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VISBREAKING OF LIBYAN HEAVY CRUDE OIL

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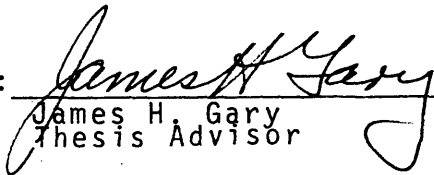
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A thesis submitted to the Faculty and Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science in Chemical and Petroleum-Refining Engineering.

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## ABSTRACT

Libyan heavy crude oils from Amal field and Faregh field were visbroken at a pressure of 200 psi in a tubular reactor. The reaction variables were studied in the ranges from 650 °F to 850 °F and from 1.7 minute to 6.5 minute residence time. Water was injected with a weight ratio to feed of 0.025 at a residence time of 1.7 minute to find how it affects the viscosity of Amal crude oil.

Increasing the severity of operation resulted in decreases in viscosity and pour point of the crude oil. The results for gas analysis were correlated with the severity factor which combined the effects of the reaction variables. Increasing the severity of operation resulted in increases in conversion by weight to both solid and gaseous products, in total volumetric gaseous yields, hydrogen and methane yields. The total reduction in viscosity for Amal crude oil is 17.09 saybolt universal seconds at a reaction temperature 650 °F and 65.19 SUS at 850 °F from original viscosity of 90.2 SUS at 100 °F. For Faregh crude oil, the total reduction is about 50.95 saybolt universal seconds at 650 °F and 64.80 SUS at 850 °F from original viscosity 89.3 SUS at 100 °F. The reduction in pour point for both Amal and Faregh are

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19.5 °F and 25 °F, respectively for original pour point  
of 67.5 °F and 75 °F.

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DEDICATION

This thesis is dedicated to my father Mabruk, my wife Sabria and my son and daughter Samer and Summer.

## INTRODUCTION

Visbreaking is a form of thermal cracking that was considered obsolete in the United States until a few years ago. The process now is being revived because it offers economic advantages to many refining schemes (1). It is a major objective for the oil refiner to produce from No. 6 fuel oil as much gas oil as possible and still maintain proper viscosity specification (2).

To understand the visbreaking process and its limitations, a few words can be said about the structure of a typical petroleum residue and its transformation during visbreaking (3).

A typical petroleum residue obtained after a vacuum distillation operation consists of three types of compounds, these are: oils, resins, and asphaltenes. The resins are thought of as very high molecular compounds which can be separated from a deasphalted residue by adsorption on adsorbents. The typical petroleum residue is a colloidal solution in which the asphaltenes are held in a colloidal suspension in the oil phase with the resins and aromatic hydrocarbons acting as peptizing agents. The asphaltenes are high molecular weight compounds held together by physical forces and they can be precipitated from a residue by paraffinic solvents.

During the thermal process of visbreaking, two processes take place. The hydrocarbons are partly cracked, producing lighter products which are distilled and at the same time carboids and coke are formed through polymerization, condensation, dehydrogenation and dealkylation reactions. These carboids and coke as well as the asphaltenes continue to be held in a stable colloidal solution or suspension up to a certain limit of conversion. Past this limit they tend to separate and to form deposits either in storage or in the equipment used for heating and burning the residual itself.

Two main objectives can be identified when the visbreaking process is considered, these objectives are: reduction of fuel oil production and reduction of fuel oil production with a simultaneous improvement of its pour point by including a mild thermal cracking step (3).

There are several methods of realizing these objectives. First, one may carry out a catalytic hydrodesulfurization operation and produce an entirely distillate product. A second method of processing heavy residue is that of coking. This route is effective in eliminating the blending of distillate cutter stocks in residuals, but here one must substitute coke for residual fuel as a product in the marketing program (2).

Few studies of the visbreaking process have been done for heavy crude oil. The latest study by Frank Stolfa (4) indicated that visbreaking reduced the production of fuel oil by about 20 percent. Approximately 10 percent of the charge was converted to gas-plus gasoline and the reduction in viscosity and pour point, which decreased the requirement for cutter stock, accounted for the other 10 percent. The combination process visbreaking plus-gas oil cracking for pour point reduction was developed in the early 1960's primarily for North Africa waxy crudes.

The objective of this first trial of overall research was to study the determining effects of operating variables on visbreaking processes with a major goal of reducing the viscosity and pour point.

It has been postulated and generally accepted, but not conclusively proved, that asphaltic materials contained in oils exist in a colloidal state. Acceptance of this theory has materially advanced the progress of asphalt chemistry, and in addition, satisfactorily explained the mechanism of instability of the visbroken product (11). Katz and Ben (12) examined thin films of asphalt with the electron microscope to search for colloidal particles. Micrographs obtained at 156,000 diameters indicated that colloidal particles, if present in undiluted asphalt, are less than 65A in diameter.

From unpublished data and an excellent article by Benthea, Goldthwait, and Offutt (18), correlations have been developed to predict visbreaking yields and product quality when operating at optimum visbreaking conditions. Since the primary purpose of visbreaking is to reduce the production of residual fuel oil, these correlations were developed on the following bases:

- The correlations are valid for vacuum residuum visbreaker charge stock only. Atmospheric distillation operations will not result in minimizing residual fuel oil yield.
- The visbreaking reaction is carried out at maximum severity as limited by fuel oil thermal stability requirements for Navy Special Fuel oil. For well-designed visbreaking furnaces, this severity will be within the operating limit dictated by excessive furnace coking.

Visbreaking, like thermal cracking, is a first-order reaction. Visbreaking operating conditions rarely approach the severity required to give the secondary reactions of polymerization and condensation a chance to occur. This is due to the visbreaking severity limit imposed by the fuel oil stability requirements.

## PREVIOUS STUDIES

The Phillips Petroleum Company (7) has recently placed in operation a high vacuum unit, operating in the range of 100 microns (0.1 mmHg) to 800 microns (0.8 mmHg) with encouraging results. High yields of gas oil have been produced from feed stocks having 12% to zero of material boiling below 1000 °F. The application of high vacuum to recover heavy hydrocarbons from crude presented the problem of disposing of the high viscosity vacuum residuum. The obvious solution of blending back the residuum with low viscosity oil to fuel oil specifications may not be the best choice, not only because it degrades the fluxing oil to fuel oil level but requires selecting cut back stocks and blending techniques which will avoid settling of the blend from lack of compatibility of the stocks. But by visbreaking, or mild cracking of high viscosity vacuum residuum, fuel oil yields are greatly reduced over those obtained by cutting back the residuum to fuel oil specifications.

A pilot plant trial was made to investigate visbreaking a cracked residuum. The charge was a vacuum reduced residuum from one pass topped crude cracking of Texas pan-handle reduced crude. First attempts at visbreaking were unsuccessful due to coil coking. However, by using a small

coil and cold oil velocities of 2 ft per sec., conversion of 47 LV % of the charge to 900 °F and lighter was obtained.

In a commercial visbreaking operation(7), the high vacuum unit residuum, representing approximately 13 LV % of the crude, was charged to the visbreaker furnace through a small surge tank. Then the furnace outlet was quenched immediately with gas oil and charged to a flash drum. The amount flashed was controlled by the pressure on the flash drum and by gas oil or steam injection ahead of flash drum. The heavy residuum made was sent to storage off the flash drum bottom and the overhead vapors were charged to the bubble tower. The gas oil was cooled and a portion recycled to the furnace outlet as quenched oil with the remainder going to storage.

The description by Lummus Company (8) states, that the pour points of reduced oils (70-100°F) are reduced by 20-25 °F by visbreaking. They also stated that the pour points of waxy vacuum tower distillates are reduced 40-50 °F by visbreaking.

In one of the Western Petroleum Refiner's Association panel discussions, Fischbeck stated that mild cracking (visbreaking) reduced the pour point by 20-30 °F. In this case the gas oil had been removed and this indicated that visbreaking the entire residue might give even lower pour

points. Greater reductions in pour points occurred at higher severities.

Two samples of East Texas reduced crude (105-110 °F pour point) were subjected to visbreaking with results as following:

	<u>API</u>	<u>Viscosity SSF at 122 °F</u>	<u>Pour</u>
No. 1	11.6	228	50 F <sup>0</sup>
No. 2	9.5	380	60 F <sup>0</sup>

and two tests of a 20 vol % Kuwait residue (100 °F pour) yielded fuel oils by visbreaking which had pour points of 55 and 65 °F. So most generally it seems that a reduction in pour point of at least 20-30 °F is possible by visbreaking.

Benther, Goldthwait, and Offutt (14) discuss in detail the effect of degree of visbreaking on the stability of visbreaker fuel oils. They found that the stability is a function of the amount of n-pentane insolubles and Ring and Ball softening point. If these properties are low, the stock contains more oil, and less asphaltenes, and it is a good feedstock.

During visbreaking, the heavy oil cracks into lower-viscosity, lower-boiling oils. Most approximately, a n-pentane insoluble reaction of less than 14% in the feed material is considered as good. Gravity alone is not directly related to the suitability of feedstock for visbreaking.

Moderate visbreaking decreases the boiling range of a 900 °F straight-run residue to a 50% temperature of 850-900 °F. Vacuum flashing of such visbreaker product at a pressure of 30-35 mmHg will cause the vaporization of about 50-60%, of which 5-10% is gasoline and the rest, visbreaker gas oil boiling up to about 900 °F. Several analytical methods are used to determine the stability of the residual fuel. These are (3):

- Sediment
- Navy boiler and turbine laboratory tests
- Hot filtration test
- Shell filtration test

Although all of these represent certain aspects of the stability of the visbreaker residue, they are not equivalent. Some of these are only qualitative measures of this stability.

In 1960 the combination process visbreaking plus-gas oil cracking for pour point reduction was developed for North Africa waxy crudes. In this process a waxy reduced crude were charged to a visbreaking coil (4) and the effluent from the coil was fractionated. In addition to gas plus gasoline, a light distillate was recovered. The residue was vacuum flashed and the recovered visbroken vacuum gas oil was thermal cracked in a second coil to light

distillate and thermal tar. The light distillate, thermal tar and thermal vacuum residue were then blended to low pour point fuel oil specification (4).

During the past 20 years, Lummus has built several units for improving viscosity and pour point (3). All these units had two heaters, one fed with virgin residue and the second with vacuum gas oil boiling-range material. The pour point reduction unit, by virtue of their selective two heater system, allowed an important production of distillates, but it may be debatable whether they retain viability in view of today's high energy costs (3,4).

Viscosity breaking also may be achieved by injecting residuum into the hot-cracked product resulting from normal cracking operations at the point where these products leave the cracking furnace. The quantity of heat supplied in this manner to the residuum is sufficient to obtain the desired degree of cracking. This method of reducing viscosity of the residuum was referred to as the injection flow method (8).

Shell International Petroleum, Maatschapy, The Hague, Netherlands (7) maintained that the thermal cracking rates constant  $k$  has the usual Arrhenius-type relationship,

$$k = k_0 - e^{-ERT}$$

in which  $k_0$  is a constant

E is the energy of activation

R is the gas constant

The energy of activation, E, depends on the molecular size, being lower for large molecules than for smaller molecules. This leads to a relatively greater difference between the cracking rates of, say  $C_{15}$  and  $C_{30}$  molecules at lower temperature (soaker cracking) than at high temperatures (furnace cracking).

The factor which leads to a selectivity of visbreaker yields in favor of gas oil range products in soaker cracking is the residence time of vapor in the cracking zone. In furnace cracking the vapor phase which develops along the coil and which preferably should not be cracked any further, has a residence time in the cracking zone of about 1/2 to 1/5 of that of the liquid phase which contains the cracking feedstock. Tables 1 and 2 show the estimation of visbreaking yields from light Arabian reduced crude, vacuum bottoms and reduced crude for gas oil recovery respectively.

Pilot plant operations were successful in visbreaking high vacuum tar (0.1 mmHg-0.8mmHg) using radiant type heating with high uniform heat transfer rates and high oil velocities through the coil. Higher conversions and less coil coking were possible at cold oil velocities of 2 ft per second than 0.3 ft per second. (7). The most severe

TABLE 1. ESTIMATED VISBREAKING YIELDS FROM LIGHT ARABIAN REDUCED CRUDE

Charge Products	Wt%	API	VOL%	S Wt%	N PPM	BR NO	POUR FLASH	VISC EST 122°F
	100	16.9	100	3.0	1600		59	480
H <sub>2</sub> S	0.2							
C <sub>4</sub>	2.1							
C <sub>5</sub> /C <sub>6</sub>	1.4	82.0	2.0	0.8				
C <sub>7</sub> -365°F	4.7	51.3	5.8	0.9	30	30		
365-700°F	10.7	33.2	11.9	1.3	100	26	10/155	2.6
700°F+Res	<u>80.9</u>	<u>14.7</u>	<u>79.7</u>	<u>3.1</u>				<u>300</u>
	100.0							

TABLE 2. ESTIMATED VISBREAKING YIELDS FROM LIGHT ARABIAN VACUUM BOTTOMS

Charge Products	WT%	API	VOL%	S WT%	N PPM	BR NO	POUR OF	VISC AT (122 °F)
	100	6.9	100	4.0	3100	-	105	225,000
H <sub>2</sub> S	0.3							
C <sub>4</sub>	2.2							
C <sub>5</sub> /C <sub>6</sub>	1.3	82.0	2.0	0.8				
C <sub>7</sub> -365 °F	4.6	51.0	6.1	1.0	50	62	85/165	
365-700 °F	<u>91.6</u>	7.2	91.8	4.0	-	-	-	6,000
	100.0							

cracking attained without excessive coke formation converted 48.8 LV% of charge to material boiling below 950 °F. This temperature was chosen because 950 °F closely approximated the initial point of visbreaker charge..

Pilot plant and bench scale visbreaking tests (12) were run on four different charge stocks. Two stocks were from a paraffinic base Texas crude. The third residuum for visbreaking was from an intermediate base crude and and the fourth from vacuum-reduced light crude. Tables 3 and 4 show the comparisons between pilot plant and bench-scale yields for visbreaking of various crude residuums and the yields for different stocks. Table 3 shows the comparison between pilot plant and commercial plant visbreaking.

The Lummus viscosity-breaking (15) process is designed to operate on high pour, high sulfur-content reduced crude to produce minimum yields of low pour, low viscosity fuel oil with maximum yields of low-pour cracked gas oil. Two-coil visbreaking units have been used. One coil is used for once through visbreaking of the reduced crude and the other coil for recycle cracking of the high-pour heavy gas oil produced in the first coil. Alternately, both coils can be employed in parallel for recycle visbreaking operations.

TABLE 3. PILOT PLANT AND BENCH SCALE VISBREAKING CHARGE STOCKS (VIRGIN RESIDUUMS)

	<u>Texas Crude</u>	<u>Intermediates as Crude</u>
Volume % of crude	11.7	47.2
Boiling blow 1100°F	2.0	12
Viscosity SFS at 122°F	1000+	-
Viscosity SFS at 210°F	163	110
Carbon Residuum	10.1	17.4
Softening Point(Ring & Ball)	-	123
Sulfur wt%	0.77	6.9
BS x W %	0.2	-
Gravity	17.8	6.9

TABLE 4. PILOT PLANT VISBREAKING OF A VACUUM REDUCED  
CRACKED RESIDUUMOperating Conditions:

Coil inlet Temp. °F	540
Coil outlet Temp °F	(caked)
Inlet pressure psig	182
Outlet pressure psig	156
Cold oil velocity ft/sec	1.9

Charge Stock:

V % of crude	8.5
Viscosity SFS at 122 °F	1321
Viscosity SFS at 210 °F	62
Carbon residue wt%	14.5
Pour point °F	70
Gravity API	12.5

Vacuum Distillation:

IBP	802
5% Cond.	872
10% Cond.	413
20% Cond.	475
30% Cond,	1015
40% Cond.	1033
50% Cond.	Cracked

The high-pour point waxy vacuum-tower sidestream is charged to the gas oil cracking coil where its pour point is reduced by 40-50 °F. When heavy reduced crudes having gravities in the range of 12.0 to 16.0 °A.P.I, viscosities from 300-800 S.S.F at 122 °F and pour points from 70-100 °F are charged to the unit, a finished fuel oil with a viscosity of 125 S.S.F at 122 °F and a pour point of 20-25 °F is produced.

