Deep conversion of black oils with Eni Slurry Technology

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Abstract

Eni Slurry Technology represents a significant technological innovation in residue conversion and unconventional oils upgrading. EST allows the total conversion of heavy feedstocks into useful products, mainly transportation fuels, with a great major impact on the economic and environmental valorization of hydrocarbon resources.

The peculiar characteristics of EST in terms of yields, products quality, absence of undesired by-products and feedstock flexibility constitute its superior economic and environmental attractiveness.

The first full scale industrial plant based on this new technology will be realized in Eni's Sannazzaro refinery (23,000 bpd). Oil in is scheduled by 4th quarter 2012.

Introduction

Crude oil upgrading is of major economic importance for both downstream and upstream industry.

In the downstream business, the high demand for transportation fuels coupled with a sharp drop in residual fuel oil have resulted in a renewed interest in the bottom-of-the-barrel processing using various conversion processes /1- 2/. Focusing on the upstream and midstream sector, we well know that the huge estimates for "oil in place" (about 4.6 Trillions bbl /3/) give unconventional oil a tremendous potential compared with conventional oil resources. The reservoirs containing these so called "unconventional oils" are geographically widespread but three main deposits are especially concentrated in Western Canada, Venezuela and the Former Soviet Union, even if in this last case the estimates of the deposits are less sure since recent certification of these reserves are not available and in addition, these deposits are quite scattered. Although based on today's upstream technology, only 10 to 15% of these resources can be considered "recoverable", this is a huge amount, close to 560 billion bbl. Because the current world oil consumption is close to 30 billion bbl per year, this means a potential supply of about 20 years. These numbers highlight the importance of the "unconventional oil" in the future energy scenario and for these reasons the IEA foresees a growing role for both heavy oil and bitumen in the medium-long term /4/.

A key role for a proper exploitation of the heavy feedstock is played by the downstream processes that are required to upgrade and convert them into valuable products. Among the various process alternatives available on the market or under development, i.e. Coking (Delayed, Fluid or Flexicoking, and similar), Fixed and Ebullating Bed Hydrocracking as well as Slurry Catalyst Hydrocracking, Delayed Coking (DC) is by far the most used upgrading process because of its reliability and relative low capital cost. Majority of Coking capacity (Delayed and Fluid) is installed in North America (more than 50% of the total installed capacity), but the importance of DC is increasing in Asia and ME, as shown in Figure 1. If we focus on the typical unconventional oil business, DC is by far the most used upgrading process, both in Canada and Venezuela.

Nevertheless, one of the main drawbacks of DC is the production of a low value by-product such as petcoke, whose handling is quite complex and costly. Petcoke is normally used in electric power plants, steel mills, and cement industry or similar, while petcoke produced in remote location, such as Northern Alberta, is currently stockpiled.

Focusing on the market, the world petcoke output has risen during recent years; its use in the growing cement and steel markets and, increasingly, its competition with coal for electricity generation, have all strengthened its position. Nevertheless, its portion of the market is still small as the petcoke supply represents only ~2% of world coal usage. In the future, although an important expansion of the worldwide Coker capacity is expected, the petcoke demand will remain supply driven (i.e. the petcoke supply as a percentage of coal will still be relatively small). However, it is possible that the petcoke price could deteriorate with increasing supply to the point that refiners (or upgraders) once again see negative netbacks as they are forced to find a disposal for their coke.

Moreover, future CO_2 emissions regulations may also have an impact on the market of low H/C fuels, such as petcoke and coal, which would likely be reflected in their prices. Historically, petcoke is priced based on its fuel value to end-user and for this reason, because petcoke is only readily substitutable with coal, there is a strong relationship between coke and coal price. Alternatively, petcoke can be used within the upgrading complex for the hydrogen production via gasification, the noncatalytic partial oxidation (POx) of hydrocarbons to yield synthesis gas /5/. Nevertheless, petcoke gasification is quite expensive compared to the classic steam methane reforming (SMR) and it can be considered as a real economically attractive solution at very high natural gas prices.

The real alternative solution to avoid petcoke production is based on the use of deep-conversion Hydrogen-addition technologies /6-7/. Among them, slurry catalyst hydrocracking processes are particularly suited to upgrade the heaviest and more polluted feedstock. The utilization of a hydrogen-addition technology eliminates the logistic impact associated with the huge production of petcoke. This aspect becomes particularly attractive when the upgrader is located in remote sites, where coke transportation facilities do not exist.

