Unconventional crude upgrading challenges

Case studies of upgrader technology selection such as blending of syncrude with bitumen and other intermediates. Unconventional crude quality is dependent on production location and method, design and final blending

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Crude markets are being influenced by increasing prices, stagnate discovery rates, increased world demand, and competition from alternate sources such as biofuels, coal and unconventional crude. Future crude supplies from conventional sources are anticipated to be incrementally replaced in part by the production of unconventional crude from Western Canada and Venezuela, in addition to other sources. Upgrading unconventional crude presents processing challenges both for the upgrader and the oil refinery. These challenges require careful consideration to ensure viable operation over the project's lifecycle. Adding to the challenge is the fact that upgraders are being expanded almost before they are in operation due to high market demand. Uncertainties surrounding construction costs, the availability of skilled manpower and the political climate put added pressure on the challenges facing upgrade operations.

Unconventional Canadian and syncrude crude quality

	Bitumen	SCO	DilBit	SynBit	CokerBit
Production method	SAGD	Same	SAGD	SAGD	SAGD
% diluent in blend, v%	0	0	30	50	50
w%	–	–	21.5	43.0	60.2
API	9.0	31.8	22.1	46.9	26.8
Elemental analysis, dry w%					
C	84.1	88.9	84.5	86.2	86.0
H	10.0	10.5	10.9	10.2	10.3
S	4.6	0.5	3.6	2.8	3.0
N	0.4	0.1	0.3	0.3	0.3
Metals, wppm					
Ni	60	0	47	34	24
V	170	0	134	97	68
Others	300	0	236	171	120
Oxygen, w%	0.8	0	0.6	0.5	0.3
Total, w%	100	100	100	100	100
TAN + = high	++	N/A	+	+	+

Note the examples of Table 1 use the following definitions: Bitumen, Athabasca tar sands oil; Syncrude (or SCO), a low-sulphur zero bottoms product; DilBit, bitumen diluted with condensate; SynBit, syncrude used as the bitumen diluent; CokerBit, coker distillates as the bitumen diluent.

Table 1

What is an upgrader?

The term upgrader is used to describe the unconventional crude processing plants designed to produce crude for conventional oil refinery consumption. Raw unconventional crude from the oil sands is high in viscosity and requires dilution to enable pipeline transportation. Even if it could be delivered, conventional refineries cannot process large volumes of raw crude. Upgrader operations utilise unique technologies to produce suitable synthetic crude for conventional refinery operations. The selection and bundling of upgrading technologies determines the product's flexibility and the range of refineries that can be serviced by a given design.

Unconventional crude is located mainly in Canada's Alberta Province and Venezuela's Orinoco Belt region. The unconventional crude deposits in Canada are estimated to be 1.7 trillion barrels, of which only 10% is recoverable using current technology. Recovery methods are expected to improve, increasing the quantity that is recoverable.[6]

The Canadian oil sands investment profile is expected to increase, peaking in 2008 or 2009 and then slowly declining until 2012.[10] The investment is in line with increasing production from the current 1.0 mmbpd level to 3.0 mmbpd in 2012. The Venezuelan Orinoco Belt region is producing about 600 mbpd and is located in the centre of the country.

The effect of the recent nationalisation of foreign assets on production has not been fully assessed. However, it is anticipated that production will be reduced from current levels due to a lack of skilled foreign labour to advise and assist in the operations. Although current production may not be affected, future planned investment to expand production has been stopped and projects are not progressing.

Unconventional crude and upgraded crude quality

The quality of the unconventional crude is dependent on the production location, production method, upgrader design and final blending. Unconventional crude production from Canada differs from that in Venezuela in the use of mining for some of the production, due to the shallow depth of the deposit. When possible in Canada, steam-enhanced methods for new production are used, just as in Venezuela.

The finished product from an upgrader is generally referred to as syncrude. Recent trends in Canada due to the blending of syncrude with bitumen and other intermediates have opened the possibility of custom-blending a crude for a given refinery configuration. The synergy between the upgrader and refinery operation is recognised, with Encana Energy/ConocoPhillips and Shell Canada

Venezuelan unconventional crude quality				
Description Bitumen production	**Orinoco**	**SCO Upgrader**	**Naphtha Returned to field as diluent**	**DILORIN Feed to upgrader**
% diluent in blend, v%	0	0	0	30
w%	–	–	–	22
API	8.5	32.2	59.7	20.8
SG	1.010	0.864	0.740	0.929
Elemental analysis, dry w%				
C	86	87.4	86	86
H	9	12.5	14	10.5
S	3.8	0.1	0.01	2.7
N	0.6	0.03	0.0002	0.4
Metals, wppm				
Ni	89	0	–	62
V	414	0	–	290
Oxygen, w%	0.5	0	–	0.4
Total, w%	100	100	100	100