If the available residual charge stocks have low pour points but high viscosities, the production of low-viscosity fuel oils can be accomplished in a simple once-through operation. Such a unit costs about 70 percent as much as the two stage visbreaking and pour reduction unit.

Cracking tests were made on a reduced crude oil from the Oficina field (16). The crude oil had an A.P.I. gravity of 33.5, and the reduced crude represented 48 percent of the original oil. The reduced crude was cracked in a Dubbs two-coil pilot plant. The conditions of operation were selected to produce a marketable fuel oil having a Furol viscosity of approximately 250 seconds at 122 °F, and 400 °F end point, 10 psi Reid vapor pressure gasoline. A heavy oil transfer temperature of 890 °F was maintained during the run along with a light oil transfer temperature of 960 °F. Pressure at the exit of the heavy oil coil was

220 psi, and 250 psi at the exit of the light oil coil.

Mixed Eastern Venezuela reduced crudes (17) were cracked in two ways to produce a marketable fuel oil residuum having a Furol viscosity between 200 and 250 seconds at 122 °F. The runs were made in a two-coil pilot plant using a heavy oil transfer temperature 915 °F and light oil transfer from 950 to 960 °F. The pressure was 250 psi. In the first run, normal two-coil recycle operation was employed and a residuum of the desired viscosity was produced directly.

In a second run the so-called cut-back operation was employed. In this method residuum of higher viscosity was produced and a fraction of intermediate boiling range cracked distillate was recovered and added to the residuum to lower its viscosity. A 400 °F end point gasoline and the desired viscosity fuel oil were produced in the normal operation. In the cut-back operation conditions were regulated so that a residuum having a Furol viscosity of 800 to 900 seconds at 122 °F was produced and sufficient intermediate boiling range cracked distillate was withdrawn from the final fractionator to cut back the viscosity of the residuum to 200 to 250 seconds.

A typical layout of a visbreaker processing unit is shown in Figure 1. The cracking takes place either in the

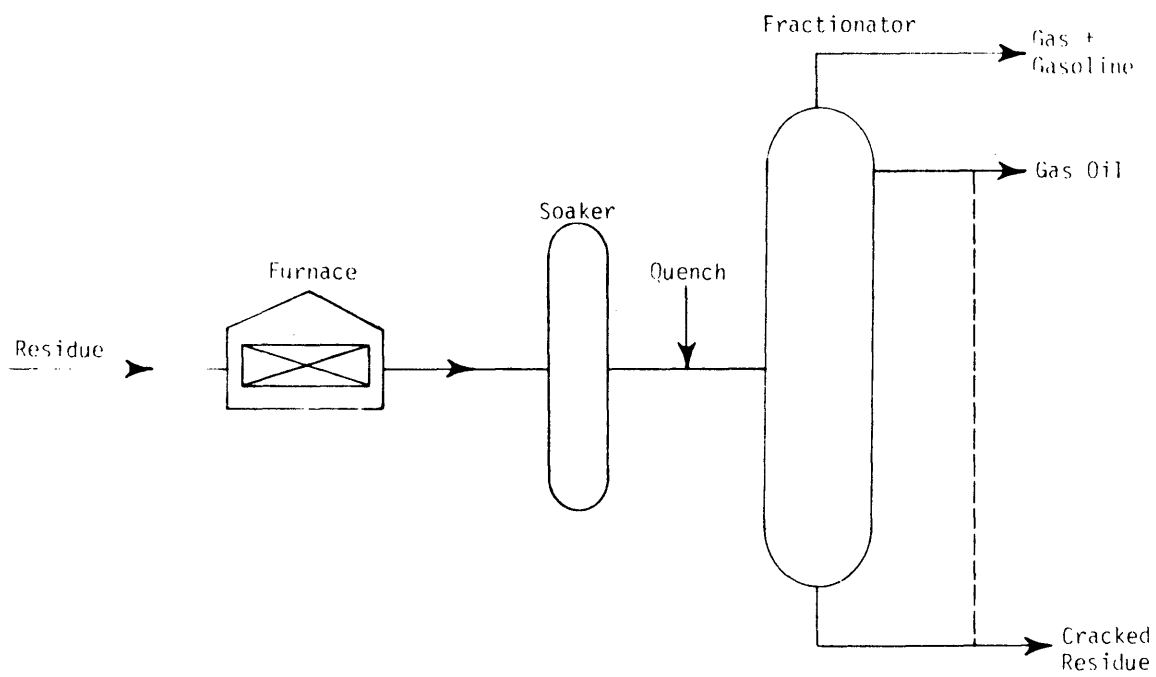


Figure 1.--Visbreaking residue using a soaker.

furnace (without soaker) or in a soaker (reaction chamber) just downstream of the furnace (20).

The soaker provides for a prolonged residence time and therefore requires a lower cracking temperature which is advantageous as regards cost of furnace and fuel. Furnace size can be decreased as much as 30% with a soaker. For this reason several non-Shell refineries are building visbreakers applying Shell's soaker technology.

The cracking temperature is about 485 °C in the furnace cracking case and about 440 °C in the soaker case. The main problem of visbreaking (1) is the instability of the fuel produced after blending with a cutter stock. If the cracking severity is too high, phase separation of fuel oil may appear as well as sludge formation. This is mainly due to presence of asphaltenes. During the cracking, the character of the asphaltenes changes (20). The colloidal solution cannot be maintained and asphaltenes tend to precipitate, forming sludge.

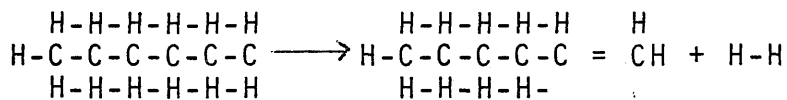
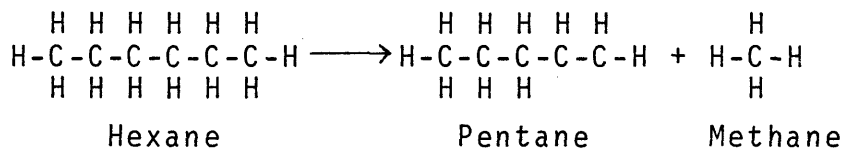
#### Coke Formation

An increase in visbreaking severity, such as that obtained by increasing furnace temperature, results in an increase in yields of distillate and gaseous hydrocarbons and reduction in the amount of cutter oil required to blend specification viscosity residual fuel oil (2).

At higher severities there is an increased tendency to form coke deposits in the furnace which if carried to extremes, would result in permanent shutdown for decoking of the cracking furnace.

## EXPERIMENTAL BASIS

Visbreaking is a non-catalytic, highly endothermic chemical change of substance by means of heat alone, including thermal rearrangements into isomers, thermal polymerization, and thermal decompositions (5). High temperature, large hydrocarbon molecules containing many atoms decompose into smaller molecules. When oil is heated, it cracks and breaks down into materials that boil at lower temperatures and have properties different from those of the original oils. The more drastic the cracking conditions, the smaller the molecules, and the lower is the boiling range of the cracked product. At extremely high temperatures, all hydrocarbons decompose into their elements, carbon and hydrogen. A hydrocarbon molecule can be decomposed in a variety of ways. Some of these reactions may be visualized by considering a few of the many theoretically possible splittings of a molecule of a saturated hydrocarbon using Hexane, for illustrative purposes.



From those reactions, it may be seen that gases, and liquids are formed during the cracking processes. The quantity of each of course, depends upon the severity of operation.

Actual reactions that occur in visbreaking are much more complicated than the reactions shown. Some highly unsaturated hydrocarbons are also formed.

## EXPERIMENTAL EQUIPMENT

The visbreaking unit used in this study Figure 2 is similar to pyrolysis units used by the Institute of Gas Technology (9) and by Griswold (5). The system is divided into four sections.

- 1) Feed system
- 2) Reactor system
- 3) Condenser system
- 4) Sampling system

### Feed System

Heavy crude oil is gravity fed from 1000 ml pyrex burets to a piston pump. The flow of oil is controlled by varying the stroke length and speed of stroke. The oil is pumped through 1/4 inch O.D., 316 tubing and preheated with an 8 ft thermotrace heating tape wrapped around a 1.5 ft section of oil line. Power to heating tape is supplied by a powerstate 10 amp, 1-KVa rheostat. The heating tape is rated up to 450 °C to maintain the temperature in the line. The tubing is wrapped with four layers of asbestos cloth as insulation.

### Preheater System

The preheater system is a 36.6 inch length of 0.285 inch O.D., 1/4 inch I.D., 316 SS tubing. The preheater is heated with a Lindberg one-zone tube furnace. The

temperature of the preheater is controlled by a Lindberg one-zone control unit that operates in the range of 200-1200 °C and responds to one thermocouple in the middle of the furnace. The outlet temperature of the preheater is measured by a thermocouple No. 19, located as shown in Figure 2. The thermocouples are interfaced with an automatic thermocouple scanner, digital readout in °F.

#### Reactor System

The reactor system is a 46.63 inch length of 0.535 inch O.D., 1/2 inch I.D., 316 SS tubing. The reactor is heated with a tube furnace. The temperature of the furnace is measured by two thermocouples 17 and 18 as shown in Figure 2. The outlet temperature of the reactor is measured by a thermocouple No. 21 as shown in Figure 2. The thermocouples are interfaced with an automatic thermocouple scanner, digital redout in °F.

#### Sampling System

The liquid received from the bottom of the flask tank is collected in a sample flask and the gas is diverted through a 250 ml glass bomb for about 10 minutes before collecting the gas sample. The liquid is tested for viscosity and pour point and the gas sample analyzed by gas chromatograph analysis.

TABLE 5. LIST OF EQUIPMENT

1. 1 - 1000 ml burets, oil feed
2. 1 - 250 m. burets, water feed
3. Piston pump
4. Single Lindberg furnace
5. Thermo trace heating tap
6. Furnace and reactor
7. Condenser
8. Flash drum
9. Sample flask
10. Glass wool filter
11. Dry gas test meter
12. Gas bomb
13. Control valve (pressure)
14. Relief valve up to 350 psi
15. Rupture disc up to 390 psi
16. Drum receives waste from rupture and rupture disc
17. Outlet furnace temperature measurement
18. Inlet furnace temperature measurement
19. Outlet thermocouple measurement
20. Rupture disc
21. Outlet reactor temperature measurement
22. Inlet reactor temperature measurement

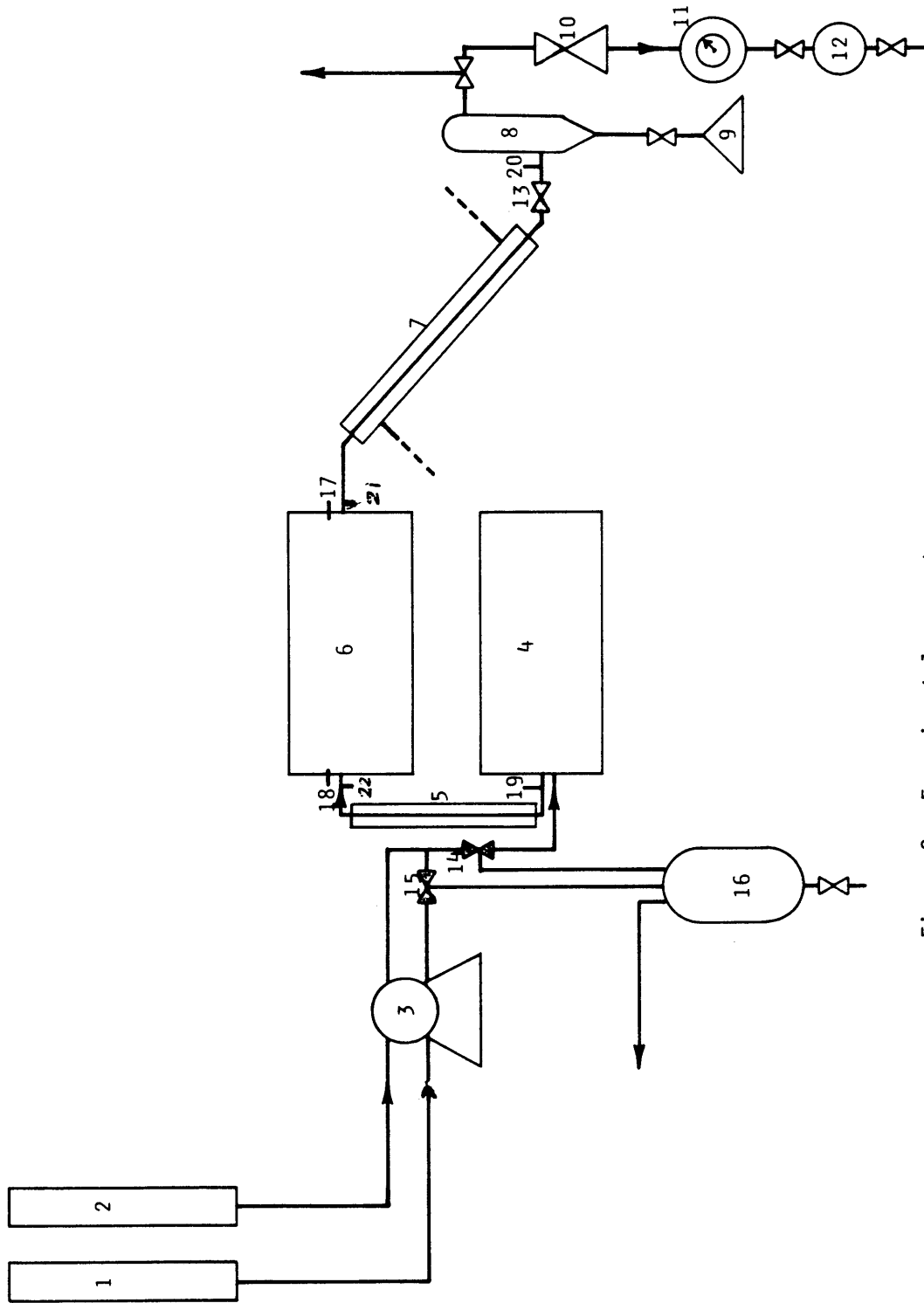


Figure 2.--Experimental apparatus

Chromatograph System

The product gas is analyzed with a Carle Model II (20) analytical gas chromatograph equipped with a series-bypass switching option. Three columns separate the product gas component:

Column 1A: 15 ft x 1/8 in., 28% Bis (EE) A + 4.7% squalane + 2% carbowax 1540 on 80/100 chromosorb PAQ

Column 1B: 16 in x 1.8 in, 1% tetraethylene-glycol dimethyl ether on 80/100

Column 2: 4.5 ft x 1/8 in. porapak Q, 80/100 mesh

The chromatograph sampling system operates under vacuum with a helium carrier gas. Component peaks are recorded by a Houston Instrument #7302 omniscrite 1 mV recorder complete with integrator.

