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Study and Demonstration of a Process to Extract Bitumen from Utah Tar Sand

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Abstract

The successful implementation of a demonstration scale, continuous flow, modified hot water process to extract bitumen from Utah tar sands has potentially significant economic implications to the future of mineable hydrocarbon production in the United States.

In 1999 and 2000 a 20-ton per hour demonstration facility was operated to definitively test all aspects of a proposed hot water extraction process to extract bitumen from the Asphalt Ridge tar sand deposit near Vernal, Utah. Detailed analysis was performed on oil-water emulsions, solvent losses to rejected solids, recycle water quality and bitumen extraction efficiency.

Although the process concept is similar to Canadian oil sand operations, a fundamental difference between the Asphalt Ridge demonstration process and commercial Canadian operations is the production of dry tailings. This area of the process also required detailed investigation and optimization.

The demonstration facility was operated as three processes: extraction, froth treatment and refining. Although these areas were not operated in concert due to available equipment sizes, each area was operated successfully to equilibrium and for significant time thereafter to prove steady state operation.

The demonstration facility operation culminated in a 12 day, uninterrupted operation of the extraction process in September 2000.

The results of the study have concluded the demonstration process was operated long enough to achieve steady state conditions with an economic quantity of solvent losses and high bitumen extraction efficiency. Significant amounts of data were collected with which to design a full-scale extraction and froth treatment operation.

Introduction

In 1999 a pilot facility was installed at an existing heavy oil refinery for the purpose of extracting bitumen from the Asphalt Ridge tar sands located near Vernal, Utah. Asphalt Ridge is one of many known tar sands deposits located in the Uinta Basin. The pilot facility was designed and operated at approximately 20-ton per hour tar sands feed, resulting in bitumen production of approximately 250 bbls per day.

The process is a derivative of the Clark hot water extraction technology that has been in commercial operation in the Fort McMurray (Athabasca) region of Alberta for over 35 years. A comprehensive bench scale study of the Asphalt Ridge tar sands ore was undertaken in 1999. Based on the positive bench study results, it was decide to pursue operation of a fully integrated pilot facility at the site.

Although the process is derived from the Clark process used in Alberta, the Asphalt Ridge process contains some unique aspects. The most notable difference between the processes is the production of “stackable”, dry sand and clay tailings from the Asphalt Ridge process versus the use of tailings pond impoundments in Alberta operations. It is also noteworthy that Asphalt Ridge bitumen viscosity averages 10 to 100 times higher than Athabasca bitumen, creating unique processing and handling challenges.

The pilot facility was operated from November 1999 through December 2000. The process operation was fully comprehensive and included mining, extraction, bitumen froth treatment, bitumen separation by distillation, continuous process water recycle, and stacking of the sand tailings back into the mine area. Bitumen recovery from the pilot facility ranged from 80 to 95%. Bitumen froth produced from the extraction plant was of very high quality (60% bitumen). The froth treatment circuit consistently produced refinery specification bitumen feed (<0.5% BS&W). Specification asphalt was produced from the refinery. Process water recycle was found to be a key operational issue and much of the piloting effort was focused on optimization of this circuit. Pilot operations culminated in a continuous 12 day run where recycle water solids and dissolved ion concentrations were demonstrated to be at equilibrium from day three through day twelve.

Background

Mining of the Asphalt Ridge tar sands deposit, for street paving, dates back to at least the 1920’s. The Uinta County government developed the pit site for major county road projects in the 1950’s and has been actively mining since that time. Various efforts have been made, notably in the 1970’s and 1980's to evaluate the Asphalt Ridge deposit for commercial application but no commercial activities have succeeded to date. Several major oil companies performed extensive drill testing of the Asphalt Ridge area during that time frame[1].

The Asphalt Ridge tar sand deposit occurs in the Mesaverde and Duchesne formations. The Utah Geological Survey reports the range of estimated bitumen resource to be 1.148 – 1.173 billion barrels[1]. Economic dilution of the resource based on mining strip ratios places the recoverable resource at approximately 100 million barrels. Asphalt Ridge is located nearby to several other tar sands deposits. Two major deposits of note are the PR Springs and Sunnyside deposits that have an estimated combined resource of over 10 billion barrels bitumen[1].

It is noteworthy that at the time of this writing, three commercial tar sands facilities are in operation in Alberta, producing over 700,000 bbl/day of synthetic crude oil (syncrude). Several expansion projects and startup projects are in various stages of study or engineering and production is expected to surpass 1 million bbl/day of syncrude in the next 3 – 5 years[2].

