A NEW APPROACH TO HEAVY OIL AND BITUMEN UPGRADING

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ABSTRACT

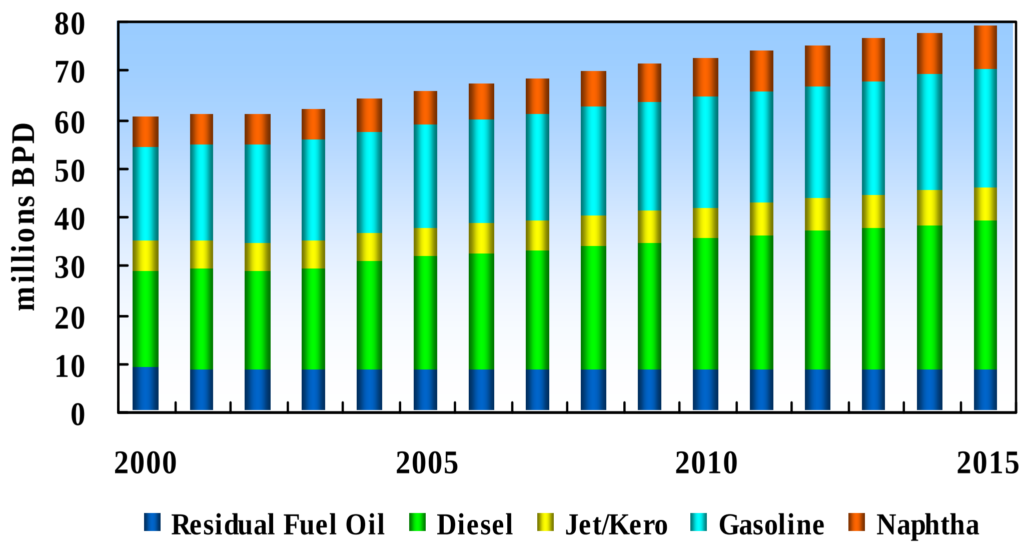
The current growth in transportation fuel demand is outpacing the supply of traditional crude oil sources. This gap is being filled through increased production of non-traditional hydrocarbon deposits, such as Canadian oil sands, Venezuelan heavy oils and stranded crudes. These deposits are considered non-traditional as they can not be transported via pipeline due to low API gravity, high viscosity or high pour point. The producers of these non-traditional deposits must solve the pipeline issues at a cost that will still produce a positive return. Optimizing revenue depends on a number of factors including location, availability of natural gas, and proximity to power. The degree of upgrading for these deposits is highly dependent on local infrastructure, with some being upgraded via hydrogen addition and/or carbon rejection and others being minimally processed to just meet pipeline specifications.

This paper introduces a new process designed to minimize investment while satisfying pipeline specifications. A key component of the process is that it is self-supporting in that it satisfies all of it own requirements for power and steam consumption, with significant potential to be a net generator of both. Additionally, no residual waste products or fuel are left in the oil field.

INTRODUCTION

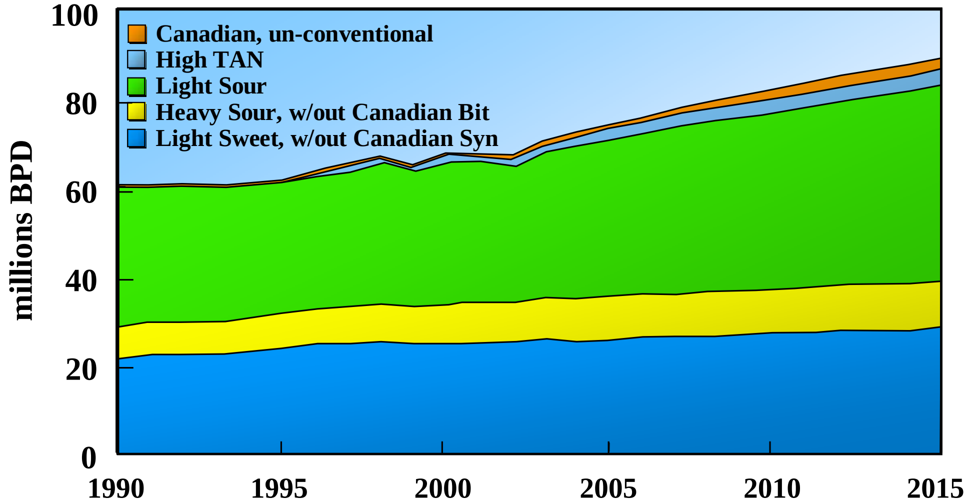
Figure 1, from Purvin & Gertz' most recent ***Global Petroleum Market Outlook*** study, shows how petroleum product demand has grown since 1995 and how it is expected to continue to grow through 2015. The study shows a 1.7 % per annum growth in world wide demand and that this growth rate will continue over the next 15 years.