## EXPERIMENTAL PROCEDURE

Prior to each run, the reactor system and the preheated lines were dismantled, weighed and cleaned. This was necessary to measure and remove the coke and pitch produced in the previous run. The condensing system was also weighed and cleaned before each run in order to measure and collect the liquid products which condense as a thick pitchy material in the collection flask. The system was then assembled for operation and the preheated furnace and soaker turned on. The pumps were adjusted to certain flow rates. The start up motor oil was used (without any additives to heat the system. When the outlet furnace temperature reaches the desired temperature, the start up motor oil is stopped and the crude oil is allowed to flow through the system for about twenty minutes. After making sure the system has reached the steady state, the timer is started and collection of the liquid and gas samples is begun. During the runs we have to control the pressure at 100 psi.

To conclude the experiment, the furnace should be turned off before the water and oil pump and electrical equipment is turned off. The volume of oil and water passed through the system is recorded and the gas sample analyzed by conventional gas chromatograph procedures.

Gas composition is calculated with the procedure described by Young (10). The liquid received was tested for viscosity and pour point. The viscosity was measured by the D-88 method and the pour point by the D-97 method.

TABLE 6. CHARACTERIZATION OF FAREGH CRUDE OIL

Viscosity SUS at 100 °F	89.3
Pour Point °F	75
Wax Content of Stock	32.21 Wt. %
Gravity, API	30.5
ASTM Distillation D-86	

IBP	230 °F
5%	290
10%	370
20%	450
30%	580
40%	672
50%	715
60%	780
80%	830
90%	884
FBP	980

TABLE 6. CHARACTERIZATION OF FAREGH CRUDE OIL (cont.)

## HYDROCARBON ANALYSIS FOR FAREGH CRUDE OIL

<u>Component</u>	<u>Mol %</u>	<u>WT.%</u>
Hydrogen	Nil	Nil
Carbon Dioxide	Nil	0.57
Nitrogen	1.27	0.42
Methane	54.87	10.33
Ethane	4.27	3.27
Propane	5.79	2.44
Iso-Butane	0.73	0.50
n-Butane	2.53	1.73
Iso-Pentane	0.50	0.42
n-Pentane	1.06	0.90
Hexanes	1.43	1.46
Heptanes Plus	<u>21.42</u>	<u>77.41</u>
	100.00	100.00

TABLE 7. CHARACTERIZATION OF AMAL CRUDE OIL

Viscosity SUS at 100 °F	90.2
Pour Point °F	67.5
Gravity, API	25.13
ASTM Distillation D-86	
IBP	154 °F
5%	202
10%	259
20%	350
30%	430
40%	512
50%	617
60%	667
70%	742
80%	808
90%	854
FBP	884

## RESULTS

A number of runs on heavy Libyan crude oils from the Amal and Faregh fields were made to determine the effects of the reaction variables on the viscosity and pour point reduction. Three runs were made to check the reproducibility of the system. Information on the reaction conditions and corresponding product analysis are summarized in Table 8 and 9.

### Effect of Temperature

Temperature effects on the reactions were determined by running tests at different temperatures in the range of interest 650 °F - 850 °F, holding, the residence time in the intermediate range of 1.7 to 6.5 minutes at a pressure of 200 psi.

As shown in Figure 3 viscosity for Amal crude oil decreases from 73.11 SUS at a reaction temperature 650 °F to 25.01 SUS at 850 °F from original viscosity of 140 SUS. At corresponding temperatures, Figure 4 shows that viscosity for using other Faregh crude oil decreases from 38.35 SUS to 24.5 SUS from original value of 110 SUS at 100 °F.

Pour point for Amal crude as shown in Figure 9 decreases from 62.0 °F at reaction temperatures 650 °F to 42.5 °F at a reaction temperature of 850 °F from original value of 69.5 °F. The reduction in pour point for Faregh crude

TABLE 8. RESULTS

<u>Run #</u> <u>Amal Crude</u>	<u>Temp(°F)</u>	<u>Time</u> <u>(min)</u>	<u>Viscosity</u> <u>SUS</u>	<u>Pour Point</u> <u>(°F)</u>	<u>Water</u> <u>Ratio</u>
1	650	3.27	73.11	62.0	
2	750	4.3	40.20	52.7	
3	750	3.26	51.32	56.0	
4	850	3.26	38.13	54.0	
5	850	4.3	32.41	50.0	
6	650	4.3	46.23	55.0	
7	650	6.5	38.06	46.5	
8	850	6.5	25.01	42.5	
9	750	6.5	34.15	44.7	
10	650	1.7	77.12	68.12	
11	750	1.7	57.10	60.4	
12	850	1.7	40.54	57.1	
13	850	1.7	38.12	52.30	0.025
14	650	1.7	55.0	66.20	0.025
15	750	1.7	53.2	64.5	0.025

TABLE 8. (CONT.)

<u>Run #</u> <u>Faregh Crude</u>	<u>Temp (°F)</u>	<u>Time</u> <u>(min)</u>	<u>Viscosity</u> <u>SUS</u>	<u>Pour Point</u> <u>(F)</u>
16	650	3.26	38.35	71.0
17	650	6.5	32.0	65.0
18	750	6.5	27.0	57.0
19	850	4.3	28.21	55.0
20	850	6.5	24.5	46.0
22	750	4.3	31.50	61.0
24	750	3.26	33.12	66.0
27	650	4.3	35.47	68.0
31	850	3.26	30.80	63.0

TABLE 9. MASS BALANCE

<u>Run #</u> <u>Amal Crude</u>	<u>Oil (ml)</u>	<u>Oil (gm)</u>	<u>Liquid (gm)</u>	<u>Solid (gm)</u>	<u>Gas (gm)</u>	<u>Total (gm)</u>
1	329.9	300.9	237.4	1.5	37.58	276.48
2	440.8	402.0	340.6	3.1	58.81	402.5
3	253.5	231.2	203.2	2.0	35.56	240.8
4	472.3	430.8	299.3	4.1	92.39	395.8
5	329.1	300.2	210.9	5.0	84.07	299.97
6	274.1	250.0	188.3	2.3	33.62	224.22
7	361.8	330.0	250.7	3.3	48.28	302.28
8	307.5	280.5	204.2	4.8	90.33	299.33
9	252.4	230.2	185.6	3.1	64.65	253.35
10	403.8	368.26	215.3	2.4	30.83	248.53
11	242.1	220.8	205.6	1.3	31.23	238.13

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TABLE 9. MASS BALANCE (cont.)

<u>Run #</u>	<u>Oil (ml)</u>	<u>Oil (gm)</u>	<u>Liquid (gm)</u>	<u>Solid (gm)</u>	<u>Gas (gm)</u>	<u>Total (gm)</u>
Amal Crude						
12	219.7	200.36	188.18	0.7	26.80	215.68
13	371.0	338.35	289.6	0.5	35.76	325.86
14	230.4	210.12	201.3	1.2	23.93	226.4
15	356.9	325.5	312.2	1.3	26.98	340.48
Faregh Crude						
16	301.4	237.8	220.5	1.5	31.42	253.42
17	521.6	411.6	310.9	2.98	72.90	386.78
18	233.8	184.5	140.3	3.4	67.19	210.8
19	335.3	264.6	195.2	4.3	93.29	292.8
20	317.9	250.8	182.3	4.5	98.77	285.6
22	317.2	250.3	170.5	3.4	77.44	251.3
24	361.9	285.5	221.3	2.3	68.4	292.0
27	308.7	243.6	208.6	1.8	45.16	255.6
31	290.7	229.4	170.3	3.2	67.33	240.8

