Heavy Oil Upgrading by the Separation and Gasification of Asphaltenes

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Introduction
Upgrading heavy oil – be it heavy crude oil in the oil field or heavy bottoms streams in the refinery – is an increasingly prevalent means of extracting maximum value from each barrel of oil produced. Upgrading can convert marginal heavy crude oil into light, higher value crude, and can convert heavy, sour refinery bottoms into valuable transportation fuels. On the downside, most upgrading techniques leave behind an even heavier residue whose disposition costs may approach the value of the upgrade itself.

Solvent deasphalting is used in refineries processing heavy crude oils to upgrade heavy bottoms streams to deasphalted oil that may be processed to produce transportation fuels. The process may also be used in the oil field to enhance the value of heavy crude oil before it gets to the refinery. The byproduct of deasphalting is an asphaltene stream for which it is often difficult to find a beneficial use.

By integrating heavy oil deasphalting design with that of gasification, important synergies may be realized. These include reductions in capital cost, increases in energy efficiency, and enhanced performance and profitability of each unit. Environmental benefits are also obtained. In fact, the combined deasphalting – gasification unit may provide benefits that economically justify the combined processes in instances where neither of the technologies is justifiable on its own.

The Texaco Gasification Process is a market leader in the conversion of heavy oils, petroleum coke, and other heavy petroleum streams, to valuable products. The TGP is often employed as a means to beneficially use lower value streams that are produced by existing units. In this case, the design and operation of the bottoms processing unit and the TGP unit are done independently.

The TGP allows conversion of hydrocarbons, including asphaltenes, into synthesis gas that consists primarily of hydrogen, carbon monoxide, carbon dioxide, and water. The Texaco Gasification Power System technology combines the TGP with combined-cycle power and cogeneration technology to produce steam and power. The Texaco Hydrogen Generation Process combines TGP technology with that of hydrogen production. The syngas may also
be used as a precursor of other varied chemicals such as methanol, ammonia, and oxo-chemicals.

**Technology Applications**

An integrated solvent deasphalting/gasification facility is an attractive alternative for upgrading heavy oils economically. The technology can be utilized by refiners that process heavy crude oils and by oil field producers of heavy crude oils.

*Refinery applications:* For refiners, an integrated solvent deasphalting/gasification unit can increase the throughput or the crude flexibility of the refinery without creating a new, highly undesirable heavy oil stream.

Typically, the addition of a solvent deasphalting unit to process vacuum tower bottoms increases a refinery’s production of diesel oil. The deasphalted oil is converted to diesel using hydro treating and catalytic ("cat") cracking. Unfortunately, the deasphalter bottoms often need to be blended with product diesel oil to produce a viable outlet for these bottoms.

The Texaco Gasification Process (TGP) is capable of converting these deasphalter bottoms to synthesis gas ("syngas"). This syngas may be utilized by the refiner in a number of ways. The syngas can be converted to hydrogen by use of the Texaco Hydrogen Generation Process (THGP), which may be used in the refinery for hydrocracking and hydro treating. The syngas may also be used by Texaco Gasification Power Systems (TGPS) cogeneration facilities to provide low cost power and steam to the refinery. If the refinery is part of a petrochemical complex, the syngas can be used a chemical feed stock.

*Oil fields:* For heavy crude oil producers, the integrated solvent deasphalting/gasification unit can increase the value of their crude. Deasphalting removes the heavy components, reduces the metal content, reduces the Conradson carbon, and increases the API gravity of the crude. The lighter crude is more easily transported and has properties much closer to the design crude oils of most refineries. This allows the refinery to maximize refined product production allowing the refinery to justify a higher crude price.

The gasification unit provides the oil producer with syngas that can be handled in several ways. Most commonly, the syngas would feed a TGPS cogeneration unit to produce power and steam. The steam generated would then be used for well injection to enhance oil production in the field, and the power would be sold. The syngas also may be sold to third parties for its chemical value.
Process Descriptions

Deasphalting: A diagram of a deasphalting unit is given as Figure 1.