Within Eni, a large experience with residue conversion is present since in the Eni downstream refining system all most referenced residue conversion technologies are in use:

- Fixed bed Resid Hydroconversion Unit in Taranto Refinery: 25,000 bpd (by Shell - Chevron Lummus Global - since 1995)
- Ebullating Bed Hydroconversion in Milazzo refinery: 25,000 BPSD LC-Finer (by Chevron Lummus Global - since 1998)
- Delayed Coking 1 in Gela Refinery: 4,600 TPD (by - Kellogg - since 1963)
- Delayed Coking 2 in Gela Refinery: 3,300 TPD (by Conoco - since 1990)
- Gasification of VB Tar in Sannazzaro Refinery: 400,000 TPY - 200 Mwe (by Shell Global Solution - since 2005)

Beyond their economic benefits, all approaches show some limitations in fulfilling the goal of avoiding the production of low value-low demand co-products (the Holy Grail of *zero fuel oil – zero coke* refinery) or increasing the distillates output at the same CDU capacity. A superior deep conversion technology was needed. On these premises, since early 1990s Eni has initiated the development of a new concept for full conversion and upgrading of the bottom of the barrel. The long lasting journey of this effort has brought to the development of a proprietary technology, Eni Slurry Technology (EST), which allows almost total conversion to distillates of the heaviest refinery bottoms as well as high upgrading performance by removing heteroatoms or reducing them to a level manageable in conventional refinery operations.

Once a semi-scale Commercial Demonstration Plant had demonstrated the technical viability and the reliability of the EST process, Eni took the decision to build the first full scale EST industrial plant in the Sannazzaro (Italy) Eni refinery, whose startup is expected within 4Q2012.

The Sannazzaro EST complex will be the first industrial scale slurry hydroprocessing plant in the world.

Eni Slurry Technology

From the technological point of view, EST is a hydrocracking process based on the unique features of a nano-dispersed (slurry) catalyst and a special homogeneous isothermal reactor synergistically working in a novel process scheme that allows an almost total feedstock conversion to distillates as well as high upgrading performance /8-10/.

The active phase of the EST catalyst is unsupported molybdenite (MoS_2) in form of nano-lamellae generated in situ from oil-soluble precursors. This catalyst remains practically unchanged during the whole operation eliminating the aging phenomena, thus avoiding the need of catalyst substitution (and the relevant plant turn down) typical of all catalytic hydrotreating processes, Contrary to the conventional supported catalysts utilized in fixed and ebullating bed reactors, EST catalyst does not suffer for the plugging problems due to the metals and coke deposits within the pores of the supports. The lower effect of coke, the high surface area, and the absence of mass transfer diffusion resistances help the catalyst to be more active than supported ones. The very high specific activity allows therefore the catalyst concentration to be kept at level of few thousand ppm. Temperature control with a dispersed catalyst is uniform whereas supported catalyst could be subjected to hot spots. The use of unsupported slurry catalysts is particularly useful in case of feedstock containing high concentration of pollutants, particularly metals and asphaltenes.

Another important feature of EST is the use of a tailored-designed bubble column reactor operating in slurry phase. The reactor behaves homogeneously due to the small size of catalyst particles and isothermally due to the high degree of back mixing fluid-dynamically controlled in the slurry phase ensuring almost flat axial and radial temperature profiles. It contributes to make the reactor intrinsically safe against temperature runaway.

The synergetic combination of catalyst development and reactor development enables EST to adopt a process configuration based on the recycle of unconverted heavy ends achieving overall complete feedstock conversion, and avoiding fuel oil *fatal* production of current hydroprocessing technologies.