FIGURE 3

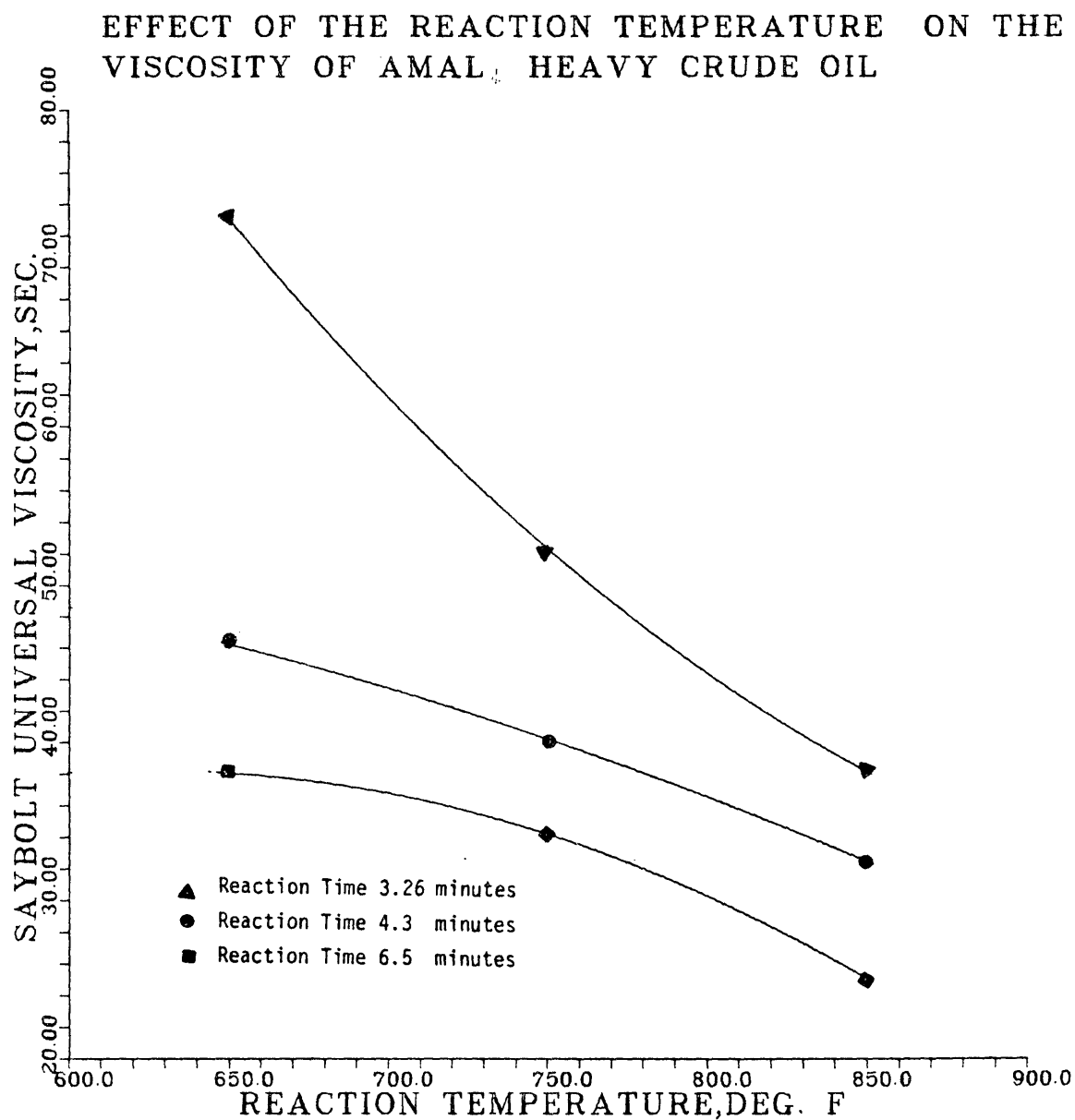


FIGURE 4

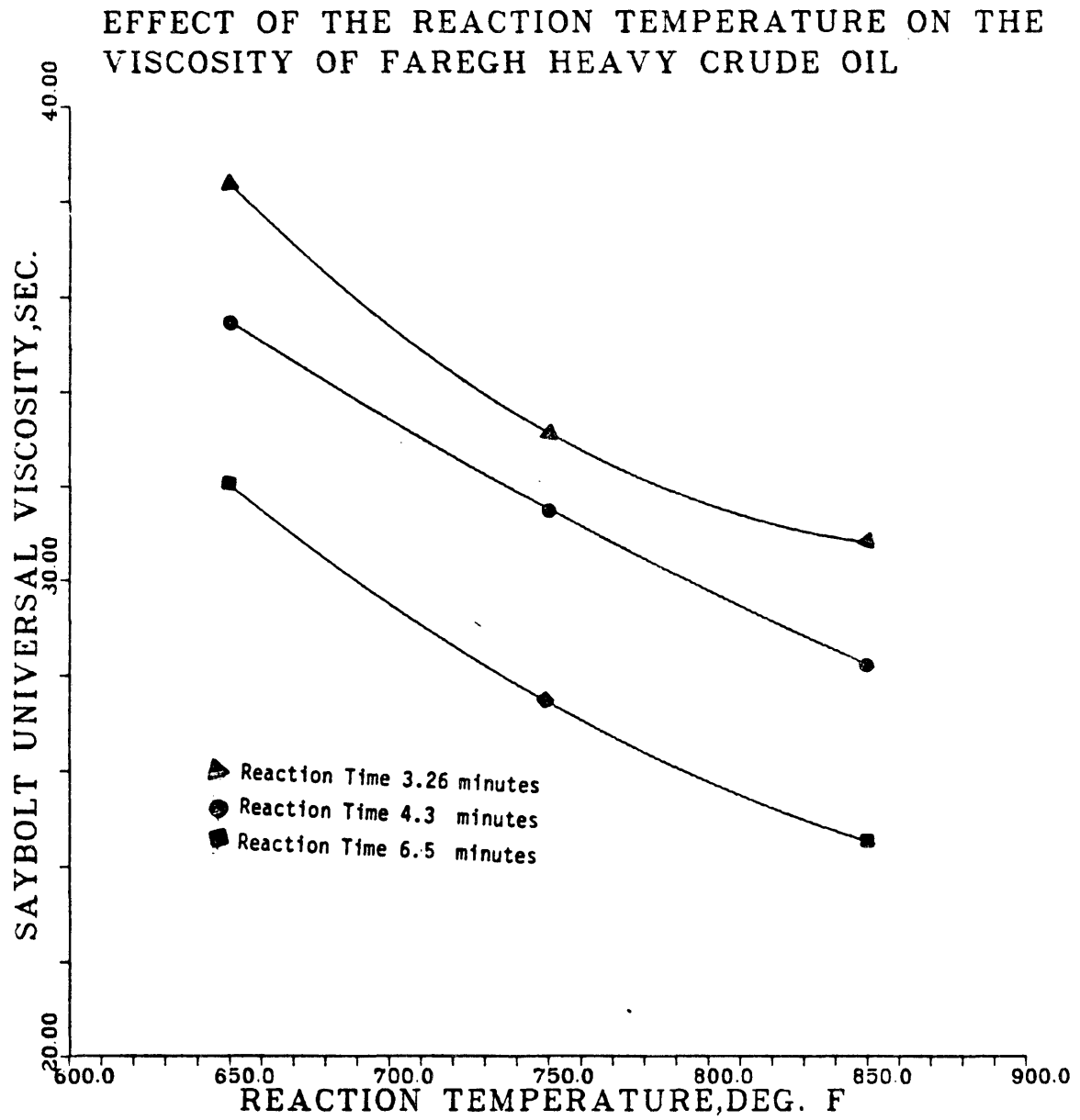


FIGURE 5

EFFECT OF THE RESIDENCE TIME ON THE  
VISCOSITY OF AMALE HEAVY CRUDE OIL

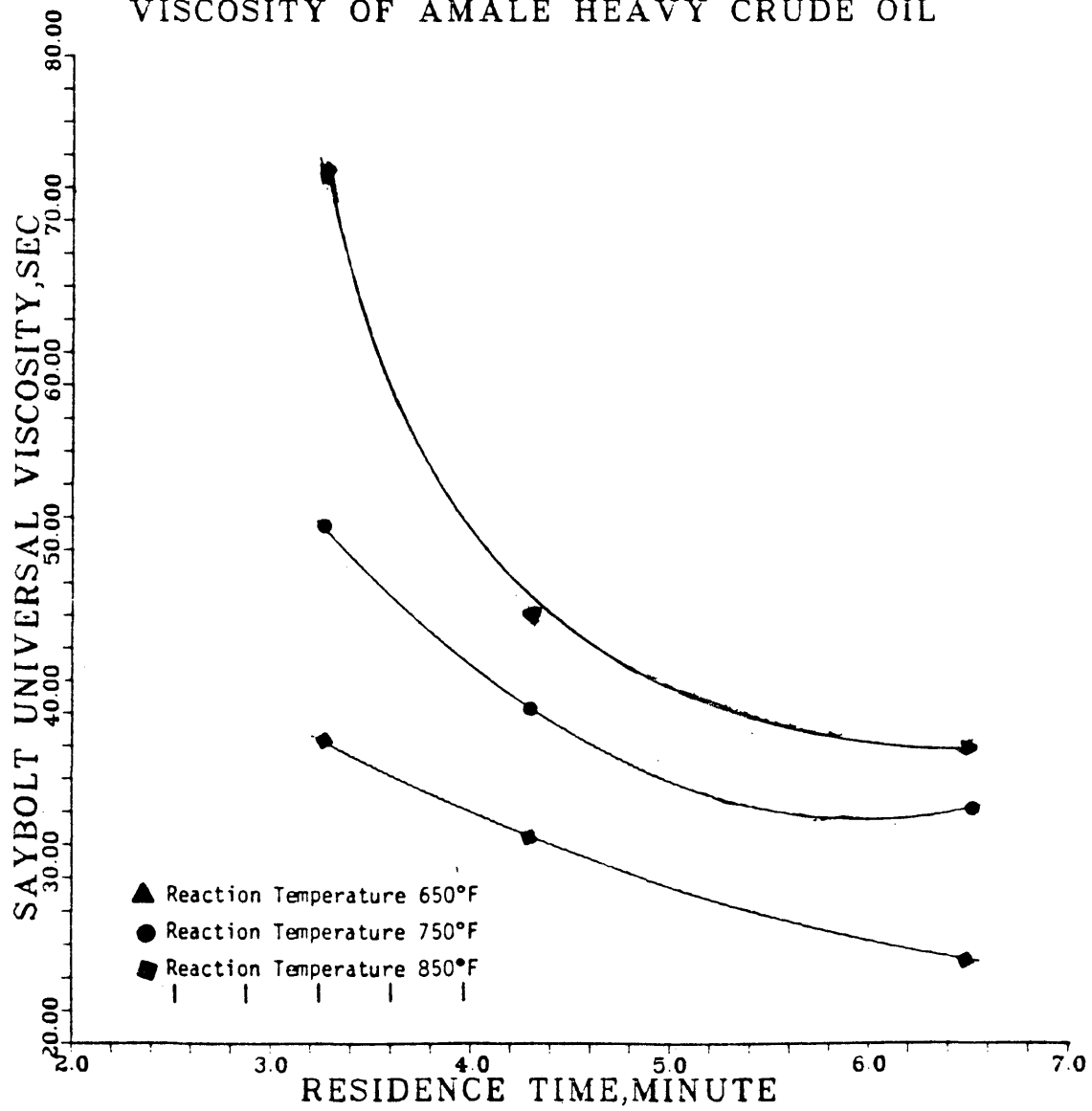
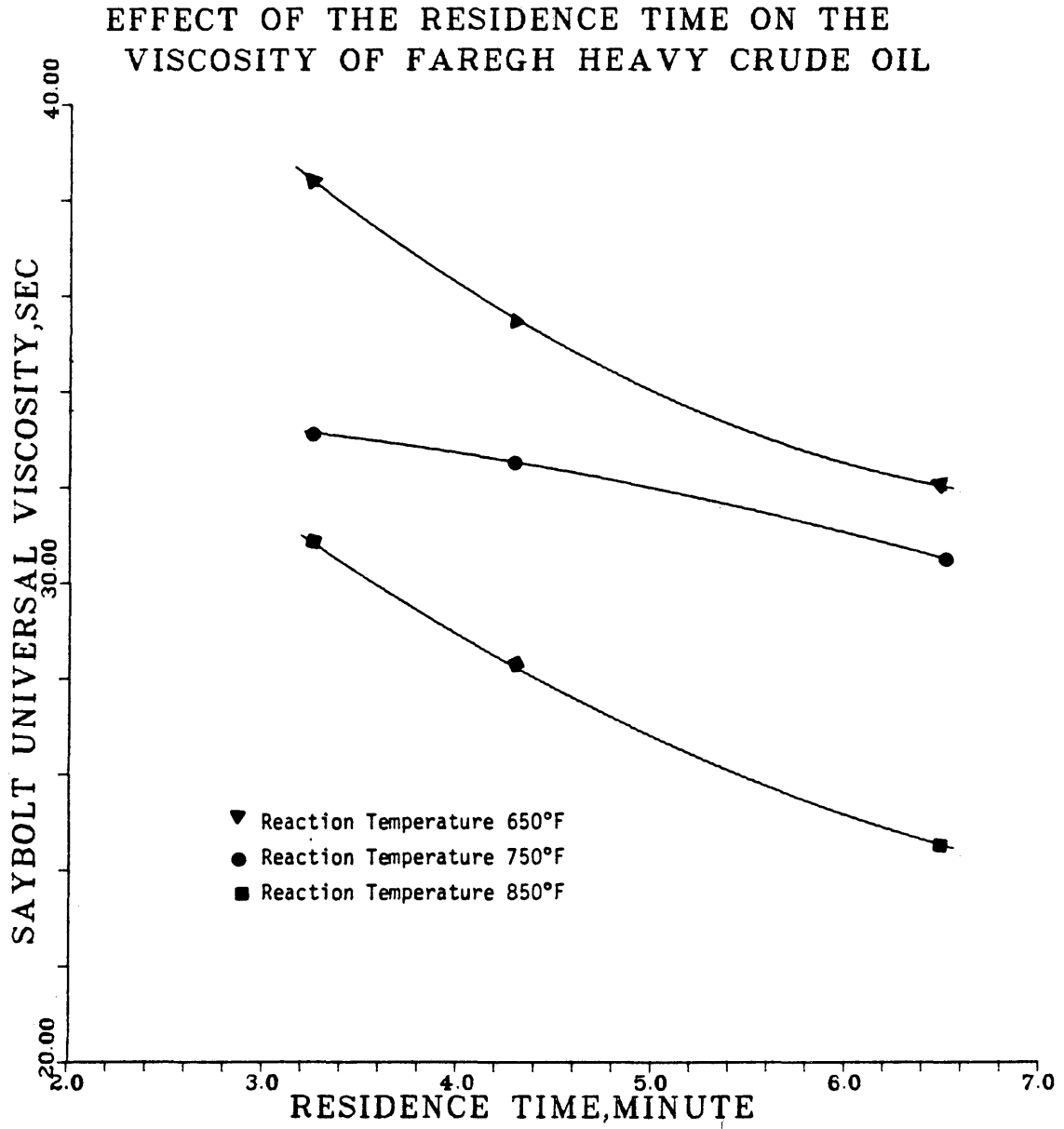


FIGURE 6



oil as shown in Figure 10 is 25.0 °F from original pour point of 75 °F.

### Residence Time

The effect of residence time within the reactor was determined over the range of residence times from 1.7 to 6.5 minutes. As shown in Figure 5, viscosity for Amal crude oil decreases from 73.11 SUS at 3.26 minutes to 25.0 SUS at 6.5 minutes. For Faregh crude oil the decrease is ranging as shown in Figure 6 from 38.35 SUS at 3.26 minutes to 24.5 SUS at 6.5 minutes. Figure 7 and 8 show at corresponding residence times, the pour point for both Amal and Faregh crude oil decreasing from 62.2 °F to 42.5 °F and from 71.0 °F to 46.0 °F respectively.

### Water Hydrocarbon Ratio

The study also included an injection of water to determine the effect of the water on the viscosity and pour point.

The ratio used was 0.025 distilled water/to oil. As shown in Figure 11, the viscosity decreases for Amal crude oil from 55.0 SUS at 650 °F to 38.12 SUS at 850 °F while without water injection, the viscosity decreases from 77.12 at a reaction temperature of 650 °F to 40.54 at 850 °F.

### Severity Factor

The severity factor is an attempt to combine the effects of all the reaction variables on product compositions and yields into one variable. The common form of the severity factor for petroleum or shale oil (19) is:

FIGURE 7

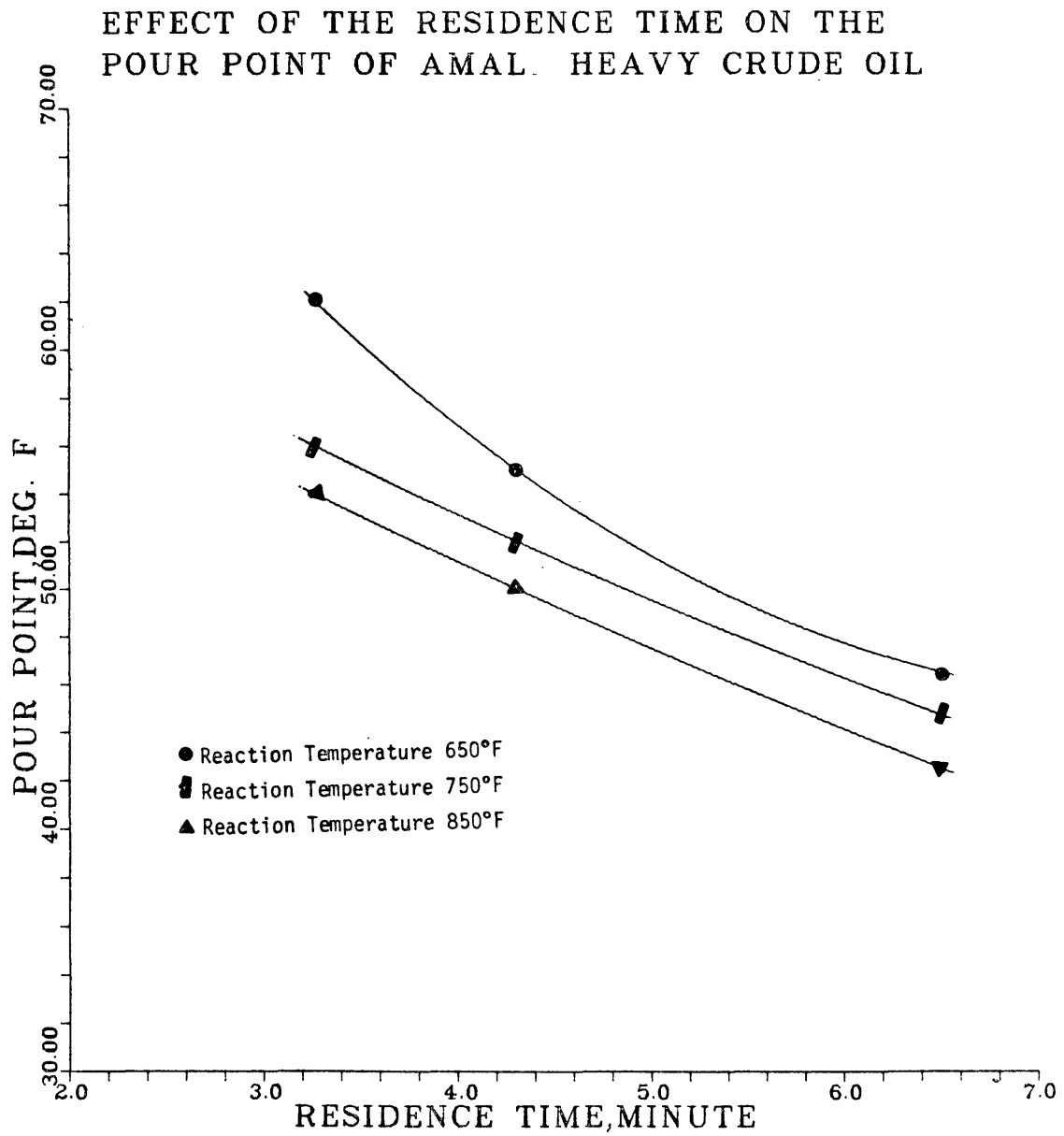


FIGURE 8

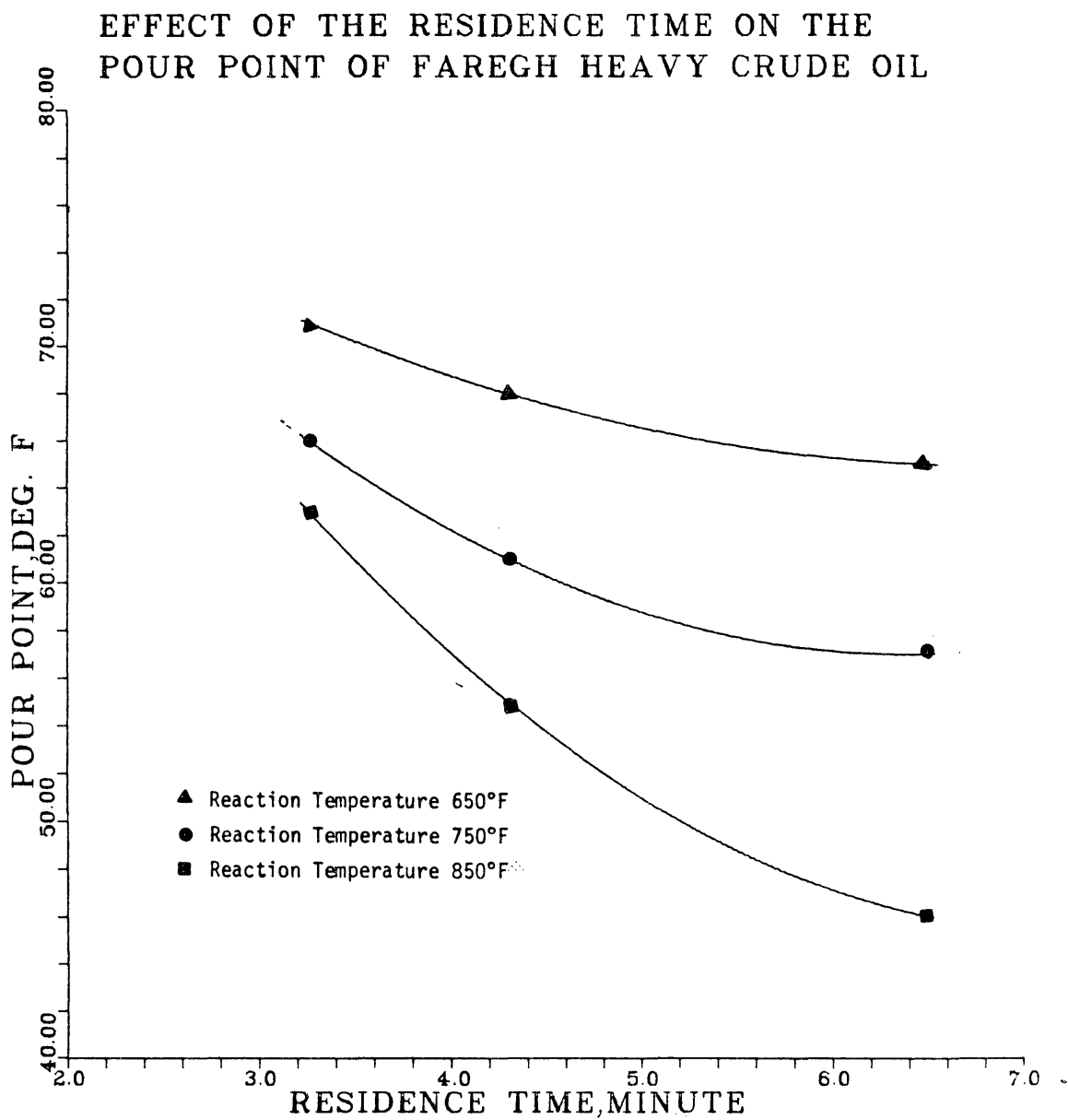


FIGURE 9

EFFECT OF THE REACTION TEMPERATURE ON THE  
POUR POINT OF AMAL, HEAVY CRUDE OIL

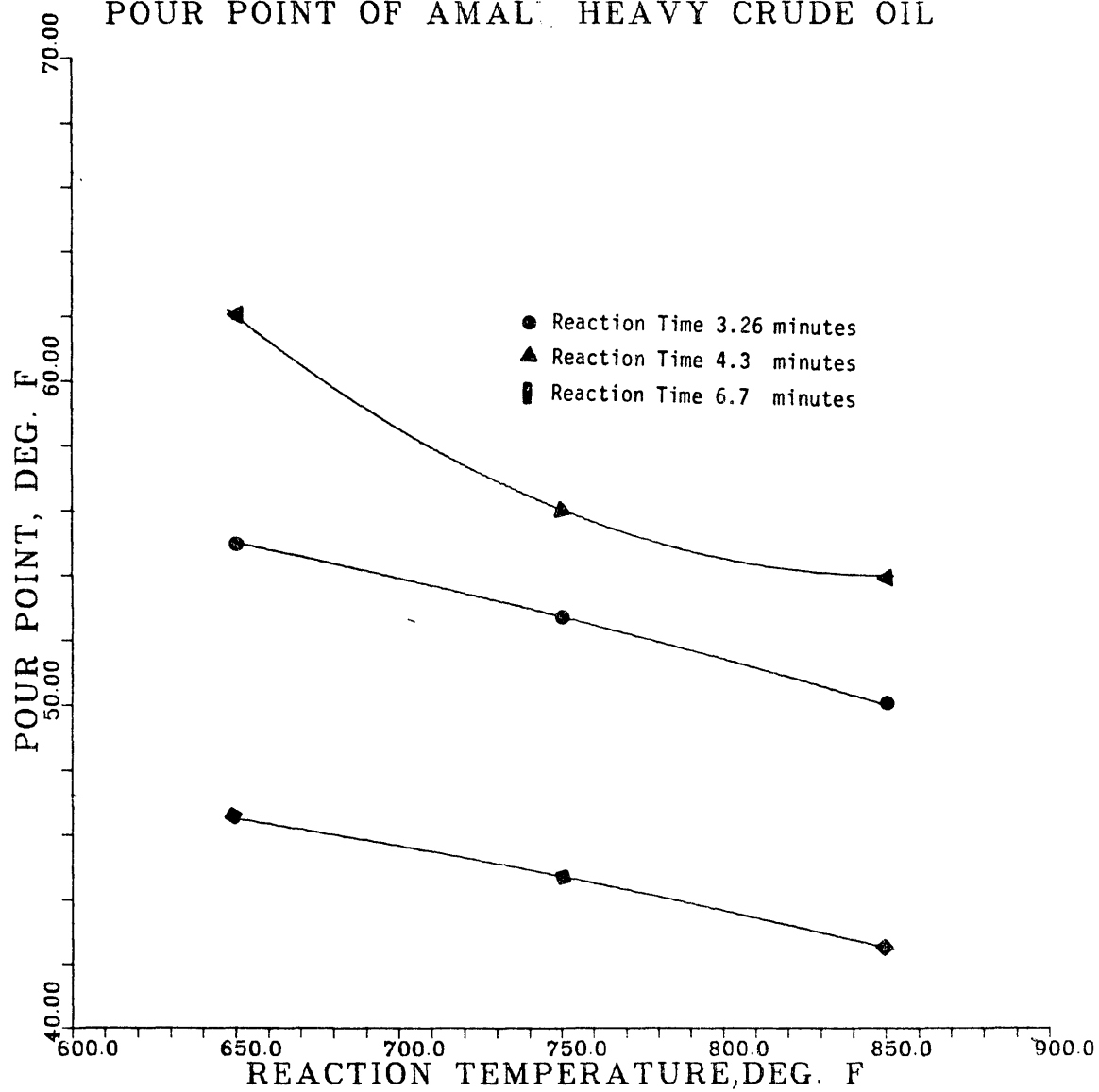


FIGURE 10

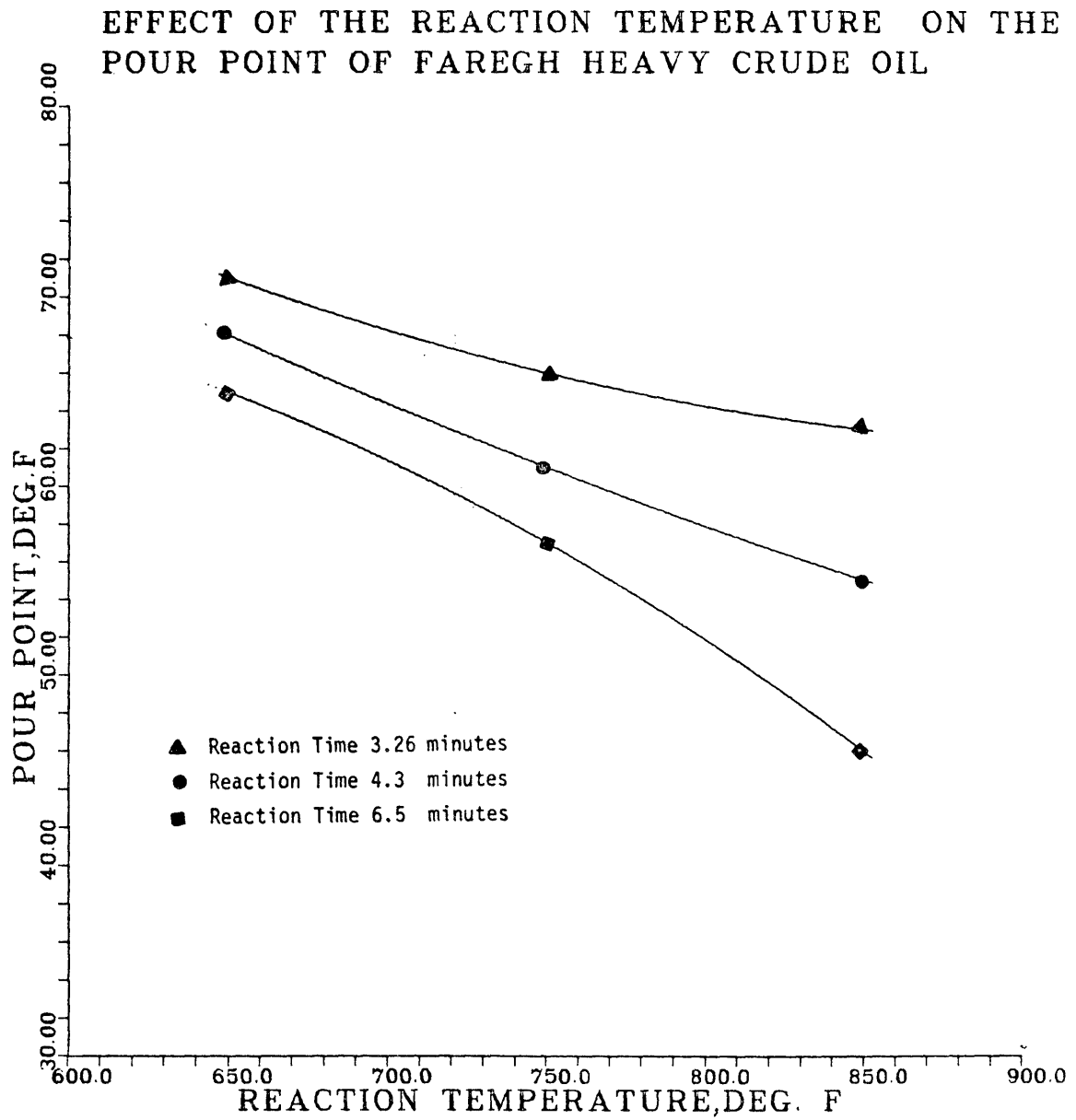


FIGURE 11

EFFECT OF THE REACTION TEMPERATURE AND WATER RATIO ON THE VISCOSITY OF AMALE HEAVY CRUDE OIL

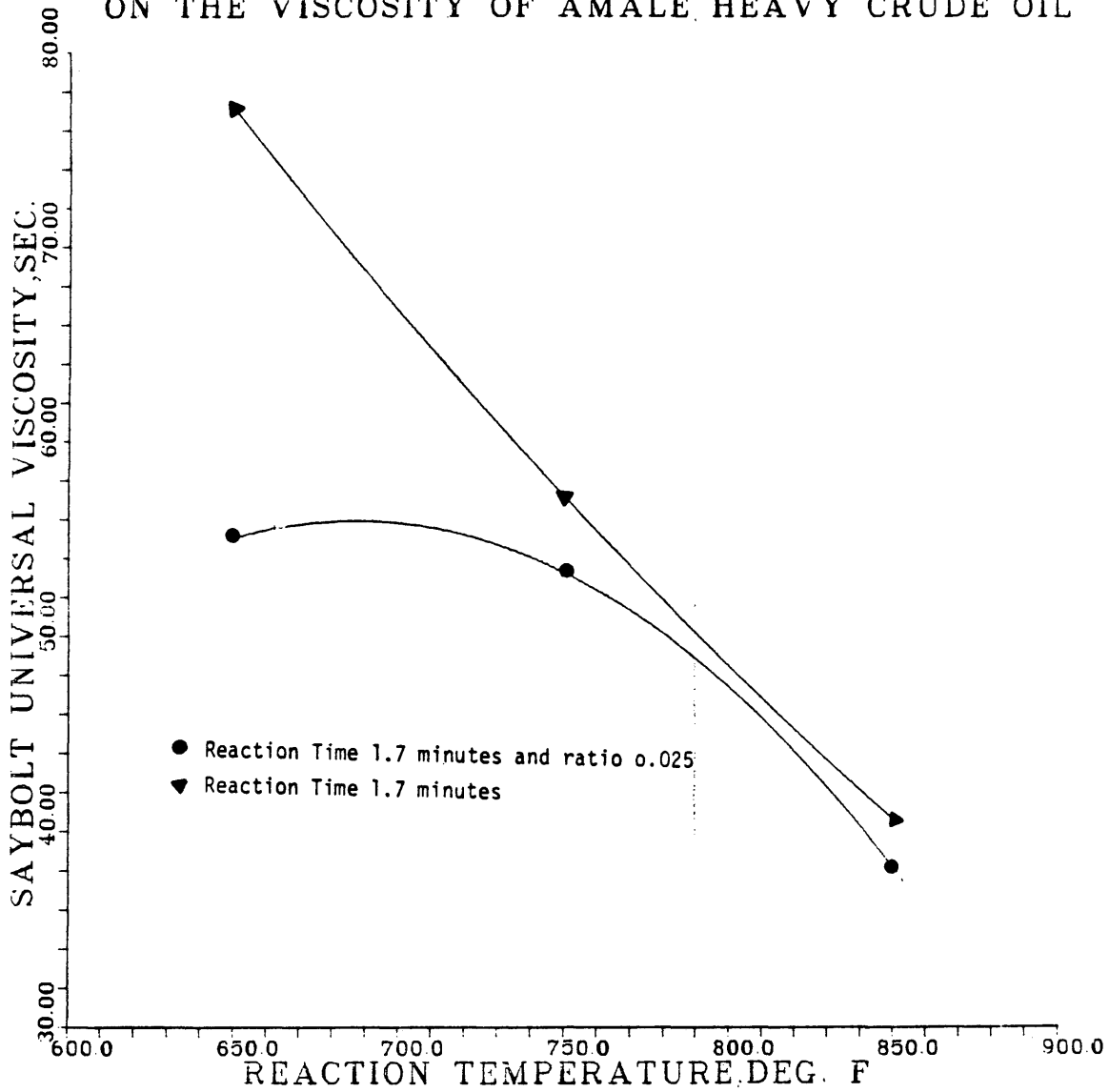
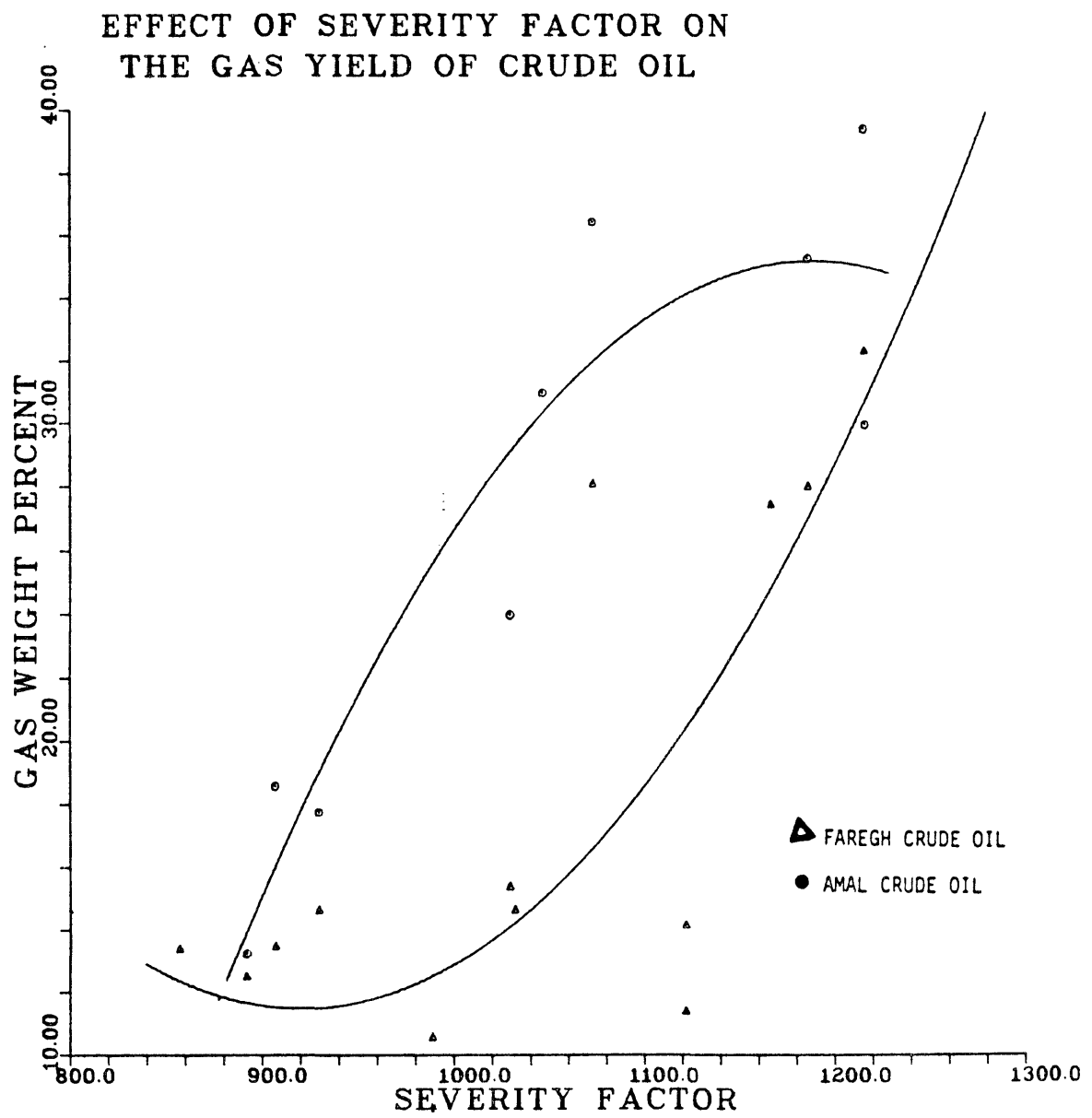


FIGURE 12



Reproducibility:

Possible errors encountered in the gas product analysis come from those errors encountered in the gas chromatography analysis and errors encountered in measuring the viscosity and pour point. Two duplicate runs were made on each sample to check for the deviation of viscosity, pour point, gas wt.% of feed, solid wt.% of feed, and liquid wt.% of feed for Run 1 were respectively 1.2%, 2.05%, 11.6%, 10.52% and 2.07%.