The latest effort to recover bitumen from Asphalt Ridge was based on a solvent extraction technology. A 2,200 bbl/day bitumen extraction facility and refinery was built at the site in 1997-1998 for the production of diesel, vacuum gas oils, and performance grade asphalt. Operation of the facility yielded poor economic results and attention was turned from solvent extraction technology to the previously mentioned hot water extraction technology. It was generally thought in industry that the hot water extraction process would yield poor results on what was thought to be oil wet tar sands. The pilot facility to explore the application of hot water extraction technology was constructed in 1999.

Process and Operation Overview

A simplified process flow diagram of the pilot process is presented in Figure 1.

Mining

Mining of the tar sands ore was accomplished in similar manner to operations by Uinta County for local road paving. After overburden removal, a dozer ripped the consolidated tar sands with a drag tine and prepared the ore for loading. Ore was then loaded to trucks with a front-end loader. Ore was then trucked and delivered to a plant feed stockpile.

Extraction

Ore from the feed stockpile was delivered to the process via a front-end loader. The ore was first prepared for processing by breaking down hard tar sand lumps using a roll breaker and delumper. Once the ore was sized for handling, it was introduced into a blade mill where steam and hot water were added. The blade mill was effective in heating the ore, attritioning remaining tar sand lumps, and preliminary conditioning of the bitumen.

Discharging solids/bitumen/water slurry from the blade mill was then pumped to the conditioning tanks. The ore slurry temperature ranged from 150°F to 180°F. Conditioning is the process of liberating bitumen from the sand/clay matrix and introducing air for bitumen flotation. Conditioning was finalized in a series of agitated vessels. The resulting slurry was then diluted with hot water to promote an optimal flotation environment for the bitumen.

Diluted slurry from the conditioning vessels was pumped to the primary separation cell (PSC). The PSC operated as a quiescent separation vessel with three resulting streams: bitumen froth, middlings and sand tails. Bitumen froth collected at the top of the PSC and typically contained 60% bitumen, 15% fine solids, and 25% water. The froth overflowed a weir and was deareated for pumping to the froth treatment circuit. The middlings contained water, fine solids (clay) and small quantities of bitumen that had not floated to the top of the PSC. The sand tails contained predominately sand and water, and was pumped at approximately 60% solids for further dewatering.

Clean sand tails from the PSC was pumped to a series of sand classifiers and the sand was dewatered. Recovered water from the sand classifiers was combined with the PSC middlings to feed the mechanical flotation circuit for secondary bitumen recovery. The mechanical flotation circuit introduced large air volume and mechanical agitation to promote flotation of bitumen not recovered in the PSC. Floated froth from the mechanical floatation cells was then pumped to the PSC feed line for bitumen recovery. Mechanical flotation tails contained small amounts of un-recovered bitumen with dispersed clay and water.

Clays in the mechanical flotation tails were coagulated and then settled. The settled clays were further dewatered using a solid bowl centrifuge. Centrifuge solids (cake) was then conveyed and added to the dewatered sand. Centrifuge water (centrate) was added to the recovered water from the clay settlers and the resulting clean water stream was sent to the recycle water tank for reuse.

Dewatered sand and clay were conveyed to a discharge stockpile. The clean discharge sand was then loaded via front-end loader and used as mine backfill material.

Froth Treatment

As previously stated, bitumen froth from the Primary Separation Cell typically contained 60% bitumen, 15% clay, and 25% water. The froth constitutes a stable emulsion that can be broken using dilution and separation via high gravity centrifuges.

Bitumen froth was heated to 160°F to 180°F and blended with a diesel-like solvent for viscosity dilution. The resulting diluted bitumen emulsion was then fed to a high gravity solid-bowl centrifuge. Centrifuge solids (cake) typically discharged at approximately 60% solids. The liquid fraction of the cake was dominated by water with very small concentrations of diluted bitumen. The cake was conveyed to join the clean sand from the extraction circuit and then on to mine backfill.

Solid-bowl centrifuge liquid (centrate) was typically diluted with hot water and fed to a high gravity disk stack centrifuge. Solids and water removed from the disk stack centrifuge were pumped to the secondary flotation circuit in extraction. Disk stack centrate typically measured less than 0.5% BS&W and was sent to the refinery charge tank.

Diluent Recovery and Refining

Diluted bitumen from the froth treatment circuit was held in the refinery charge tank. Since the refinery was originally designed for approximately 2,200 bbl/day bitumen feed, it was unable to operate continuously with the 250 bbls/day produced from the pilot facility. Diluted bitumen was stored in the refinery charge tank until the charge tank was full. The refinery was then operated for three to five days at a time to process the diluted bitumen.

