The catalytic hydrodesulfurization of Wyoming fuel oil
by John R Hartwig

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering
Montana State University


Abstract:
This investigation was primarily concerned with the effect of gas recycle on the catalytic hydrodesulfurization of a number-three-fuel oil from a sulfur content of 2.2 percent to 0.5 percent or below. Initial gas compositions were either pure hydrogen or a gas mixture that was approximately 84 percent hydrogen. In the runs with an initial gas composition of pure hydrogen the make-up gas added was also pure hydrogen. Make-up gas for runs where gas mixtures were used was the same composition as the initial gas composition (i. e. approximately 84 percent hydrogen).

Nickel oxide and nickel hydroxide catalysts were studied briefly, but the major emphasis was on molybdenum sulfide catalysts.

Optimum desulfurization conditions were not evaluated. The emphasis was on the determination of gas consumption during continuous gas recycle operation.

Conditions for the nickel study runs were: space velocity 0.1 to 3.0 gm. oil/gm. cat-hr., temperature 385 to 390°C, pressure 60 to 100 psig, and gas recycle rate from 0.4 to 2.0 liters gas/gm oil. Process variables for the molybdenum runs were: space velocity 0.7 to 1.3 gm oil/gm cat-hr, temperature 410 to 415°C pressure 500 psig, and gas recycle rate 0.9 to 1.8 liters gas/gm oil.

The gas. consumption when pure hydrogen was used as the recycle gas was approximately 140 SCF/bbl and the gas consumption with a gas mixture on recycle was between 250 to 300 SCF/bbl. These consumption figures were obtained with molybdenum catalysts.

The effectiveness of the desulfurization process when a gas recycle system was used was hot noticeably different than that when the process ; was carried out with the gas oh a one pass system. Specification oil was produced with molybdenum catalysts and a recycle gas with a hydrogen con-tent as low as 80 percent by volume.

The molybdenum catalysts were far superior to the nickel catalysts as far as catalyst life and the degree of desulfurization were concerned.

# THE CATALYTIC HYDRODESULFURIZATION OF WYOMING FUEL OIL

by

JOHN R. HARTWIG

A THESIS

Submitted to the Graduate Faculty

in

partial fulfillment of the requirements

for the degree of

Master of Science in Chemical Engineering

at

Montana State College

Approved:

Lloyd Berg

Head, Major Department

Lloyd Berg

Chairman, Examining Committee

J. A. Nelson

Dean, Graduate Division

Bozeman, Montana
August, 1952

TABLE OF CONTENTS

## ABSTRACT

This investigation was primarily concerned with the effect of gas recycle on the catalytic hydrodesulfurization of a number three fuel oil from a sulfur content of 2.2 percent to 0.5 percent or below. Initial gas compositions were either pure hydrogen or a gas mixture that was approximately 84 percent hydrogen. In the runs with an initial gas composition of pure hydrogen the make-up gas added was also pure hydrogen. Make-up gas for runs where gas mixtures were used was the same composition as the initial gas composition (i. e. approximately 84 percent hydrogen).

Nickel oxide and nickel hydroxide catalysts were studied briefly, but the major emphasis was on molybdenum sulfide catalysts.

Optimum desulfurization conditions were not evaluated. The emphasis was on the determination of gas consumption during continuous gas recycle operation.

Conditions for the nickel study runs were: space velocity 0.1 to 3.0 gm. oil/gm. cat-hr., temperature 385 to 390°C, pressure 60 to 100 psig, and gas recycle rate from 0.4 to 2.0 liters gas/gm oil. Process variables for the molybdenum runs were: space velocity 0.7 to 1.3 gm oil/gm cat-hr, temperature 410 to 415°C, pressure 500 psig, and gas recycle rate 0.9 to 1.8 liters gas/gm oil.

The gas consumption when pure hydrogen was used as the recycle gas was approximately 140 SCF/bbl and the gas consumption with a gas mixture on recycle was between 250 to 300 SCF/bbl. These consumption figures were obtained with molybdenum catalysts.

The effectiveness of the desulfurization process when a gas recycle system was used was not noticeably different than that when the process was carried out with the gas on a one pass system. Specification oil was produced with molybdenum catalysts and a recycle gas with a hydrogen content as low as 80 percent by volume.

The molybdenum catalysts were far superior to the nickel catalysts as far as catalyst life and the degree of desulfurization were concerned.

## INTRODUCTION

The depletion of low sulfur content crudes in the United States is forcing refiners to employ increasing amounts of high sulfur crudes. Utilization of these crudes has forced refiners to develop economical processes for removal or conversion of sulfur compounds in the various products refined from them. Methods commonly used for desulfurization of gasoline are not satisfactory for the treatment of higher boiling petroleum fractions such as diesel and fuel oils. Such commercial processes as the Unisol process, the Solutizer and Tannin Solutizer processes, hypochlorite treatment, Gray desulfurization, treatment with bauxite catalysts, as well as caustic and acid washes, either do not reduce the sulfur content in the heavier distillates to the desired percentages or hydrocarbon losses are excessive. Although the identification of specific sulfur compounds in any particular petroleum fraction is a difficult task, and research in this direction has not been extensive until fairly recently (8) (9), it has been fairly well established (9) that the sulfur compounds in kerosine and fuel oil distillates are predominantly thiophenic in nature. These compounds are not receptive to any of the desulfurization treatments mentioned above.

Successful desulfurization of fuel oil distillates to very low limits has been accomplished by catalytic hydrodesulfurization. Work by Green (6) and Munro (3) with a molybdenum sulfide catalyst in a hydrogen atmosphere reduced the sulfur content in a number three fuel oil from approximately 2.2 percent to less than 0.5 percent. Several commercially adaptable

catalytic desulfurization processes have been patented by the Anglo-Iranian and Union Oil Companies (10) (11). These processes utilize cobalt and molybdena catalysts and hydrogen gas atmospheres at various pressures (200-700 psig).

The inherent economic disadvantage of these catalytic hydrodesulfurization processes is the need for a relatively rich (greater than 90%) hydrogen gas supply. This difficulty can be overcome, however, by using the desulfurization process in conjunction with a "catforming" unit for upgrading low octane gasoline. In a typical catalytic reforming process (12) there is a net make of a gas mixture which is predominantly hydrogen (approximately 90%), with small quantities of methane, ethane, and propane present.

The capacity of such a desulfurization unit would naturally be regulated by the quantity of make gas from the catformer and the amount of gas consumed in the desulfurization process. The primary objective of this research was the determination of gas consumption (as SCF/bbl.) for the catalytic hydrodesulfurization process developed here in the past few years by Koski (2), Munro (3), and Green (6). This process was developed for the desulfurization of Husky Oil Company's number three fuel oil. The sulfur content in this fuel oil was to be reduced from 2.2 percent to 0.5 percent or below. As mentioned previously, the catalyst used was molybdenum sulfide (approximately 15% Mo) impregnated on an alumina carrier. The process variables for this catalyst were fairly well established in the preceding work. The optimum conditions found were: pressure, 500

psig; temperature 400-410°C (752-770°F); gas to oil ratio, 1.3 to 1.5 liters gas/gm oil; and a variable space velocity, (this varied between approximately 0.4 and 1.0 gm oil/gm cat.-hr., depending upon the activity of the catalyst).

Aside from the stated objective of the determination of gas consumption data, three runs were made using nickel catalysts. The purpose of these runs was a final attempt (see work by Coykendall (7) and Haas (5)) to determine if there was any true catalytic effect with nickel catalysts, and to prove whether the process with nickel catalysts would work in the recycle apparatus used for the molybdenum catalyst studies.

The gas recycle study (GRS) and the molybdenum comparison run (MCR) were made using pure hydrogen gas. The catforming gas study run (CGR) used a gas mixture typical of the make gas from a "catforming" unit.

In all the runs with molybdenum catalysts (i.e., GRS, MCR & CGR), the effect of gas recycle on catalyst activity was also observed. The molybdenum comparison run (MCR), as the name indicates, was primarily a comparison test on a different batch of molybdenum catalyst delivered from the Harshaw Chemical Company.

# EQUIPMENT, MATERIALS, AND METHODS

## EQUIPMENT

A schematic diagram of the recycle unit is shown in Figure 1. The reactor itself is the same as that used by both Munro (3) and Green (6). Essentially it consists of a 16 inch length of $1\frac{1}{2}$ inch extra strong black iron pipe fitted with a $1\frac{1}{2}$ to 3/4 inch reducer at the top and a $1\frac{1}{2}$ to $\frac{1}{2}$ inch reducer at the bottom. Both the top and bottom of the reactor were fitted with unions to allow for easy takedown of the reactor for loading and unloading. Fitted on the top of the reactor were two crosses and an assembly of valves for gas, oil, and regeneration air inlet. A blow-out line and thermowell tube were also fitted to this assembly. The thermowell tube was a $\frac{1}{4}$ inch black iron pipe which extended from the cross at the top of the reactor down through the vertical axis of the reactor to within one inch of the bottom. It was possible to position three thermocouples at any point within the reactor with this system. The thermocouples were iron-constantan and were used in conjunction with a Leeds and Northrup indicating potentiometer for temperature measurement.

Fitted at the bottom of the reactor was a water cooled condenser. At the bottom of the condenser, connected from a cross, was the reactor pressure gage, high pressure product receiver (a 12 inch Jerguson sight gage), a standpipe, and the reactor back pressure valve.

At the bottom of the Jerguson product receiver was the receiving flask, caustic scrubbing train, and a wet test meter manufactured by the Precision Scientific Company. A constant oil level was maintained in the

Jerguson receiver by hand adjustment of a needle valve at the bottom of the receiver.

