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"THE H-OIL® PROCESS: A *WORLDWIDE LEADER IN VACUUM RESIDUE HYDROPROCESSING*"

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SUMMARY

With the uncertainty of market trends, refiners will need to hedge their investment strategies in the future by adding processing units that provide them with flexibility to meet the changing market. The various process configurations involving the H-Oil® Process described in this paper have been tested commercially and provide the refiner with the latest state of the art technology.

ABSTRACT

The H-Oil® Process is a catalytic hydrocracking process, invented by HRI, Inc., a division of IFP Enterprises, Inc. which is used to convert and upgrade petroleum residua and heavy oils. Today the H-Oil Process accounts for more than 50 percent of the worldwide vacuum residue hydroprocessing market due to its unique flexibility to handle a wide variety of heavy crudes while producing clean transportation fuels. The process is also flexible in terms of changes in yield selectivity and product quality. The unconverted vacuum residue from the process can be utilized for fuel oil production, blended into asphalt, routed to resid catalytic cracking, directly combusted or gasified to produce hydrogen.

This paper will discuss additional background information on the H-Oil Process, some of the key advances made to the process and applications for the Latin America market. The paper will also discuss the status of recent commercial plants which are in operation or which are under design or construction and which utilize these new advances.

1. INTRODUCTION

Current economic trends are requiring refiners to change their product slate to meet the increasing demand for kerosene and diesel fuels. With residual fuel oil demand decreasing, refiners are considering the addition of incremental conversion capacity by utilizing residue hydrocracking to increase both middle distillate yield and quality. Many modern refineries already have one or more of the following units; Fluid Catalytic Cracking "FCC", Gas Oil Hydrocracking or Delayed Coking.

Incremental conversion capacity can be easily integrated within a modern refinery with a residual oil hydrocracker, such as HRI's H-Oil Process. This paper will address various ways to economically integrate an H-Oil Unit into an existing refinery. The flexibility of this unit to handle a variety of feedstocks, due to changing crude prices will also be discussed. HRI and its parent company, Institut Francais du Petrole "IFP", have specific technologies which can be used to produce higher yields of distillates from lower priced refinery feedstocks.

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2. MARKET TRENDS

Worldwide economic growth, particularly in the developing regions of the world, is causing increased demand for middle distillate fuels. Diesel fuel is the dominate transportation fuel in many of the developing regions and the strong economic growth of these regions is stimulating the transport of goods and people. In many countries, buses, trains and taxis are the principal means of transport and these vehicles utilize diesel instead of gasoline. Middle distillate consumption in some developing regions of the world is expected to increase by approximately 5 percent per year through the year 2000[1]. Even though the present cost of crude oil is at relatively low levels, refiners that choose to add crude distillation capacity to increase the middle distillate production rate will be faced with a surplus of residual fuel oil in a decreasing market for heavy fuel. Figure 1 shows the regional demand for heavy fuel oil as a percentage of total refined products.

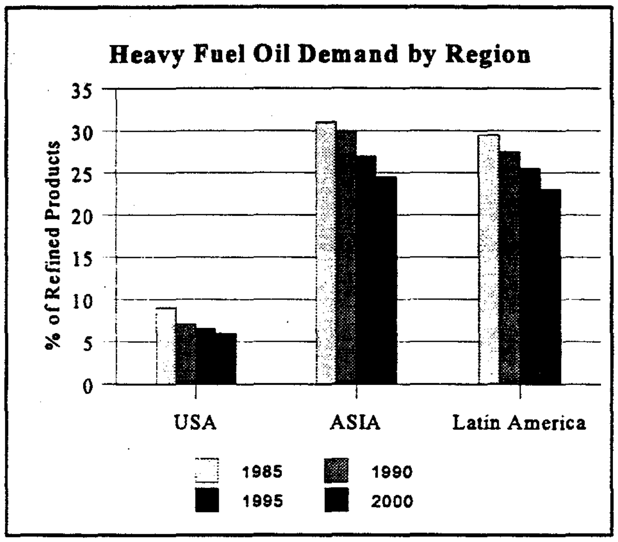

Figure 1

The result of these market trends should be an ever widening price differential between high quality transportation fuels and high sulfur fuel oil. Price differentials approaching $10 (US) per barrel provide significant incentives to increase the conversion of vacuum residua to meet the changing market demands. This explains the recent surge in demand for residue hydrodesulfurization and hydrocracking. The H-Oil Process, based on the ebullated-bed reactor system which was invented by HRI, has the majority of the vacuum residue hydroprocessing market as shown in Figure 2. New developments in H-Oil Processing[2] have increased the selectivity toward diesel fuels while improving product quality to meet new environmental requirements. This is accomplished in only two H-Oil Reactors in series where other technologies require three to five reactors. This efficiency in upgrading translates into a major investment savings for the refiner.