The duplication for Run 20 gave a percent deviation in viscosity, pour point, gas wt.%, solid wt.% and liquid wt.% respectively 1.23%, 3.97%, 3.43%, 5.5% and 4.11%.

TABLE 10 REPRODUCIBILITY ANALYSIS

Duplicate Runs

<u>Amal Crude Oil</u>	<u>Run 1</u>	<u>Run 2</u>	<u>% Deviation</u>
Viscosity at 212 <sup>0</sup> F, second	73.11	75.02SUS	1.2
Pour point F <sup>0</sup>	62.0	59.5	2.05
Gas wt.% of feed	12.59	15.90	11.6
Solid wt.% of feed	0.51	0.63	10.52
Liquid wt.% of feed	87.01	83.47	2.07

<u>Faregh Crude Oil</u>	<u>Run 20</u>	<u>Run 20R</u>	<u>% Deviation</u>
Viscosity at 212 <sup>0</sup> F, second	24.5	25.11	1.23
Pour point F <sup>0</sup>	46.0	49.8	3.97
Gas wt.% of feed	39.38	42.18	3.43
Solid wt.% of feed	1.79	2.0	5.5
Liquid wt.% of feed	60.60	55.82	4.11

## CONCLUSIONS

1. The results of this present study of visbreaking of Libyan heavy crude oils from Amal field and Faregh field indicated a good method of lowering the viscosity and pour point. This process can be applied for other feedstock, such as vacuum residuum and reduced crude.

Results of this study also show that operation at high residence times as well as high temperature gave a good reduction of viscosity and pour point of these crude oils. The total reduction on viscosity for Amal heavy crude oil is 17.09 saybolt universal seconds at 650<sup>0</sup>F and 65.19 SUS at 850<sup>0</sup>F. For Faregh crude oil, the total reduction is about 50.95 saybolt universal seconds at 650<sup>0</sup>F and 64.80 SUS at 850<sup>0</sup>F.

2. The reduction in pour point for both Amal and Faregh heavy crude oil is 19.5<sup>0</sup>F and 25<sup>0</sup>F respectively from the original pour point of 67.5<sup>0</sup>F and 75<sup>0</sup>F respectively.

3. As the severity of operation increases, the product of total volumetric gaseous increases.

4. Weight percent of feed converted to solid carbon products increased for Amal crude oil from 0.51 wt% at reaction temperature 650<sup>0</sup>F to 1.71 wt% at 850<sup>0</sup>F. For

Faregh crude oil from 0.63 wt% at a reaction temperature 650 °F to 1.79 wt% at 850 °F.

5. Injection of water through the system has effect on viscosity of Amal crude oil. The change in viscosity is 16.88 saybolt universal viscosity in seconds at the reaction temperature range from 650 °F to 850 °F, while the change in viscosity without injection water at the same residence time and reaction temperature range is 36.58 saybolt universal viscosity in seconds.

The pour point change for Amal heavy crude oil from 11.02 °F without water injection to 13.9 °F with water injection.

## RECOMMENDATION

The present visbreaking unit can be improved in the following manner to improve and decrease the plugging problems.

Use high mass velocity through the visbreaker heater coils to enhance the heat transfer rates and limit the tube wall temperature to reduce coking rate.

## REFERENCES

1. Hourancé, R, and Kuhn, J., Tech and Notarbartolo, M., Technipetrol Rome "Visbreaking More Feed for FCC," Hydrocarbon Processing, Dec. 1979, p. 97.
2. Beuther, H., et al., "Thermal Visbreaking of Heavy Residues," Oil and Gas Journal, Vol. 57, No. 45, Nov. 9 (1959), p. 151-157.
3. Rhoe, A. and DeBlignieres, C., "Visbreaking a Flexible Process," Hydrocarbon Processing, Vol. 58, No. 1, Jan. 1979, p. 131-136.
4. Stolfa, F., "New Roles for Thermal Cracking," Hydrocarbon Processing, Vol. 59, No. 5, May 1980.
5. Griswold, C. F., Master's thesis, Colorado School of Mines, Golden, Colorado.
6. Akbar, M., and Geelen, H., Shell International Petroleum Maatschappij, The Hague, Netherlands, "Visbreaking uses Soaker Drum," Hydrocarbon Processing, May 1981, p. 81-85.
7. Allen, J. G., Little, D. M. and Waddill, P. M., Petrol. Processing 6, No 6. 612 (1951).
8. Kalichevsky, V. A., The Petroleum Engineer, Vol. 27, No. 12, Nov. 1955, p. C-11.
9. Brantly, F. E., Cox, R. J., Sohns, H. W., Brant, W. I., and Murphy, W. I. R., 1952 "High Temperature Shale Oil," Ind. Eng. Chem., Vol. 44. No. 11, p. 2641-2650.
10. Young, I. G., 1975, A Review of Post-run Calculation Techniques in Gas Chromatography: Amer. Laboratory, Vol. 7, No. 2, p. 27-36; No. 6, p. 37-44; No. 8, p. 11-21.
11. Cooper, T. A. and Ballard, W. P., "Thermal Cracking, Visbreaking and Thermal Reforming," Advances in Petroleum Chemistry and Refining, Ed. K. A. Koble and J. J. McKetta, Jr., Vol. VI. Chap. 4, Interscience, N.Y. 1962, p. 170-238.

12. Allen, J. G., Little, D. M., and Waddill, P. M.,  
Phillips Petroleum Co., Bartlesville, OK.  
"Visbreaking High Vacuum Residuum," Petroleum  
Processing, Vol. 6, No. 6, p. 621 (1951)
13. Nelson, W. L., Technical Editor and Pet. Consultant,  
Oil and Gas Journal, Nov. 10, 1969, p. 229.
14. Nelson, W. L., Technical Editor and Pet. Consultant,  
Oil and Gas Journal, Aug. 21, 1967, p. 101.
15. Lumms Co., "Visbreaking and Pour Reduction Process,"  
Oil and Gas Journal, No. 24, March 23, 1950.
16. Egloff, Gustav, Oil and Gas Journal, Vol. 43, No. 7,  
June 24, 1944, p. 74.
17. Egloff, Gustav, "Cracking of Latin American Crude Oils,"  
Oil and Gas Journal, Vol. 43, No. 36, Jan. 1945,  
p. 73.
18. Beuthea, H. E., Coldthwait, R. C., and Offutt, W. C.,  
Oil and Gas Journal, Vol. 57, No. 46, p. 451 (1959).
19. Shultz, Emgene, Guyer, John J. Jr., and Linden, Henry,  
R., Institute of Gas Technology, Chicago, IL,  
Industrial and Engineering Chemistry, Vol. 47.,  
No. 12, Dec. 1955, p. 2479.
20. Aalund, L. R., "Europe Still Holds Keyrole for Thermal  
Cracking," Oil and Gas Journal, Vol. 76, No. 45,  
Nov. 6, 1978, p. 56-59.

APPENDIX

## A. Reactor Volume

$$\frac{\pi}{4} D^2 L = \text{volume of reactor}$$

$$\frac{\pi}{4} (0.5)^2 46.63 = 9.15 \text{ cubic inch}$$

## B. Residence time

$$= \frac{\text{reactor volume}}{\text{total volume of oil flowed}}$$

## C. Product gas composition

1. Chromatograph component area =

$$(\text{Peak area}) (\text{attenuation}) (\text{response factor})$$

2. 100% methane calibration = (peak area) (1024)

3. Product mole fraction

$$\frac{\text{Chromatograph component area}}{100\% \text{ methane calibration}}$$

4. Normalized product gas mole fraction =

$$\frac{\text{product mole fraction}}{16} \\ \sum \text{product mole fraction}$$

5. Molecular weight of product gas =

$$\frac{16}{\sum (\text{molecular weight}) (\text{normalized mole factor})}$$

6. Product gas mass at metered P and T =

$$\frac{(P/RT) (\text{volume of product gas produced})}{\text{molecular weight of product gas}}$$

7. Gas weight % of feed =

$$\frac{\text{product gas mass}}{\text{mass of oil flowed}} \times 100$$

8. Solid weight % of feed =

$$\frac{\text{solid mass}}{\text{mass of oil flowed}} \times 100$$

TABLE 11. SUMMARY OF GAS ANALYSIS

<u>Run #</u>	<u>Temp (°F)</u>	<u>Time (Min)</u>	<u>Severity Factor</u>	<u>Gas wt%</u>	<u>Solid wt%</u>	<u>Liquid wt%</u>	<u>Water Ratio</u>
1	650	3.26	892.0	12.49	0.51	87.01	
2	750	4.3	1031.9	14.63	0.771	84.59	
3	750	3.26	1029.3	15.38	0.876	83.74	
4	850	3.26	1166.5	27.44	0.95	77.6	
5	850	4.3	1186.0	28.0	1.66	70.34	
6	650	4.3	907.0	13.45	0.92	85.63	
7	650	6.5	929.7	14.63	0.97	84.40	
8	850	6.5	1215.8	32.2	1.71	66.09	
9	750	6.5	1072.8	28.08	1.3	70.57	
10	750	1.7	989.8	8.3	0.65	91.04	0.025
11	850	1.7	1121.8	14.14	0.58	85.27	0.025
12	650	1.7	857.0	13.37	0.34	86.29	0.025
13	750	1.7	989.8	10.56	0.14	89.29	
14	850	1.7	1121.8	11.39	0.57	88.03	
15	650	1.7	857.0	8.28	0.39	91.32	

TABLE 11. SUMMARY OF GAS ANALYSIS (cont.)

<u>Run #</u> <u>Faregh</u>	<u>Temp (°F)</u>	<u>Time</u> <u>(Min)</u>	<u>Severity</u> <u>Factor</u>	<u>Gas wt%</u>	<u>Solid wt%</u>	<u>Liquid wt%</u>
16	650	3.26	892.0	13.21	0.63	86.16
17	650	6.5	929.7	17.73	0.72	81.26
18	750	6.5	1072.8	36.42	1.84	61.73
19	850	4.3	1186.1	35.25	1.62	63.12
20	850	6.5	1215.8	39.38	1.79	60.60
22	750	4.3	1046.5	30.94	0.918	68.14
24	750	3.26	1029.3	23.96	0.805	75.23
27	650	4.3	907.0	18.54	0.73	80.72
31	850	3.26	1215.8	29.93	1.40	68.67

GAS CHROMATOGRAPHY ANALYSIS

Run # 10001

Reaction Temperature 650 °F

Residence time 3.26 minute

Severity factor 892.0

<u>Component</u>	<u>ATT</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.2	0.123	2.01	0.2472	0.0155
CO	128	60	0.0267	28	0.7476	0.0468
CH <sub>4</sub>	512	300	0.533	16	8.5703	0.5366
C <sub>3</sub> H <sub>8</sub>	8	450	0.0125	44	0.5500	0.0344
C <sub>3</sub> H <sub>6</sub>	128	85	0.0379	42	1.5906	0.0996
1C <sub>4</sub> H <sub>10</sub>	8	930	0.0259	56.1	1.4530	0.0910
nC <sub>4</sub> H <sub>10</sub>	8	170	0.0047	58.12	0.2732	0.017
1-Butene	32	10	0.0011	56.1	0.0625	0.0039
Trans 2-Butene	8	500	0.0139	56.1	0.7811	0.0489
C <sub>i,s</sub> 2-Butene	8	260	0.0072	56.1	0.4062	0.0254
Butadiene	32	230	0.0256	54.09	1.3857	0.0868
CO <sub>2</sub>	8	120	0.0033	56.00	0.1537	0.0010

Molecular weight of product gas = 46.46

Mass of product gas = 37.58 gm

Gas wt% of feed = 12.59%

Solid wt% of feed = 0.51%

Liquid wt% of feed = 87.01%

Run # 10002  
 Reaction Temperature 750 °F  
 Residence time 4.3 min  
 Severity factor 1031.9

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.2	0.2411	2.01	0.4846	0.0246
CO	128	173	0.0577	28	1.6155	0.0821
CH <sub>4</sub>	512	330	0.4451	16	7.8048	0.3969
C <sub>3</sub> H <sub>8</sub>	8	640	0.0135	44	0.5940	0.0302
C <sub>3</sub> H <sub>6</sub>	128	300	0.1011	42	4.2462	0.2159
iC <sub>3</sub> H <sub>10</sub>	8	340	0.0072	56.1	0.4039	0.0205
nC <sub>4</sub> H <sub>10</sub>	8	170	0.0036	58.12	0.2092	0.0106
1-Butene	32	90	0.0076	56.1	0.4264	0.0217
Trans 2-Butene	8	1280	0.0270	56.1	1.5147	0.0770
C <sub>is</sub> 2-Butene	8	340	0.0072	56.1	0.4039	0.0205
Butadiene	32	495	0.0417	54.09	2.2556	0.1147
CO <sub>2</sub>	8	150	0.0032	46	0.1454	0.0074
C <sub>2</sub> H <sub>4</sub>	256	10	0.0067	28.05	0.1879	0.0096

Molecular weight of product gas = 36.44  
 Mass of product gas = 58.81 gm  
 Gas wt% of feed = 14.63%  
 Solid wt% of feed = 0.771%  
 Liquid wt% of feed = 84.59%

Run # 1003  
 Reaction Temperature 750 °F  
 Residence time 3.26 min.  
 Severity factor 1029.3

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.23	0.2512	2.0108	0.5049	0.0336
CO	128	150	0.0492	28	1.3776	0.0917
CH <sub>4</sub>	512	315	0.4136	16	6.6183	0.4406
C <sub>3</sub> H <sub>8</sub>	8	600	0.0123	44	0.5411	0.0360
C <sub>3</sub> H <sub>6</sub>	128	240	0.0952	42	1.8984	0.1264
iC <sub>4</sub> H <sub>10</sub>	8	565	0.0116	56.1	0.6508	0.0433
nC <sub>4</sub> H <sub>10</sub>	8	185	0.0038	58.12	0.2204	0.0147
1-Butene	32	85	0.0070	56.1	0.3927	0.0261
Trans-2 Butene	8	1120	0.0230	56.1	1.2903	0.0859
C <sub>is</sub> -2 Butene	8	320	0.0066	56.1	0.3703	0.0247
Butadiene	32	480	0.0344	54.09	1.8540	0.1238
CO <sub>2</sub>	8	120	0.0025	46	0.1133	0.0075
C <sub>2</sub> H <sub>4</sub>	256	10	0.0066	28.05	0.1842	0.0123

Mass of product gas = 41.19  
 Mass of product gas = 35.56 gm  
 Gas wt% of feed = 15.38%  
 Solid wt% of feed = 0.876%  
 Liquid wt% of product gas = 83.74%

Run # 10004

Reaction temperature 850 °F

Residence time 3.26 min.