The reactor pressure was maintained by a Mason-Neilan small-volume air-to-close regulator valve. This pressure regulator was controlled by a Fisher Wizard proportional controller.

A two cylinder, adjustable stroke, high pressure piston pump and an oil reservoir comprised the oil feed system.

Three 33-foot lengths of beaded Nichrome wire, supplied with current from three 110-volt Powerstat autotransformers, provided variable heat input for the reactor. Two of these heating coils were located near the bottom of the reactor to heat the catalyst section and one was located higher up on the reactor to heat the preheat section. Alundum balls were used as preheat media.

Gas flow to the reactor was metered by a Fisher flowrater and regulated by a needle valve manufactured by the American Instrument Company. This needle valve was located ahead of the flowrater.

The remaining equipment of the unit made up the gas recycle system. The compression pump was a two cylinder Hills-McCanna high pressure proportioning pump. The feed tank was made from a number one gas cylinder and the surge and compression tanks were made from number two gas cylinders. A Brook's Rotameter metered the flow from the make-up tank.

Extra strong black iron pipe and high pressure fittings were used throughout the unit where piping is indicated by double lines on Figure 1. Single lines on the drawing indicate 1/8 inch stainless steel high pressure

tubing.

Before the recycle unit as shown in Figure 1 was constructed, a different unit was used. This unit was essentially the same as the later unit with the exception of the gas recycle system. Instead of using an oil displacement method for gas compression, a small refrigerator compressor was used to move the gas from the surge tank to the feed tank. This system worked quite well until the middle of the "catforming" gas study run. At that time repeated compressor breakdowns caused so much trouble and unit shutdown time that the recycle unit as shown on Figure 1 was constructed. This unit did not cause any operational troubles and proved to be a great improvement over the old system.

## MATERIALS

The oil used throughout this work was Husky Oil Company's number three fuel oil. The sulfur content of this oil varied between 2.09 and 2.19 percent. Additional data for this oil can be found on Table I in the appendix.

Table II presents data for all the catalysts used in this research.

Recycle gas used was either pure hydrogen or a gas mixture. The hydrogen was obtained from the Whitmore Oxygen Company of Salt Lake City, Utah. The gas mixture was obtained from the Matheson Chemical Company in East Rutherford, New Jersey. The composition of this gas mixture (as ordered) was: hydrogen, 89 percent; methane, 3.5 percent; ethane, 1.5 percent; propane, 2.5 percent; and propylene, 3.5 percent. To obtain this gas composition a Husky gasoline stock was sent to the Atlantic Refining

Company and run through their catalytic reforming unit. Analysis of the make gas from the run with the Husky stock gave the above composition.

## METHODS

The unit was started by applying heat to the heating coils with the gas flowing through the reactor. The reactor was set at the desired pressure during this period or when the catalyst temperature reached 300°C. Oil flow was started and the space velocity adjusted when the catalyst temperature reached 380°C. Readings were recorded after the desired catalyst temperature was reached, with the gas flow, reactor pressure, and space velocity properly adjusted and maintained.

As the product oil collected in the Jerguson pressure receiver it was allowed to drip slowly to the receiving flask. The receiving flask was removed and replaced at the desired sampling periods. Dissolved gases (predominately $H_2S$), which flashed from the oil when the oil left the pressure receiver, went to the caustic scrubbing train and then to the wet test meter where the gases were metered and passed to the exhaust line.

In the operation of the unit, the recycle gas flowed from the feed tank through the flowrator and to the reactor. After the gas passed through the reactor and the reactor back-pressure regulator, it flowed to the surge and compression tanks. When the pressure in these two tanks reached 300 psig the surge tank was isolated from the compression tank and the compression pump was started. Compression oil (Husky's number three fuel oil) was pumped from the compression oil reservoir to the compression tank, compressing the gas in the compression tank. When the pressure in

the compression tank became equal to that in the feed tank (usually between 550 and 560 psig) the valve between these two tanks was opened and the gas in the compression tank was pushed over to the feed tank. When all the gas in the compression tank had been pushed to the feed tank (as indicated by the appearance of oil in the sight glass on the compression tank) or when the pressure in the feed tank reached 600 psig, the compression pump was stopped and the valve between the feed and compression tank was closed. The valve between the surge and compression tank was then opened. The oil in the compression tank was forced back to the compression oil reservoir by the pressure from the surge tank when the valve between the oil reservoir and the compression tank was opened. The compression cycle was started again when the pressures in the compression and surge tanks again reached 300 psig. The compression cycle usually took about 1.5 hours for completion with 45 minutes to an hour between cycles.)

Arbitrary, standard pressures were set for the feed tank and the compression and surge tanks; that for the feed tank was 600 psig, and for the compression and surge tanks it was 250 psig. When the pressure in the surge and compression tanks fell below 250 psig (with the pressure in the feed tank up to 600 psig) at the end of a compression cycle, make-up gas was added to bring the pressure in these two tanks back to 250 psig. Gas flow from the make-up tank was metered through the Brooks rotameter and this flow was timed with a stopwatch.

When desired, recycle gas samples were taken from a bleed-off valve located on the downstream side of the reactor back pressure regulator.

The gas sample was passed through the caustic scrubbing train and the wet test meter before it was collected over water in eight liter glass sample bottles. Analysis of the gas samples was made in a low temperature fractionation column.

Sulfur analysis of each oil sample was made by the lamp method (1).

## CALCULATIONS

Tables IV, V, VI, VII, and VIII contain the tabulated data for all the runs made in this investigation.

The space velocity recorded was based on input oil. Each individual sample weight was corrected by the percent loss over a longtime period of the run as calculated from oil weight balances.

For example:

Percent loss, wt. basis = 2%. Then, for an individual sample weighing 800 gms., input weight = $\frac{800}{.98}$ = 816 gms. Then, for an 8 hr. sample period with a 100 gm. catalyst charge, space velocity =

$$\frac{816 \text{ gms. oil}}{(100 \text{ gms. cat.})(8 \text{ hrs.})} = 1.020.$$

The gas flow (as recycle gas, SCF/bbl.) was calculated by dividing the gas flow per sample period by the oil weight per sample period.

For example:

With an 800 gm. oil sample (816 corrected wt.) and a gas recycle rate (as indicated by the Fisher flowrater) of 1070 liters (STP) per 8 hours; $\frac{1070}{816}$ = 1.3 liters gas/gm oil. Then 1.31 liters gas/gm. oil x .875 gm. oil/cc. oil x 1000 cc/liters x $\frac{28.32}{7.48}$ liters/gal x 42 gal/bbl x $\frac{1}{28.32}$ $Ft^3$/ liters = 6430 $Ft^3$/bbl. (STP).

Hydrogen consumption was calculated from the make-up and bleed-off gas figures recorded for each sample period. Bleed-off figures were the wet test meter readings. Make-up figures were from the Brook's rotameter readings.

For example:

For an 800 gm-oil sample (816 corrected) and gas make-up equal to 40 liters (STP) and bleed-off equal to 8 liters (STP), the gas consumed would be 32 liters (STP).

Then $\frac{32}{816} \times \frac{1000}{1} = 39.2$ liters consumed/kilogram oil.

$39.2 \times 4.91$ (conversion factor) = 193 $Ft^3$ consumed/bbl oil.

Gas consumption for any individual sample period varied widely so the figures presented in the data were cumulative averages.

For example:

After ten samples, total gas consumtion equalled 3100 $Ft^3$. Then for the tenth sample, $\frac{3100}{10} = 310$ $Ft^3$/bbl.

The catalyst temperatures presented in the data are averaged temperatures for each sample period indicated. The thermocouples for the catalyst bed were located at the top and bottom of the catalyst bed. The top and bottom catalyst temperatures were averaged and these average temperatures were averaged over the sample period.

A thermodynamic study of probable reaction mechanisms for the catalysts used and reported in this paper was not made since this was done previously by Munro (3) and Green (6) for the molybdenum sulfide catalysts, and by Haas (5) for the nickel catalysts.

## RESULTS AND DISCUSSION

With the exception of three relatively short runs using nickel catalysts, only one type of catalyst ($MoS_2$) was used. The primary concern of this research was the study of the effect of gas recycle on the desulfurization process, with determination of gas consumption especially emphasized. Tabulated data for all runs made in this study are presented in the appendix.

All of the studies made on nickel catalysts were made primarily to observe the effectiveness of these nickel catalysts in the recycle unit and to determine whether the nickel catalysts' desulfurization action was a chemical or catalytic reaction. In respect to the type of reaction of the nickel catalysts, Haas (5) has already stated that the desulfurization by nickel catalysts was strictly a chemical reaction.

If desulfurization was accomplished through a catalytic mechanism when nickel catalysts were used, a certain amount of hydrogen would necessarily have to be consumed. The hydrogen is consumed by the combination with the sulfur in the oil (to form $H_2S$) and the combination with the hydrocarbon from which the sulfur was removed. However, for NSR-I and NSR-II (Tables III and IV) gas was produced and it was not necessary to add any make-up gas. For the third nickel study run (NSR-III, Table V) a total of 21.8 SCF/bbl was consumed. When compared to gas consumption with molybdenum catalysts (140 to 300 SCF/bbl) the consumption of 21.8 SCF/bbl is not large.

A possible conclusion to be drawn from the above discussion would be

that the sulfur was removed by some other means (e.g. by chemical combination with the nickel) and not by carbon to sulfur bond fissure with subsequent formation of $H_2S$, and resultant hydrogen consumption.

