The Oil Drum: Canada
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Extracting Heavy Oil: Using Toe to Heel Air Injection (THAI)

Posted by Gail the Actuary on August 27, 2007 - 10:00am in The Oil Drum: Canada
Topic: Supply/Production
Tags: heavy oil, oil, tar sands, thai [list all tags]

This post reflects collaboration between Don, also known as 1observer, and myself. Don is an arms-length investor in Petrobank Energy and Resources Ltd., the company that patented THAI. Otherwise, he has no ties with the company. This post is based on an analysis of publicly available documents. I want to thank Don for all of his hard work that went into this.

1. What is toe to heel air injection technology?

Toe to heel air injection (THAI) is a new method of extracting oil from heavy oil deposits which may have significant advantages over existing methods. The method was developed by Malcolm Greaves of the University of Bath and has been patented by Petrobank. According to the Petrobank website:

> THAI™ is a evolutionary new combustion process, that combines a vertical air injection well with a horizontal production well. During the process a combustion front is created where part of the oil in the reservoir is burned, generating heat which reduces the viscosity of the oil allowing it to flow by gravity to the horizontal production well. The combustion front sweeps the oil from the toe to the heel of the horizontal producing well recovering an estimated 80 percent of the original oil-in-place while partially upgrading the crude oil in-situ.

2. Could you explain this a little more?

This method uses a horizontal well with a vertical well at the toe of the horizontal interval. For the first three months, steam is injected in the vertical well to heat the horizontal well and condition the reservoir around the vertical well. After the first three months, air is injected in the vertical well and combustion initiated. The combustion raises temperatures to approximately 400 to 600 degrees Centigrade (751 to 1,111 degrees Fahrenheit). At these temperatures, both thermal cracking and coking occurs. In this process, about 10% of the oil (the coked portion) is consumed. The thermal cracking causes the remaining oil to be upgraded. According to Petrobank's Second Quarter 2007 Financial Report:

> Ongoing analysis of the produced oil has shown a continuous upgrading effect. The produced oil is a blend of oil directly affected by combustion and oil that is mobilized and drained by heat conducted into the reservoir beyond the combustion front, which results in a varying quality of produced oil. The produced oil has consistently been of a

> materially lower viscosity and higher gravity than the native bitumen (500,000 centipoises, 7.6 degree API gravity). The quality of the produced oil has been, at times, up to 16 degrees API and less than 100 centipoises.

Once combustion is started, combustion continues as long as air is injected. In the test wells, it is estimated that this will be about five years. The combustion gasses bring the mobilized oil and vaporized water to the surface, so no pumps are needed.

These are some additional pictures of the process, showing the process in varying stages of development:

3. How much water is used in this process?

Water (and natural gas) are used during the first three months to create the steam which is injected in the well when it is first started. For the remainder of the life of the well (five years in the case of the test wells), neither water nor natural gas is used.

The second quarter report indicates that on the test wells, the oil cut is over 50%. This is in line with what is planned. Since no new water is added after the first three months, the water that is produced is from the ground. According to the quarterly report:

> . . . the produced water has been of very high quality, with clean oil/water segregation and minimal emulsion to process. Analysis of the produced water indicates that it will, with minor further processing, be suitable for other industrial uses.

4. Is Petrobank actually able to recover 80% of oil originally in place?

The material on the Petrobank web site indicates that it is expected that THAI will recover 70% to 80% of oil originally in place. If 10% of the oil originally in place is burned in the process, this would leave 10% to 20% of the oil originally in place in the ground. It is not clear from the published material regarding tests whether they are yet at the target level.

According to the Petrobank website, besides yielding 70% to 80% recoverable, THAI can be used in many areas where steam methods cannot:

- Thinner reservoirs, less than 10 meters thick
- Where top or bottom water is present
- Where top gas is absent
- Areas with "shale lenses" that act as barriers to steam
- In general, lower pressure, lower quality and deeper reservoirs than current steam-based processes

By comparison, recovery using current steam processes is estimated to be 20% to 50% in the high-grade, homogeneous areas where steam methods can be used.

5. What tests have been done on THAI?

There was considerable laboratory testing of THAI, before field testing was ever begun. This is discussed in this presentation.

Field tests started a little over a year ago. As of the writing of the second quarterly financial report, there were three well pairs in operation -- one had been in production for over 12 months, one for over 7 months, and one for over over one month.

Each of the pilot well pairs was designed for 1,000 barrels a day of fluid at a 60% oil cut, so each was designed to produce 600 barrels of oil per day. According to the second quarter financial report, what they are actually producing is "up to 2,000 barrels per day and oil cuts of over 50%". Actual production has been choked back from the 2,000 barrel per day level because of sand:

> The wells have exhibited high sand production volumes and we have had to run them on very low choke settings, significantly restricting flow rates in order to achieve higher on-stream factors through the surface facilities. A small test sand knock-out vessel demonstrated that the sand can easily be removed from the produced fluids, providing the data necessary to design the larger knock-out vessels required to operate each of the wells at their demonstrated capacity. The first, single well, sand knock-out vessel is expected to be fully operational next week, and we expect to have all three vessels in operation by mid-October. Production rates and on-stream factors are expected to increase significantly with the installation of the new sand knock-out facilities that will allow the wells to operate at their demonstrated combined capacity of up to 6,000 barrels per day of gross fluid, with oil cuts of over 50 percent.