Severity factor 1166.5

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.3	0.323	2.01	0.6492	0.0244
CO	128	165	0.0549	28	1.5372	0.0577
CH <sub>4</sub>	512	370	0.4923	16	7.8775	0.2956
C <sub>4</sub> H <sub>8</sub>	8	650	0.0135	44	0.5940	0.0223
C <sub>3</sub> H <sub>6</sub>	128	400	0.1331	42	5.5902	0.2098
iC <sub>4</sub> H <sub>10</sub>	8	1400	0.0291	56.1	1.6325	0.0613
nC <sub>4</sub> H <sub>10</sub>	8	420	0.0087	58.12	0.5056	0.0190
1 Butene	32	93	0.0077	56.1	0.4320	0.0162
Trans 2-Butene	8	800	0.6416	56.1	2.3338	0.0876
C <sub>is</sub> -2 Butene	8	1500	0.0312	56.1	1.7503	0.0657
Butadiene	32	850	0.0707	54.09	3.8242	0.1435
CO <sub>2</sub>	8	170	0.0035	46	0.1626	0.0061
C <sub>2</sub> H <sub>4</sub>	256	30	0.200	28.05	0.5610	0.0251

Molecular weight of product gas = 42.84

Mass of product gas = 92.39 gm

Gas wt% of feed = 21.44%

Solid wt% of feed = 0.95%

Liquid wt% of feed = 77.6

Run # 10005  
 Reaction temperature 850 °F  
 Residence time 4.3 min.  
 Severity factor 1186.0

<u>Component</u>	<u>ATI.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.33	0.3412	2.01	0.6858	0.0256
CO	128	210	0.0689	28	1.9292	0.0719
CH <sub>4</sub>	512	380	0.4990	16	7.9840	0.2975
C <sub>3</sub> H <sub>8</sub>	8	28	0.0006	44	0.0264	0.0010
C <sub>3</sub> H <sub>6</sub>	128	377	0.1238	42	5.1996	0.1937
iC <sub>4</sub> H <sub>10</sub>	8	970	0.0199	56.1	1.1164	0.0416
nC <sub>4</sub> H <sub>10</sub>	8	580	0.0119	58.12	0.6916	0.0258
1 Butene	32	1300	0.1067	56.1	5.9859	0.2230
Trans-2 Butene	8	1130	0.0232	56.1	1.3015	0.0485
C <sub>js</sub> -2 Butene	8	440	0.0090	56.1	0.5049	0.0188
Butadiene	32	170	0.0140	54.09	0.7573	0.0282
CO <sub>2</sub>	8	250	0.0051	46	0.2360	0.0088
C <sub>2</sub> H <sub>4</sub>	256	40	0.0263	28.05	0.7377	0.0311

Molecular weight of product gas = 41.38  
 Mass of product gas = 84.07 gm  
 Gas wt% of feed = 28.01%  
 Solid wt% of feed = 1.66%  
 Liquid wt% of feed = 70.34%

Run # 10006  
 Reaction temperature 650 °F  
 Residence time 4.3 min.  
 Severity factor 907.0

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.2	0.218	2.01	0.4382	0.0346
CO	128	.75	0.0246	28	0.6888	0.0544
CH <sub>4</sub>	512	307	0.4048	16	6.4775	0.5112
C <sub>3</sub> H <sub>8</sub>	8	500	0.0103	44	0.4532	0.0358
C <sub>3</sub> H <sub>6</sub>	128	93	0.0305	42	1.2810	0.1011
iC <sub>4</sub> H <sub>10</sub>	8	1000	0.0205	56.1	1.1501	0.0908
nC <sub>4</sub> H <sub>10</sub>	8	190	0.0039	58.12	0.2267	0.0179
1 Butene	32	30	0.0025	56.1	0.1403	0.0111
Trans-2 Butene	8	600	0.0123	56.1	0.6900	0.0545
C <sub>is</sub> -2 Butene	8	300	0.0062	56.1	0.3478	0.0275
Butadiene	32	250	0.0205	54.09	1.1088	0.0875
CO <sub>2</sub>	8	110	0.0023	46.00	0.1058	0.0158

Molecular weight of product gas = 46.1697  
 Mass of product gas = 33.62 gm  
 Gas wt% of feed = 13.45%  
 Solid wt% of feed = 0.92%  
 Liquid wt% of feed = 85.63T

Run # 10007  
 Reaction temperature 650 °F  
 Residence time 6.5 min.  
 Severity factor 929.7

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.22	0.2430	2.01	0.4884	0.0342
CO	128	90	0.0295	28	0.8260	0.0578
CH <sub>4</sub>	512	312	0.4104	16	6.5657	0.4595
C <sub>3</sub> H <sub>8</sub>	8	550	0.0113	44	0.4972	0.0348
C <sub>3</sub> H <sub>6</sub>	128	110	0.361	42	1.5162	0.1061
iC <sub>4</sub> H <sub>10</sub>	8	1300	0.0267	56.1	1.4979	0.1013
nC <sub>4</sub> H <sub>10</sub>	8	205	0.0042	58.12	0.2441	0.0171
1 Butene	32	80	0.0066	56.1	0.3703	0.0259
Trans-2 Butene	8	640	0.0131	56.1	0.7349	0.0514
C <sub>is</sub> -2 Butene	8	370	0.0076	56.1	0.4264	0.0298
Butadiene	32	320	0.0263	54.09	1.4226	0.0996
CO <sub>2</sub>	8	200	0.0041	46.0	0.1886	0.0220

Molecular weight of product gas = 45.75  
 Mass of product gas = 48.28 gm  
 Gas wt% of feed = 14.63%  
 Solid wt% of feed = 0.97%  
 Liquid wt% of feed = 84.40%

Run # 10008  
 Reaction temperature 850 °F  
 Residence time 6.5 min.  
 Severity factor 1215.8

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.32	0.3441	2.01	0.6916	
CO	128	217	0.0712	28	1.9936	0.0763
CH <sub>4</sub>	512	385	0.3939	16	6.3024	0.2413
C <sub>3</sub> H <sub>8</sub>	8	35	0.0007	44	0.0308	0.0012
C <sub>3</sub> H <sub>6</sub>	128	400	0.1313	42	5.5146	0.2111
iC <sub>4</sub> H <sub>10</sub>	8	980	0.0201	56.1	1.1276	0.0432
nC <sub>4</sub> H <sub>10</sub>	8	610	0.0125	58.12	0.7265	0.0278
1 Butene	32	1335	0.1096	56.1	6.1486	0.2354
Trans-2 Butene	8	1211	0.0248	56.1	1.3913	0.0533
C <sub>1s</sub> -2 Butene	8	502	0.0103	56.2	0.5778	0.0221
Butadiene	32	192	0.0158	54.09	0.8546	0.0327
CO <sub>2</sub>	8	701	0.0144	46	0.6624	0.0254
C <sub>2</sub> H <sub>4</sub>	256	43	0.0282	25.05	0.7910	0.063

Molecular weight of product gas = 40.18  
 Mass of product gas = 90.33 gm  
 Gas wt% of feed = 32.2 %  
 Solid wt% of feed = 1.71%  
 Liquid wt% of feed = 66.09%

Run # 10009  
 Reaction temperature 750 °F  
 Residence time 6.5 min.  
 Severity factor 1353.8

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.31	0.3321	2.01	0.6675	0.0285
CO	128	150	0.0486	28	1.3609	0.0643
CH <sub>4</sub>	512	339	0.4452	16	7.1226	0.2342
C <sub>3</sub> H <sub>8</sub>	8	27	0.0005	44	0.0220	0.0010
C <sub>3</sub> H <sub>6</sub>	128	335	0.1085	42	4.5570	0.2153
iC <sub>4</sub> H <sub>10</sub>	8	816	0.0165	56.1	0.9257	0.0437
nC <sub>4</sub> H <sub>10</sub>	8	512	0.0104	58.12	0.6044	0.0286
1 Butene	32	1200	0.0972	56.1	5.4529	0.2571
Trans-2 Butene	8	900	0.0182	56.1	1.0210	0.0482
C <sub>is</sub> -2 Butene	8	480	0.0097	56.1	0.3442	0.0257
Butadiene	32	158	0.0128	54.09	0.6924	0.0327
CO <sub>2</sub>	8	671	0.0136	46	0.6256	0.0296
C <sub>2</sub> H <sub>4</sub>	256	22	0.0143	28.05	0.4011	0.0190

Molecular weight of product gas = 41.01  
 Mass of product gas = 64.65 gm  
 Gas 25% of feed = 28.08%  
 Solid wt% of feed = 1.3 %  
 Liquid wt% of feed = 70.57%

Run # 100010  
 Reaction temperature 750 °F  
 Residence time 1.7 min.  
 Severity factor 5984.86

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.1	0.1230	2.0	0.2472	0.0254
CO	128	37	0.0120	28	0.3360	0.0345
CH <sub>4</sub>	512	280	0.3629	16	5.8065	0.5955
C <sub>3</sub> H <sub>8</sub>	8	327	0.0066	44	0.2904	0.0298
C <sub>3</sub> H <sub>6</sub>	128	73	0.0237	42	0.9954	0.1021
iC <sub>4</sub> H <sub>10</sub>	8	750	0.0152	56.1	0.8527	0.0875
nC <sub>4</sub> H <sub>10</sub>	8	103	0.0021	58.12	0.0697	0.0071
1 Butene	32	10	0.0008	56.1	0.0449	0.1592
Trans-2 Butene	8	411	0.0083	56.1	0.4656	0.0478
C <sub>is</sub> -2 Butene	8	170	0.0034	56.1	0.1907	0.0196
Butadiene	32	140	0.0113	54.09	0.6112	0.0627
CO <sub>2</sub>	8	96	0.0019	46.0	0.0874	0.0090

Molecular weight of product gas = 45.88  
 Mass of product gas = 30.83 gm  
 Gas wt% of feed = 8.31%  
 Solid wt% of feed = 0.65%  
 Liquid wt% of feed = 91.04%

Run # 100011  
 Reaction temperature 850 °F  
 Residence time 1.7 min  
 Severity factor 1121.8

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.1	0.1301	2.01	0.2615	0.0241
CO	128	55	0.0183	28	0.5124	0.0473
CH <sub>4</sub>	512	282	0.3752	16	6.0040	0.5544
C <sub>3</sub> H <sub>8</sub>	8	380	0.0079	44	0.3476	0.0321
C <sub>3</sub> H <sub>6</sub>	128	85	0.0283	42	1.1886	0.1098
iC <sub>4</sub> H <sub>10</sub>	8	810	0.0168	56.1	0.0425	0.0870
nC <sub>4</sub> H <sub>10</sub>	8	125	0.0026	58.12	0.1511	0.0140
1 Butene	32	13	0.0011	56.1	0.0617	0.0057
Trans-2 Butene	8	415	0.0086	56.1	0.4825	0.0446
C <sub>1s</sub> -2 Butene	8	180	0.0037	56.1	0.2076	0.0192
Butadiene	32	192	0.0160	54.09	0.9654	0.0799
CO <sub>2</sub>	8	75	0.0016	46.0	0.0736	0.0068

Molecular wt of product gas = 45.58  
 Mass of product gas = 31.23 gm  
 Gas wt% of feed = 14.14%  
 Solid wt% of feed = 0.58%  
 Liquid wt% of feed = 85.27%

Run # 10012  
 Reaction temperature 650 °F  
 Residence time 1.7 min.  
 Water Ratio 0.025  
 Severity Factor 857.0  
Component      ATT.

	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.1100	2.01	0.2211	0.0368
CO	128	0.0115	28	0.3220	0.0536
CH <sub>4</sub>	512	0.1556	16	2.4899	0.4143
C <sub>3</sub> H <sub>8</sub>	8	0.0068	44	0.2992	0.0498
C <sub>3</sub> H <sub>6</sub>	128	0.0174	42	0.7308	0.1216
iC <sub>4</sub> H <sub>10</sub>	8	0.0145	56.1	0.8135	0.1354
nC <sub>4</sub> H <sub>10</sub>	8	0.0019	58.12	0.1104	0.0184
1 Butene	32	0.0010	56.1	0.0361	0.0093
Trans-2 Butene	8	0.0082	56.1	0.4600	0.0765
C <sub>is</sub> -2 Butene	8	0.0036	56.1	0.2020	0.0336
Butadiene	32	0.0098	54.09	0.5301	0.0882
CO <sub>2</sub>	8	0.0002	46.0	0.0094	0.0016

Molecular weight of product gas = 46.13  
 Mass of product gas = 26.80 gm  
 Gas wt% of feed = 13.37%  
 Solid wt% of feed = 0.34%  
 Liquid wt% of feed = 86.29%

Run # 100013  
 Reaction temperature 750 °F  
 Residence time 1.7 min.  
 Water Ratio 0.025  
 Severity Factor 989.8

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.12	0.1301	2.01	0.2615	0.0427
CO	128	30	0.0098	28	0.2744	0.0448
CH <sub>4</sub>	512	117	0.1543	16	2.4686	0.4027
C <sub>3</sub> H <sub>8</sub>	8	330	0.0068	44	0.2992	0.0488
C <sub>3</sub> H <sub>6</sub>	128	70	0.0230	42	0.9660	0.1576
iC <sub>4</sub> H <sub>10</sub>	8	705	0.0145	56.1	0.8135	0.1327
nC <sub>4</sub> H <sub>10</sub>	8	89	0.0018	58.12	0.1046	0.0171
1 Butene	32	12	0.0010	56.1	0.0561	0.0092
Trans-2 Butene	8	400	0.0082	56.1	0.4600	0.0750
C <sub>is</sub> -2 Butene	8	132	0.0027	56.1	0.1515	0.0247
Butadiene	32	110	0.0090	54.09	0.4868	0.0794
CO <sub>2</sub>	8	53	0.0011	46.0	0.0506	0.0083

Molecular wt of product gas = 46.00  
 Mass of product gas = 35.76 gm  
 gas wt% of feed = 10.56%  
 Solid wt% of feed = 0.14%  
 Liquid wt% of feed = 89.29%

Run # 100014  
 Reaction temperature 850 °F  
 Residence time 1.7 min.  
 Water Ratio 0.025  
 Severity Factor 1121.8  
Component  
ATI.