For all the nickel study runs, gas analysis of the recycle gas revealed a high hydrocarbon gas buildup (predominately methane). The hydrocarbon buildup in the recycle gas that occurred when nickel catalysts were used indicates to some extent the non-selectivity of these catalysts when they are used as desulfurization agents. Instead of breaking the carbon to sulfur bonds the nickel catalysts evidently induced a predominate carbon to carbon cracking with the production of large amounts of methane.

Haas (5) also states that the desulfurization depends in a large part on space velocity. This is amply demonstrated by comparison of NSR-I and NSR-II with NSR-III. The average space velocity for the first two runs was approximately 3.0 gm oil/gm cat.-hr, whereas that for the last run (NSR-III) was 0.1 gm oil/gm cat.-hr. In the first two runs no specification oil was produced at all, whereas approximately 12 throughputs (i.e. $\frac{\text{2400 gms oil}}{\text{200 gms. cat.}}$) were achieved by blending samples 1 through 27 in the third nickel study run.

The different pressures used (i.e. 60 psig for NSR-I and NSR-II, and 100 psig for NSR-III) in the nickel runs did not have any apparent affect on the degree of desulfurization.

Results from the three nickel runs show that the nickel catalysts do not have a long catalyst life and that their desulfurization action is quickly lost after only a few oil throughputs.

Operating conditions for the NSR runs were established by the research laboratory of Husky Oil Company in Cody, Wyoming.

The Gas Recycle Study (GRS, Table VI) was the first run made with gas recycle operation with an $MoS_2$ catalyst. The molybdenum catalyst used for this run had been used previously by Green (6) in his mixture study run for a total of 607 hours. Successful desulfurization was accomplished for an additional 526 hours with this catalyst. During the GRS run the space velocity varied between 0.5 and 0.8 gm oil/gm cat.-hr. Gas recycle varied between 6000 and 11,000 SCF/bbl. Pure hydrogen was used as make-up during this run.

At the start of the run the recycle gas was approximately 100 percent hydrogen. At the end of the run the hydrocarbon buildup in the recycle gas did not exceed five percent.

Gas consumption calculations were not made during the first 26 samples of this run. During this period, considerable difficulty was encountered in establishing operating procedures with the gas recycle system, and in establishing standard tank pressures to assure continuous gas flow and an accurate gas balance.

Calculation of gas consumption was started after sample 26. From sample 26 through 36 there was a gas leak in one of the valve stems on the unit. Rather than shut down the unit and repair this leak, the gas escaping from the valve stem was metered and the run was continued. The amount of gas leaking from the valve stem was approximately one-tenth of the gas recycle rate. Gas consumption during this period of gas bleed-off and

including the gas bleed-off was between 220 to 275 SCF/bbl oil.

From sample 37 to the end of the run the gas leak was repaired and with no gas bleed-off the gas consumption leveled off at about 140 SCF/bbl.

Gas samples were taken from the recycle unit at various times during the GRS run. Analysis of these gas samples revealed a buildup of hydrocarbon gases. In order to ascertain the trend of this hydrocarbon gas buildup a method had to be developed to correlate the hydrocarbon buildup with some factor which would be independent of the size of the recycle unit and the total amount of gas being recycled.

When the space velocity and gas flow are kept constant, the rate of hydrocarbon gas buildup should also remain constant. However, the time it would take to obtain a specified hydrocarbon buildup would vary with the size of the reactor system and the total amount of gas in the system. Correlation between hydrocarbon gas buildup and hours on stream would be meaningless if applied to other reactors. To overcome this, the number of gas recycles was calculated at each gas sample period and in this way it was possible to compare the hydrocarbon content of the recycle gas with the number of times the total volume of gas in the reactor system had been passed through the reactor proper.

The following calculation was applied to the GRS run to determine the number of recycles at each gas sample period. The calculation cited is for a ten day period of the run.

109 = average cubic feet recycled per day.

10 = number of days for which the calculation was made.

70 = cubic feet of gas in the reactor system at the arbitrary standard pressures.

12 = average cubic feet of make-up gas added per day during the period of calculation.

$$\frac{(109)\ (10)}{70 + 12} = 13 \text{ recycles.}$$

When the above method of calculation was applied to the GRS run the hydrocarbon buildup after 8 recycles was 4.4 percent (volume percent), after 9 recycles it was 5.0 percent, after 11 recycles it was 6.0 percent, and after 13 recycles the hydrocarbon content in the recycle gas was 4.6 percent. These calculations indicate that the amount of hydrocarbon gas buildup in the recycle gas was not excessive and that the percentage increase in hydrocarbon content per recycle was relatively small (i.e. after 8 recycles it was .55 percent per recycle and after 13 recycles it was .35 percent per recycle).

Oil losses for the gas recycle study on a weight basis were 3.1 percent. In the work by Munro (3) and Green (6), oil losses averaged around 6.0 percent. In their studies the oil samples were collected at atmospheric pressure and some oil was carried off as a mist. With the recycle unit the oil samples were collected under pressure and no oil loss as a mist occurred.

The $MoS_2$ catalyst used in the GRS (Table VI) run was used previously by Green (6) in his mixture study run. The same operating conditions were used for the first 34 samples of Green's mixture study run as were used in the gas recycle study. The only difference in that part of the mixture

study run being cited and the GRS run was the recycle of gas during the GRS run. With this in mind a comparison of the relative catalyst activity during the GRS run can be made with the activity of the same catalyst when no gas recycle was being used. Green's mixture study run had an average space velocity (samples 1 through 34) of approximately 0.7 gm oil/gm cat.-hr. With this space velocity the average sulfur content of the effluent oil was approximately 0.3 percent. In the gas recycle study the average space velocity was also approximately 0.7. The average sulfur content in the product oil was about 0.4 percent. From these figures it would seem that the catalyst was not as active under gas recycle conditions. However, when the deactivation of catalyst with use is considered (the mixture study run by Green added 333 hours on stream time to the catalyst before it was used in the gas recycle study) the activity of the catalyst with gas recycle would seem to be the same as that without gas recycle.

The molybdenum comparison run (MCR, Table VII) was started with approximately the same operating conditions as were used for the gas recycle study. This run was made to compare the activity of $MoS_2$ catalysts used in the past with a $MoS_2$ catalyst prepared on a larger scale by the Harshaw Chemical Company. With an initial space velocity of 0.7 gm oil/gm cat.-hr the sulfur content of the effluent oil was only 0.1 percent.

When the space velocity was nearly doubled, the percent sulfur in the product oil also increased, but it did not exceed 0.5 percent until the space velocity was raised above 1.35 gm oil/gm cat.-hr. The percent sulfur dropped from .519 to .304 when the space velocity was lowered from 1.331 to

.869 gm oil/gm cat.-hr.

Although this run (MCR) was comparatively short (160 hours), the above results demonstrate readily the higher activity of the $MoS_2$ catalyst used as compared to any of the molybdenum sulfide catalyst used previously, either in this research or in the work by Munro (3) and Green (6). In these studies specification oil was rarely produced if the space velocity exceeded 1.0. The average gas consumption was 140 SCF/bbl which was the same as the gas consumption for the gas recycle study. The buildup of hydrocarbons in the recycle gas was 4.2 percent after 10 recycles. This is also comparable to the gas recycle study.

There is no apparent reason for the greater activity shown by the catalyst used in the MCR run (Table VII). The composition of this catalyst was nearly the same as the composition of $MoS_2$ catalysts used previously (see Table II). The catalyst used for this run was a part of a somewhat larger batch than was usually ordered from the Harshaw Chemical Company for desulfurization studies. Usually, small (5 to 10 pounds) samples of catalyst were ordered, but in this case about 40 pounds of the catalyst was made. A possible reason then, for the higher catalyst activity could be the method of manufacture of the catalyst.

The same catalyst that was used for the MCR run was used for the "catforming" gas study run (CGR), Table VIII. The catalyst had been used for 160 hours during the MCR run. It was not regenerated or treated in any other way prior to its use in the CGR run. This catalyst exhibited a somewhat higher activity than those used in the past, but as the CGR run

progressed the activity of the catalyst did decline.

During the CGR run two air regenerations of the catalyst were made. The regenerations were made with the catalyst in the reactor. The first air regeneration was made after sample 61. In a total time of $2\frac{1}{4}$ hours 938 liters (STP) of air was passed over the catalyst. The average temperature during this time was 450°C and the maximum temperature attained in the catalyst bed was 600°C. In the second catalyst regeneration (after sample 168) a total of 700 liters (STP) of air was passed over the catalyst for a period of 2 hours. The maximum temperature of the catalyst during this regeneration was 620°C. The level of the catalyst activity was increased after each air regeneration. Sample 61 had a sulfur content of .533 percent. Sample 62 (the first sample after the first catalyst regeneration) had a sulfur content of .279 percent. The sulfur content of the product oil before the second regeneration was .589 percent. After this regeneration the sulfur content dropped to .264 percent.

The gas used for the CGR run was a gas mixture considered typical of the make gas from a "catforming" unit. The analysis of this gas (as volume percent) was presented in the materials section. An analysis of the gas delivered was made as a check on its composition. Presented below is this analysis along with the composition specified when the gas mixtures were ordered.

| | $H_2$ | $CH_4$ | $C_2H_6$ | $C_3H_6$ | $C_3H_8$ |
|---|---|---|---|---|---|
| Specified composition (percent by volume) | 89 | 3.5 | 1.5 | 3.5 | 2.5 |
| Delivered composition | 84 | 6.0 | 3.7 | 3.9 | 2.4 |

This check analysis indicated a somewhat leaner hydrogen composition than was anticipated.