Figure 1: Global Demand for Refined Products



The Purvin & Gertz study also states that the growth in crude supplies from 60 million barrels per day in 1990 to 75 million barrels in 2005 will continue up to 95 million barrels per day in 2020. Figure 2, from the study, shows the crude quality mix that refiners have had and can expect to have over this time period. The synthetic crudes being produced in Canada are upgraded to light sweet crudes or are blended with bitumen to form heavy sour crude. Figure 2 breaks out the Canadian synthetic crude production, which is by far the largest component of the world wide synthetic crude production, so that the growing importance of the component can be seen on total world crude production. The Canadian growth over the next 15 years is expected to be 2.1 million barrels per day or 10 % of the gap between current production rates and the projected need. This demonstrates the importance of non-traditional supplies in the world oil supply picture.

Figure 2: World Crude Supply Predictions.



The recent run up in crude prices has generated interest in many oil fields that were previously considered uneconomical for production. Many of these fields do not fit the Canadian bitumen model of upgrading to high quality synthetic crude in the oil field. The decision to fully upgrade crude oil in the field, or to transport minimally processed crude to a refining center, is one of economics. Natural gas and electrical power supplies play a significant role in determining economic viability of these projects. Remote fields seldom have power but often have natural gas. Natural gas in a remote field is often synergistic because it can be used to hydrotreat the non-conventional crude to make a synthetic crude meeting pipeline specifications. This is an alternative way to transport the hydrogen to market.

It is apparent that increasing amounts of petroleum will come from non-traditional sources. The most common of these being the Canadian oil sands projects in Alberta and the Orinoco belt of Venezuela. There are many other examples of isolated crude supplies in the world that are not currently exploited. Columbia for example has heavy oil supplies which are as isolated as the Venezuelan Orinoco play. These supplies have not been exploited because of their isolation, not meeting pipeline specifications and their lack of proximity to natural gas and power supplies.

META PETROLEUM

Rubiales Holding Limited, a joint ownership of RHC Limited of the Cayman Islands and PetroSynergy of the Bahamas, is the parent company of both Tethys Petroleum Company

Limited (Tethys) and Meta Petroleum, Ltd (Meta). Tethys and Meta own the oil field licenses for the 361 square kilometer Rubiales concession and the 253 square kilometer Piriri concession in the Llanos basin in Colombia.

Meta, the sole risk field operator, is currently producing heavy oil from the Rubiales field. The Rubiales field is located 470 kilometers from Bogotá and 1900 kilometers from Cartagena. The location of the field, coupled with the crude oil properties (see Table 1, Rubiales Crude Properties), makes export of the field's production difficult.

