 200 | 1.98 | 154.0 |
| 200 | 0.792 | 270.0 |
| 200 | 0.396 | 300.0 |
| 250 | 79.20 | 30.55 |
| 250 | 39.60 | 31.9 |
| 250 | 15.84 | 35.5 |
| 250 | 7.92 | 41.5 |
| 250 | 3.96 | 52.0 |
| 250 | 1.98 | 66.0 |
| 250 | 0.792 | 95.0 |
| 250 | 0.396 | 130.0 |
| 300 | 79.20 | 13.3 |
| 300 | 39.60 | 14.4 |
| 300 | 15.84 | 17.25 |
| 300 | 7.92 | 20.5 |
| 300 | 3.96 | 25.0 |
| 300 | 1.98 | 32.0 |
| 300 | 0.792 | 55.0 |
| 300 | 0.396 | 60.0 |

TABLE 13 Continued

VISCOSITY DATA

HDS-74 Total Liquid Product

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 100 | 16.80 | 802 |
| 100 | 8.40 | 808 |
| 100 | 3.36 | 830 |
| 100 | 1.68 | 860 |
| 100 | 0.84 | 880 |
| 100 | 0.42 | 920 |
| 100 | 0.168 | 1000 |
| 100 | 0.084 | 1400 |
| 150 | 15.84 | 108.0 |
| 150 | 7.92 | 112.5 |
| 150 | 3.96 | 124.0 |
| 150 | 1.98 | 146.0 |
| 150 | 0.792 | 195.0 |
| 150 | 0.396 | 240.0 |
| 200 | 79.20 | 32.0 |
| 200 | 39.60 | 32.9 |
| 200 | 15.84 | 35.5 |
| 200 | 7.92 | 37.0 |
| 200 | 3.96 | 46.0 |
| 200 | 1.98 | 54.0 |
| 200 | 0.792 | 85.0 |
| 200 | 0.396 | 90.0 |
| 250 | 79.20 | 13.9 |
| 250 | 39.60 | 14.5 |
| 250 | 15.84 | 16.5 |
| 250 | 7.92 | 18.5 |
| 250 | 3.96 | 22.0 |
| 250 | 1.98 | 24.0 |
| 250 | 0.792 | 40.0 |
| 250 | 0.396 | 60.0 |

TABLE 13 Continued

VISCOSITY DATA

HDS-78 Total Liquid Product

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 100 | 3.36 | 3765 |
| 100 | 1.68 | 3850 |
| 100 | 0.84 | 4000 |
| 100 | 0.42 | 4160 |
| 100 | 0.168 | 4400 |
| 100 | 0.084 | 4800 |
| 150 | 16.80 | 276 |
| 150 | 8.40 | 284 |
| 150 | 3.36 | 295 |
| 150 | 1.68 | 300 |
| 150 | 0.84 | 320 |
| 150 | 0.42 | 360 |
| 150 | 0.168 | 500 |
| 150 | 0.084 | 600 |
| 200 | 79.20 | 49.5 |
| 200 | 39.60 | 49.6 |
| 200 | 15.84 | 51.75 |
| 200 | 7.92 | 57.0 |
| 200 | 3.96 | 63.0 |
| 200 | 1.98 | 76.0 |
| 200 | 0.792 | 115.0 |
| 200 | 0.396 | 150.0 |
| 250 | 79.20 | 18.9 |
| 250 | 39.60 | 19.5 |
| 250 | 15.84 | 20.5 |
| 250 | 7.92 | 22.5 |
| 250 | 3.96 | 25.0 |
| 250 | 1.98 | 34.0 |
| 250 | 0.792 | 55.0 |
| 250 | 0.396 | 70.0 |

TABLE 13 Continued

VISCOSITY DATA

HDS-81 Total Liquid Product

| Temperature, °F | Shear Rate, $sec.^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 150 | 3.36 | 4500 |
| 150 | 1.68 | 4620 |
| 150 | 0.84 | 4820 |
| 150 | 0.42 | 5040 |
| 150 | 0.168 | 5400 |
| 150 | 0.084 | 5800 |
| 200 | 16.80 | 385 |
| 200 | 8.40 | 390 |
| 200 | 3.36 | 395 |
| 200 | 1.68 | 420 |
| 200 | 0.84 | 440 |
| 250 | 39.60 | 68.4 |
| 250 | 15.84 | 72.0 |
| 250 | 7.92 | 79.5 |
| 250 | 3.96 | 94.0 |
| 250 | 1.98 | 106.0 |
| 250 | 0.792 | 125.0 |
| 250 | 0.396 | 160.0 |
| 300 | 79.20 | 23.35 |
| 300 | 39.60 | 23.9 |
| 300 | 15.84 | 24.75 |
| 300 | 7.92 | 28.0 |
| 300 | 3.96 | 34.0 |
| 300 | 1.98 | 46.0 |
| 300 | 0.792 | 80.0 |
| 300 | 0.396 | 90.0 |