The initial hydrogen content of the recycle gas was 84 percent. The hydrogen content of the recycle gas after 1341 hours of operation had dropped to 81.1 percent. This small decrease in hydrogen content did not noticeably affect the effective desulfurization during the run. Green (6) investigated the effect of gas composition on effective desulfurization and Silvey (4) has made a more thorough search in this direction.

The average gas consumption for the CGR run was approximately twice that found for previous runs (GRS and MCR) where pure hydrogen was used for recycle and make-up. Average consumption data for the CGR run varied between 280 to 290 SCF/bbl.

The temperature readings shown on the data for samples 30, 35, and 36 (Table VIII) are not the actual temperatures for these samples. The dry cell in the temperature indicating potentiometer was nearly dead for the period between samples 30 to 36. For the three samples cited, a close check on the standardization of the potentiometer was not made and the temperatures for samples 30, 35, and 36 were lower than the actual readings taken. The fact that temperature is a critical factor in effective desulfurization is readily shown by these three sample periods. They show that when the temperature is below a certain critical level (Munro (3) thought this was below 400°C) the sulfur content is correspondingly higher. For samples 30, 35, and 36 respectively the sulfur content of the effluent oil was .646, .552, and .568 percent. The other samples taken during this

period were all below 0.5 percent sulfur.

From sample 99 to sample 106 gas consumption calculations were not made. At this time the method of gas compression was changed (see Equipment section), and establishment of new operating procedure precluded any gas balance or gas consumption calculations.

The period of the run from sample 130 to sample 145 also did not have any gas consumption data. At this time the pressure in the gas make-up cylinder fell below the pressure for which the Brooks rotameter was calibrated and it was not possible to measure the quantity of make-up gas added to the reactor system. When new cylinders of the make-up gas were delivered the gas consumption calculations were resumed with sample 146.

The primary purpose of the CGR run (Table VIII) up to sample 61 was the determination of gas consumption and catalyst life using the "cat-forming" gas on recycle. After sample 61 it was decided to run at a space velicity of 1.0 until the sulfur content in the product oil exceeded 0.5 percent. When this occurred the catalyst was to be regenerated and the process repeated until the time between regeneration periods became excessively short. As the run progressed from sample 61, the decision was then made to run until the composite blend of the product oil samples reached 0.5 percent sulfur. The catalyst would then be regenerated, and a composite blend equal to 0.5 percent sulfur would again be the point at which catalyst regeneration would take place.

The run was ended, however, when it became obvious that the time interval between catalyst regeneration was prohibitively long if the

ultimate deterioration of the catalyst was to be determined.

## CONCLUSIONS

The brief studies made with nickel catalysts indicate that these catalysts are inferior to molybdenum catalysts as far as catalyst life and the degree of desulfurization are concerned. Data from these studies also substantiate in some measure the contention that the nickel catalysts desulfurize for the most part through a chemical reaction mechanism and that they do not act as true catalytic desulfurization agents.

Gas consumption data found with $MoS_2$ catalysts indicate a higher consumption figure with a "catforming" gas mixture than with pure hydrogen when these gases are recycled.

When either hydrogen or a gas mixture was used as the recycle gas, the hydrocarbon gas buildup per recycle was not excessive and the buildup of hydrocarbon gases that did occur did not noticeably affect the desulfurization process.

Use of a gas mixture in the desulfurization process, as well as the continuous recycle of the effluent gases, did not noticeably affect the degree of desulfurization obtained with $MoS_2$ catalysts.

Deactivation of the molybdenum catalysts with prolonged use was indicated by the studies made, but air regeneration restored the activity of these catalysts to a higher level than that of the fresh catalyst.

Although the molybdenum catalysts did exhibit some deterioration with use, specification oil was produced for 526 hours without catalyst regeneration when pure hydrogen was used as make-up and for 493 hours

before regeneration was necessary when "catforming" gas was used as make-up.

ACKNOWLEDGEMENT

The author wishes to thank the Husky Oil Company who sponsored the fellowship under which this work was carried out.

## LITERATURE CITED

(1) A. S. T. M. STANDARDS ON PETROLEUM AND LUBRICANTS, American Society for Testing Materials, Philadelphia, (1941).

(2) Koski, O. H., M.S. Thesis, Montana State College (1951).

(3) Munro, B. L., M.S. Thesis, Montana State College (1952).

(4) Silvey, F. C., M.S. Thesis, Montana State College (1953).

(5) Haas, P. A., M.S. Thesis, Montana State College (1951).

(6) Green, K. J., M.S. Thesis, Montana State College (1952).

(7) Coykendall, J. W., M.S. Thesis, Montana State College (1952).

(8) Brown, H. R., and Meyerson, S., Ind. Eng. Chem., 44, No. 11, 2620-2631, (1952).

(9) Hatch, L. F., Petroleum Refiner, 32, No. 6, 105-107 (1953).

(10) Anon, Petroleum Refiner, 31, No. 6, 108 (1952).

(11) Anon, Petroleum Refiner, 31, No. 9, 226 (1952).

(12) Anon, Petroleum Refiner, 31, No. 9, 114 (1952).

## APPENDIX

TABLE I
FUEL OIL INSPECTION DATA

| Sample Designation | Charge Stock No. 3 Oil | C G R Comp. 103-107 | C G R Comp. 60-168 |
|---|---|---|---|
| A.P.I | 30.6 | 34.6 | 34.2 |
| A.S.T.M. Distillation | °F | °F | °F |
| I.B.P. | 425 | 160 | 146 |
| 5% | 504 | 418 | 411 |
| 10% | 520 | 462 | 461 |
| 20% | 536 | 497 | 494 |
| 30% | 548 | 513 | 512 |
| 40% | 558 | 526 | 524 |
| 50% | 567 | 538 | 536 |
| 60% | 575 | 550 | 548 |
| 70% | 584 | 562 | 560 |
| 80% | 594 | 572 | 575 |
| 90% | 611 | 603 | 599 |
| 95% | 625 | 630 | 627 |
| E. P. | 652 | 649 | 645 |
| Recovery | 99.0% | 97.0% | 97.5% |
| Residue | 0.8% | 1.25% | 1.5% |
| Loss | 0.2% | 1.75% | 1.0% |
| Wt. % Sulfur | 2.19% | .460% | .539% |

TABLE II
CATALYSTS

| Run Number | Catalyst and Composition | Identification Code |
|---|---|---|
| NSR-I and NSR-III | Nickel Oxide<br>NiO 10%<br>$Al_2O_3$ Balance | Harshaw Number 3<br>Calcined<br>Ni-0301 T 1/8" |
| NSR-II | Nickel Hydroxide<br>$Ni(OH)_2$ | Harshaw Number 3 |
| GRS | Molybdenum Sulfide<br>$MoS_2$ 15%<br>$Al_2O_3$ Balance | Harshaw Mo-X-L321<br>-42 T 1/8" |
| MCR and CGR | Molybdenum Sulfide<br>Mo 9.66%<br>S 7.97%<br>$Al_2O_3$ Balance | Harshaw Mo-0801-T 1/8"<br>RI 34-1 Lot 191 A-1-1 |

TABLE III

TABULATED DATA FOR NICKEL STUDY RUN ONE (NSR-I)

Run Number: NSR-I
Grams Catalyst: 100
Catalyst Reference: NiO Harshaw #3 Calcined, Ni-0301 T 1/8"
Oil Charge °API: ~30
Percent Sulfur: 2.19

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Reactor psig | Space Vel. Gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 734 | 59 | 1.94 | 3530 | | 190 | .68 | 96.9 | 3.1 |
| 2 | 3 | 673 | 60 | 3.12 | 2100 | | 612 | 1.22 | | |
| 3 | 5 | 711 | 61 | 3.07 | 2070 | | 600 | 1.24 | | |
| 4 | 7 | 732 | 63 | 3.24 | 2010 | | 634 | 1.43 | | |
| 5 | 9 | 714 | 60 | 2.66 | 2260 | | 520 | 1.68 | | |
| 6 | 11 | 723 | 64 | 2.67 | 2260 | | 522 | 1.71 | | |
| 7 | 13 | 730 | 64 | 3.21 | 1920 | | 629 | 1.69 | | |
| 8 | 15 | 729 | 61 | 3.03 | 2040 | | 594 | 1.61 | | |
| 9 | 17 | 729 | 62 | 3.41 | 2010 | -7.13 | 658 | 1.76 | 83.4 | 16.6 |

Yield: Wt.% 97.7

TABLE IV

TABULATED DATA FOR NICKEL STUDY RUN TWO (NSR-II)

Run Number: NSR-II
Grams Catalyst: 100
Catalyst Reference: $Ni(OH)_2$, Harshaw #3
Oil Charge °API: ~30
Percent Sulfur: 2.19

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Reactor psig | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 757 | 59 | 2.09 | 3120 | | 206 | .83 | ~100 | - |
| 2 | 2 | 729 | 61 | 3.07 | 1970 | | 304 | 1.18 | | |
| 3 | 4 | 725 | 58 | 2.99 | 2130 | | 590 | 1.44 | | |
| 4 | 6 | 721 | 60 | 3.37 | 1890 | | 665 | 1.58 | | |
| 5 | 8 | 725 | 57 | 3.12 | 2040 | | 615 | 1.70 | | |
| 6 | 10 | 725 | 58 | 3.05 | 2030 | | 601 | 1.70 | | |
| 7 | 12 | 725 | 61 | 3.22 | 1870 | | 635 | 1.71 | | |
| 8 | 14 | 725 | 61 | 2.89 | 2210 | | 572 | 1.76 | | |
| 9 | 16 | 725 | 61 | 3.12 | 1980 | | 616 | 1.82 | | |
| 10 | 18 | 725 | 62 | 3.08 | 2060 | | 608 | 1.82 | | |
| 11 | 20 | 725 | 60 | 3.14 | 2030 | | 620 | 1.87 | | |
| 12 | 21 | 725 | 61 | 3.47 | 1880 | -9.65 | 342 | 1.89 | 86.7 | 13.3 |