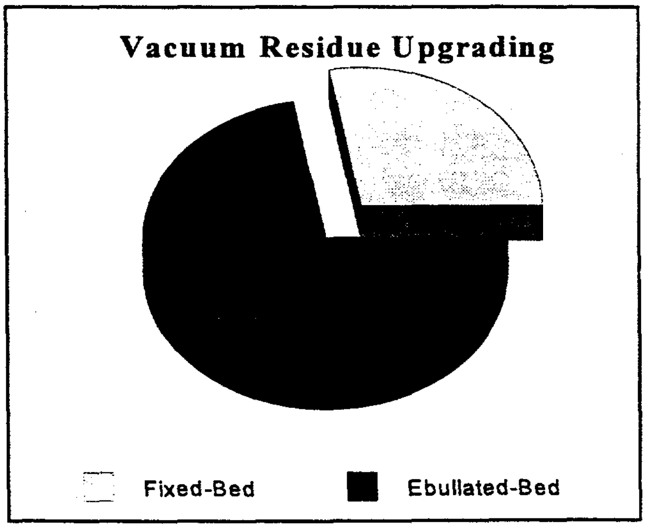

Figure 2

3. FLEXIBILITY IS THE KEY

Adding additional conversion capacity is an expensive undertaking for any refinery especially in times of scarce capital. To justify these expenditures, project planners must show the ability of a process to adapt to short term changes in the marketplace.

If history is any guide to the future, we should examine two possible scenarios; (1) heavy/light crude price differentials shrink while margins (price difference between diesel and high sulfur fuel oil) remain constant or (2) when margins increase while crude price differentials remain constant. To examine these effects in the marketplace, we shall look at an H-Oil Unit designed to operate on 100 percent Arabian Medium vacuum residue. As changes in the marketplace occurs, we will analyze how the refiner can change operating conditions and feedstock to take advantage of these changes to maximize their profitability.

The base case H-Oil Process Plant for this study processes 30,000 BPSD (1,630 kMTA) of an Arabian Medium vacuum residue. The equivalent crude rate to the refinery would be approximately 160,000 BPSD (7,200 kMTA). The H-Oil Plant feedstock inspections for this case are shown below:

Table 1 - Arabian Medium Residue Feedstock Inspections

Cutpoint, °C+	566
Specific Gravity (°API)	1.037 (4.9)
Sulfur, W%	5.35
Nitrogen, Wppm	4,380
Conradson Carbon Residue, W%	23.3
Vanadium, Wppm	132
Nickel, Wppm	32

The base case operation (Case 1) is for 65 V% conversion of the 565°C+ residue in this feedstock to distillates. This is accomplished using a single train with two H-Oil Reactors in series, HRI's patented vacuum bottoms recycle and a high HDS activity H-Oil catalyst. Each reactor weighs approximately 1,100 metric tons. The H-Oil Plant is integrated with an FCC Unit to maximize profitability. A block flow diagram for this configuration is shown in Figure 3. The slurry oil from the FCC Unit can be recycled

Block Flow Diagram for Cases 1 through 4

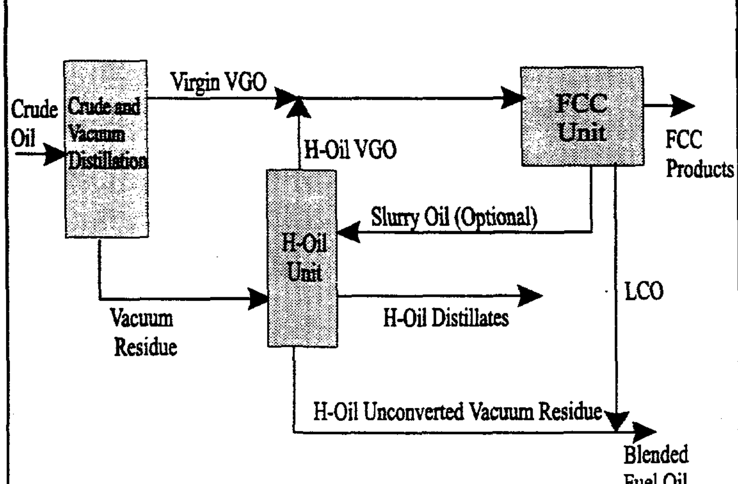

Figure 3

to the H-Oil Unit for additional conversion to premium fuels. The reactor yields for this plant and fuel oil quality are shown below:

Table 2 - Case 1 (Base) Yields

	W%	V%	Spec. Gravity	S, W%	N, Wppm	Ni+V, Wppm	CCR, W%
H_2S, NH_3, H_2O	5.52	-					
C_1-C_3	3.22	-					
Naphtha (C_4-177ºC)	8.89	13.10	0.705	0.03	85		
Diesel (177-343ºC)	18.16	21.95	0.858	0.08	480		
Vacuum Gas Oil (343-566ºC)	32.12	36.05	0.924	0.25	1,880	<2	1.3
Bottoms (566ºC$^+$)	33.98	35.00	1.007	1.24	5,190	63	21.2
Total	101.89	-					
C_4^+	93.15	106.10	0.911	0.56	2,640	23	8.2
Fuel Oil	65.1	70.00	0.964	0.79	3,280	33	11.1

As shown in Table 2, this base case produces a relatively high yield (22 V% on fresh feed) of diesel product (177-343ºC) which contains 0.08 W% sulfur. The sulfur level in the diesel can be adjusted, if required, by varying the catalyst replacement rate to the reactors. The VGO product is suitable for feeding directly into an FCC Unit since its hydrogen content is 11.8 W%. The unconverted residue is combined with FCC Light Cycle Oil "LCO" (0.3 W% sulfur) to produce a stable, 0.8 W% sulfur fuel oil with a viscosity of 100 cSt at 50°C. The fuel oil meets all typical USA specifications including a viscosity at 50°C of less than 180 cSt and a potential sediment content of less than or equal to 0.20 W%. This sediment is by the IP-390A test which utilizes an accelerated aging of the fuel oil sample to estimate the stability of the fuel oil product(3).

This process configuration is typical of modern H-Oil Plants which operate with two H-Oil Reactors in series, utilizing second generation catalysts and producing premium quality distillates. The use of HRI's patented VBR is utilized for all cases in order to minimize reactor temperature and hydrogen consumption. For moderate conversion operations, VBR will aid in the production of a stable fuel oil, for higher conversion operations, the use of VBR will require a less severe set of operating conditions.

3.1. Changes in Crude Price Differential - As the price differential between heavy and sweet crudes varies, H-Oil Unit operators can react such to maintain their overall profitability. This unique flexibility is a result of the H-Oil ebullated-bed reactors which can operate over a wide range of severity (residence time and temperature) and catalytic activity achieved through adjustments in the type of catalyst and the catalyst replacement rate. If for example, the crude price differential diminishes, it may be more profitable for the refiner to process a lighter crude and operate at a higher conversion level in their existing H-Oil Plant. Case 2 investigates this operation with an Arabian Light crude at 75 V% conversion. On the other hand, if higher crude price differentials are realized in the marketplace, then it would be advantageous for the refiner to process Arabian Heavy crude (Case 3). Both of these cases are shown in Table 3 below.

Table 3 - Operation with Lighter/Heavier Feedstocks

	Base Case 1	Case 2	Case 3
Crude	Arabian Medium	Arabian Light	Arabian Heavy
Yield of Vacuum Residue, V%	19	15	23
Crude Feedrate, BPSD	160,000	160,000	160,000
H-Oil Plant Feedrate, BPSD	30,000	24,000	37,000
H-Oil Plant Conversion, V%	65	75	55

A lighter crude will have a lower yield of vacuum residue from the crude unit and less material will be fed to the H-Oil Unit. As a result, the H-Oil Unit would be operated at higher residue conversion (75 V% versus 65 V% in the Base Case) while still producing a stable fuel oil product from the unconverted residue. This is due to the lighter feedstock and higher H-Oil Reactor residence time caused by the change in crude type. This operation will result in a higher distillate production rate and less chemical hydrogen consumption per quantity of vacuum residue processed. Alternatively, the refiner could switch on-line to a high conversion catalyst for Case 2 and operate the H-Oil Unit at 85 V% conversion and maximize mid-distillates even more but with some decline in mid-distillate product quality. Blending calculations with the diesel pool downstream and integration with other process units will ultimately decide the optimal level of operation for the refiner.