The following figure 1 shows the simplified reaction section scheme of the EST process:

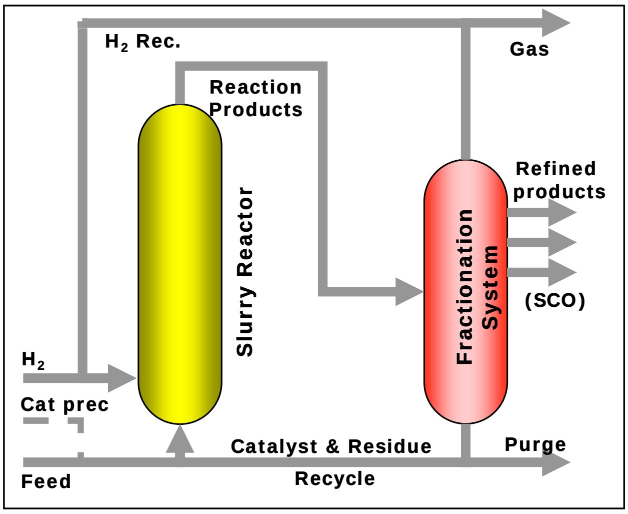

Figure 1: EST process concept

The heart of the process is a slurry reactor in which the heavy feed is hydrocracked to lighter products in the presence of the slurry molybdenum based catalyst.

The upgraded oil moves from the reactor to a separation system to recover gas, naphtha, middle distillates and catfeed The gas phase goes to the amine wash section and the clean gas, after recompression and addition with the make-up hydrogen, is recycled to the reaction section. Distillates are recovered from the liquid phase, and the unconverted bottom material, together with the dispersed catalyst, is recycled back to the reactor. Depending upon the feedstock, the process severity (reaction time and temperature) are optimized in order to generate a residue well within the limit of stability avoiding the phenomenon of asphaltene precipitation that could generate coke and foul the process equipment. The operation of recycling and blending the partially converted residue with the fresh feed, contributes to maintain stability of the recycle stream so that it can be reprocessed to get almost total conversion. After repeated cycles, the system reaches a sort of *steady state* so that the net result is the total conversion of the feed to valuable products. A small purge (<3%) is necessary to limit the build-up of metals (Ni and V) fed with the heavy feed. Purge is processed to recover residual hydrocarbons and metals including molybdenum. In this way, EST can handle heavy feedstock assuring very high conversion to distillates because does not generate significant amounts of by-product, such as coke or heavy fuel oil.

EST Development Road

The original idea of developing in Eni a hydrotreating process based on micronic catalyst goes back to the late 1980s. After an intensive R&D activity carried out at laboratory level during the 1990s, all the process steps have been integrated in a 0.3 BPSD Pilot Plant build and operated in 2000-2003. Pilot plant operation, mock up studies with mimic fluids, and development of suitable models made available all information needed for designing and constructing a semi-scale 1,200 BPSD Commercial Demonstration Plant (CDP) inside the battery limits of the Eni Refinery in Taranto (Italy). Since its start up at the end of 2005, more than 230.000 bbl of black feed were processed successfully in the CDP unit (Table 1) /11/. The CDP operation has allowed to consolidate the know how on the technology confirming the expected process performance obtained at the pilot scale and assessing the fluid dynamics of the in-house developed and designed slurry bubble column reactors and relevant internals /12/.

Figure 2: EST Commercial Demonstration Plant in Taranto Refinery – The reaction section

One of the main characteristics of the EST process is the excellent feedstock flexibility. The CDP operation has validated the technical and economical viability of the EST process with safe and steady run, even with a feed close to instability (Visbroken tar).

	Ural VR	Athabasca Bitumen VR	Basrah VR	VB Tar
TBP cut	500°C$^+$	450°C$^+$	500°C$^+$	410°C$^+$
API Gravity	9.0	5.0	5.6	0.1
H/C	1.49	1.47	1.45	1.33
S (wt. %)	2.9	5.4	4.9	5.9
N (wt. %)	0.53	0.38	0.39	0.49
Ni (ppm)	90	86	35	68
V (ppm)	253	230	119	125
Asphaltene (wt. %)	12.6	19.9	13.9	22.5
CCR (wt. %)	18	17	20	27

Table 1: Feedstock tested in the CDP runs

With all feedstock used in the CDP, EST has demonstrated the possibility to get the total conversion of the residue to light, medium and heavy distillates with minimum purge. Table 2 shows the experimental yields from CDP obtained in a wide range of operating conditions (mainly temperature, fresh feed residence time, recycle ratio, catalyst concentration).

Table 2 shows that the appropriate selection of operating conditions can privilege the production heavier or lighter slate according to the refinery configuration.