As crude oils are vacuum distilled, long chain paraffinic material and asphaltenes accumulate in the bottoms, or vacuum residue. As much as 80% of the residue from vacuum crude oil towers is paraffinic material that can be upgraded to diesel fuel.

The paraffinic components must be separated from the asphaltenes so that they can be cracked in conventional cracking units. This separation may be accomplished using solvent extraction. The extractor uses a hydrocarbon such as propane, butane or pentane to extract the paraffinic components from the feed stream. The heavy oil feed is mixed with the solvent. The asphaltenes are insoluble in the solvent and are separated from the paraffinic components by settling. The extractor produces solvent-rich deasphalted oil (DAO) and an asphaltene stream that contains some residual solvent.

The solvent-rich DAO is heated and flashed to recover the solvent. Alternatively, the solvent-rich DAO is heated to supercritical conditions and separated by settling. In either case, heat must be supplied to the process to achieve separation of the solvent from the DAO. Fired heaters and high-pressure steam are common sources for the heat. The solvent is returned to the extractor, and DAO is routed to a steam stripper for final solvent recovery. Typically the DAO is then hydro-treated to remove sulfur and acids and to maximize yield in the downstream cracking units.
The solvent that is entrained in the asphaltenes must also be recovered. The solvent-containing asphaltenes are heated above the minimum asphalt pumping temperature. This ensures that the asphalt will be pumpable after the solvent is removed. The heat source is typically a fired heater or high-pressure steam. The solvent is steam stripped from the asphaltenes in a trayed tower. The solvent is recycled to the extractor. The asphaltenes leave the stripper hot and must be cooled prior to blending for sales.

Solvent deasphalting is a cost-effective way to produce oil that can be converted to diesel from residual distillation products. The bottoms from the process are highly viscous at ambient temperature. To market this material, it must be “cut” - blended with a significant amount of expensive distillate products. This requirement it is often detrimental to the unit’s overall economics.

The deasphalting unit requires significant amounts of heat to recover the solvent used in the extraction. Whether a fired heater generates this heat or it is obtained by the use of high-pressure steam, the energy cost is significant. Finally, when a fired heater is used, stack emissions result.

**Texaco Gasification Process:** The Texaco Gasification Process was developed in the late 1940s. It was intended to produce hydrogen and carbon monoxide - syngas - for chemical plant and refinery applications. It was designed to be fed natural gas. In the 1950s, it was modified for heavy oil feeds, in the 1970s for solid feeds like coal, and in the 1980s for petroleum coke.

Nearly from its inception, the process has been an attractive means for hydrogen production. The technology for this production has become the Texaco Hydrogen Generation Process (THGP). In the late 1970s, the process was modified to mate to a combined cycle power plant. This technology became specialized to the degree that it has become its own technology, now named Texaco Gasification Power Systems (TGPS).

Texaco gasifiers will soon produce 4.6 billion standard cubic feet of syngas per day in forty-nine currently operating installations around the world and nineteen more in engineering and construction phases. The majority of this capacity is still used for chemicals production, but the percentage used for power production has been rising the fastest. Soon at least 45% of the syngas generated by Texaco gasifiers will be used for power production.

Among commercially proven technologies, Texaco Gasification Process based plants remain the most environmentally benign means of generating valuable products from sulfur-containing feedstocks. Power plants with TGPS technology emit a fraction of the NOx and SOx pollutants that are produced from conventional or fluidized bed boiler installations. And even advanced boiler systems produce solid wastes in quantities far in excess of those produced in TGPS plants.
Texaco gasification converts heavy oils such as vacuum residue and asphaltenes into synthesis gas (syngas) which is primarily hydrogen and carbon monoxide. Syngas has a variety of uses. Power, steam, hydrogen, and other products can be produced in any combination. To obtain maximum economic benefit from the unit, a low value feedstock is desirable.