TABLE 14

VISCOSITY DATA

HDS-68 Recycle Solvent

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 100 | 3.36 | 2855 |
| 100 | 1.68 | 2890 |
| 100 | 0.84 | 2940 |
| 100 | 0.42 | 2960 |
| 100 | 0.168 | 3000 |
| 100 | 0.084 | 3600 |
| 150 | 15.84 | 202.75 |
| 150 | 7.92 | 207.0 |
| 150 | 3.96 | 214.0 |
| 150 | 1.98 | 236.0 |
| 150 | 0.792 | 300.0 |
| 150 | 0.396 | 420.0 |
| 200 | 79.20 | 39.9 |
| 200 | 39.60 | 40.4 |
| 200 | 15.84 | 41.75 |
| 200 | 7.92 | 48.0 |
| 200 | 3.96 | 56.0 |
| 200 | 1.98 | 76.0 |
| 200 | 0.792 | 105.0 |
| 200 | 0.396 | 160.0 |
| 250 | 39.60 | 13.8 |
| 250 | 15.84 | 16.75 |
| 250 | 7.92 | 17.0 |
| 250 | 3.96 | 19.0 |

HDS-74 Recycle Solvent

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 150 | 8.40 | 1418 |
| 150 | 3.36 | 1445 |
| 150 | 1.68 | 1470 |
| 150 | 0.84 | 1500 |
| 150 | 0.42 | 1560 |
| 150 | 0.168 | 1700 |
| 150 | 0.084 | 1800 |

TABLE 14 Continued

VISCOSITY DATA

HDS-74 Recycle Solvent

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 200 | 16.80 | 144 |
| 200 | 8.40 | 146 |
| 200 | 3.36 | 150 |
| 200 | 1.68 | 160 |
| 200 | 0.84 | 180 |
| 200 | 0.42 | 200 |
| 200 | 0.168 | 300 |
| 250 | 79.20 | 28.8 |
| 250 | 39.60 | 29.7 |
| 250 | 15.84 | 31.25 |
| 250 | 7.92 | 36.5 |
| 250 | 3.96 | 48.0 |
| 250 | 1.98 | 66.0 |
| 250 | 0.792 | 100.0 |
| 250 | 0.396 | 160.0 |
| 300 | 79.20 | 11.75 |
| 300 | 39.60 | 12.0 |
| 300 | 15.84 | 12.5 |
| 300 | 7.92 | 14.5 |
| 300 | 3.96 | 18.0 |
| 300 | 1.98 | 26.0 |

HDS-78 Recycle Solvent

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 150 | 8.40 | 1198 |
| 150 | 3.36 | 1220 |
| 150 | 1.68 | 1230 |
| 150 | 0.84 | 1260 |
| 150 | 0.42 | 1320 |
| 150 | 0.168 | 1600 |
| 150 | 0.084 | 1800 |
| 200 | 16.80 | 146 |
| 200 | 8.40 | 148 |
| 200 | 3.36 | 155 |
| 200 | 1.68 | 160 |
| 200 | 0.84 | 160 |
| 200 | 0.42 | 240 |
| 200 | 0.168 | 300 |

TABLE 14 Continued

VISCOSITY DATA

HDS-78 Recycle Solvent

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 250 | 79.20 | 28.35 |
| 250 | 39.60 | 29.3 |
| 250 | 15.84 | 32.0 |
| 250 | 7.92 | 38.0 |
| 250 | 3.96 | 52.0 |
| 250 | 1.98 | 78.0 |
| 250 | 0.792 | 145.0 |
| 250 | 0.396 | 200.0 |
| 300 | 79.20 | 12.4 |
| 300 | 39.60 | 12.9 |
| 300 | 15.84 | 15.75 |
| 300 | 7.92 | 20.0 |
| 300 | 3.96 | 28.0 |
| 300 | 1.98 | 30.0 |
| 300 | 0.792 | 40.0 |

HDS-81 Recycle Solvent

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 150 | 16.80 | 384 |
| 150 | 8.40 | 386 |
| 150 | 3.36 | 390 |
| 150 | 1.68 | 390 |
| 150 | 0.84 | 400 |
| 150 | 0.42 | 440 |
| 150 | 0.168 | 600 |
| 200 | 39.60 | 56.2 |
| 200 | 15.84 | 57.75 |
| 200 | 7.92 | 60.5 |
| 200 | 3.96 | 63.0 |
| 200 | 1.98 | 72.0 |
| 200 | 0.792 | 95.0 |
| 200 | 0.396 | 100.0 |