Experimental Yields from CDP	wt% on Fresh Feed
H_2 Consumption	2.9-3.3
$H_2S + NH_3$	3-5
C_1-C_4	6-9
Naphtha	6-20
AGO	35-55
Catfeed	12-55
Purge before PTU	2-3

Table 2: Experimental Yields from CDP

Moreover, in all cases the process assures a complete metal removal, an excellent CCR and sulfur reduction and a fairly good denitrogenation. Another peculiar characteristic of the EST is the production of high quality Diesel oil and Catfeed with a low sulfur and aromatic content that can be further converted into transportation fuels (diesel and/or gasoline) via HDC or FCC as a function of the market requirements, assuring the product flexibility.

Typical overall performances achieved in the reaction system, by recycling unconverted bottoms show:

- ✓ Metal removal (HDM) > 99%;
- ✓ Conradson Carbon Residue reduction (HDCCR) > 97%;
- ✓ Sulfur reduction (HDS) > 85%;
- ✓ Nitrogen reduction (HDN > 40%

In terms of economic evaluation, it is important to underline that the volume yield of the products is over 110% of the fresh feed.

The EST/CDP runs have been crucial for developing and consolidating the technology at a size that could safely allow the scale up to a full-scale commercial plant. Additionally the CDP experience has allowed:

- to learn how to tailor the technology with different feedstock;
- to develop and tune process simulation models;
- to develop and test operating procedures for start-up, steady-state operation and emergency conditions;
- to train operation and maintenance personnel;
- to train process engineers;
- to evaluate the performance of selected construction materials against corrosion in harsh environment and;
- to evaluate the performance of different kind of instrumentation with heavy, fouling fluids.

Today CDP is still in operation for demonstrating on a useful scale the most updated process schemes and optimizing the proper operating conditions for any new feedstock.

The EST Unit in Sannazzaro Refinery

The positive results obtained to date have encouraged the decision to build the first full scale industrial plant based on this new technology at Eni Sannazzaro de' Burgondi Refinery (Pavia, Italy) /13/.

The Sannazzaro Refinery has a balanced refining capacity of 170,000 BPSD and one of the highest conversion indexes in Italy (52% hydroskimming conversion index, and 85% effective conversion). The realization of an additional conversion plant employing the Eni Slurry Technology has been demonstrated extraordinarily profitable in that site taking into accounts some unique features of the refinery, such as:

- Strategic and logistical issues; in fact the refinery has a key position for European diesel market and is the knot of an efficient network of pipeline for oil supply and product distribution.
- The EST unit will allow a synergic integration with the current facilities and existing unit refinery, mainly due to the presence of the high capacity conversion units able to process the less valuable product produced from EST (i.e. heavy gasoil).
- The refinery will be able to process 100% of extra heavy crude with high sulfur content producing high quality middle distillates, in particular diesel; it should be considered that since AR from sweet crude feeds FCC: this may currently become a limitation in crude slate heaviness increasing.
- Increase of conversion by reducing the yield of fuel oil to zero (a minimum amount of asphalt as per market request will be assured).
- Increase up to 10% the current throughput of the refinery without increasing the environmental impact .

The chosen EST technological configuration incorporates all the operating experience matured and all innovation demonstrated in the Taranto CDP, thus mitigating technological risk. Reactors of maximum size in terms of internal diameter and weight will be installed to establish a sound reference in view enhancing major industrial initiatives.

The EST Unit has a design capacity of 23,000 BPSD of Vacuum Residue and includes (figure 3):

- ✓ Reaction Section,
- ✓ Fractionation Section,
- ✓ Products Upgrading Section,
- ✓ Purge Treatment Unit

Additionally the EST Complex includes:

- ✓ Steam Reforming Unit - Capacity: 100,000 Nm^3/h of Hydrogen.
- ✓ Sulfur Plant (2 lines) - Capacity: 80 TPD each
- ✓ Utilities & Offsites

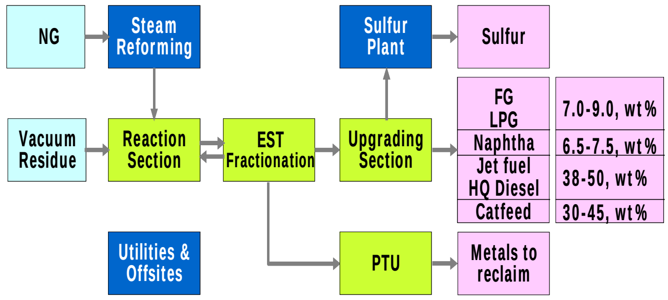

Figure 3: Block flow Diagram of EST Complex at Sannazzaro

The EST Unit has been designed to treat the Ural Vacuum Residue type (lower S, higher N and metals) and as alternative feed the Basrah Vacuum Residue type (higher S, lower H/C ratio).