Table 1: Rubiales Crude Properties

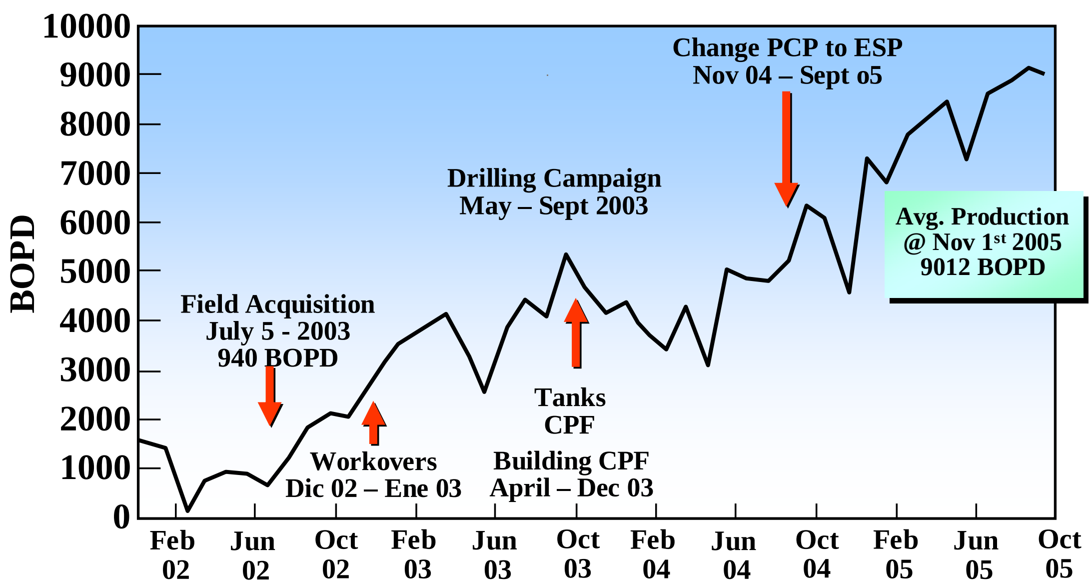
API Gravity	12.8
UOP K	11.4
Nickel, wt-ppm	42.0
Vanadium, wt-ppm	152.0
Sulfur, wt-%	1.3
Con-Carbon, wt-%	12.9
Viscosity, cSt @ 122 F	933.3

The remoteness of the oil field can be seen from the map shown in Figure 3.

Figure 3. Meta's Rubiales Crude Upgrader Location.

The Rubiales field was acquired by Meta in mid-2003 when the field's production was 940 BPSD. As seen in Figure 4, the crude oil production rate from the Rubiales field has steadily increased since 2003 to the current 9,000 BPSD. The crude oil is transported from site using a fleet of 400 tanker trucks on a continuous ten day round-trip to the Colombian coast, where it is used as fuel oil, refinery feed, marine fuel and raw material for asphalt.

Figure 4: Average Monthly Crude Oil Production



Meta's goal is to increase the Rubiales field production to 100,000 BPSD by 2008. However, current transportation logistics make an 11 fold increase in field capacity nearly impossible. Estimates are that the maximum field capacity by tanker truck would only be 15,000 BPSD using all 600 of Colombia's tanker supply.

In order to increase production Meta investigated transportation of the heavy crude oil by pipeline. It was discovered that the Rubiales crude did not meet pipeline specifications for viscosity or API gravity (see Table 2, Pipeline Specifications).

Table 2: Crude Oil Pipeline Specifications

Viscosity, cSt @ 100 °F	250
API	16
Vapor Pressure, psia	14.9

With these findings, Meta decided to investigate methods for upgrading Rubiales crude oil to a synthetic crude oil meeting minimum pipeline specifications.

The decision to build an upgrading facility for the Rubiales crude presented Meta with some significant challenges. Due to the remote location of the field, and the extremely limited infrastructure available (none within 230 kilometers) Meta generated a list of project requirements that needed to be met for any upgrading facility.

1. The facility had to provide a synthetic crude that could meet the pipeline specifications
2. Utilities and operations requirements should be limited
3. Reliability should be maximized
4. Saleable liquid product should be maximized
5. By products from the unit had to be minimized
6. Capital costs should be minimized
7. Simplest possible facility to minimize project implementation

Meta used this list to vet the popular upgrading technologies and found them lacking due to high capital costs, extensive utility requirements and complexity of design. Meta did not want to build a refining complex; they only wanted to build an upgrading unit.

CLASSIC SOLUTIONS

There are four ways that are currently practiced in bringing heavy crude oil, such as the Rubiales crude, to market.

The first method is to upgrade the material in the oil field and leave much of the material behind as coke, and then pipeline the upgraded material out as synthetic crude. In this method, the crude is fractionated and the residue is coked. The products of the coking operation, and in some cases some of the residue, are hydrotreated. The hydrotreated materials are recombined with the fractionated light materials to form synthetic crude that is then transported to market in a pipeline. A portion of the crude may or may not be bypassed around the processing units. There are several examples of this type of processing in the current Canadian oil sands operations seen around Fort McMurray in Alberta, Canada. This option is made attractive by the presence of abundant natural gas in the area as well a local electrical power source. The current operations leave the coke produced by the various operators as back fill into the open pit mines producing the oil sands.