Thus, if the sand knock-out vessels work, oil production is expected to be over 3,000 barrels for the three well pairs combined, compared to planned production of 1,800 barrels per day. Results of the tests indicate that the spacing can be increased from the current 100 meters between wells to at least 125 meters between wells.

6. What additional tests are planned ?

According to the East-West Energy Chronicle Petrobank plans to start three additional test wells in the latter part of 2007. These additional wells will test a potential enhancement to THAI, called CAPRI. With CAPRI, a nickel-based catalyst is added to the well bore, in order to increase the amount of upgrading that occurs. According to Chris Bloomer, Petrobank's Vice-President for heavy oil, "We think THAI is effectively an in-situ coker, and we hope CAPRI could be an in-situ catalytic cracker."

In addition to these three test wells, the company plans to develop an initial 10,000 barrel per day commercial project. Design work and submission of the regulatory application is expected to be completed in 2007. The cost is estimated to be about $150 million dollars, or $15,000 a flowing barrel. It is expected this could be constructed in a year. Since CAPRI has not yet been tested (except in the laboratory), this project would presumably be a THAI-only project.

7. To what extent can heavy oil be upgraded using THAI and CAPRI?

Based on a document from 2002, the hope is THAI can upgrade by 6-8 ºAPI, and CAPRI can upgrade an additional 8 ºAPI. If this can be done, there is the potential to upgrade heavy oil of 8-10 ºAPI gravity to a light oil of 24-26 ºAPI. Medium heavy crude, such as some of that found on the United Kingdom Continental Shelf, could be upgraded from 20-24 to 36-42 ºAPI.

Even if it is not possible to make such large changes in ºAPI, the hope is that the amount of dilutent can be greatly reduced.

8. How does the environmental impact compare to that of current production

methods?

It is much less. According to the Petrobank website, the THAI methodology has

• Negligible fresh water use
• 50 percent less greenhouse gas emissions
• Smaller surface footprint and easier reclamation

This is an image of what the above ground operation looks like. One can see that the footprint is quite small.

According to the 2002 document, heavy metals are expected to be reduced by 90+% by this method, and sulfur is expected to be reduced by 30% to 40%.

9. What are the economics of THAI expected to be?

According to the Petrobank website, economics are expected to be much better than current methods:

• Lower capital cost – only one horizontal well, minimal steam and water processing facilities
• Lower operating cost – negligible natural gas, minimal steam generation and minimal water processing - estimated to be 50% of steam assisted methods
• Potential for higher netbacks for partially upgraded product and less dilutent use
• Faster project execution time

According to the The East-West Energy ChronicleThe first commercial project discussed in Question 6 is expected to cost $15,000 per barrel of productive capacity and take 12 months to build.

10. What areas are under consideration for application of THAI technology?

According to the Petrobank website, THAI technology can be used on almost any area with heavy or medium oil. One possible application of THAI is to areas which have already been mined using steam methods. Because of the higher recovery percentage, considerable additional oil is expected to be extracted.

According to the Petrobank web site, Columbia is currently at the forefront of Petrobank's work on THAI outside of Canada. Other countries where agreements are in place are Brazil, Ecuador, Venezuela, and China.

There are many other parts of the world with heavy oil where THAI could also be used, including Texas, Africa, and Russia. This methodology could also be used on medium heavy oils, such as in some of the fields on the United Kingdom Continental Shelf. Since the percentage of oil recovery is so high, the method can be considered a method of Enhanced Oil Recovery, and can be used to extend the life of otherwise-depleted wells.

11. What stands in the way of the wide application of THAI?

At this point, the methodology is not fully tested. The sand problem looks solvable, but it has not been tested in practice yet. CAPRI has not been field tested at all yet. There are various enhancements to THAI and CAPRI that Petrobank would like to look at. This presentation talks about the current status of various Petrobank projects, including THAI.

If THAI is to be used more widely, the technology would need to be licensed to other users. Companies with licenses may also want to do their own tests. Even though the wells are fairly quick to build, it seems likely that it will be several years before any substantial number of wells

using this technology can be built, because of the lead times in planing new facilities, getting appropriate permits, and getting pipelines in place. Because of these lead times, it is likely that peak oil will be here before substantial numbers of wells using THAI technology can be put into operation. THAI may help mitigate the down slope, and, if it lives up to its promise, it is possible production may again increase.

It might be noted that there are other new heavy oil technologies under development as well. The booklet Unleashing the Potential of Heavy Oil discusses several other possible techniques, in addition to THAI. One such new technique uses electricity to recover bitumen. The electricity itself could be generated from the bitumen. This method produces no greenhouse gasses in the recovery process. Another method under development uses geothermal energy. These techniques may also be shown to have merit.