TABLE 14 Continued

VISCOSITY DATA

HDS-81 Recycle Solvent

| Temperature, °F | Shear Rate, $sec.^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 250 | 79.20 | 17.75 |
| 250 | 39.60 | 18.1 |
| 250 | 15.84 | 19.5 |
| 250 | 7.92 | 22.0 |
| 250 | 3.96 | 28.0 |
| 250 | 1.98 | 42.0 |
| 250 | 0.792 | 50.0 |
| 250 | 0.396 | 60.0 |
| 300 | 79.20 | 8.75 |
| 300 | 39.60 | 9.4 |
| 300 | 15.84 | 10.5 |
| 300 | 7.92 | 12.5 |
| 300 | 3.96 | 15.0 |
| 300 | 1.98 | 20.0 |
| 300 | 0.792 | 25.0 |

HDS-83 Recycle Solvent

| | | |
|---|---|---|
| 150 | 16.80 | 626 |
| 150 | 8.40 | 632 |
| 150 | 3.36 | 635 |
| 150 | 1.68 | 660 |
| 150 | 0.84 | 680 |
| 150 | 0.42 | 720 |
| 150 | 0.168 | 800 |
| 150 | 0.084 | 1000 |
| 200 | 39.60 | 74.1 |
| 200 | 15.84 | 74.5 |
| 200 | 7.92 | 80.5 |
| 200 | 3.96 | 90.0 |
| 200 | 1.98 | 112.0 |
| 200 | 0.792 | 155.0 |
| 200 | 0.396 | 230.0 |

TABLE 14 Continued

VISCOSITY DATA

HDS-83 Recycle Solvent

| Temperature, $^{o}F$ | Shear Rate, $sec.^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 250 | 79.20 | 21.45 |
| 250 | 39.60 | 22.1 |
| 250 | 15.84 | 23.0 |
| 250 | 7.92 | 25.5 |
| 250 | 3.96 | 32.0 |
| 250 | 1.98 | 44.0 |
| 250 | 0.792 | 55.0 |
| 250 | 0.396 | 60.0 |
| 300 | 79.20 | 9.9 |
| 300 | 39.60 | 10.4 |
| 300 | 15.84 | 13.0 |
| 300 | 7.92 | 14.0 |
| 300 | 3.96 | 20.0 |
| 300 | 1.98 | 22.0 |
| 300 | 0.792 | 30.0 |

## TABLE 15

### VISCOSITY DATA
### HIGH THROUGHPUT RUN

HDS-87A First Reactor Blend of Recycle Product and Coal Paste

| Temperature, °F | Shear Rate, $Sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 200 | 39.60 | 73.1 |
| 200 | 15.84 | 74.5 |
| 200 | 7.92 | 76.5 |
| 200 | 3.96 | 80.0 |
| 200 | 1.98 | 86.0 |
| 200 | 0.792 | 105.0 |
| 200 | 0.396 | 150.0 |
| 250 | 79.20 | 23.65 |
| 250 | 39.60 | 27.7 |
| 250 | 15.84 | 23.75 |
| 250 | 7.92 | 24.0 |
| 250 | 3.96 | 28.0 |
| 250 | 1.98 | 28.0 |
| 250 | 0.792 | 40.0 |
| 250 | 0.396 | 60.0 |
| 300 | 79.20 | 10.35 |
| 300 | 39.60 | 10.7 |
| 300 | 15.84 | 11.5 |
| 300 | 7.92 | 13.5 |
| 300 | 3.96 | 18.0 |
| 300 | 1.98 | 28.0 |
| 300 | 0.792 | 40.0 |
| 300 | 0.396 | 60.0 |
| 350 | 79.20 | 6.45 |
| 350 | 39.60 | 6.7 |
| 350 | 15.84 | 7.5 |
| 350 | 7.92 | 10.0 |
| 350 | 3.96 | 11.0 |
| 350 | 1.98 | 14.0 |
| 350 | 0.792 | 25.0 |