Diluted bitumen was heated and fed to the atmospheric distillation column. A diesel cut was taken from this column and fed to the diluent storage tank. A majority of the diesel returned to the storage tank was reused in the froth treatment process as bitumen froth diluent. Excess diesel was loaded and sold.

Atmospheric column bottoms were heated and pumped to the vacuum distillation column. Vacuum gas oils were collected from the vacuum column and sent to a storage tank for sale. Vacuum column bottoms were also sent to a storage tank for sale as performance grade asphalt.

Testing and Results

Thousands of samples were produced during the course of the pilot run. Samples were tested to determine bitumen recovery, water chemistry, diluent losses and tailings disposal characteristics. Data were also gathered to provide information for future plant construction.

Bitumen Recovery

Samples were gathered at each major exit point of the process to determine overall bitumen recovery and loss. Based on laboratory results and use of material balance calculations, the average bitumen recovery during the pilot operation was 84%. Although good, the recovery is expected to be much higher for a full scale operation. Athabasca operators report 90 to 95% bitumen recovery. From laboratory analysis, a bitumen recovery potential of 90% with a standard deviation of 8% is calculated. Observed bitumen recovery is considered to be conservative because of inefficiencies observed in the small scale pilot primarily due to the limited selection of equipment available for the pilot operation. For example, as shown in Figure 2, an undersized mechanical flotation cell permitted up to 25% bitumen loss, depending on residence time.

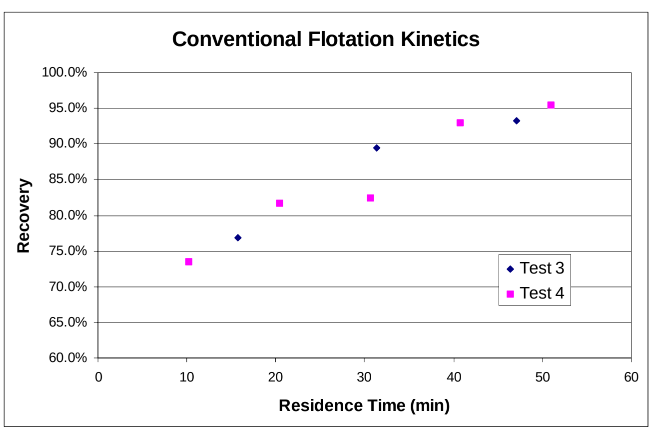

Figure 2: Bitumen Recovery vs. Residence Time

Water Quality in Recycle

As reported, water is used in the process to heat the tar sand ore, aid in the bitumen extraction process and provide a transport medium for the bitumen. The water is required to be sufficiently clean at the start of the process so that soluble ion concentrations and solids do not build up in the process and degrade the extraction efficiency. The water cleaning circuit included a thickener, clarifier, underflow centrifuges and a clean water recycle tank. In addition, various water treating chemicals were used to promote water clarity. Samples were gathered at the clean water recycle tank, clarifier overflow and clarifier underflow centrifuge centrate for analysis. The soluble ion concentration was observed during the course of the pilot test as an indication of when steady state operations were achieved. At a minimum, the pilot operation was to achieve steady state conditions so that stable process conditions could be evaluated. Steady state conditions were achieved in approximately 3 days of continuous operation. Another important indicator of the ability to control water quality is the quantity of solids buildup in the process water. As Figure 3 shows, the volume of solids in the clean recycle water never exceeded 0.6% by volume.

Diluent Losses

Diluent loss to tailings was based on the laboratory analysis of clean clay from the discharge of the solid bowl centrifuge and disk stack centrifuge used to remove solids and water in the froth treatment circuit. Using these analyses a material balance was performed and the diluent losses were calculated. Based on the calculations, the diluent lost to tails is 47% of the total diluent available from the extracted bitumen. In other words, 53% of the diluent fraction from extracted bitumen is available for sales. Laboratory testing in Canada suggests this is conservative and that much more, up to 90%, of the diluent should be available for sales.[3]

Tailings Disposal Characteristics

The disposal of the tailings was a concern from both an environmental and geotechnical standpoint. A geotechnical engineering firm was retained during pilot operation to observe and test the resulting sand/clay tailings for suitability of mine backfill. It was concluded that the tailings have moderate to high strength and will support mine backfill and future equipment trafficking and/or reclamation activities. Mine backfill tailings were also sampled under the observation and strict protocol of an independent laboratory for environmental testing. Results of this testing demonstrated the pilot operation produced tailings in compliance with site operating permits.