Yield: Wt. % 98.6

TABLE V

TABULATED DATA FOR NICKEL STUDY RUN THREE (NSR-III)

Run Number: NSR-III
Grams Catalyst: 200
Catalyst Reference: NiO Harshaw #3 Calcined
Oil Charge °API: ~30
Percent Sulfur: 2.19

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Reactor psig | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 579 | 102 | .0588 | 18,400 | | 31 | 1.18 | ~100 | - |
| 2 | 11 | 741 | 100 | .0264 | 40,300 | | 37 | .27 | | |
| 3 | 15 | 720 | 98 | .0869 | 11,300 | | 61 | .09 | | |
| 4 | 19 | 723 | 99 | .1081 | 9,080 | | 76 | .17 | | |
| 5 | 23 | 723 | 99 | .1243 | 8,500 | | 88 | .14 | | |
| 6 | 27 | 725 | 97 | .1238 | 9,230 | | 87 | .13 | | |
| 7 | 31 | 725 | 101 | .1211 | 9,430 | | 85 | .19 | | |
| 8 | 35 | 723 | 97 | .1205 | 8,800 | | 84 | .22 | | |
| 9 | 39 | 725 | 98 | .1175 | 9,710 | | 82 | .25 | | |
| 10 | 43 | 725 | 98 | .1191 | 8,250 | | 84 | .24 | | |
| 11 | 47 | 723 | 100 | .1300 | 8,150 | | 92 | .26 | | |
| 12 | 51 | 725 | 100 | .1175 | 9,720 | | 82 | .31 | 34.4 | 65.6 |
| 13 | 55 | 723 | 102 | .1125 | 9,420 | | 80 | .38 | | |
| 14 | 59 | 725 | 103 | .1250 | 8,500 | | 88 | .36 | | |
| 15 | 63 | 725 | 105 | .1053 | 10,100 | | 74 | .41 | | |
| 16 | 67 | 725 | 102 | .1204 | 8,800 | | 84 | .43 | | |
| 17 | 71 | 723 | 103 | .1225 | 8,660 | | 86 | .47 | | |
| 18 | 75 | 725 | 105 | .1125 | 9,440 | | 79 | .56 | | |
| 19 | 79 | 725 | 104 | .1175 | 9,700 | | 82 | .65 | | |
| 20 | 83 | 725 | 101 | .1132 | 8,660 | | 81 | .68 | | |
| 21 | 87 | 725 | 102 | .1090 | 9,010 | | 76 | .77 | | |
| 22 | 91 | 725 | 99 | .1211 | 8,750 | | 85 | .84 | | |
| 23 | 95 | 725 | 99 | .1225 | 8,660 | | 86 | .90 | | |
| 24 | 99 | 725 | 101 | .1131 | 8,690 | | 80 | .92 | | |
| 25 | 103 | 725 | 101 | .1190 | 8,910 | | 84 | .97 | | |

TABLE V (continued)

TABULATED DATA FOR NICKEL STUDY RUN THREE (NSR-III)

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Reactor psig | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas He |
|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 107 | 725 | 97 | .1190 | 8,910 | | 84 | 1.04 | | |
| 27 | 111 | 725 | 99 | .1131 | 9,370 | | 80 | 1.08 | | |
| 28 | 115 | 725 | 98 | .1219 | 8,710 | | 86 | 1.10 | | |
| 29 | 119 | 723 | 98 | .1225 | 8,660 | | 86 | 1.10 | | |
| 30 | 123 | 725 | 96 | .1769 | 6,040 | | 124 | 1.20 | 37.7 | 62.3 |

Yield: Wt. % 87.8
Vol. % 90.4

Composite Samples #1-27: .514% S.
Composite Samples #1-27 consumed 21.8 $Ft^3$ $H_2$/bbl oil.

# TABLE VI
## TABULATED DATA FOR GAS RECYCLE STUDY

Run Number: GRS
Grams Catalyst: 100
Catalyst Reference: Harshaw MoX-L321-42
Oil Charge °API: ~30
Percent Sulfur: 2.19

| Samp. No. | Total Hours | Avg. Cat. Temp °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 770 | .900 | 5,350 | --- | 500 | .681 | ~100 | --- |
| 2 | 14 | 770 | .664 | 8,740 | --- | 493 | .566 | | |
| 3 | 22 | 770 | .637 | 10,000 | --- | 474 | .511 | | |
| 4 | 30 | 772 | .670 | 9,340 | --- | 497 | .471 | | |
| 5 | 38 | 770 | .540 | 12,020 | --- | 401 | .453 | | |
| 6 | 46 | 770 | .575 | 11,100 | --- | 426 | .415 | | |
| 7 | 54 | 770 | .572 | 11,150 | --- | 425 | .400 | | |
| 8 | 62 | 770 | .550 | 11,250 | --- | 408 | .396 | | |
| 9 | 70 | 770 | .535 | 11,200 | --- | 397 | .397 | | |
| 10 | 78 | 770 | .554 | 11,100 | --- | 410 | .375 | | |
| 11 | 86 | 770 | .565 | 11,100 | --- | 418 | .403 | | |
| 12 | 94 | 774 | .561 | 11,600 | --- | 416 | .403 | 96.5 | 3.5 |
| 13 | 102 | 772 | .566 | 10,900 | --- | 418 | .375 | | |
| 14 | 110 | 774 | .527 | 11,450 | --- | 391 | .388 | | |
| 15 | 118 | 770 | .530 | 11,300 | --- | 394 | .356 | | |
| 16 | 126 | 770 | .604 | 10,200 | --- | 464 | .397 | | |
| 17 | 134 | 768 | .655 | 9,620 | --- | 504 | .452 | | |
| 18 | 142 | 770 | .636 | 9,660 | --- | 488 | .437 | | |
| 19 | 150 | 770 | .626 | 10,000 | --- | 481 | .402 | | |
| 20 | 158 | 768 | .631 | 9,430 | --- | 484 | .397 | | |
| 21 | 166 | 770 | .632 | 9,720 | --- | 476 | .423 | | |
| 22 | 174 | 770 | .655 | 9,230 | --- | 502 | .458 | | |
| 23 | 182 | 770 | .655 | 9,360 | --- | 502 | .417 | 95.7 | 4.3 |
| 24 | 190 | 768 | .619 | 9,610 | --- | 474 | .403 | | |

TABLE VI (continued)
TABULATED DATA FOR GAS RECYCLE STUDY

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|
| 25 | 198 | 768 | .648 | 9,520 | --- | 498 | .438 | | |
| 26 | 206 | 770 | .681 | 9,230 | 174 | 521 | .408 | | |
| 27 | 214 | 770 | .650 | 9,660 | 217 | 499 | .413 | | |
| 28 | 222 | 770 | .664 | 9,030 | 277 | 504 | .431 | | |
| 29 | 230 | 772 | .641 | 9,520 | 286 | 490 | .393 | 95.2 | 4.8 |
| 30 | 238 | 768 | .652 | 9,030 | 275 | 499 | .417 | | |
| 31 | 246 | 768 | .633 | 9,370 | 242 | 484 | .428 | | |
| 32 | 254 | 770 | .622 | 9,660 | 269 | 476 | .395 | | |
| 33 | 262 | 772 | .633 | 9,910 | 246 | 485 | .382 | | |
| 34 | 270 | 770 | .672 | 9,180 | 258 | 514 | .397 | | |
| 35 | 278 | 770 | .718 | 8,840 | 257 | 552 | .412 | | |
| 36 | 286 | 770 | .682 | 9,080 | 249 | 523 | .414 | | |
| 37 | 294 | 774 | .967 | 6,480 | 55 | 750 | .528 | | |
| 38 | 302 | 772 | .854 | 7,410 | 68 | 660 | .504 | 96.3 | 3.7 |
| 39 | 310 | 772 | .606 | 10,450 | 89 | 464 | .425 | | |
| 40 | 318 | 770 | .567 | 11,100 | 94 | 434 | .358 | | |
| 41 | 326 | 770 | .531 | 11,440 | 96 | 425 | .381 | | |
| 42 | 334 | 772 | .672 | 9,420 | 82 | 518 | .422 | | |
| 43 | 342 | 772 | .688 | 9,130 | 82 | 532 | .456 | | |
| 44 | 350 | 770 | .678 | 8,980 | 82 | 523 | .454 | | |
| 45 | 358 | 772 | .688 | 9,270 | 73 | 532 | .455 | | |
| 46 | 366 | 770 | .685 | 9,130 | 69 | 530 | .447 | | |
| 47 | 374 | 768 | .713 | 8,740 | 89 | 552 | .467 | | |
| 48 | 382 | 770 | .690 | 8,940 | 103 | 532 | .447 | | |
| 49 | 390 | 770 | .690 | 9,040 | 123 | 532 | .452 | | |
| 50 | 398 | 770 | .697 | 9,220 | 131 | 535 | .454 | | |
| 51 | 406 | 772 | .705 | 8,880 | 133 | 550 | .460 | | |
| 52 | 414 | 770 | .715 | 8,740 | 134 | 558 | .467 | | |
| 53 | 422 | 770 | .707 | 8,740 | 141 | 551 | .481 | | |
| 54 | 430 | 770 | .722 | 8,780 | 134 | 560 | .474 | 95.6 | 4.4 |
| 55 | 438 | 772 | .712 | 8,840 | 132 | 553 | .464 | | |