TABLE 15 Continued

VISCOSITY DATA
HIGH THROUGHPUT RUN

HDS-87B First Reactor Blend of Recycle Product and Coal Paste

| Temperature, °F | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 200 | 39.60 | 77.3 |
| 200 | 15.84 | 78.75 |
| 200 | 7.92 | 82.0 |
| 200 | 3.96 | 86.0 |
| 200 | 1.98 | 96.0 |
| 200 | 0.792 | 125.0 |
| 200 | 0.396 | 150.0 |
| 250 | 79.20 | 21.0 |
| 250 | 39.60 | 21.4 |
| 250 | 15.84 | 22.0 |
| 250 | 7.92 | 22.0 |
| 250 | 3.96 | 24.0 |
| 250 | 1.98 | 32.0 |
| 250 | 0.792 | 40.0 |
| 250 | 0.396 | 60.0 |
| 300 | 79.20 | 10.05 |
| 300 | 39.60 | 10.5 |
| 300 | 15.84 | 10.75 |
| 300 | 7.92 | 11.5 |
| 300 | 3.96 | 12.0 |
| 300 | 1.98 | 20.0 |
| 300 | 0.792 | 30.0 |
| 300 | 0.396 | 40.0 |
| 350 | 79.20 | 6.2 |
| 350 | 39.60 | 6.3 |
| 350 | 15.84 | 7.5 |
| 350 | 7.92 | 8.0 |
| 350 | 3.96 | 8.0 |
| 350 | 1.98 | 10.0 |
| 350 | 0.792 | |

TABLE 15 Continued

VISCOSITY DATA
HIGH THROUGHPUT RUN

HDS-87C First Reactor Blend of Recycle Product and Coal Paste

| Temperature, $^{o}F$ | Shear Rate, $sec^{-1}$ | Apparent Viscosity, Centipoise |
|---|---|---|
| 200 | 39.60 | 99.2 |
| 200 | 15.84 | 101.0 |
| 200 | 7.92 | 105.5 |
| 200 | 3.96 | 114.0 |
| 200 | 1.98 | 130.0 |
| 200 | 0.792 | 180.0 |
| 200 | 0.396 | 210.0 |
| 250 | 79.20 | 34.6 |
| 250 | 39.60 | 34.9 |
| 250 | 15.84 | 36.25 |
| 250 | 7.92 | 38.0 |
| 250 | 3.96 | 43.0 |
| 250 | 1.98 | 54.0 |
| 250 | 0.792 | 80.0 |
| 250 | 0.396 | 120.0 |
| 300 | 79.20 | 16.85 |
| 300 | 39.60 | 17.6 |
| 300 | 15.84 | 19.0 |
| 300 | 7.92 | 21.0 |
| 300 | 3.96 | 28.0 |
| 300 | 1.98 | 38.0 |
| 300 | 0.792 | 40.0 |
| 300 | 0.396 | 50.0 |
| 350 | 79.20 | 9.05 |
| 350 | 39.60 | 9.6 |
| 350 | 15.84 | 12.25 |
| 350 | 7.92 | 14.0 |
| 350 | 3.96 | 18.0 |
| 350 | 1.98 | 28.0 |
| 350 | 0.792 | 35.0 |
| 350 | 0.396 | 40.0 |