		Design feed	Alternative feed
	unit	Ural VR type	Basrah VR type
350-500°C	wt%	5	5
500+	wt%	95	95
Asphaltenes C_5	wt%	15	15.6
Sp. Gravity	kg/m3	1004	1039
Sp. Gravity	°API	9.4	4.7
Viscosity	cst	982@100°C	1126@80°C
Viscosity	cst	159@135°C	436@100°C
Pour Point	°C	51	51
Sulfur	wt%	3	6
Nitrogen	wt%	0.7	0.4
Ni	ppm wt	68	46
V	ppm wt	214	164
CCR	wt%	20.2	18.5
H/C ratio		1.41	1.37

Table 3: Characteristics of feedstock

Product slates wt% of fresh feed and distillate quality are reported in table 4.

Products	Yield wt.%	S ppm	N ppm	sp. gr.
H_2S+NH_3 wt%	3.2-4.0			
C_1-C_4 wt%	7.0-9.0			540 (LPG)
Naphtha (C_5-170°C) wt%	6.5-7.5	<10		700
Kero + AGO wt%	38-50	<10		840
Catfeed (350-500°C) wt%	30-45	<400	<700	920
Purge before PTU wt%	2.5-3.8			.

Table 4: Product slate and quality

Noticeably due to the hydrogenation, reaction of the feed the volume of liquid products is about 15% higher than the volume of the feed.

The EST Sannazzaro EPC project

The Sannazzaro EST Project is a Fast Track one: currently it is already in the EPC phase and works on site are already in progress.

EPCM contract has been awarded to Saipem.

Basic Design Package (BDP) and Front End Engineering Design (FEED) have been completed by Saipem (formerly Snamprogetti) in 2008. Environmental Impact Study (SIA) and Environmental Impact Evaluation Application (VIA) have been completed.

Procurement of Long Lead Equipment (20-31 months from purchase order) like high-pressure equipment, compressors, etc has already started. Assembling of high-pressure reactors is already in progress at the site since October 2009 lasting up to March 2011 (figure 4).

Construction and commissioning activities will last about 32 months, and start up of the facilities is scheduled by 4Q 2012.

Figure 4: Slurry Reactor slice at GE yard, Massa (Italy)

The EST complex covers an area of 220,000 sqm (+190,000 sqm during construction). The Sannazzaro refinery is a very crowded area and it has been necessary to enlarge the fence incorporating a neighboring paddy field where EST complex had to be located. This has involved a significant impact on the project execution, site preparation, and interconnecting/utilities costs. Additionally to the process packages and usual offsites, ancillaries include new sour water stripper unit (SWS), amine regeneration unit (ARU), blow down and flare.

Some additional information can give an idea of the EST Project huge size:

- about 1,300,000 Home Office hours,
- 3.000 man months for supervision,
- 32 months of yard duration,
- about 7,500,000 construction hours,
- 36,000 ton of bulk material and piping,
- 17,000 ton equipment,
- 700 km instrumentation wiring.

A Case Study: Venezuela Upgrading Complex

To evaluate the benefis deriving from the application of EST process in upstream context, a typical comparative analysis of different process schemes to upgrade Venezuelan extra-heavy oil, in terms of mass and energy balance and indicative relative economics, has been carried out /14/.

The study covers various upgrading process schemes based on DC as well as on the novel EST process to upgrade a typical Venezuelan Extra Heavy Oil (EHO) with a gravity of 8.4 API and 4.1 wt % sulfur (Table 5) to produce a bottomless Synthetic Crude Oil (SCO) at similar quality (38-39 API gravity) or even better quality products, such as LPG, Naphtha and Diesel oil. The alternative configurations have been studied using in-house and licensors based process data.