For a high crude price differential, the refiner would purchase a heavier feedstock, for example Arabian Heavy (Case 3). In this case, the H-Oil Unit would be fed additional vacuum residue from the crude unit and would operate at a conversion level of 55 V% which is less than the base value of 65 V%. This is required in order to maintain reasonable reactor temperatures and hydrogen consumption due to the lower residence time. In this case, the feedstock has become substantially heavier (2.9°API versus 4.9°API for Arabian Medium) and the reactor residence time has deceased due to the higher feedrate. The net effect of the higher H-Oil plant feedrate and the operation at lower residue conversion level would be that the net production of distillates would be nearly the same as in the Base Case but the production of low sulfur residual fuel oil would increase by more than 50 V%.

The overall plant yields and fuel oil production rates for Cases 2 and 3, relative to Case 1 (Base Case) are shown in Table 4 below:

Table 4 - Operation with Lighter/Heavier Feedstocks

	Base Case 1	Case 2	Case 3
Crude	Arabian Medium	Arabian Light	Arabian Heavy
H-Oil Plant Feedrate, BPSD	30,000	24,000	37,000
H_2 Consumption, MM SCFD	39.3	34.1	41.8
Product Rate, BPSD			
Naphtha	3,930	3,660	3,390
Diesel	6,590	6,120	6,420
VGO	10,800	9,950	12,350
Bottoms to Fuel Oil	10,500	6,000	16,650
Total	31,820	25,730	38,810
Total Distillates	21,320	19,730	22,160
Fuel Oil S / μ @50°C, cSt	0.79 / 100	0.79 / 80	0.96 / 135

The liquid yields are also shown graphically in Figure 4. Although the crude type and feedrate to the H-Oil Unit can vary substantially for the above cases, the rate of distillate products is nearly constant at 20-22,000 BPSD. The bottoms to fuel oil production, however varies from 6,000 BPSD for the Arabian Light case to more than 16,000 BPSD for the Arabian Heavy feed case.

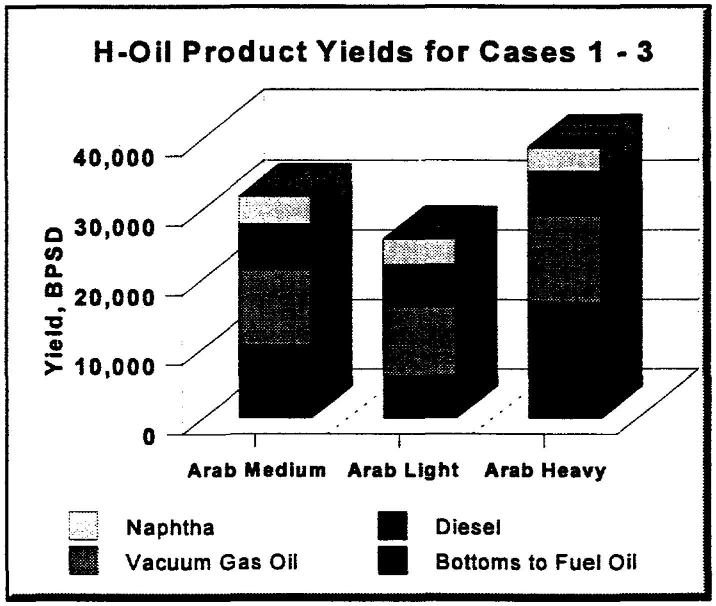

Figure 4

3.2 Changes in Product Price Differential - This differential is the price difference between low-sulfur diesel and high sulfur fuel oil (No. 6 type). As this differential widens, it becomes more profitable for the H-Oil Operator to increase residue conversion in order to maximize middle distillate production. The flexibility of the H-Oil ebullated-bed reactor allows for changes in reactor temperature, VBR rate, catalyst type and catalyst usage rate. The yields and product qualities for this higher conversion case (Case 4) using a second generation, high conversion H-Oil catalyst are shown in Table 5 below.