FIGURE 12

30% COAL PASTE VISCOSITY VS. SHEAR RATE

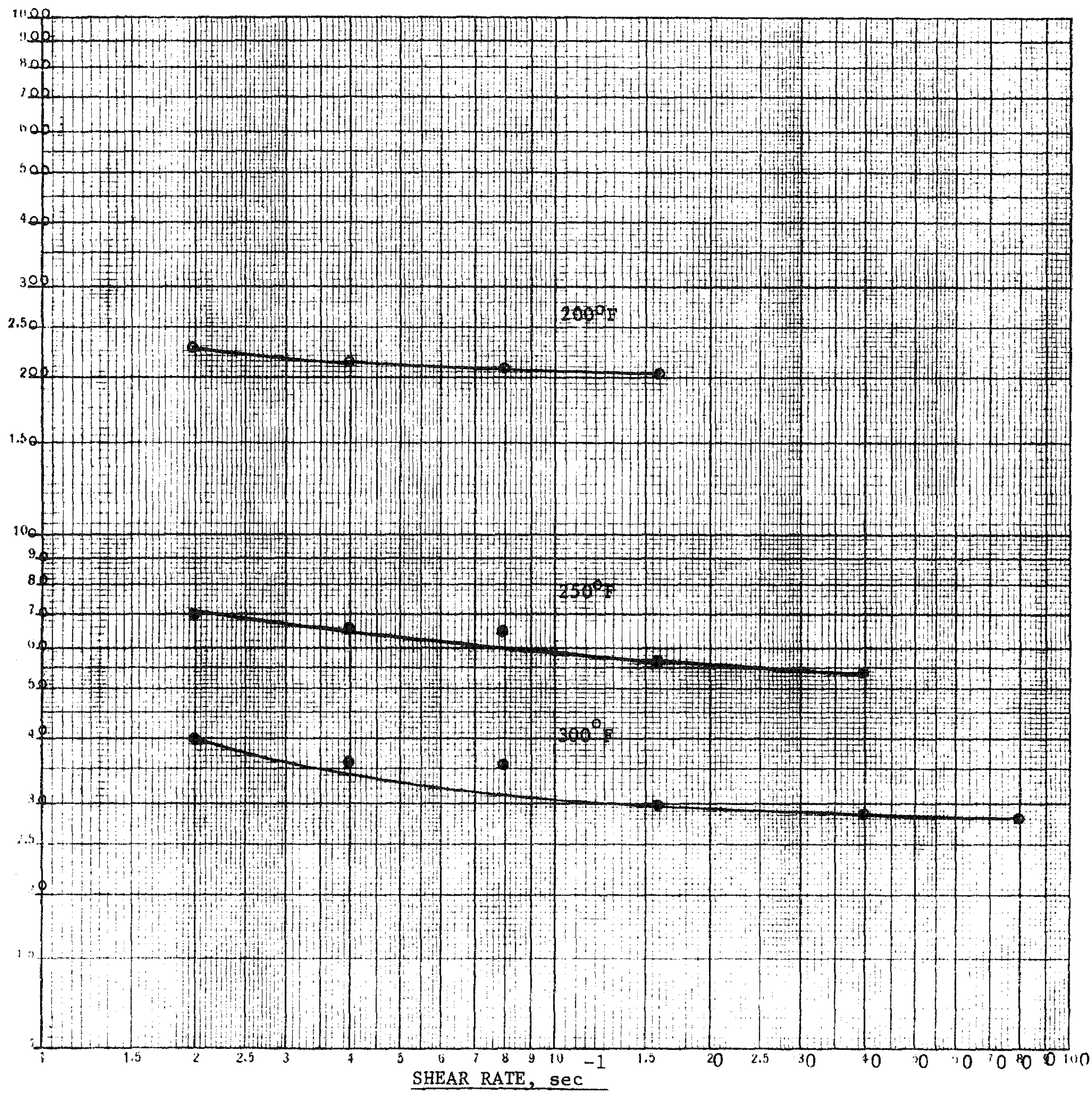


FIGURE 13

35% COAL PASTE VISCOSITY VS. SHEAR RATE

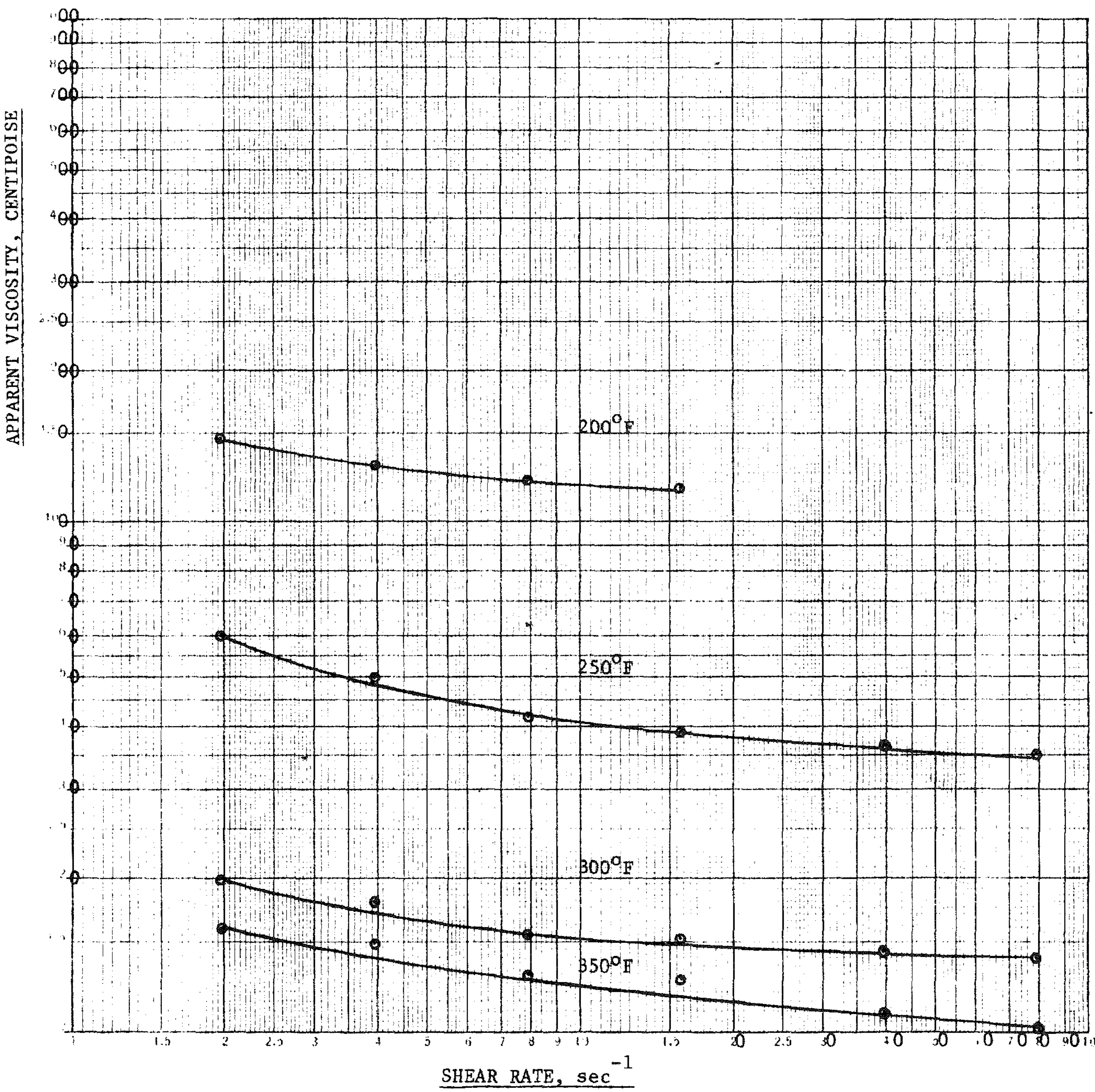