Table 2

Unconventional crude quality concerns		
Property	**Comment**	**Impact**
API	Typically, the gravity approaches water are near, requiring a diluent to separate water from hydrocarbon	Water/oil separation
S	High sulphur levels requiring H_2 for removal, producing H_2S	Corrosion
N	High nitrogen levels requiring H_2 for removal, producing NH_3	Corrosion
Metals Ni/V/Fe	High catalyst replacement	Catalyst deactivation
Metals Na/Ca/As/Ti	Alkaline metals; special guard-bed catalysts for removal	Corrosion/catalyst deactivation
Asphaltenes	Potential for fouling, requiring S/D to clear	Fouling
Naphthanic acids	High levels causing corrosion	Corrosion/fouling
Chlorides	Typically associated with alkaline metal	Corrosion
Viscosity	Too high to pump; requires diluents	High transportation costs

Table 3

announcing separate projects to capture the economic benefits.[10]

A summary of the qualities for some of the production methods is shown in Table 1 for unconventional Canadian crudes.[11] Typical Venezuela Orinoco Basin syncrude is summarised in Table 2.[12] Due to the quality difference of the unconventional crudes, making each one requires different treatment options. A summary of the major quality concerns and their significance is discussed in Table 3.

Unconventional crude upgrading technology

Given the quality of unconventional crude, primary upgrades are required to convert this material into something typical refineries can process. Most upgraders receive the crude with diluents, which must be removed. The upgrader uses a conventional crude fractionation system to remove the diluents. Using a diluent with these materials may cause some incompatibility, unless the diluent is aromatic. Incompatibility between crude and diluent may cause fouling and sedimentation. Aromatic diluents are depleting in volume and replacements are being sought through processing of the bitumen. The majority of the crude (or bitumen) is produced at 975°F+ and requires further upgrades that include carbon rejection, H_2 addition and solvent separation.

Carbon rejection involves processes that increase product hydrogen content by removing carbon from the feed. Examples of these processes are coking and fluid catalytic cracking, of which only coking is appropriate for this service. Delayed and fluid coking were used in the first upgrading operations. The products are high in sulphur and olefins, requiring hydrotreating to produce low-sulphur syncrude.

Recent trends include using coker products as a diluent to produce a blend suitable for pumping in the pipeline, but they require special handling at the refinery. The co-ordination between upgrading technology and refining process is one of the key factors in a successful business.

Primary H_2 addition is accomplished by ebullated-bed processes. The ability to add catalyst allows these units to continue to process high containment levels. The use of these units is a technological challenge and requires specialist knowledge to operate successfully. The products have a volume swell and are lower in sulphur and nitrogen. Further treating is needed to produce finished fuels, and a significant quantity of hydrogen is required per barrel of feed.

A recent trend is to consider the use of solvent extraction or a solvent deasphalting unit (SDU) to produce a deasphalted oil (DAO) to further upgrade and a tar for either coking or gasification. Solvent deasphalting selectively removes the asphaltenes from the oil portion of the bitumen. The concept is that the metals and other contaminants will remain in the asphalt and the deasphalted oil will be clean.

Secondary systems

The products from delayed coking, fluid coking or H_2 addition require further hydrotreating to produce a low-sulphur syncrude. The hydrotreating equipment is mostly fixed bed in design. The use of guard-bed reactors and graded catalyst is necessary for activity maintenance and long catalyst life.

The aromatic nature of the unconventional crude and the heteroatoms remaining in the cracked lighter products require removal via hydrotreating. The workhorse of the upgrader is the fixed-bed hydrotreating unit. These units process all of the oil leaving the upgrader, and remove sulphur, nitrogen, metals and other impurities, replacing them with hydrogen. The hydrotreater operation is severe, requiring higher temperatures and pressures, with shorter run lengths than similar refinery processes.

Hydrogen production for the majority of existing or planned upgraders is via steam methane reforming (SMR). Declining natural gas production and a projected shortfall have made the consideration of gasification a trend. The quantity of bitumen needed to be gasified for H_2 production is about 10-12% of the feed bitumen to the upgrader. Gasification technology has been proven, but it is more expensive and complex to operate than SMR.

The use of H_2 addition combined with bottoms coking produces a bottomless syncrude. Using SDU ahead of an ebullated-bed unit produces a syncrude low in sulphur, but it contains about 10% 975°F+ bitumen. Coking followed by hydrotreating also produces a bottomless syncrude.

The upgrader can provide a variety of products, from LPG to clean VGO. Products such as LPG and ULSD are typically for local consumption. Diluent is produced to replace the diminishing quantities of condensate produced with natural gas. The different syncrudes and synbits combinations can be produced to meet refinery requirements.

Model requirement	
Heat and material balance	Unit operation model
Thermo packages	Distillation
Kinetic models	Fired heaters
Coking	Heat exchanger
Hydrotreating	
Hydrocracking	

Table 4

Technology and upgraded products

The selection of different technologies changes the investment and operating cost structures of the venture. Each of these decisions has different associated risks requiring evaluation. These include technology, business, environmental and political risks.

Proven technology in crude oil refining does not necessarily operate as well in the upgrading environment. The complexity of the upgrading train and the susceptibility to contaminants or fouling determine unit run length and maintenance costs for cleaning. The trade-off between product quality and risk sets future profitability.

The risk factors associated with upgrading are the same as for any large capital-intensive project. Additional recent risks are manpower shortages, rising construction material costs and a tightening capital market. The government's stance on Kyoto and environmental regulations further complicates the business horizon.