12. Isn't THAI the same in-situ combustion process that was used decades ago in California and several other places around the world? [Revised 8/29/2007]

No. In that process, vertical producer wells were arranged in a circle around a central air injection well. Combustion was started in the center, and air pressure was gradually increased to maintain combustion as the burned out central area became larger. There was no directional control--the fire would burn in whichever direction there was least resistance. There were two problems with this method:

• Much oil was by-passed, as the combustion extended in whichever direction it chose. Typical efficiencies were less than 30%, according to Greaves' patent.

• Air breakthroughs to the vertical producing wells were common, because of the air high pressure required in the expanding open area and because of the openings to the surface (vertical producer wells) available for air escape. The hot combustion gasses would rise and explosively break through one or more of the vertical wells. The drop in air pressure would stop combustion.

In 1992, Eugene Ostapovich (Mobil Oil) patented a partial improvement over the original in situ combustion design. Ostapovich used a horizontal producer well, but instead of the single air injector well used by Greaves, Ostapovich used multiple injector wells and multiple vent wells. This arrangement still did not work well, because the gasses could still break through one or more of the vent wells.

In 1995, Malcomb Greaves was granted a patent, improving on the invention of Eugene Ostapovich. In Greaves patent, a horizontal producer well was used with a single air injection well. With this approach, the only places for the hot combustion gasses to escape were (1) the single air injection well (which was blocked by the air or air/oxygen mixture it was injecting) or (2) through the horizontal producer well.

With Greaves invention, THAI, the heat from the combustion front liquefied the heavy oil in front of it, filling the horizontal producer well with an oil/water mixture. The combustion gasses could therefore not escape, except by helping to push the oil/ water mixture through the horizontal producer well. Thus, the combustion gasses could no longer break through to the surface. Instead, they push the oil/water mixture, eliminating the need for a pump to bring the mixture out of the horizontal producer well.

The design of THAI also provides directional control. As the mobilized oil is drained from the reservoir, a vacuum or a low pressures area is created into which air is injected. Draining the oil/water/gas mixture out of the horizontal well keeps pulling the low pressure area forward and moves the combustion in the desired direction.

13. What open issues are there with respect to THAI? [Added by Gail 8/29/2007]

These are some issues we have identified:

• The technology has only been tested for a little over a year. Will the combustion really continue for a little over five years as planned (or perhaps longer, if wells are longer)? What percentage of oil will really be recovered? How much upgrading will actually occur with THAI? With CAPRI? Are there other problems (perhaps with emissions or groundwater pollution) that will crop up several years into the test?

• How widely can this technology really be applied? The three test wells are in one location, but Petrobank believes that this technology can be used in a range of geological conditions. It really needs to be tested in a range of conditions, to know this for certain how diverse geological conditions will affect the process. Additional tests will allow people to better know what percentage of oil will be recovered, how much upgrading will occur, and what emissions or ground water pollution issues (if any) there might be under a range of conditions. Additional tests will also better determine what costs are likely to be.

• Costs of implementation are likely to vary from location to location, because of external factors such as amount and type of geological testing required; amount and type of pollution or emissions control, if any; cost of land; amount of pipeline that needs to be laid; and the amount of royalty payments that will be required. One cannot know whether THAI will be economic in a particular location without a full analysis of the costs in that location.

• In Centralia, Pennsylvania, there has been a problem with a long-burning coal mine, raising the issue of whether this kind of thing can happen with THAI. With THAI, it is necessary to inject air or an air/ oxygen mixture under pressure to maintain combustion. Because of this, the possibility of combustion extending to unwanted areas seems extremely remote. Further testing would clarify whether there is any chance of this being an issue.

• This analysis is not intended to look at the question of whether Pettrobank would profit if the technology is successful. Anyone wanting to analyze this will need to need to look at Petrobank's plans, its proposed business model, patents, competing technologies, regulatory issues, and other issues that might impact the future profitability of the company.

• We have said that THAI might help mitigate the down slope after peak oil, or may even allow oil production to begin to rise again. Without further analysis, it is not clear how much benefit THAI will provide. One issue is whether THAI really works in a wide range of applications. Another is the speed with which it might be applied, in real-world situations. A third issue is how fast the remaining oil supply is depleting. The impact may be only a little, quite late.

• There are a variety of documents relating to THAI which we have not examined, but a person wanting to dig deeper will want to review. These include:

http://www.petrobank.com/webdocs/whitesands/whitesands_application.pdf

http://www.petrobank.com/webdocs/whitesands/whitesands_eub_response.pdf

http://www.nt.ntnu.no/users/skoge/prost/proceedings/aiche-2004/pdffiles/...

Other References

Besides the links shown above, here are a few other references of interest:

This is a link to Petrobank THAI FAQ's.

This is a link to the presentation from the 2002 launch meeting for THAI.

This is a link to Malcolm Greaves staff profile at the University of Bath.