	Zuata Crude
API gravity	8.4
Sulfur, wt.%	4.1
Nitrogen, ppm	5890
Viscosity, cSt @ 120°C	100
Pour Point, °C	18
K Factor	11.3
Ni, ppm	110
V, ppm	500
Distillation, wt.%	
343°C-	12.8
Atm. Residue	33.1
Vacuum Residue	54.1

Table 5: Chemical composition of Zuata Extra Heavy Oil

In all cases a hypothetical 260,000 bpsd plant located on the Venezuela coast, consisting of 200,000 bpsd of EHO and 60,000 bpsd of diluent naphtha, is considered. The reference process block flow diagram involves a crude unit including desalting followed by atmospheric and vacuum distillation to yield a 540°C+ vacuum residue that is sent to the conversion unit, i.e. DC or EST that are fully integrated with various Hydroprocessing units. The hydrogen production via steam-methane reforming (SMR) is included in all schemes, although the petcoke partial oxidation (POx) has been also considered as possible alternative.

In this paper, a summary of the results of the comparison between the following Upgrading Complexes is reported:

1. Delayed Coking to Final Products scheme:

The major pieces of equipment in the DC section are the coke drums, furnaces, and furnace charge pumps. The proposed configuration consists of two trains of four drums each. The upgrading section includes the Naphtha HDT for the saturation of olefins and di-olefins and for the removal of sulfur and nitrogen, the Light Coker Gasoil HDS for the sulfur and nitrogen reduction; a Dearomatization section is added to the atmospheric Gasoil HDS to further reduce the aromatics content in the Gasoil to meet the Cetane Index and Specific Gravity according to EU Specs. The straight-run atmospheric Gasoil is processed in the same unit. The combined vacuum gasoil from straight run and conversion units are mixed and further processed with HDC Full Conversion type to obtain Final Products only (LPG, Naphtha and Diesel oil).

2. EST to Final Products scheme:
The major pieces of equipment in the EST section are the slurry hydrocracking reactors that are fully integrated with the vacuum gasoil HDC, wich is of Full Conversion type to obtain Final Products only (LPG, Naphtha and Diesel oil).
Even in this Case, the straight run gasoil is mixed with the same stream from EST and processed together. The upgrading section includes the Naphtha HDT and a Dearomatization section to treat the atmospheric gasoil.

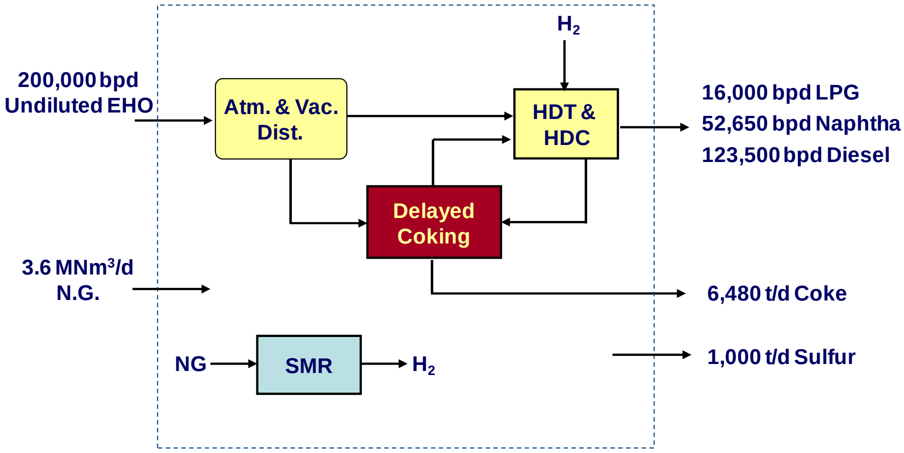

Figure 5: Case 1. Process Scheme based on DC to yield Final Products.