A second solution is to build upgrading facilities at an established port area with abundant gas and electric resources. The upgrading facility fractionates the VGO and lighter materials out of the crude and cokes the residue material. The liquid products from the coking operation are then hydrotreated and mixed back with the virgin materials. The virgin VGO, AGO and diesel may also be hydrotreated in the complex depending on availability of natural gas and economic considerations. A pipeline from the complex to the oil field transports cutter stock to the oilfield in sufficient quantity to produce pipeline acceptable crude. There are several examples of this kind of facility located in the Jose, Venezuela area that enables the production of heavy crude from the Orinoco River Basin.

A third solution in common practice is to use traditional crude which is located in the general area to dilute the non-traditional crude to produce an acceptable pipeline material. This option is a great solution but has a number of limitations. For example, the amount of non-traditional crude production could be limited by the amount of traditional crude available for dilution. Another problem is compatibility. The two crudes may have limited compatibility which would limit the amount of dilution and again could limit the amount of non-traditional crude produced.

A final solution is closely related to the established port area solution where a substantial oil field is located far from other fields, from power or from natural gas. This solution includes building a reverse pipeline from a refinery to the oilfield as well as a crude pipeline. This can be a solution for high quality waxy crude as well as heavier crude oil.

THE UOP SOLUTION

In March 2005, after investigating the other crude oil upgrading scenarios, Meta contacted UOP in an effort to find a new approach to upgrading that would meet all of Meta's goals for the project. UOP evaluated the Rubiales crude assay and determined that all of Meta's project objectives could be met. In April 2005, Meta met with UOP to discuss the UOP Catalytic Crude UpgradingUpgrading (CCU) process.

The CCU process is a stand alone upgrading process based on the UOP Fluid Catalytic Cracking (FCC) technology. The CCU process takes a portion of the heavy raw crude oil and processes it to create cutter stock for the remainder of the produced crude oil. In the case of Meta, it was estimated that between 20-40% of the crude oil would have to be processed to meet the pipeline specifications for the Rubiales synthetic crude mix.

After the initial discussion with UOP, Meta determined that the CCU process was the best fit for the upgrading facility and commissioned UOP to complete a process engineering study to provide more details. As the process engineering study progressed, it became evident that there were several advantages the CCU process had over the other upgrading technologies.

CCU PROCESS ADVANTAGES

The advantages of the CCU process over other technologies lay not only in the ability to meet the pipeline specifications, but also in being able to meet all of Meta's other project requirements. Specifically, the CCU process achieves the following.

1. Self sufficiency with regards to utilities
2. Minimized crude processing (30% of production capacity)
3. Lower capital cost
4. Increased product margin due to API gravity being above pipeline minimum
5. Less volume loss than other upgrading technologies
6. No waste by-product

The key to the CCU process, and its ability to meet Meta's goals, stem from the yield and selectivity benefits associated with a catalytic conversion system over those of a thermal system. Table 3 below details the material balance from the CCU unit. The three products from the CCU unit are the recovered liquid used as cutter stock for the bypassed crude oil, coke on the spent catalyst, and off gas from the CCU unit absorber section.

Table 3: CCU Unit Material Balance

Material Balance	Reactor Products lb/hr	Off Gas lb/hr	Net Product lb/hr
Feed	429,200	---	---
H_2S	1,904	1,363	541
Hydrogen	1,218	1,218	0
C_1	2,764	2,763	1
C_2's	4,744	4,703	41
C_3's	14,670	4,942	9,278
C_4's	26,076	2,886	23,190
C_5's	26,256	2,472	23,784
C_6^+	286,822	2,368	284,454
Coke	64,746	---	---
Total, lb/hr	429,200	22,715	341,739
Total, BPSD			28,413
API of Liquid			39.70

*Off gas total shown does not include entrained inerts and water totaling 5,709 lb/hr

Despite the attractiveness of the project due to the yield slate from the CCU unit, utilities remained a large concern for Meta due to the remote location. The only utility available to Meta is a consistent water source that can be treated to produce boiler feed water and cooling water. As the CCU process is an FCC process derivative, it requires coke to be burned off the catalyst in the CCU unit regenerator. This coke burning, coupled with auxiliary firing of off-gas from the CCU absorber section, provides steam and electric energy in excess of what is required to run the entire upgrading complex (see Table 4: Steam and Power Balance).