The heat generated by the gasification reaction is recovered as the product gas is cooled. When the quench version of Texaco gasification is employed, the steam generated is of medium and low pressure. A quench gasification flow scheme as would be applied to the integration with deasphalting is shown in Figure 2. Note that the low-level heat used for deasphalting integration is the last stage of syngas cooling. In non-integrated cases, much of this heat is uneconomical to recover and is lost to air fans and to cooling water exchangers.

Integrated Gasification – Deasphalting: A summary of the feeds and products of integrated deasphalting and gasification is given in Figure 3. Integrating solvent deasphalting with gasification enhances the operation and economics of both technologies. There are three main synergies between the deasphalter and the gasifier:

- Beneficial use of the asphaltenes
- Internal consumption of low-level heat
- Production of hydrogen for DAO treating
- Recovery of hydrogen from hydro treating purge gas
The bottoms from the deasphalter, the asphaltenes, may be gasified. This eliminates the need to use expensive distillate blending streams to make it marketable. The asphaltenes are a low value feedstock for gasification, which enhances its profitability. In non-integrated deasphalters, however, the bottoms’ viscosity may be high enough to make pumping them to the gasifier difficult.

Heating the asphaltenes may be done to improve its pumping characteristics. Unfortunately, this material has poor heat transfer characteristics and heating it without coking is prohibitively expensive. Instead, the asphaltenes are typically cut with light oil to make them pumpable. This too is expensive.

The viscosity of the asphaltenes is higher when longer chain solvents such as pentane are used in the deasphalting process. Pentane solvent is used instead of shorter chain solvents such as propane or butane because they result in a “deeper cut”, that is, a greater yield of deasphalted oil. The pentane asphaltenes are more concentrated, and require higher temperatures to maintain pumpable viscosity.

With the integrated deasphalter-gasification unit, the gasifier feed is taken directly from the asphalt stripper. The asphalt is heated to the temperature required for optimal pumping to the gasifier prior to solvent removal, when its heat transfer characteristics are more favorable. The result is that viscosity limits on the asphaltenes are eliminated.

Most importantly, high severity deasphalting with pentane produces a higher yield of DAO and ultimately enhances the refinery’s production of diesel oil.
The gasifier charge pump draws from the bottom of the stripper and routes the material directly to the gasifier. The working volume in the bottom of the stripper acts as a charge drum for the gasifier and minimizes the storage time for the asphaltenes. This short storage time eliminates the potential of the hot asphaltenes to polymerize.

If the deasphalter shuts down, the gasifier continues to operate using the heavy oil feed to the deasphalter. The feed to the deasphalter can be gasified with only minor adjustments to the operating parameters. The deasphalter feed is not as economically advantageous a feed as the deasphalter bottoms. However, it will allow the gasifier to remain operating during deasphalter outages.

A key synergy of integrated solvent deasphalting and gasification is the sharing of each process’ heat. The solvent deasphalting process requires a significant amount of heating to recycle the solvent used in the asphaltene extraction. The heat is used to strip the solvent from the oil and the asphaltene streams so that it can be recovered and returned to the process. The gasification process produces heat that can be used for this solvent recovery in the deasphalting unit.

Integrating the solvent deasphalter and the gasification unit enhances the energy balance between both units. The low-level heat from quench gasification is used directly in a multi-stage sub-critical vaporization. No external source of heat is required to separate the solvent from the DAO. The mid-level heat from gasification is used to minimize stripping and asphalt fired heater duties.

The products of deasphalting and gasification can also be beneficially integrated. The deasphalted oil (DAO) requires hydro treating and cat cracking to become diesel. Hydrogen is required for this treating, which is a primary product of gasification. The hydrogen can be generated from the asphaltene to eliminate the need for any externally supplied hydrogen.