	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	0.15	0.1521	2.01	0.3057	0.0618
CO	45	0.0148	28	0.436	0.0886
CH <sub>4</sub>	135	0.1780	16	2.8484	0.1068
C <sub>3</sub> H <sub>8</sub>	390	0.0080	44	0.3521	0.0716
C <sub>3</sub> H <sub>6</sub>	88	0.0289	42	1.2134	0.2466
iC <sub>4</sub> H <sub>10</sub>	701	0.0144	56.1	0.8069	0.1639
nC <sub>4</sub> H <sub>10</sub>	91	0.0019	58.12	0.1085	0.0221
1 Butene	19	0.0016	56.1	0.875	0.0178
Trans-2 Butene	550	0.0113	56.1	0.6331	0.1287
C <sub>is</sub> -2 Butene	143	0.0029	56.1	0.1646	0.0335
Butadiene	135	0.0111	54.09	0.5993	0.1223
CO <sub>2</sub>	20	0.0004	46.	0.0189	0.0038

Molecular wt of product gas = 40.87  
 Mass of product gas = 23.93 gm  
 Gas wt % of feed = 11.39%  
 Solid wt% of feed = 0.57%  
 Liquid wt% of feed = 88.03%

Run # 100015  
 Reaction temperature 650 °F  
 Residence time 1.7 min.  
 Severity factor 857.8

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.1	0.1221	2.01	0.2454	0.0542
CO	128	32	0.0105	28	0.2940	0.0725
CH <sub>4</sub>	512	115	0.1510	16	2.4162	0.5296
C <sub>3</sub> H <sub>8</sub>	8	320	0.0066	44	0.2904	0.0716
C <sub>3</sub> H <sub>6</sub>	128	62	0.0204	42	0.8568	0.2113
iC <sub>4</sub> H <sub>10</sub>	8	741	0.0152	56.1	0.8527	0.2103
nC <sub>4</sub> H <sub>10</sub>	8	95	0.0019	58.12	0.1104	0.0272
1 Butene	32	7	0.006	56.1	0.0337	0.0083
Trans-2 Butene	8	390	0.0080	56.1	0.4488	0.1107
C <sub>is</sub> -2 Butene	8	150	0.0031	56.1	0.1739	0.0429
Butadiene	32	135	0.0111	54.09	0.6004	0.1481
CO <sub>2</sub>	8	85	0.0017	46.00	0.0782	0.0193

Molecular weight of product gas = 46.66  
 Mass of product gas = 26.98 gm  
 Gas wt% of feed = 8.28%  
 Solid wt% of feed = 0.39%  
 Liquid wt% of feed = 91.32%

Run # 100016  
 Reaction temperature 650 °F  
 Residence time 3.26 min  
 Severity factor 892.0

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.1	0.1310	2.01	0.2633	0.0248
CO	128	100	0.0328	28	0.9184	0.0618
CH <sub>4</sub>	512	240	0.3072	16	4.9145	0.4627
C <sub>3</sub> H <sub>8</sub>	8	10	0.0002	44	0.0088	0.0006
C <sub>3</sub> H <sub>6</sub>	128	230	0.0755	42	3.1710	0.2133
iC <sub>4</sub> H <sub>10</sub>	8	615	0.0126	56.1	0.7069	0.0475
nC <sub>4</sub> H <sub>10</sub>	8	470	0.0096	58.12	0.5580	0.0375
1 Butene	32	1020	0.0837	56.1	4.6956	0.3158
Trans-2 Butene	8	920	0.0189	56.1	1.0603	0.0713
C <sub>is</sub> -2 Butene	8	260	0.0041	56.1	0.2300	0.055
Butadiene	32	90	0.0074	54.09	0.4003	0.0767
CO <sub>2</sub>	8	55	0.0011	46	0.0506	0.0034
C <sub>2</sub> H <sub>4</sub>	256	7	0.0046	28.05	0.1240	0.005

Molecular weight of product gas = 43.15  
 Mass of product gas = 31.45 gm  
 Gas wt% of feed = 13.21%  
 Solid wt% of feed = 0.63%  
 Liquid wt% of feed = 86.16%

Run # 100017  
 Reaction temperature 650 °F  
 Residence time 6.5 min  
 Severity factor 929.7

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.2	0.2215	2.01	0.4452	0.0221
CO	128	200	0.0657	28	1.8396	0.0936
CH <sub>4</sub>	512	280	0.3588	16	5.7409	0.2658
C <sub>3</sub> H <sub>8</sub>	8	20	0.0004	44	0.0176	0.0009
C <sub>3</sub> H <sub>6</sub>	128	300	0.0985	42	4.1370	0.2105
iC <sub>4</sub> H <sub>10</sub>	8	830	0.0170	56.1	0.9537	0.0485
nC <sub>4</sub> H <sub>10</sub>	8	509	0.0104	58.12	0.6044	0.0308
1 Butene	32	1270	0.1042	56.1	5.8456	0.2974
Trans-2 Butene	8	1000	0.0205	56.1	1.1501	0.0585
C <sub>is</sub> -2 Butene	8	320	0.0066	56.1	0.3703	0.0188
Butadiene	32	120	0.0098	54.09	0.5301	0.0270
CO <sub>2</sub>	8	60	0.0012	46	0.0552	0.0028
C <sub>2</sub> H <sub>4</sub>	256	20	0.0131	28.05	0.3675	0.0187

Molecular weight of product gas = 42.22  
 Mass of product gas = 72.90 gm  
 Gas wt% of feed = 17.73%  
 Solid wt% of feed = 0.72%  
 Liquid wt% of feed = 81.26%

Run # 100018  
 Reaction temperature 750 °F  
 Residence time 6.5 min  
 Severity factor 1072.8

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.1	0.1120	2.01	0.2251	0.0126
CO	128	80	0.0256	28	0.7168	0.0455
CH <sub>4</sub>	512	230	0.2946	16	4.7133	0.2648
C <sub>3</sub> H <sub>8</sub>	8	45	0.0003	44	0.0132	0.0008
C <sub>3</sub> H <sub>6</sub>	128	380	0.1058	42	4.4436	0.2818
iC <sub>4</sub> H <sub>10</sub>	8	1115	0.0223	56.1	1.2510	0.0793
nC <sub>4</sub> H <sub>10</sub>	8	300	0.0060	58.12	0.3487	0.0221
1 Butene	32	505	0.0404	56.1	2.2664	0.1437
Trans-2 Butene	8	900	0.0180	56.1	1.0098	0.0640
C <sub>is</sub> -2 Butene	8	1300	0.0260	56.1	1.4586	0.0925
Butadiene	32	903	0.162	54.09	0.8763	0.0556
CO <sub>2</sub>	8	300	0.0060	46	0.2760	0.0175
C <sub>2</sub> H <sub>4</sub>	256	25	0.0160	28.05	0.4488	0.0285

Molecular weight of product gas = 43.03  
 Mass of product gas = 67.19 gm  
 Gas wt% of feed = 36.42%  
 Solid wt% of feed = 1.84%  
 Liquid wt% of feed = 61.73%

Run # 100019  
 Reaction temperature 850 °F  
 Residence time 4.3 min  
 Severity factor 1186.1

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.2	0.2311	2.01	0.4645	0.0210
CO	128	120	0.0389	28	1.0891	0.0479
CH <sub>4</sub>	512	300	0.3844	16	6.1510	0.2751
C <sub>3</sub> H <sub>8</sub>	8	30	0.0006	44	0.0264	0.0012
C <sub>3</sub> H <sub>6</sub>	128	410	0.1329	42	5.5818	0.2569
iC <sub>4</sub> H <sub>10</sub>	8	1500	0.0301	56.1	1.6886	0.0777
nC <sub>4</sub> H <sub>10</sub>	8	400	0.0081	58.12	0.4708	0.0217
1 Butene	32	600	0.0486	56.1	2.7265	0.1255
Trans-2 Butene	8	1200	0.0243	56.1	1.3632	0.0627
C <sub>js</sub> -2 Butene	8	1550	0.0314	56.1	1.7615	0.0011
Butadiene	32	300	0.0243	54.01	1.3144	0.0605
CO <sub>2</sub>	8	700	0.0142	46	0.6532	0.0301
C <sub>2</sub> H <sub>4</sub>	256	50	0.0324	28.05	0.9088	0.0418

Molecular weight of product gas = 41.78  
 Mass of product gas = 93.79 gm  
 Gas wt% of feed = 35.25%  
 Solid wt% of feed = 1.62%  
 Liquid wt% of feed = 63.12%

Run # 100020  
 Reaction temperature 850 °F  
 Residence time 6.5 min.  
 Severity factor 1215.8

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.3	0.3220	2.01	0.6472	0.0248
CO	128	130	0.0438	28	1.2264	0.0432
CH <sub>4</sub>	512	340	0.4357	16	6.9711	0.2629
C <sub>3</sub> H <sub>8</sub>	128	40	0.0001	44	0.0396	0.0014
C <sub>3</sub> H <sub>6</sub>	8	509	0.1730	42	7.2660	0.2562
iC <sub>4</sub> H <sub>10</sub>	8	1716	0.0364	56.1	2.0420	0.0720
nC <sub>4</sub> H <sub>10</sub>	32	518	0.0110	58.12	0.6393	0.0225
1 Butene	8	730	0.0620	56.1	3.4782	0.1226
Trans-2 Butene	8	1400	0.0297	56.1	1.6662	0.0587
C <sub>is</sub> -2 Butene	8	2000	0.0425	56.1	2.3843	0.0841
Butadiene	32	270	0.0229	54.09	1.2387	0.0437
CO <sub>2</sub>	8	717	0.0152	46	0.6992	0.0247
C <sub>2</sub> H <sub>4</sub>	256	60	0.0408	28.05	1.1444	0.0403

Molecular weight of product gas = 40.58  
 Mass of product gas = 98.77 gm  
 Gas wt% of feed = 39.38%  
 Solid wt% of feed = 1.79%  
 Liquid wt% of feed = 60.60%

Run # 100022  
 Reaction temperature 750 °F  
 Residence time 4.3 min  
 Severity factor 1046.5

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.2	0.2250	2.01	0.4523	0.0258
CO	125	71	0.0230	28	0.6440	0.0421
CH <sub>4</sub>	512	240	0.3111	16	4.9770	0.2824
C <sub>3</sub> H <sub>8</sub>	8	32	0.0006	44	0.0264	0.0017
C <sub>3</sub> H <sub>6</sub>	128	315	0.1021	42	4.2882	0.2801
iC <sub>4</sub> H <sub>10</sub>	8	1100	0.0223	56.1	1.2510	0.0817
nC <sub>4</sub> H <sub>10</sub>	8	300	0.0061	58.12	0.3545	0.0232
1 Butene	32	480	0.0389	56.1	2.1823	0.1425
Trans-2 Butene	8	710	0.0144	56.1	0.8078	0.0528
C <sub>is</sub> -2 Butene	8	1201	0.0243	56.1	1.3632	0.0890
Butadiene	32	139	0.0153	54.09	0.8276	0.0541
CO <sub>2</sub>	8	220	0.0045	46	0.2070	0.0135
C <sub>2</sub> H <sub>4</sub>	256	25	0.0162	28.05	0.4544	0.0297

Molecular weight of product gas = 42.31  
 Mass of product gas = 77.44 gm  
 Gas wt% of feed = 30.94%  
 Solid wt% of feed = 0.918%  
 Liquid wt% of feed = 68.14%

Run # 100024  
 Reaction temperature 750 °F  
 Residence time 3.26 min.  
 Severity factor 1029.3

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.21	0.2340	2.01	0.4703	0.0285
CO	128	56	0.0185	28	0.518	0.0314
CH <sub>4</sub>	512	221	0.2843	16	4.5488	0.2753
C <sub>3</sub> H <sub>8</sub>	8	10	0.0002	44	0.0088	0.0006
C <sub>3</sub> H <sub>6</sub>	128	290	0.0959	42	4.0278	0.2867
iC <sub>4</sub> H <sub>10</sub>	8	1030	0.0213	56.1	1.1949	0.0850
nC <sub>4</sub> H <sub>10</sub>	8	288	0.0060	58.12	0.3487	0.0248
1 Butene	32	450	0.0372	56.1	2.086	0.1485
Trans-2 Butene	8	700	0.0145	56.1	0.8135	0.0579
C <sub>is</sub> -2 Butene	8	1000	0.0207	56.1	1.1613	0.0827
Butadiene	32	181	0.0150	54.09	0.8114	0.0578
CO <sub>2</sub>	8	195	0.0040	46	0.1840	0.0131
C <sub>2</sub> H <sub>4</sub>	256	18	0.0119	28.05	0.333	0.0237

Molecular weight of product gas = 42.8  
 Mass of product gas = 68.4 gm  
 Gas wt% of feed = 23.96%  
 Solid wt% of feed = 0.805%  
 Liquid wt% of feed = 75.23%

Run # 100027  
 Reaction temperature 650 °F  
 Residence time 4.3 min  
 Severity factor 907.0

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.2	0.2330	2.01	0.4683	0.0244
CO	128	120	0.0405	28	1.1340	0.0660
CH <sub>4</sub>	512	238	0.3102	16	4.9630	0.2569
C <sub>3</sub> H <sub>8</sub>	8	17	0.0004	44	0.0176	0.0010
C <sub>3</sub> H <sub>6</sub>	128	270	0.0910	42	3.8220	0.2225
iC <sub>4</sub> H <sub>10</sub>	8	701	0.0148	56.1	0.8303	0.0483
nC <sub>4</sub> H <sub>10</sub>	8	467	0.0098	58.12	0.5696	0.0332
1 Butene	32	1160	0.0978	56.1	5.4866	0.3195
C <sub>is</sub> -2Butene	8	550	0.0116	56.1	0.6508	0.0379
Butadiene	32	270	0.0057	56.1	0.3198	0.0186
CO <sub>2</sub>	8	121	0.0102	54.09	0.5517	0.0321
C <sub>2</sub> H <sub>4</sub>	256	65	0.0014	46	0.0644	0.0037
C <sub>2</sub> H <sub>6</sub>	32	11	0.0074	28.05	0.2076	0.0121

Molecular weight of product gas = 42.49  
 Mass of product gas = 45.16 gm  
 Gas wt% of feed = 18.54%  
 Solid wt% of feed = 0.75%  
 Liquid wt% of feed = 80.72%

Run # 100031  
 Reaction temperature 850 °F  
 Residence time 3.26 min.  
 Severity factor 1215.8

<u>Component</u>	<u>ATT.</u>	<u>Count</u>	<u>Mole</u>	<u>MW</u>	<u>Wt</u>	<u>Wt%</u>
H <sub>2</sub>	1	0.3	0.330	2.01	0.6633	0.0308
CO	128	115	0.0378	28	1.058	0.0537
CH <sub>4</sub>	512	249	0.3190	16	5.1040	0.2379
C <sub>3</sub> H <sub>8</sub>	8	29	0.0006	44	0.0264	0.0013
C <sub>3</sub> H <sub>6</sub>	128	405	0.133	42	5.586	0.2731
iC <sub>4</sub> H <sub>10</sub>	8	1309	0.0269	56.1	1.509	0.0738
nC <sub>4</sub> H <sub>10</sub>	8	381	0.0078	58.12	0.453	0.0221
1 Butene	32	516	0.0424	56.1	2.378	0.1162
Trans-2 Butene	8	1139	0.0234	56.1	1.312	0.0641
C <sub>is</sub> -2 Butene	8	1400	0.0288	56.1	1.615	0.0784
Butadiene	32	290	0.0238	54.09	1.227	0.0629
CO <sub>2</sub>	8	650	0.0134	46	0.616	0.0301
C <sub>2</sub> H <sub>4</sub>	256	26	0.0171	28.05	0.479	0.0234

Molecular weight of product gas = 41.8  
 Mass of product gas = 67.33 gm  
 Gas wt% of feed = 29.93%  
 Solid wt% of feed = 1.40%  
 Liquid wt% of feed = 68.67