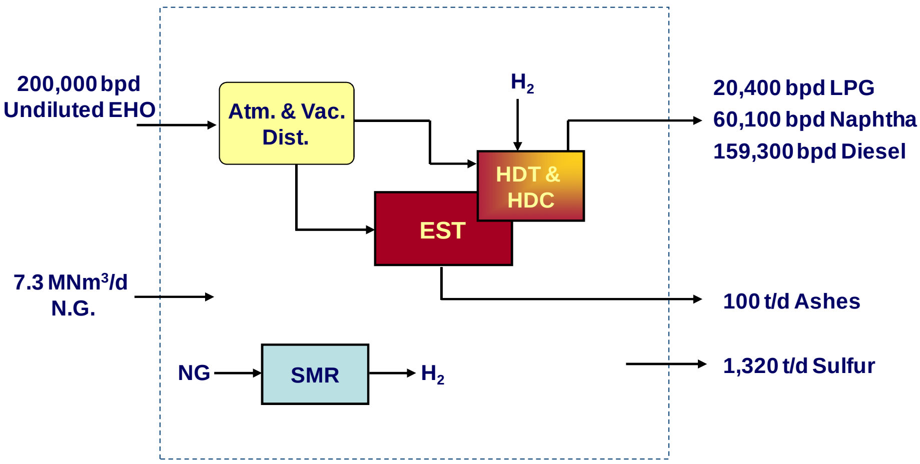

Figure 6: Case 2. Process Scheme based on EST to Final Products.

Case Study: Economic results

The merit of implementing the different Upgrading Complexes are investigated by conducting a Discounted Cash Flow Analysis and by calculating the inherent profitability indexes. Cash flow projections have been carried out in current US$ (2%/y inflation) and unlevered terms (100% Equity Funding) using the following parameters:

- ✓ Upgrader design and construction: 4 years, starting from FEED availability
- ✓ Evaluation year: 2009
- ✓ Start-up year: 2016
- ✓ Operating period: 20 years
- ✓ Depreciation (straight line): 17 years
- ✓ Corporate tax rate: 50 %
- ✓ Royalties (on petcoke and sulfur sales): 3%/year
- ✓ Cost escalation during construction: 3%/year
- ✓ Exportation fees: 15 US$/ton (solids)

Capital costs are based on Q1 2009 US Gulf Coast costs. The Capex estimates are sufficiently accurate for comparing Cases but do not necessarily depict the actual cost of an upgrader, which will depend on the project location. In our study, we used a Brent price of US$55/bbl at the year 2012 to calculate the value for the heavy oil feedstock and the upgraded products, i.e. the SCO and the different distillates. The natural gas price has been valued in accordance with the oil scenario @ 4.52 US$/MBtu (Henry Hub).

Although the EST options involve higher investment cost and require higher natural gas volumes, the significant increase in the liquid yields production assures much higher profitability than DC. Table 7 shows the US$ margin available when upgrading the EHO to Final Products (taxes are not included). The higher EST costs are notably rewarded by the incremental production of Distillates (much higher upgraded feed value) due to EST higher intrinsic conversion capabilities. For this reason, EST ensures higher profitability index, with about 1.6% increase of the IRR, that means an additional upgrading margin of more than 10 US$/bbl higher than DC.

Reference Technology	DC FP	EST FP
Upgraded feed value	77.1	94.7
less:		
Opex	*5.4*	*9.7*
Capex (@ 8%)	*18.6*	*22.2*
Fixed Costs	*4.2*	*4.9*
Netback crude price	48.9	57.9
less:		
Base crude price	*28.0*	*28.0*
UPGRADING MARGIN (@ 12.5%/y)	20.9	29.9

Table 7: Upgrading margins for a 200.000 bpd upgrading complexes based on DC and EST process to produce Final Products (all figures in US$/bbl)

Conclusions

Eni Slurry Technology is a real breakthrough technology enabling the oil industry to solve crucial problems in the upstream and the downstream sectors. EST allows the valorization to fuels of mandated higher quality of unconventional crude oils, bitumen, and increasing and worsening refinery bottoms. It also provides to refiners the necessary *fit* between the rigidity of supply and variability of refined product demand.

EST, using of a special homogeneous isothermal intrinsically safe reactor, and operating in the presence of a nano-dispersed non-ageing catalyst, converts more than 98% of any type of residues to about 110% vol. of light products and distillates. As typical performances HDS is >85%, HDM >99% and HDCCR >97%.

EST has been scaled up to a 1,200 bpd semi-scale Commercial Demo Plant in operation since 2005, validating the technical viability of the process. Based on this consolidated know how the implementation of the first EST industrial plant (23,000 bpd) at Eni Sannazzaro Refinery is in advanced progress.