The purge gas from hydro treating may be routed to the gasifier. Hydrogen is then recovered in the same process used to generate syngas-borne hydrogen. This eliminates losses of hydrogen to the fuel gas system. In addition, this allows the sulfur in the DAO to be captured internally without increasing the load on the refinery sulfur facilities.

Some of the advantages of integrated deasphalting and gasification may be realized by adding TGP units to existing solvent deasphalters. The gasification of the bottoms eliminates the need to blend the bottoms stream for sale. They can also generate hydrogen for the hydro-treating needs of the refiner. These benefits can be obtained without retrofitting the existing deasphalting unit. The benefits of heat integration may be added if the facility is willing to retrofit the deasphalter.
Integration Advantages
As indicated in the preceding paragraphs, there are numerous benefits obtained in integrating deasphalting and gasification:

- **The integration allows heavy oils to be upgraded economically.**
The asphaltenes are gasified, converting this the lower value material to high value syngas. Syngas can be used as a source for hydrogen, carbon monoxide, as a precursor of oxo-chemicals, or as a fuel in combustion turbines. This eliminates the need to use expensive distillate to blend off the heavy material. In addition, the gasification unit is able to supply most of the heat required by the deasphalting unit.

- **The integration reduces capital and operating costs of both processes.**
In conventional deasphalters, a fired heater or high-pressure steam from a boiler is typically used to produce the heat necessary for the deasphalting process. This represents a significant use of fuel. When the process heat available from the gasifier is used to heat the deasphalter streams, the capital and operating cost of deasphalting is reduced.

The capital cost of the integrated gasification/solvent deasphalting unit is lower due to shared equipment. In conventional deasphalters, heat exchangers or fired heater are required to provide energy for solvent separation. In the gasification unit, heat exchangers and airfan coolers are required to cool the syngas. These services are combined in the integrated unit, reducing the total number of exchangers required and the overall capital cost.

In addition, other heat exchange surface area typically found in conventional deasphalters may be eliminated. When high level energy is used to supply heat for solvent recovery, an effort is made to recover as much heat as possible so that operating costs can be minimized. When the heat for solvent separation is being supplied from waste heat from the gasification process, this heat recovery is unwarranted.

In the integrated solvent deasphalting and gasification process, the deasphalting maximizes the use of low level heat (below 350 F) instead of using large amounts of high level heat: steam at 1000-1500 psig or fired heaters. The total heat consumption in the deasphalting is 20-40% higher with the integrated scheme. However, the operating cost is lower, because most of the heat used by the deasphalting is supplied from the gasifier. The energy from gasification would otherwise be expelled to the atmosphere. The operating costs are reduced, because a minimal amount of fuel is required supply heat to the solvent recovery process.

- **The integration allows higher yields of deasphalted oil (DAO).**
Often the recovery of DAO is limited by a viscosity specification for the asphaltenes. Without such a limit, the asphaltenes may require large amounts of high value light oil to produce a pumpable stream or a marketable product. This requirement increases with increasing asphaltene viscosity, and may eventually seriously harm the unit’s economics.
With the integrated flow scheme the asphalt viscosity need not be limited. This is due to the close coupling of the gasifier feed pump to the asphalt stripper and the additional upstream heating of the asphalt solvent mixture. Without this viscosity limit, the refinery may operate the deasphalter more severely, increasing their DAO yield and ultimately, increasing their diesel oil production.

- *The integration results in lower emissions.*

Since the integration of the deasphalter and gasification units minimizes the amount of fuel that must be consumed to generate the heat required for solvent recovery, less NOx, and carbon dioxide are emitted.

Also, the asphaltene material produced in the extractor typically contains a significant amount of sulfur components. These sulfur components become part of the residual fuel oil when the asphaltenes are blended with distillates. The sulfur is emitted when the residual fuel oil is combusted.