FIGURE 14

HIGH THROUGHPUT RUNS

HDS-87A, B, C FIRST REACTOR BLEND OF PRODUCT & COAL PASTE

VISCOSITY VS. SHEAR RATE

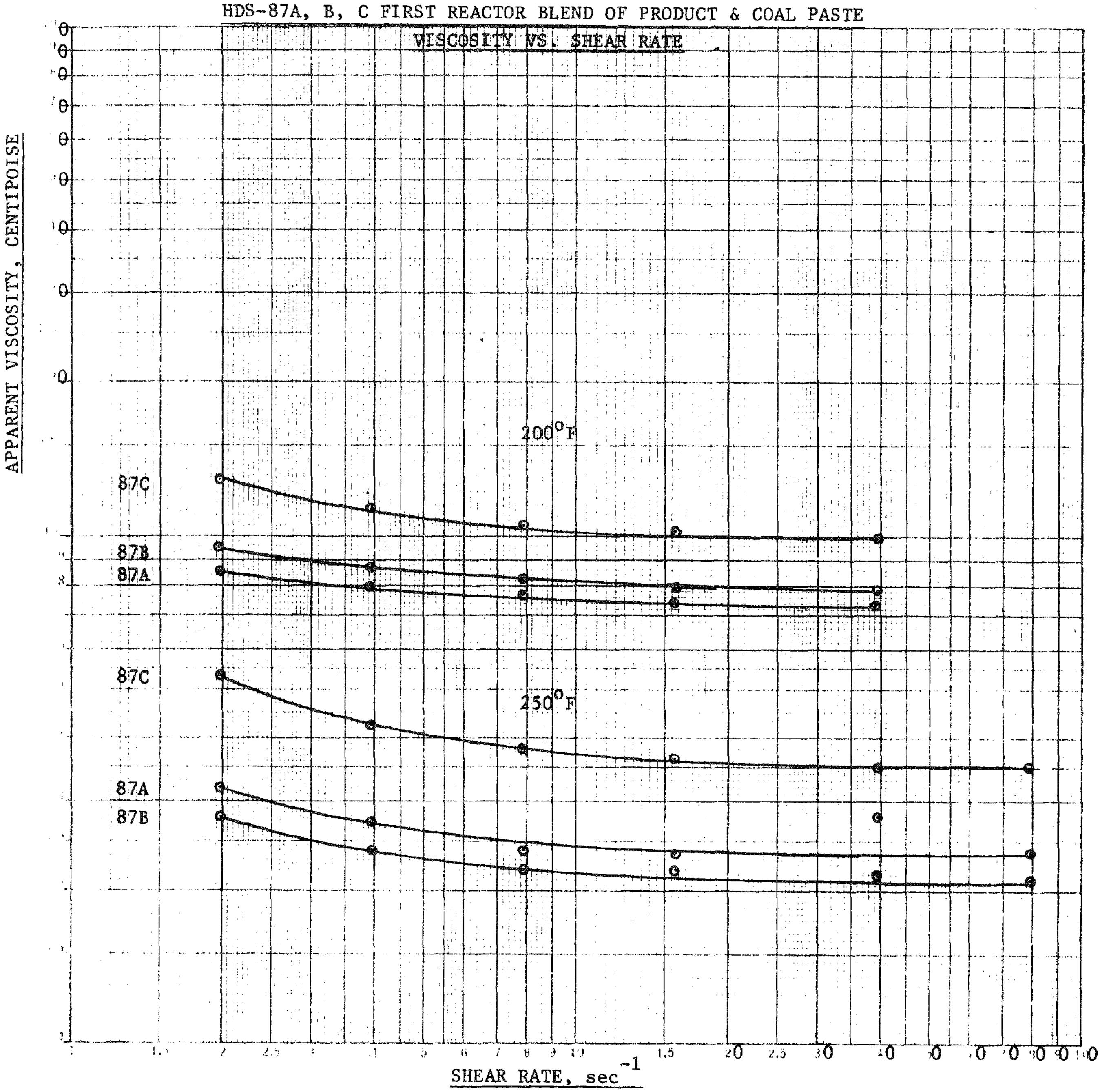


FIGURE 15

HIGH THROUGHPUT RUNS