TABLE VI (continued)
TABULATED DATA FOR GAS RECYCLE STUDY

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Hc |
|---|---|---|---|---|---|---|---|---|---|
| 56 | 446 | 768 | .713 | 8,780 | 142 | 560 | .464 | | |
| 57 | 454 | 770 | .699 | 9,080 | 137 | 543 | .472 | 95.0 | 5.0 |
| 58 | 462 | 770 | .718 | 8,740 | 135 | 558 | .471 | | |
| 59 | 470 | 770 | .725 | 8,740 | 134 | 564 | .481 | | |
| 60 | 478 | 770 | .720 | 8,840 | 132 | 560 | .476 | | |
| 61 | 486 | 772 | .675 | 9,340 | 131 | 525 | .443 | | |
| 62 | 494 | 770 | .703 | 9,080 | 130 | 546 | .480 | | |
| 63 | 502 | 770 | .691 | 9,230 | 134 | 536 | .471 | 94.0 | 6.0 |
| 64 | 510 | 772 | .692 | 9,520 | 137 | 537 | .478 | | |
| 65 | 518 | 768 | .680 | 9,230 | 141 | 528 | .455 | | |
| 66 | 526 | 770 | .769 | 8,590 | 140 | 596 | .478 | 95.4 | 4.6 |

Yield: Wt. % 96.9

TABLE VII

TABULATED DATA FOR MOLYBDENUM COMPARISON RUN

Run Number: MCR
Grams Catalyst: 100
Catalyst Reference: Harshaw Mo-0801 T 1/8" RI 34-1 Lot 191A-1-1
Oil Charge °API: ~30
Percent Sulfur: 2.19
Reactor Pressure: 500 psig

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 761 | .743 | 8,550 | 128 | 574 | .101 | ~100 | — |
| 2 | 16 | 768 | .697 | 9,000 | 126 | 538 | .086 | | |
| 3 | 24 | 770 | .694 | 8,820 | 74 | 536 | .109 | | |
| 4 | 32 | 770 | .961 | 6,260 | 100 | 743 | .211 | | |
| 5 | 40 | 770 | 1.012 | 6,180 | 110 | 783 | .255 | | |
| 6 | 48 | 770 | 1.021 | 6,060 | 107 | 790 | .224 | | |
| 7 | 56 | 768 | 1.289 | 4,800 | 127 | 997 | .421 | | |
| 8 | 64 | 770 | 1.301 | 4,540 | 138 | 1017 | .413 | 95.6 | 4.4 |
| 9 | 72 | 772 | 1.298 | 4,920 | 123 | 1002 | .419 | | |
| 10 | 80 | 768 | 1.296 | 4,780 | 130 | 1001 | .420 | | |
| 11 | 88 | 770 | 1.300 | 4,650 | 133 | 1016 | .423 | | |
| 12 | 96 | 772 | 1.300 | 4,750 | 123 | 1011 | .442 | | |
| 13 | 104 | 770 | 1.310 | 4,860 | 140 | 1015 | .457 | | |
| 14 | 112 | 768 | 1.300 | 4,710 | 141 | 1011 | .491 | 95.5 | 4.5 |
| 15 | 120 | 770 | 1.365 | 4,600 | 132 | 1065 | .496 | | |
| 16 | 128 | 772 | 1.350 | 4,600 | 138 | 1052 | .515 | | |
| 17 | 136 | 768 | 1.369 | 4,550 | 141 | 1067 | .532 | | |
| 18 | 144 | 770 | 1.331 | 4,810 | 134 | 1039 | .519 | | |
| 19 | 152 | 772 | .869 | 5,140 | 139 | 678 | .304 | | |
| 20 | 160 | 770 | .868 | 5,150 | 143 | 677 | .317 | 95.8 | 4.2 |

Composite Yield: Wt. % 97.5

TABLE VIII

TABULATED DATA FOR CATFORMING GAS STUDY RUN

Run Number: CGR
Grams Catalyst 100
Catalyst Reference: Harshaw Mo-0801 T 1/8" RI 34-1, Lot 191A-1-1, Previously on MCR 160 Hrs.
Oil Charge °API: ~30
Percent Sulfur: 2.19
Reactor Pressure: 500 psig

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 766 | 1.140 | 5,610 | -83 | 333 | .515 | 84.0 | 16.0 |
| 2 | 11 | 770 | .936 | 5,600 | -82 | 730 | .441 | | |
| 3 | 19 | 768 | .662 | 9,550 | 216 | 515 | .304 | | |
| 4 | 27 | 768 | 1.031 | 6,040 | 234 | 825 | .427 | | |
| 5 | 35 | 770 | .849 | 7,280 | 279 | 660 | .377 | | |
| 6 | 43 | 772 | 1.000 | 6,250 | 245 | 779 | .457 | | |
| 7 | 51 | 768 | .901 | 7,120 | 247 | 701 | .421 | | |
| 8 | 59 | 766 | .740 | 8,640 | 296 | 576 | .379 | | |
| 9 | 67 | 766 | 1.005 | 6,400 | 284 | 783 | .459 | | |
| 10 | 75 | 765 | 1.008 | 6,350 | 288 | 785 | .498 | | |
| 11 | 83 | 768 | 1.045 | 6,130 | 288 | 814 | .491 | | |
| 12 | 91 | 768 | 1.012 | 6,230 | 286 | 786 | .481 | | |
| 13 | 99 | 772 | 1.004 | 6,070 | 284 | 781 | .450 | | |
| 14 | 107 | 770 | .990 | 6,380 | 293 | 779 | .495 | | |
| 15 | 115 | 770 | 1.078 | 5,940 | 301 | 838 | .518 | | |
| 16 | 123 | 768 | 1.012 | 6,190 | 298 | 787 | .474 | | |
| 17 | 131 | 768 | .895 | 7,240 | 306 | 696 | .472 | | |
| 18 | 139 | 770 | .874 | 7,500 | 311 | 670 | .473 | | |
| 19 | 147 | 770 | .917 | 7,350 | 318 | 716 | .478 | | |
| 20 | 155 | 765 | .944 | 7,050 | 314 | 734 | .496 | | |
| 21 | 163 | 772 | .946 | 6,730 | 308 | 736 | .479 | | |
| 22 | 171 | 770 | .926 | 7,000 | 306 | 720 | .448 | | |
| 23 | 179 | 775 | .940 | 6,860 | 292 | 732 | .453 | | |

TABLE VIII (continued)
TABULATED DATA FOR CATFORMING GAS STUDY RUN

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 187 | 768 | .906 | 7,250 | 291 | 705 | .483 | 82.6 | 17.4 |
| 25 | 195 | 772 | .964 | 6,760 | 275 | 751 | .483 | | |
| 26 | 203 | 759 | .860 | 7,460 | 261 | 669 | .494 | | |
| 27 | 211 | 770 | .934 | 6,840 | 276 | 727 | .438 | | |
| 28 | 219 | 770 | .943 | 6,960 | 263 | 734 | .481 | | |
| 29 | 227 | 770 | .934 | 6,900 | 255 | 726 | .576 | | |
| 30 | 235 | 763* | .918 | 7,000 | 264 | 714 | .646 | | |
| 31 | 243 | 772 | .869 | 7,400 | 268 | 675 | .482 | | |
| 32 | 251 | 770 | .765 | 8,410 | 264 | 594 | .439 | | |
| 33 | 259 | 774 | .732 | 8,910 | 262 | 569 | .448 | | |
| 34 | 267 | 770 | .784 | 8,260 | 264 | 610 | .467 | | |
| 35 | 275 | 770* | .793 | 8,060 | 265 | 624 | .552 | | |
| 36 | 283 | 770* | .789 | 8,220 | 267 | 613 | .568 | | |
| 37 | 291 | 772 | .773 | 8,320 | 258 | 600 | .456 | | |
| 38 | 299 | 772 | .808 | 8,290 | 265 | 628 | .425 | | |
| 39 | 307 | 770 | .782 | 8,320 | 266 | 608 | .468 | | |
| 40 | 315 | 768 | .797 | 8,020 | 263 | 628 | .450 | | |
| 41 | 323 | 772 | .865 | 7,660 | 262 | 673 | .436 | 82.3 | 17.7 |
| 42 | 341 | 768 | .842 | 7,770 | 261 | 655 | .465 | | |
| 43 | 349 | 770 | .921 | 6,980 | 260 | 718 | .447 | | |
| 44 | 357 | 768 | 1.048 | 6,070 | 258 | 816 | .496 | | |
| 45 | 365 | 770 | .888 | 7,150 | 258 | 692 | .514 | | |
| 46 | 373 | 770 | .864 | 7,550 | 258 | 673 | .483 | | |
| 47 | 381 | 774 | .957 | 6,810 | 257 | 747 | .482 | | |
| 48 | 389 | 770 | .854 | 7,610 | 254 | 666 | .496 | | |
| 49 | 397 | 770 | .743 | 8,650 | 256 | 578 | .455 | | |
| 50 | 405 | 772 | .692 | 9,210 | 257 | 541 | .393 | | |
| 51 | 413 | 770 | .695 | 9,300 | 259 | 542 | .417 | | |
| 52 | 421 | 772 | .698 | 9,260 | 260 | 543 | .368 | | |
| 53 | 429 | 772 | .706 | 9,110 | 261 | 550 | .415 | | |