However, when the asphaltenes are gasified the sulfur is converted to hydrogen sulfide. This is removed from the syngas using conventional acid gas absorption technology and converted to elemental sulfur. As a result, the ultimate emissions of sulfur oxides to the atmosphere are substantially reduced. An example of a typical reduction in sulfur content leaving the refinery is shown in Figure 4.

![Refinery Fuel-Based Sulfur Emissions](image)

*Basis: 100,000 BBL/D crude with 2.5% sulfur*
Sample Economics

Refining: The integrated gasification/solvent deasphalting technology is a very attractive technology for facilities processing heavy oils. Profit margins of a refinery can be increased because the technology:

- Allows the refinery to run heavier crude
- Produces a diesel precursor from vacuum residuum
- Eliminates the asphaltenes by gasification
- Reduces the need for cutter stock
- Produces valuable products such as hydrogen, power, and steam

For example, a nominal 150,000 bbl/day refinery we are working with is able to increase their throughput by 40,000 bbl/day by purchasing heavier crude and installing an integrated deasphalter/gasification unit to debottleneck their bottoms handling capabilities. The cost of the additional crude volume is approximately offset by the decrease in crude cost. Diesel yield from the refinery, boosted by the production of DAO, is increased by approximately 20,000 barrels per day. Syngas is produced for use as hydrogen, chemical feedstock, and as feed to a cogeneration unit. The net income change for this refinery, assuming the cogeneration unit is operated by a third party, is shown below:

<table>
<thead>
<tr>
<th>Change in Net Income ($/day)</th>
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<tbody>
<tr>
<td>1. Increased Crude Expense</td>
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<tr>
<td>2. Increased Diesel Sales</td>
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<tr>
<td>3. Net Syngas Product Value</td>
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<td></td>
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<tr>
<td>Total Benefit</td>
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The capital cost of the project, including modifications to existing crude, hydro treating and cat cracking units, is approximately $500 million. The cogeneration unit is assumed to have third party ownership, but the air separation unit is included. The syngas income given above is net of the cost of power required for the new units. This gives a simple payout of about 2 years for the project. Project financing for this project can potentially be used. This significantly enhances the return due to the capital-intensive nature of the project.

Oil Fields: The technology is also attractive to facilities producing heavy oil. Integrated solvent deasphalting and gasification enhances the economics of an heavy oil production by:
Increasing the value of the crude
Eliminating the asphaltenes by gasification
Producing syngas for hydrogen, power, or steam

In some heavy oil fields, an uplift of $3-$7 per barrel may be realized for the upgrade of heavy crude to deasphalted oil, distilled kerosene and diesel components. When about 100,000 bbl/day of crude are treated, revenues in the field are enhanced by about $570,000 a day.

In the simplest case, syngas produced from the asphaltenes replace natural gas in the steam flood facility’s existing cogeneration unit. The syngas is valued at current avoided natural gas prices. However, the real cost of the syngas can be fixed. This eliminates the natural gas fuel price risk over the 20-year life of the field. Typical natural gas savings may amount to about $175,000 per day.

Due to its higher volume per unit Btu as compared to natural gas, the syngas-fed cogeneration unit produces more power and steam than the natural gas fed unit. This additional power production covers nearly all of the additional power requirements of the deasphalter and gasification facilities. The production facilities revenues are enhanced by the incremental increase steam production since this increases oil production.

Again, simple payouts for this type project are about two years.

**Conclusion**
The integrated solvent deasphalting/gasification process is an economically attractive and environmentally friendly means to upgrade heavy oil. The deasphalting part of the process, especially when carried out with a longer chain solvent, allows value to be extracted from disadvantaged oil streams. The gasification part of the process converts the undesirable asphaltene byproduct into clean syngas in an environmentally superior manner.

The unique means of integrating these two processes discussed in this paper saves capital, improves each process’s efficiency, and maximizes the advantages of each process. Use of this integrated process will expand the market of each these processes beyond that which either could gain on its own.

*Note:* Patents are pending on this integrated solvent deasphalting/gasification process.