Table 4: Steam and Power Balance

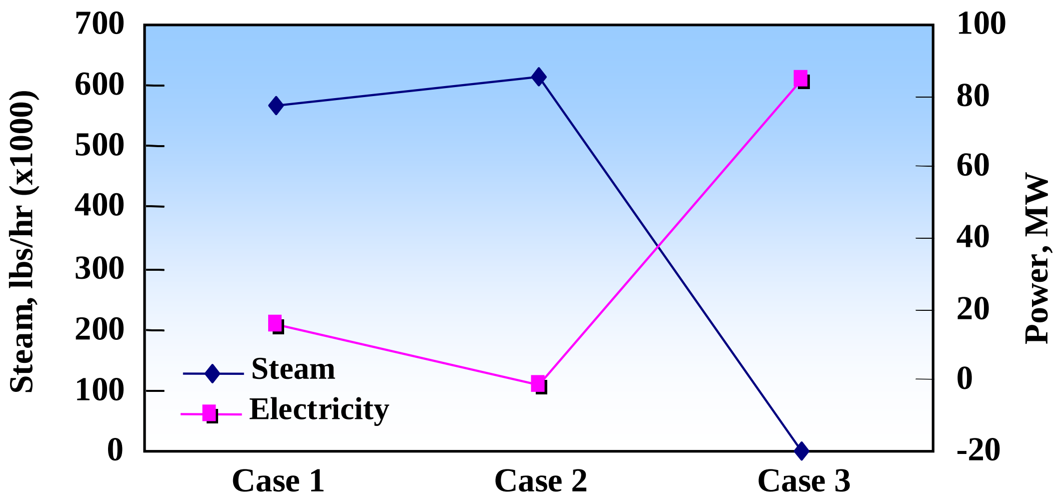
Utilities Produced	Case 1: 30% Crude Processing with Power Recovery	Case 2: 30% Crude Processing without Power Recovery	Case 3: 30% Crude Processing with Power Recovery and Steam Turbine
Electricity, KW	15,620	(1,180)	84,224*
Steam, 600 psig @ 750 °F, lbs/hr	567,199	616,435	0
Steam, 150 psig saturated, lbs/hr	(69,522)	(69,522)	(69,522)
Steam, 50 psig saturated, lbs/hr	10,599	10,599	10,599
Boiler Feed Water, lbs/hr	(835,440)	(887,267)	
Condensate, lbs/hr	238,211	240,802	
Cooling Water, gal/min	244	244	

* Based on 70% efficient full condensing steam turbine and 90 °F cooling water supply

As seen in Table 4, UOP first completed the process study to include a power recovery turbine on the flue gas section of the CCU unit. After follow-up discussions with Meta, it was decided to run an additional case without power recovery. This second case was run as the power recovery option produced too much electricity for the upgrading facility, and export lines to the Colombian power grid were not available. Case 2 focused on recovering power in the form of high pressure superheated steam, which can also be used for electrical power generation. For both cases, a portion of the steam produced by the upgrading facility will be used for the dewatering process of the crude oil, thereby eliminating the current practice of burning crude oil in the dewatering process. In the interest of determining maximum power generation capabilities of the CCU unit, UOP completed a power evaluation case where all excess steam from the facility was run though a steam turbine. The results of this evaluation are shown in Table 4 as Case 3.

Table 4 also shows how the CCU unit design for Meta provides for a significant amount of flexibility when it comes to superheated steam and power generation capabilities. These two byproducts of the CCU process can be optimized to meet the needs of the processing facility. Figure 5 shows the three utilities cases investigated by UOP for the Meta CCU unit and illustrates this flexibility of design.

Figure 5: Steam and Power Production in the Meta CCU Unit



Aside from the produced utilities benefit, the largest advantage of the CCU process over other upgrading technologies is the lower required crude oil processing capacity to meet pipeline specifications. The CCU process is catalytic, not thermal, and therefore carries with it significant conversion and yield selectivity benefits. This results in a higher API liquid product to be used for cutter stock, and less coke make than a traditional coking based facility. Table 5 below shows the combined synthetic crude properties.