TABLE VIII (continued)
TABULATED DATA FOR CATFORMING GAS STUDY RUN

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|
| 54 | 437 | 770 | .686 | 9,450 | 262 | 535 | .424 | | |
| 55 | 445 | 768 | .737 | 8,820 | 263 | 574 | .477 | | |
| 56 | 453 | 770 | .709 | 9,460 | 264 | 552 | .466 | | |
| 57 | 461 | 768 | .694 | 9,310 | 265 | 542 | .482 | | |
| 58 | 469 | 770 | .804 | 7,760 | 265 | 627 | .472 | | |
| 59 | 477 | 781 | 1.139 | 5,800 | 264 | 887 | .579 | | |
| 60 | 485 | 777 | 1.148 | 5,640 | 261 | 895 | .592 | | |
| 61 | 493 | 779 | .926 | 6,910 | 263 | 743 | .533 | 81.0 | 19.0 |
| 62 | 501 | 775 | .915 | 7,150 | 256 | 711 | .279 | | |
| 63 | 509 | 768 | .932 | 7,190 | 255 | 725 | .353 | | |
| 64 | 517 | 775 | 1.075 | 5,980 | 253 | 835 | .359 | | |
| 65 | 525 | 775 | 1.103 | 5,590 | 255 | 893 | .387 | | |
| 66 | 533 | 775 | 1.095 | 5,540 | 254 | 875 | .384 | | |
| 67 | 541 | 779 | 1.059 | 5,910 | 251 | 846 | .399 | | |
| 68 | 549 | 774 | 1.080 | 5,940 | 251 | 863 | .455 | | |
| 69 | 557 | 770 | 1.080 | 5,860 | 252 | 863 | .450 | | |
| 70 | 565 | 775 | .990 | 6,580 | 254 | 759 | .416 | | |
| 71 | 573 | 781 | .976 | 6,600 | 253 | 758 | .400 | | |
| 72 | 581 | 779 | .998 | 6,450 | 254 | 776 | .393 | | |
| 73 | 589 | 777 | 1.006 | 6,380 | 252 | 783 | .413 | | |
| 74 | 597 | 775 | 1.032 | 6,370 | 252 | 803 | .458 | | |
| 75 | 605 | 775 | .979 | 6,380 | 252 | 761 | .419 | | |
| 76 | 613 | 779 | 1.006 | 6,550 | 248 | 783 | .423 | | |
| 77 | 621 | 781 | .989 | 6,530 | 249 | 768 | .436 | | |
| 78 | 629 | 781 | .940 | 6,830 | 247 | 730 | .414 | | |
| 79 | 637 | 775 | .968 | 6,640 | 246 | 746 | .441 | | |
| 80 | 645 | 779 | .975 | 6,650 | 246 | 752 | .438 | | |
| 81 | 653 | 779 | .961 | 6,750 | 245 | 741 | .437 | | |
| 82 | 661 | 779 | .963 | 6,320 | 243 | 743 | .443 | | |
| 83 | 669 | 772 | 1.081 | 5,930 | 245 | 835 | .460 | | |
| 84 | 677 | 775 | 1.062 | 6,140 | 241 | 822 | .491 | | |

TABLE VIII (Continued)
TABULATED DATA FOR CATFORMING GAS STUDY RUN

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3/bbl$ | $H_2$ Consump. $Ft^3/bbl$ | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|
| 85 | 685 | 777 | 1.068 | 6,140 | 239 | 824 | .503 | | |
| 86 | 693 | 777 | 1.091 | 6,170 | 239 | 842 | .514 | | |
| 87 | 701 | 779 | 1.098 | 5,960 | 237 | 847 | .516 | | |
| 88 | 709 | 775 | 1.098 | 5,800 | 235 | 842 | .545 | | |
| 89 | 717 | 779 | 1.062 | 6,000 | 233 | 821 | .500 | | |
| 90 | 725 | 781 | 1.058 | 6,010 | 231 | 817 | .506 | | |
| 91 | 733 | 775 | .981 | 6,600 | 230 | 757 | .468 | | |
| 92 | 741 | 777 | .981 | 6,830 | 231 | 757 | .470 | 81.5 | 18.5 |
| 93 | 749 | 779 | .972 | 6,730 | 231 | 749 | .468 | | |
| 94 | 757 | 779 | 1.175 | 5,540 | 234 | 923 | .557 | | |
| 95 | 765 | 779 | 1.114 | 5,670 | 233 | 892 | .558 | | |
| 96 | 773 | 779 | 1.061 | 5,950 | 237 | 850 | .507 | | |
| 97 | 781 | 779 | 1.031 | 6.240 | 232 | 809 | .487 | | |
| 98 | 789 | 779 | .956 | 6,220 | 232 | 750 | .536 | | |
| 99 | 797 | 781 | .947 | 6,700 | — | 736 | .425 | | |
| 100 | 805 | 779 | .974 | 6,780 | — | 758 | .448 | | |
| 101 | 813 | 779 | .968 | 6,810 | — | 753 | .461 | | |
| 102 | 821 | 779 | .990 | 6,520 | — | 771 | .475 | | |
| 103 | 829 | 777 | .976 | 6,460 | — | 759 | .477 | | |
| 104 | 837 | 779 | .973 | 6,710 | — | 757 | .453 | | |
| 105 | 845 | 779 | .923 | 6,980 | — | 718 | .424 | | |
| 106 | 853 | 779 | .963 | 6,650 | — | 749 | .436 | | |
| 107 | 861 | 779 | .963 | 6,780 | 560 | 749 | .460 | | |
| 108 | 869 | 779 | 1.021 | 6,340 | 364 | 795 | .431 | | |
| 109 | 877 | 779 | 1.036 | 6,250 | 299 | 807 | .473 | | |
| 110 | 885 | 779 | 1.041 | 6,230 | 309 | 810 | .489 | | |
| 111 | 893 | 777 | 1.034 | 6,250 | 308 | 806 | .510 | | |
| 112 | 901 | 777 | 1.048 | 6,070 | 269 | 814 | .543 | | |
| 113 | 909 | 781 | 1.062 | 6,080 | 290 | 829 | .514 | | |
| 114 | 917 | 779 | 1.043 | 6,190 | 357 | 813 | .534 | | |
| 115 | 925 | 777 | 1.034 | 6,100 | 310 | 806 | .517 | | |

TABLE VIII (continued)
TABULATED DATA FOR CATFORMING GAS STUDY RUN

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|
| 116 | 933 | 781 | 1.019 | 6,420 | 315 | 794 | .491 | | |
| 117 | 941 | 779 | .991 | 6,540 | 282 | 772 | .502 | | |
| 118 | 949 | 770 | .991 | 6,500 | 270 | 773 | .531 | | |
| 119 | 957 | 781 | .969 | 6,680 | 298 | 754 | .500 | | |
| 120 | 965 | 777 | .945 | 6,810 | 293 | 744 | .430 | | |
| 121 | 973 | 775 | .980 | 6,400 | 304 | 763 | .535 | | |
| 122 | 981 | 779 | .968 | 5,980 | 336 | 753 | .503 | | |
| 123 | 989 | 784 | .972 | 6,670 | 363 | 756 | .517 | | |
| 124 | 997 | 772 | .940 | 6,920 | 361 | 731 | .513 | | |
| 125 | 1005 | 777 | .930 | 6,930 | 340 | 723 | .465 | | |
| 126 | 1013 | 777 | .956 | 6,750 | 354 | 744 | .469 | | |
| 127 | 1021 | 775 | 1.028 | 6,260 | 364 | 800 | .527 | | |
| 128 | 1029 | 779 | 1.039 | 6,200 | 364 | 808 | .535 | | |
| 129 | 1037 | 781 | 1.025 | 6,280 | 346 | 799 | .531 | | |
| 130 | 1045 | 779 | 1.025 | 6,280 | — | 798 | .538 | | |
| 131 | 1053 | 781 | 1.039 | 6,600 | — | 808 | .526 | | |
| 132 | 1061 | 779 | 1.011 | 5,950 | — | 787 | .514 | | |
| 133 | 1069 | 777 | 1.034 | 3,830 | — | 806 | .570 | | |
| 134 | 1077 | 779 | 1.008 | 5,450 | — | 785 | .546 | | |
| 135 | 1085 | 781 | .986 | 6,530 | — | 769 | .514 | | |
| 136 | 1093 | 775 | 1.005 | 6,420 | — | 782 | .534 | | |
| 137 | 1101 | 782 | 1.025 | 6,280 | — | 798 | .520 | | |
| 138 | 1109 | 782 | .975 | 6,610 | — | 759 | .500 | | |
| 139 | 1117 | 777 | 1.022 | 6,310 | — | 796 | .571 | | |
| 140 | 1125 | 779 | 1.006 | 6,840 | — | 783 | .558 | | |
| 141 | 1133 | 779 | 1.006 | 6,410 | — | 783 | .547 | | |
| 142 | 1141 | 777 | 1.000 | 6,450 | — | 778 | .548 | | |
| 143 | 1149 | 782 | .995 | 6,370 | — | 774 | .548 | | |
| 144 | 1157 | 779 | 1.006 | 6,410 | — | 783 | .529 | | |
| 145 | 1165 | 777 | 1.013 | 6,360 | — | 789 | .571 | | |
| 146 | 1173 | 781 | 1.031 | 6,660 | 356 | 804 | .548 | | |