Results

The pilot plant produced approximately 3,000 barrels of bitumen during the course of a 12 day operation. The bitumen was diluted in diesel to assist with solid/liquid separation and as a viscosity reduction method. The dilution ratio was 2 parts diesel to 1 part bitumen. The diluted bitumen was then processed on-site at a refinery to produce diesel fuel, vacuum gas-oil and asphalt. The refinery has an atmospheric and vacuum column and was specifically designed to produce asphalt as its main product. The asphalt quality was tested extensively and is considered to be a marketable variety of performance grade asphalt, in demand for federal and state road projects. The project is currently idle.

Conclusion

The successful operation of the demonstration scale pilot facility proves that a modified hot water extraction process can extract commercial quantities of bitumen from Utah's Asphalt Ridge tar sand deposit. Given the proper equipment sizing, bitumen recovery can be expected to exceed 84% using commercially available equipment whose use is proven in the Athabasca region of Alberta. A key issue is that the pilot operation demonstrated that dry tailings, suitable for backfill, are produced. The dry tailings are enabled because process water can be cleaned using thickeners, centrifuges and water treating chemicals to remove ultrafine clay buildup. The benefit of being able to create a dry tailing discharge is to minimize the energy (heat) lost to the environment, eliminate the need for large amounts of land for settling ponds and minimize the corresponding environmental impact.

Now that the ability to extract bitumen from Utah tar sand has been demonstrated, further understanding is needed regarding small scale upgrading facilities to fully exploit this resource. The Asphalt Ridge tar sand deposit is small in comparison to the vast Athabasca oil sand deposits and cannot supply the huge quantities of tar sand required to justify a project on the scale of the Athabasca oil sand projects. However, if upgrading technologies are developed to cost effectively upgrade smaller quantities, say 5,000 barrels bitumen per day, an opportunity may exist to cost effectively exploit this resource. Utah could contain up to 25 billion barrels of bitumen in place.[1] The size of these reserves would appear to justify further research into cost effective bitumen extraction and upgrading technology.

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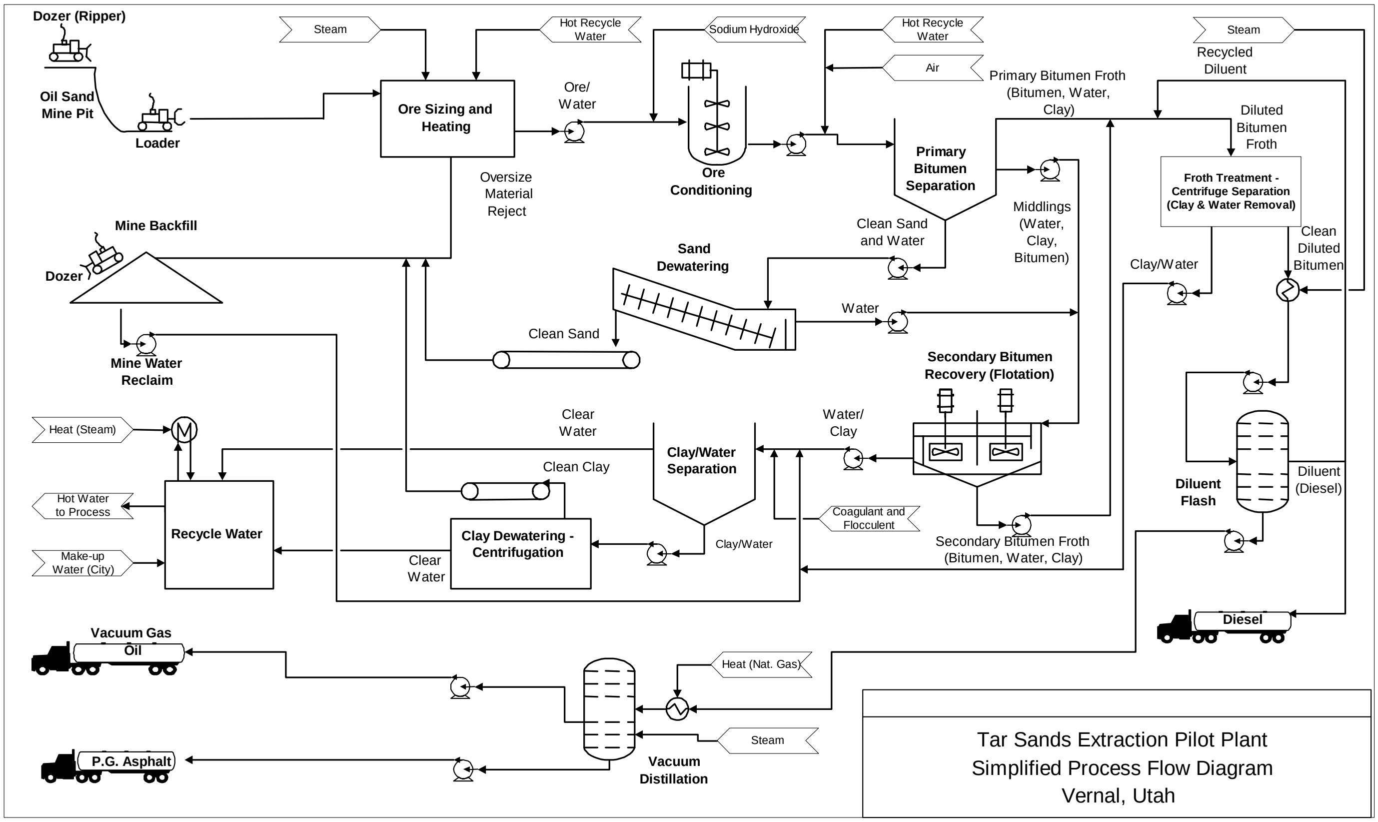