HDS-87A, B, C FIRST REACTOR BLEND OF PRODUCT & COAL PASTE

VISCOSITY VS. SHEAR RATE

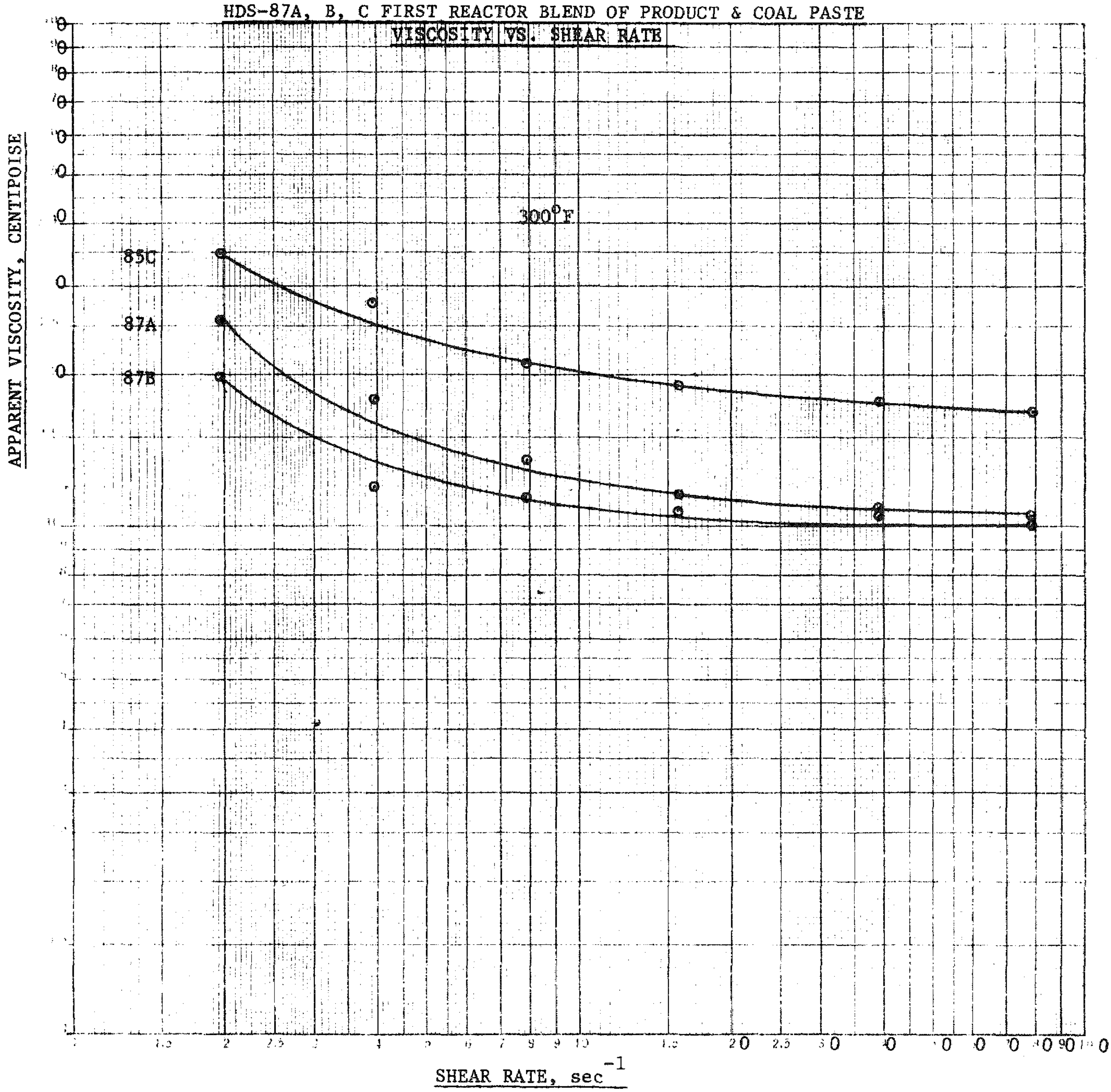
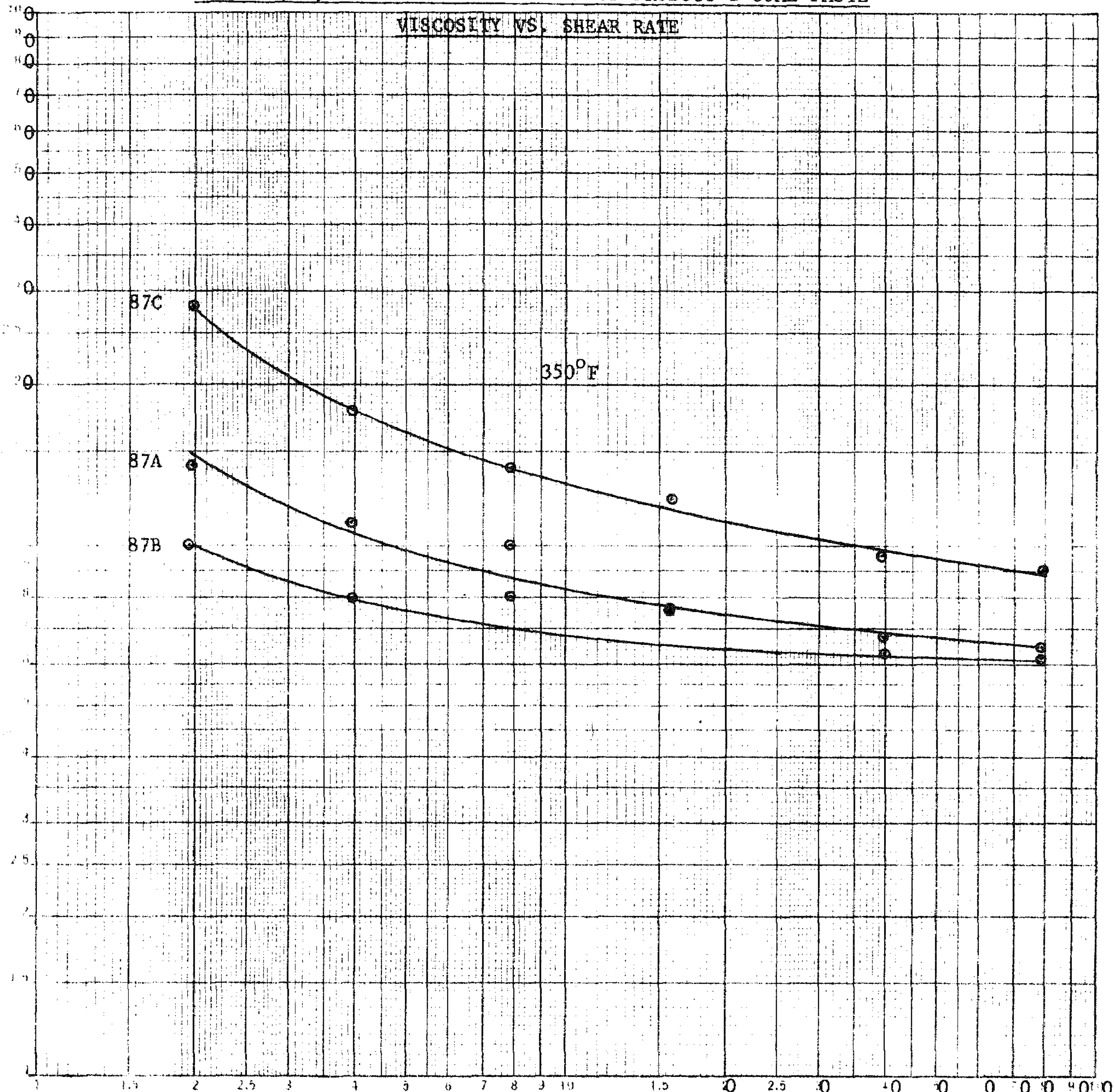


FIGURE 16

HIGH THROUGHPUT RUNS

HDS-87A, B, C FIRST REACTOR BLEND OF PRODUCT & COAL PASTE

VISCOSITY VS. SHEAR RATE




SHEAR RATE, $sec^{-1}$



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