TABLE VIII (continued)
TABULATED DATA FOR CATFORMING GAS STUDY RUN

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Recycle Gas Hc |
|---|---|---|---|---|---|---|---|---|---|
| 147 | 1181 | 779 | .992 | 6,480 | 346 | 772 | .562 | | |
| 148 | 1189 | 781 | 1.021 | 6,310 | 344 | 796 | .574 | | |
| 149 | 1197 | 779 | 1.022 | 6,300 | 348 | 797 | .565 | | |
| 150 | 1205 | 777 | 1.010 | 6,380 | 341 | 786 | .599 | | |
| 151 | 1213 | 779 | 1.007 | 6,390 | 338 | 784 | .567 | | |
| 152 | 1221 | 779 | 1.019 | 6,330 | 337 | 793 | .578 | | |
| 153 | 1229 | 777 | 1.006 | 6,830 | 326 | 783 | .645 | | |
| 154 | 1237 | 779 | 1.100 | 5,850 | 315 | 856 | .581 | | |
| 155 | 1245 | 781 | 1.079 | 5,960 | 316 | 840 | .582 | | |
| 156 | 1253 | 777 | 1.047 | 6,160 | 307 | 815 | .605 | | |
| 157 | 1261 | 779 | 1.021 | 6,310 | 310 | 796 | .517 | | |
| 158 | 1269 | 781 | 1.020 | 6,270 | 313 | 795 | .575 | | |
| 159 | 1277 | 779 | .995 | 6,510 | 322 | 774 | .465 | | |
| 160 | 1285 | 777 | 1.000 | 6,300 | 313 | 778 | .581 | | |
| 161 | 1293 | 781 | .995 | 6,530 | 319 | 775 | .548 | | |
| 162 | 1301 | 777 | .997 | 6,480 | 322 | 777 | .548 | | |
| 163 | 1309 | 779 | 1.031 | 6,250 | 320 | 803 | .618 | | |
| 164 | 1317 | 781 | 1.019 | 6,330 | 326 | 794 | .605 | | |
| 165 | 1325 | 777 | .989 | 6,510 | 317 | 791 | .617 | | |
| 166 | 1333 | 779 | .994 | 6,520 | 309 | 795 | .588 | | |
| 167 | 1341 | 781 | 1.045 | 6,230 | 321 | 836 | .578 | 81.1 | 18.9 |
| 168 | 1349 | 779 | 1.028 | 6,560 | 314 | 823 | .589 | | |
| 169 | 1357 | 779 | 1.031 | 6,280 | 313 | 803 | .264 | | |
| 170 | 1365 | 777 | .989 | 6,520 | 305 | 768 | .331 | | |
| 171 | 1373 | 781 | .945 | 6,850 | 310 | 734 | .345 | | |
| 172 | 1381 | 779 | 1.015 | 6,360 | 303 | 790 | .352 | | |
| 173 | 1389 | 775 | 1.009 | 6,370 | 300 | 786 | .359 | | |
| 174 | 1397 | 779 | 1.027 | 6,270 | 299 | 798 | .370 | | |
| 175 | 1405 | 777 | 1.002 | 6,440 | 293 | 780 | .382 | | |
| 176 | 1413 | 775 | 1.024 | 6,320 | 292 | 797 | .393 | | |
| 177 | 1421 | 781 | 1.034 | 6,250 | 297 | 806 | .423 | | |

TABLE VIII (continued)
TABULATED DATA FOR CATFORMING GAS STUDY RUN

| Samp. No. | Total Hours | Avg. Cat. Temp. °F | Space Vel. gms/gm/hr | Recycle $Ft^3$/bbl | $H_2$ Consump. $Ft^3$/bbl | Yield gms oil | Product % S | Recycle Gas $H_2$ | Hc |
|---|---|---|---|---|---|---|---|---|---|
| 178 | 1429 | 781 | .994 | 6,500 | 294 | 772 | .414 | | |
| 179 | 1437 | 779 | .949 | 6,790 | 294 | 738 | .429 | | |
| 180 | 1445 | 781 | .994 | 6,510 | 296 | 772 | .405 | | |
| 181 | 1453 | 779 | .977 | 6,600 | 297 | 758 | .448 | | |
| 182 | 1461 | 779 | .964 | 6,700 | 292 | 748 | .475 | | |
| 183 | 1469 | 779 | .982 | 6,560 | 293 | 763 | .425 | | |
| 184 | 1477 | 779 | .960 | 6,710 | 298 | 746 | .451 | | |
| 185 | 1485 | 779 | .968 | 6,660 | 295 | 753 | .445 | | |
| 186 | 1493 | 781 | .972 | 6,700 | 296 | 755 | .448 | | |
| 187 | 1501 | 779 | .940 | 7,180 | 291 | 743 | .425 | | |
| 188 | 1509 | 779 | .981 | 6,620 | 292 | 776 | .483 | | |
| 189 | 1517 | 783 | .934 | 6,900 | 287 | 739 | .458 | | |
| 190 | 1525 | 779 | 1.909 | 7,140 | 291 | 720 | .478 | | |
| 191 | 1533 | 775 | .937 | 6,900 | 290 | 741 | .467 | | |
| 192 | 1541 | 781 | .952 | 6,780 | 285 | 752 | .468 | | |
| 193 | 1549 | 777 | .945 | 6,810 | 287 | 747 | .447 | | |

Composite Yield: Wt. % 97.3 (Samples 1 through 8)
Wt. % 97.2 (Samples 9 through 61)
Wt. % 96.8 (Samples 62 through 98)
Wt. % 97.3 (Samples 99 through 123)
Vol.% 101 (Samples 99 through 123)
Wt. % 99.1 (Samples 169 through 193)

Composite % S:
.464 (Samples 62 through 123)
.502 (Samples 62 through 168)
.414 (Samples 169 through 193)

Total Oil throughput: 145,232 Gm.
First catalyst regeneration at Sample 61.
Second catalyst regeneration at Sample 168.

*Temperatures for these samples are incorrect due to non-standardization of potentiometer.

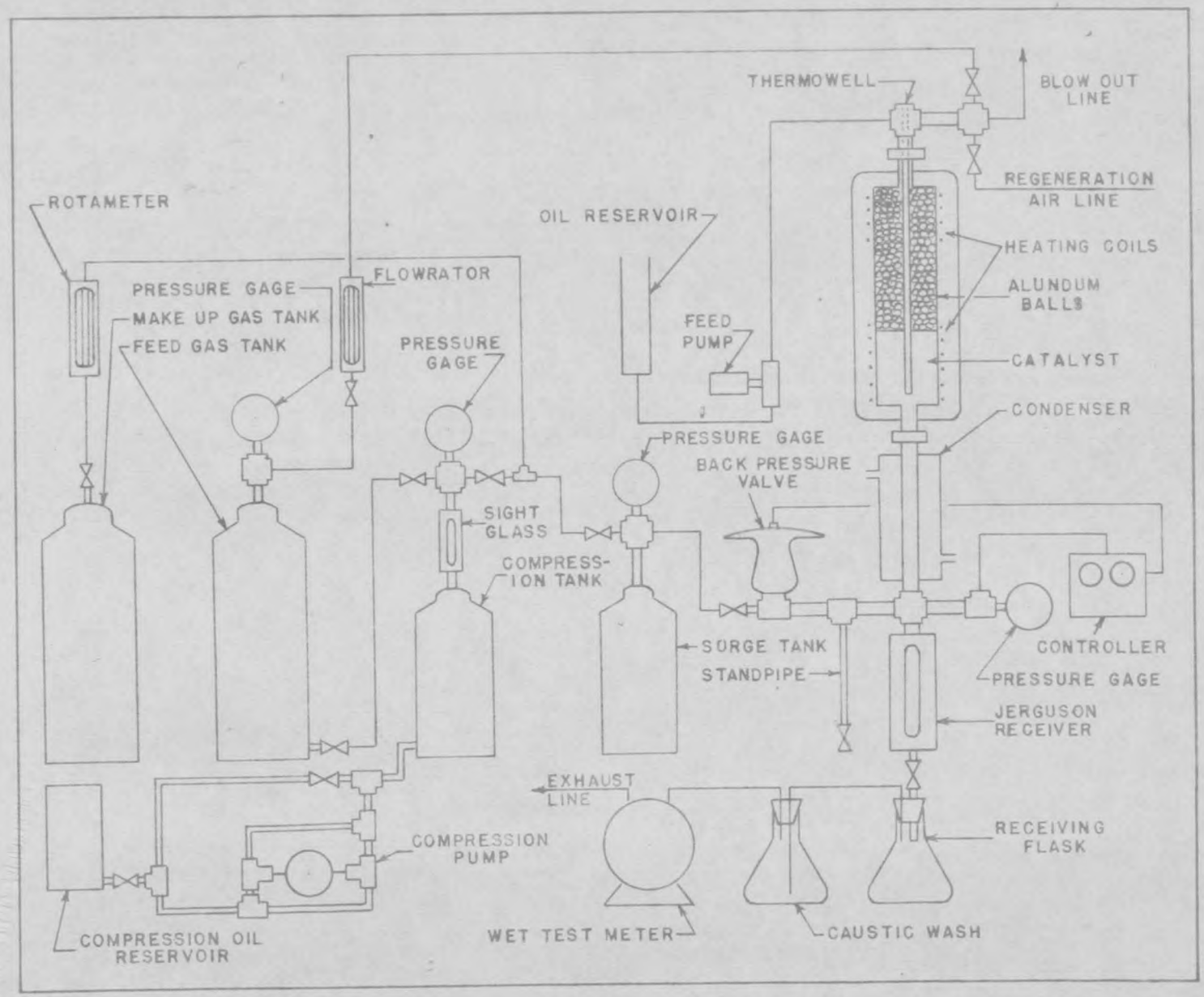


Figure 1. Reactor Diagram

Hartwig, J. R.
The catalytic hydrodesulfurization of Wyoming fuel oil.

| | NAME AND ADDRESS |
|---|---|
| SEP 25 '56 | RESERVED |
| MAR 1 3 '61 | INTERLIBRARY LOAN |
| 11-28-67 | Andrea Doornbos |
| | Quad D |
| | Andrea Doornbos |
| MAR 1 2 198 | Quad D |
| | Tom Greene |