Figure 1: Simplified Process Flow Diagram

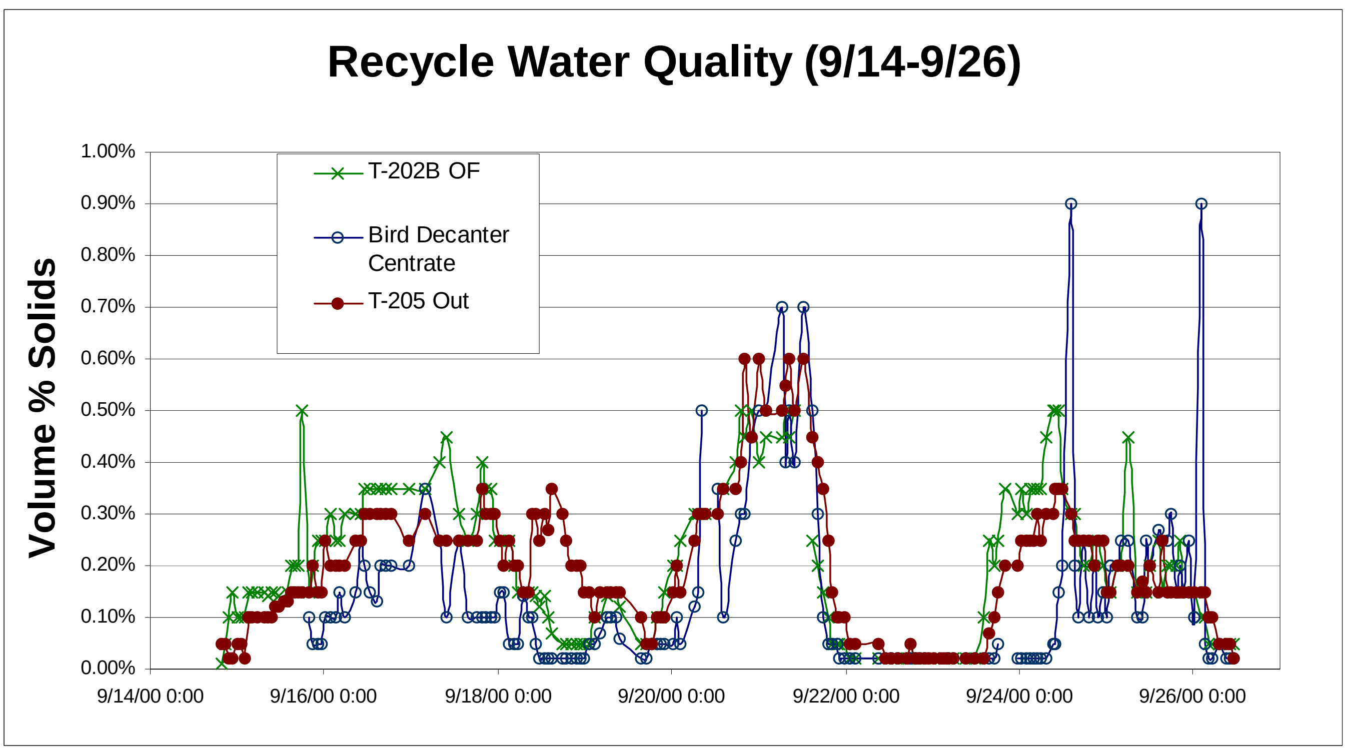

Figure 3: Recycle Water Quality, % Solids vs. Time