The high conversion catalyst is typically used for residue conversion levels in excess of 75 V%. Although the HDS activity of this catalyst is less than the high HDS catalyst used for Cases 1 through 3, it allows for the production of stable fuel oil from the unconverted vacuum residue, which is not possible with other types of catalysts at this conversion level. As shown below, the fuel oil from 80 V% conversion operation will contain 1.63 W% sulfur (unconverted vacuum residue plus LCO as a cutter stock) and will have a viscosity at 50°C of 280 cSt, meeting typical No. 6 fuel oil specifications. Because of the use of the high conversion catalyst, the fuel oil will meet a typical IP-390A sediment specification of less than 0.20 W%.

Table 5 - Case 4 Yields

	W%	V%	Spec. Gravity	S, W%	N, Wppm	Ni+V, Wppm	CCR, W%
H_2S, NH_3, H_2O	4.85	-					
C_1-C_3	4.52	-					
Naphtha (C_4-177ºC)	11.50	16.92	0.706	0.09	110		
Diesel (177-343ºC)	22.95	27.77	0.858	0.27	630		
Vacuum Gas Oil(343-566ºC)	37.79	41.99	0.933	1.18	2,520	<2	1.5
Bottoms (566ºC$^+$)	20.45	20.00	1.061	2.78	6,990	145	31.5
Total	102.0 6	-					
C_4^+	92.69	106.70	0.901	1.17	2,740	32	7.6
Fuel Oil	38.22	40.00	0.991	1.63	4,300	78	16.9

The yields of transportation fuels have increased by 27.6 V% over the base case while the quantity for residual fuel oil has been substantially reduced.

The operating conditions required to adjust the operation of the H-Oil Plant for Cases 2, 3 and 4 are well within the range of those designed for the unit in Case 1. In some cases, operating conditions remain constant and changes in feedstock result in significant improvement in conversion (i.e., Case 1 versus Case 2 & 3). The most significant change comes in Case 4 when feedrate and type remain constant and conversion level is substantially increased. A comparison of the H-Oil Plant operating conditions for Cases 1 through 4 is shown in Table 6 below.

Table 6 - H-Oil Plant Operating Conditions

	Case 1	Case 2	Case 3	Case 4
Feedstock	Arabian Med	Arabian Light	Arabian Heavy	Arabian Med
Feedrate, BPSD	30,000	24,000	37,000	30,000
Catalyst Type	High Activity	High Activity	High Activity	High Conversion
Reactor Temperature, ºC	T	T + 1	T - 2	T + 7
Residue Conversion, V%	65	75	55	80
Desulfurization, W%	90	90	87	80
Catalyst Rep. Rate, Lb/Bbl	C	C	C	C
H_2 Consumpt., Nm^3/m^3 (SCF/Bbl)	221(1,310)	240 (1,410)	190 (1,130)	239 (1,420)

4. COMMERCIAL OPERATION

H-Oil Plants have a total licensed capacity of nearly 300,000 barrels per day of vacuum residue. These plants demonstrate many of the process schemes discussed in this paper. The Star Enterprise refinery in Convent, LA USA started up in 1984 and integrates with an existing FCC Unit and a gasification unit for the production of hydrogen. This unit represented the first 2nd Generation H-Oil Plant designed by HRI with many of the latest design improvements. The start-up and operation of this unit have been described in previous papers[4,5]. The Husky Oil Unit is integrated with a delayed coker to maximize the production of distillates. With cheap natural gas available in Western Canada there is no need for the production of fuel oil. This unit also represented the first unit to be construction with the new 3 Cr 1 Mo alloy steel. The Husky Unit, operating in the extremely cold Canadian climate was automated to a larger extent than previous units. HRI worked closely with Husky to ensure the latest advanced process control technology was installed. The unit exceeded the first year goal for on-stream time and has been averaging more than 90 percent.

The oldest H-Oil Unit at KNPC's Shuaiba, Kuwait refinery integrates with a Gas Oil Hydrocracker. The newest unit to come on-stream in 1999, at Petrochemia's Plock, Poland refinery will send the bottoms directly to a boiler on-site for the generation of power. The power plant at this refinery has a seasonal demand since steam is exported to the town of Plock for heating in the winter. As a consequence, Petrochemia will adjust the conversion level in the H-Oil Unit to match the required feedrate to the power plant. This type of operation will not only provide a nice balance of power for the refinery but allow them to meet the current and future environmental specifications for sulfur dioxide emissions from the power station by reducing the sulfur levels in the H-Oil bottoms.

5. REFERENCES

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