Table 5: Combined Synthetic Crude Properties

	Rubiales Crude	CCU Product*	Meta Synthetic Crude
BPSD	100,000	28,413	98,413
Lb/hr	1,430,663	341,739	1,343,204
API	12.8	39.7	19.6
RVP @ 100 °F, psia	0.85	28.9	14.8
Viscosity @ 100 °F, cSt	933.3 (122 °F)	1.1	24.9
Viscosity @ 210 °F, cSt	127.0 (176 °F)	0.4	5.4

*Processing 30,000 BPSD of raw crude with 89% C4 and 66% C3 recovery, respectively

For Meta, Table 5 contains two key numbers. First, the liquid recovery from the upgrading facility is greater than 98% and second, the API gravity is well above the pipeline specification of 16. Both of the numbers have a direct impact on profitability.

The higher the liquid recovery the more saleable product, and the higher the API gravity the higher the per barrel selling price of the crude oil.

Both of these numbers stem not only from the use of a more selective catalytic system for the upgrading facility, but also in the minimizing of waste by-products in the CCU unit. As discussed previously, the CCU process generates coke, which is converted to power and steam by burning in the regenerator. This differs from a coking based upgrading facility where coke is formed in the process and either shipped off or accumulated at site. Additionally, the LPG and light gases produced in the CCU process are either absorbed into the final synthetic crude or used for supplemental firing of power or steam generation equipment. There is effectively no unused by-product in the CCU process.

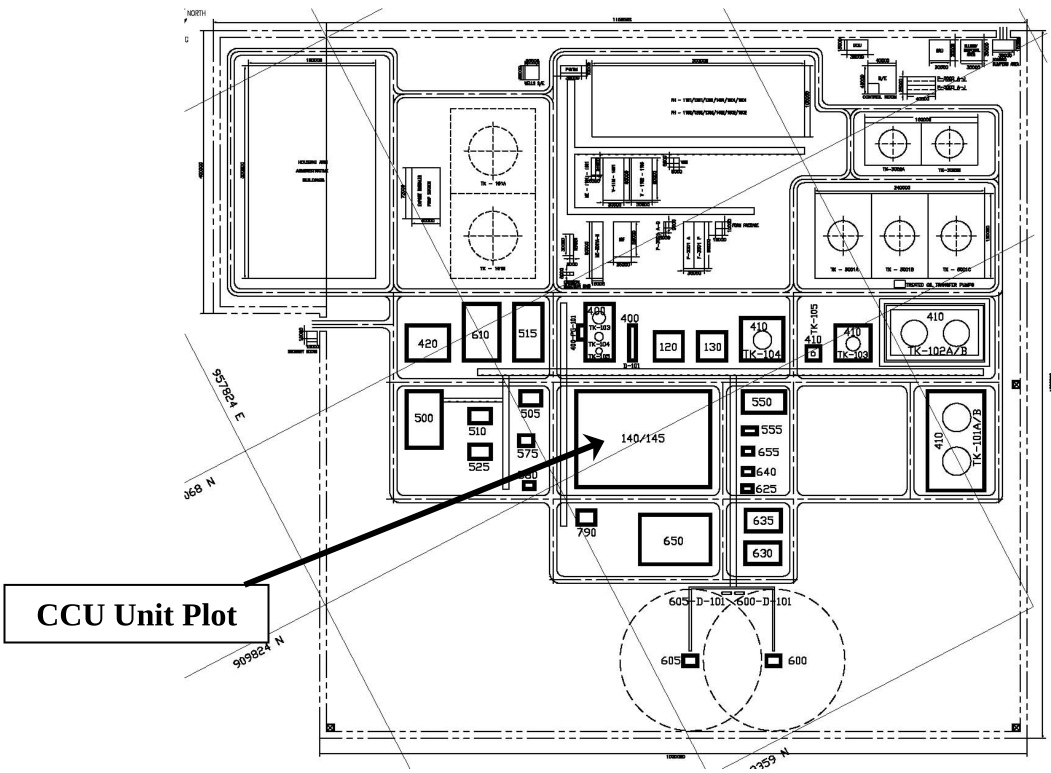
The above yield summary shows that the CCU process met the primary objective of producing synthetic crude that meets pipeline specifications. At the same time the CCU process met the project goals of minimizing capital, utilities and operations requirements while at the same time maximizing saleable liquid product. This left only reliability and project timing issues to be addressed.