Historically, the typical upgrader has been constructed and operated in remote locations. Emissions regulations have been slow to take these facilities into account, but not any more. Regulations from CO_2 capture and control, as well as other initiatives, will increase the operational and investment costs of the upgrader.

The recent nationalisation by Venezuelan President Hugo Chávez indicates political uncertainty for private enterprise in this region. The loss of these assets is a financial setback to owners, but it also represents a potential loss in production due to the reduction in skilled foreign labour to run the operations.

Continual expansion

The need to expand production from current levels, such as Canadian tar sands from 1.0–3.0 mmbpd, and the high cost of grass-roots construction put constant pressure on the upgraders to improve and change operations. The need to expand requires innovative technologies and tools to get the most return out of the existing equipment. Expansion may consist of:

— Adding extra equipment to the existing trains
— Adding a new train
— Changing the existing equipment configuration.

Processing evaluation

A solid design platform, allowing flowsheeting of the entire process, is considered the best practice for evaluating the technology options. The proprietary Petro-SIM simulation technology allows a complete model of the facilities to be developed (Table 4). This technology has been successfully used to conduct technology evaluation and selection for upgrader design and operation.

Cost escalation

The investment and upgrading costs for upgraders has steadily increased at a rate greater than inflation. The cost of raw materials, such as steel, is a significant factor if the overall cost increases. The reasons for cost increases have been discussed in previous papers.[8,9] In brief, material and labour costs due to tight markets are the major reasons for the increases. These factors are magnified in the oil sands construction areas.

Operational costs

The process operation costs (excluding maintenance) of upgraders have increased due to the cost of raw materials, catalyst and chemicals. The steady rise of natural gas costs and the uncertainty in supply has increased the cost of energy by 50–100%. Catalyst cost is partially offset due to the ability to reclaim the metals added during bitumen processing. However, these costs are also climbing.

The higher investment and operating costs have a negative impact on the initial rate of return (IRR). Each 5% increase in operating and investment costs reduces the IRR by 1% in terms of 2007 pricing. The higher cost and lower returns have caused some would-be investors to rethink their position and others to withdraw from potential projects. Construction costs in Western Canada are high relative to the historic trend. Recent announcements, such as Canadian Natural Resources Ltd's placing the planned upgrader on "hold", reflect concerns over escalating costs.[1]

The overall project risk can be reduced by recognising upgrader project risk mitigation and taking measures to mitigate the effects. Using these techniques allows the project to reach a successful conclusion and meet the project's return expectation.

Case studies

KBC was engaged to perform an upgrader expansion study in Western Canada for an existing operation to determine the feasibility of various configurations and the application of new technologies. The study consisted of:

— Modelling the base operation to determine the optimal base upgrader configuration

— Evaluating processing operational changes to increase rates above the base

— Reviewing individual unit process technology for:

> "The steady rise of natural gas costs and the uncertainty in supply has increased the cost of energy by 50–100%"

– Gap between current operation and best practices

– Configuration options to close the gap

– Recommended design modifications based on modelling

— Adding new units in a logical fashion to determine the maximum benefit (eg, increased throughput) for the minimum investment.

The study results are currently under management review.

KBC performed a reliability assessment and implemented reliability improvement systems for a Venezuelan upgrader during the initial design through to startup. Due to the nature of the unconventional crude being processed, the design team was concerned that operations would not meet production goals due to unit outages. Assessment of the site design included all major equipment, procedures and practices of the upgrader. During the design phase, statistical techniques were used to predict potential failure modes, and mitigation plans were developed for each identified mechanism. The resulting startup went smoothly and the upgrader is currently in operation.

The rising cost and diminishing supply of natural gas have resulted in increased scrutiny of upgrader energy consumption. KBC strategic energy reviews (SER) focus on the energy producers and consumers, benchmarking current performance against best practices. An upgrader in Western Canada has requested an SER to determine ways to reduce its energy consumption. The assessment identified individual unit improvements and site-wide integration potential using energy pinch analysis. The site is considering how to implement these changes, and KBC is assisting in the ongoing review.

Special units: ebullated-bed residua hydrocracker

Upgrader operations utilise unique technologies to produce suitable synthetic crude for conventional refinery operations. For example, one of these technologies utilised at three of the Western Canadian upgraders is the residua ebullated-bed hydrocracker.

One upgrading facility, for example, has requested a continuous improvement programme for an existing ebullated-bed unit to allow increased profitability with minimum major capital expenditure. Subject matter experts using advanced modelling techniques (eg, Petro-SIM), computational fluid dynamics (CFD) and other tools evaluated the existing feed system, reactor and high-pressure separators. After the review, we recommended and implemented design changes to increase the unit's performance by a conservative 20% for these systems. In addition, the fractionation and recovery systems were reviewed and improved. The recommended design modifications have been partially implemented, with full implementation being considered for the next turnaround.

Consideration of the economics for different configurations during the initial project phases drives the direction for new investment decisions. An example of an investment decision` is the consideration of ULSD production either in Canada or the US. A recently published study indicates that, depending on the investment decisions being made, either location may provide the same benefit.[11]

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