The Sannazzaro plant will be not only the first EST industrial implementation, but also the first full-scale hydroprocessing plant in the world based on slurry technology.

This is a Fast Track Project: Basic and Front End Engineering Design have been completed. The EPC phase is in progress: high pressure equipment assembling is already started up. Oil in is scheduled by 4Q 2012.

Besides, feasibility studies are under execution for the conversion to EST of existing hydroprocessing units.

The benefits of application of EST in upstream complexes have been evaluated by a comparative analysis between of two process schemes to upgrade Venezuelan extra-heavy oil, respectively based on Delayed Coking conversion unit and on Eni Slurry Technology Hydrocracking unit.

The study confirms that DC is a proven and viable solution to upgrade extra heavy oils, such as the Zuata crude, but the peculiar characteristics of EST in terms of liquid yield and absence of undesired by-products constitute its superior economic attractiveness. For these reasons EST can offer additional margins in the range of about 10 US$/bbl of feedstock over current conversion technologies, such as DC.

Acknowledgement

The development of EST from laboratory to the first commercial unit has involved several skills in a number of disciplines and roles. Many colleagues of Eni Refining & Marketing Division, Exploration & Production Division, Snamprogetti/Saipem with roles in R&D, Engineering and project execution departments, and from Taranto and Sannazzaro refineries have significantly contributed with their professional and personal commitment to the birth and growth of EST.

References

1. ERTC 12th Annual Meeting, *Technology Focus Session 2007 - Heavy Oil Processing* - November 2007
2. PIRA Energy Group, *Bottom of the Barrel: the Future for Residual Fuel Oil*, August 2007
3. RADLER, M., *Oil, Gas Reserves Inch up, Production Steady in 2007,* Oil & Gas J., December 24, 2007, 22
4. IEA, International Energy Agency. *World Energy Outlook 2008*, OECD
5. PLATT J., *Petcoke and Low-Rank Coal/Lignite Supply Outlook for IGCC Evaluations*, Rep. No.1013038 - Electric Power Research Institute Final Report, Feb. 2006

6. BUTLER G., SPENCER R., COOK B., RING Z., SHEIFFER A., RUPP M., Maximize liquid yield from extra heavy oil, *Next-generation hydrocracking processes increase conversion of residues*, Hydr. Proc. Sept. 2009, 51-55
7. STRATIEV D., PETKOV K., *Residue upgrading: Challenges and perspectives. New hydrocracking technology efficiently 'cracks' heavy end cuts for distillates*, Hydr. Proc. Sept. 2009, 93-97
8. PANARITI N., DELBIANCO A., DEL PIERO G., MARCHIONNA M., *Petroleum Residue Upgrading with Dispersed Catalysts. Part 1. Catalysts activity and selectivity,* Appl. Cat. A, 204 (2000) 203-213
9. PANARITI N., DELBIANCO A., DEL PIERO G., MARCHIONNA M., CARNITI P., *Petroleum Residue Upgrading with Dispersed Catalysts. Part 2: Effect of Operating Conditions,* Appl. Cat. A, 204 (2000) 215-222
10. RISPOLI G., PANARITI N., DELBIANCO A., MELI S., *Upgrading Unconventional Oil Resources with the EST Process*, 20th World Energy Congress Rome 2007
11. PANARITI N., *Eni Slurry Technology: the Taranto CDP unit experience*, ERTC 12th Annual Meeting, Barcelona, 19-21 November 2007
12. RISPOLI, G., *Heavy Oil Upgrading*, GE Oil & Gas Annual Meeting, January 26-27, 2009, Florence, Italy
13. RISPOLI, G., SANFILIPPO, D., A. AMOROSO, *Extra Heavy Oil and Refinery Residues Upgrading through Eni Slurry Technology – First EST Commercial Units,* World Heavy Oil Conference, Puerto la Cruz, November 2009, Paper No. 359
14. DELBIANCO A., FAGGELLA A., MONTANARI R., PETTI L., SANFILIPPO, D., AMOROSO A. *Process Selection for Upgrading Extra-Heavy Oils: Venezuela Perspective*, World Heavy Oil Conference, Puerto la Cruz, Nov. 2009, Paper No. 407