The CCU unit designed for Meta is unique not only in the use of FCC technology for upgrading raw heavy crude oil, but also in the unit configuration to provide Meta the most flexibility and unit reliability. Flexibility is important in the case of increasing oil well production from 9,000 BPSD to 100,000 BPSD as this increase does not occur overnight. There is going to be a ramped up production schedule over a period of time, and therefore the upgrading unit needed to be designed such that the unit would run effectively and meet pipeline specifications at significantly reduced throughput. To accomplish this, UOP designed the CCU unit with two identical and parallel reactor and regenerator systems, including redundancy in the flue gas systems and main product quench towers up to a common high pressure receiver and common absorption system.

The configuration permits operation of the CCU unit at 25% of design capacity as the field capacity increases and provides for redundancy in the reactor and regeneration section should a mechanical or operational upset occur. The common absorption section is suitable for all operation schemes as distinct liquid product splits are not necessary since all liquid products are recombined as cutter stock for the remainder of the crude oil production.

The redundant reactor and regenerator section requires about 50% more plot space for the CCU unit versus a similarly sized FCC unit. However, the single operating unit makes the CCU unit more attractive for plot space when compared to a multiple unit upgrader facility. As seen in Figure 6 below, the plot area of the CCU unit at Meta has very little impact on the overall site plot area.

Figure 6: Meta CCU Plot Plan



Current Status of the CCU Unit Design

UOP will complete the basic engineering design of Meta's CCU unit in April, 2006. The Meta facility is currently scheduled to start production in 2008. UOP is currently working on two additional CCU units for both viscosity and pour point reduction of stranded crude oil reserves.

Design Issues

The 12.8 API gravity and 12.9 Conradson Carbon of the Rubiales feed puts the project in class of its own when it comes to residue processing. The equipment to handle this feed pushes the limits of what has been done and requires some special design features.

Feed injection design requires some special thought and consideration. UOP has designed a unique feed injection zone to prevent fouling in the contact zone and to ensure proper control of contacting.

Handling the high Conradson Carbon in the regenerator is also a challenge. The Meta unit uses the strengths of UOP's catalyst cooler designs installed in a rather unique configuration to ensure even regenerator temperature control and therefore control of burn kinetics to achieve high CO content in the flue gas.

Catalyst Issues

Table 1 describes the feed properties for Rubiales crude. The metals content of the whole crude is 194 wppm which means the CCU unit will have to deal with elevated quantities of metals. UOP has been working with catalyst vendors and E-cat suppliers to stretch the current limits of catalyst experience. Two approaches to the Meta problem have been developed, an E-cat flush solution and a novel fresh catalyst solution.

The E-cat solution assumes 8,000 wppm of metals pick-up and 10,000 to 12,000 wppm of metals on catalyst in unit inventory. This solution would require about 125 Tons per day of high quality flush catalyst or about 2.5 lbs per barrel of oil produced. A continuing effort has been launched by UOP to determine the upper limits for metals contamination of the flush cat solution. The E-cat solution has several disadvantages such as control over additive content, metals trapping and bottoms cracking activity.

The fresh catalyst solution offers much more flexibility. The metals levels can now be elevated with a target of at least 25,000 wppm on catalyst in inventory. This solution allows much more flexibility because vanadium traps can be incorporated, bottoms cracking activity can be balanced and the unwanted catalyst additives can be controlled. At 25,000 wppm of metals pick-up the fresh catalyst make-up rate drops to 40 tons per day. The catalyst consumption is about .8 lbs per barrel of oil produced.

UOP is actively working with catalyst vendors to develop advanced catalyst systems that can tolerate up to 45,000 wppm metals while maintaining acceptable activity and cracking characteristics. This target would reduce the catalyst make-up to 22 tons/day or 0.44 lbs per barrel of oil produced.

SUMMARY

The UOP Catalytic Crude Upgrading process offers a unique solution to stranded non-traditional crude production. The process is based on traditional FCC principles but stretches the limits. By design, the CCU unit processes only enough of the crude to create sufficient cutter stock to produce a synthetic crude meeting pipeline specifications.

The process has a high coke yield, which results in the opportunity to produce large quantities of both steam and electrical power. The produced steam and power supply the utility needs of the complex as well as the surrounding oil field, the upgrading complex and the infrastructure necessary to support the project.

The process can be adapted to meet the needs of a number of stranded oil projects where natural gas and electricity supplies are unavailable. The CCU process is applicable to heavy oil projects such as the Meta project described here, and also to projects where high quality waxy crude can not be pipelined because pour point restrictions.

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