Script for Tobago Presentation:
Self lubricated transport of Bitumen Froth from concept to commercial demonstration

Dec. 18,1996

Title Slide

In the next twenty minutes I would like to tell you about our approach to technology development for bitumen froth pipelining and fill you in on some interesting results from our pilot programs. The presentation will be done from the point of view of an Industry approach to technology development, rather then purely a technical paper. For those of you that don't work directly in industry, I hope to give you a better understanding of how to get from a technical concept to commercial implementation of a technology. The paper which will be published with the proceeding of the symposium will contain more data for thoses of you who are interested.

Outline

I would like to start with the background to put the project in context. After that I'll describe the technology development program and show you the process that we used to get from a concept to a commercial demonstration.

First, we did an economic and technical screening of the available froth transfer technologies. The screening study allowed us to identify the most promising technologies for further study.

Next we did some pilot work on the most attractive options to check the assumptions that we made in the screening study.

The results from the pilot programs allowed us to select one alternative for a commercial demonstration.

Finally we updated the design and economics to reflect our much improved understanding of the technologies based on the pilot work and commercial demonstration. This work allowed us to select a technology for commercial implementation.

Oilsands Location

Syncrude Canada is located in northern Alberta, about 400 km north of Edmonton. There are four huge deposits of oilsand here, with the Syncrude operation occuring located in the Athabasca region. This region contains XX MMBBLS of recoverable crude.

Syncrude Flowsheet

This slide gives you a brief overview of the business. We mine oilsand from open pit mines. The opisand contains about 10 % bitumen, which we extract using the Clark hot water process. The bitumen is then thermally cracked and hydrotreated to make a synthetic crude.

After 25 years of operation, we run into the natural problem that the oilsand is located at increasing distances from our upgrading facilities at Mildred Lake.

Aurora Lease

The next ore body that we would like to mine is located about 35 km north east of our upgrading facilities, hence the requirement for a bitumen froth pipeline. The plan to mine this remote ore body is referred to as the Aurora Project. It involves constructing a remote mine, extraction plant, utilities plant and a pipeline. This is a $ 500 M project to produce 35 MMBBLS/Yr of bitumen starting in 2001. We plan to add a second train to Aurora in 2005 to increase production to 80 MMBBLS/Yr.

SLF Sketch

In order to understand self lubricating flow, you need to know more about bitumen froth. This slide shows a schematic of how froth is made. A slurry of oilsand and water is pumped through a pipeline in order to condition the oilsand. This conditioning liberates the bitumen droplets from the sand. The slurry is then placed in a separation vessel where the aerated bitumen floats to the top for removal. The bitumen froth is then passed through a de-aerator and placed in a surge tank before pipelining 35 km to the base plant upgrading facilities.

Bitumen

Bitumen froth is a very special kind of multi-phase material. Froth contains about 30 % water dispersed in an oil continuous phase. Dispersions of 20 to 40 % water in oil are very stable and highly viscous.

Froth viscosity is an ambigous concept since the release of dispersed water in shear lowers the shear stress required by orders of magnitude. However we can still gain some useful insight by looking at some standard rheological measurements.

Visc-Rate

We took some measurements on a froth with a 22 % water content in a parallel plate viscometer. As expected, the higher the the temperature the lower the viscosity. However we can also detect shear thinning behaviour.

Stress-Rate

This slide shows that measured shear stress tends to stop increasing for shear rates greater 100. This behaviour supports the idea that this fluid has the natural ability to lubricate.

Tech Dev.

Now that you have a feel for the background I would like to tell you about our technology development program.

We started by looking at four technologies for pipelining froth from the Aurora Mine to base plant, and I'll outline them briefly here:

For diluted froth, the scope would involve building a naphtha pipeline to Aurora, diluting the froth for viscosity reduction, then pumping it back to Mildred Lake.

Second, as I mentioned, we considered core annular flow

Emulsified froth technology calls for water and chemical addition at Aurora in order to form an oil- in-water emulsion for pipelining. The emulsion would then require chemical addition at Mildred Lake in order to invert it prior to froth treatment.

The heated froth option involves raising froth temperatures to reduce viscosity enough for reasonable pipeline pressure drops.

We started the technology development program by screening these four technologies against our understanding of the economic and technical drivers in order to shortlist the options for further, more detailed study.

Economics

We'll start with the economics. We used naphtha diluted froth as a base case, and found that the alternatives could save in the range of $ 20 to 30 M of capital because they didn't require a second pipeline to transport naphtha to Aurora.

Froth emulsion had a high operating cost for chemicals to form and invert the emulsion. This resulted in an increase in supply costs of 6 cents per barrel over the base case so we did not consider it further.

Core annular flow had the best economics with an $0.11/BBL supply cost advantage over the base case.

Technical

Now I would like to touch on the technical issues. For naphtha diluted froth, the key concern **was not** whether or not we could pipeline diluted froth, it was whether the shear that the froth is exposed to during pipelining would affect its' separability in the froth treatment plant at Mildred Lake.

Separability refers to how easily dispersed water droplets can be removed from the hydrocarbon phase by batch centrifuging. Previous has shown the negative impact of shear on the separability of diluted froth.

A second concern, is that we would like to avoid having light hydrocarbon at Aurora in the first place.

<u>Core Annular Flow</u>

Before I mention the key technical concerns for core annular flow, I would like to give you some background on the technology.

We knew that Shell had commercial experience with core flow from operating a 6" by 29 km pipeline. They transported about 12 000 BPD of 11 API crude. They did this by adding 20 to 30 % water for lubrication.

The Venezuelans have experience with a 55 km pipeline , they could successfully establish core flow, however the line would foul off over a three day period. They also had problems with high pressures when attempting to re-start the pipeline after a shutdown.

The reason that re-start is an issue, is that the stability of the layer of water at the pipewall is dependent on having a flow, *its a hydrodunamic issue*. When a pipeline is shutdown the bitumen core will tend to float or sink and the annulus is lost. When you try to re-start the pipeline, you are faced with unlubricated bitumen acting at very high viscosities. As I mentioned earlier, this can make it very difficult to get the bitumen moving again. However, the Venezualens did eventually find a couple of ways of getting around these problems.

Finally, some work at Syncrude research in 1985 proved the concept that self lubrication of bitumen froth was possible.

In summary the key technical concerns for core annular flow are pipeline fouling and the ability to re-start the pipeline.

Heated froth

For the heated froth option the energy requirements and utilities infrastructure went against our goals for Aurora of having a simple, low cost, low energy operation. Separability is also a concern since heating lowers the froth viscosity just as naphtha does.

Conclusion

In conclusion we felt that diluted froth had the best chance for technical success, however separability could be an issue.

Core annular flow had the best economic potential but needs development for this application. Given the importance of froth transfer for Aurora, we chose to pursue both technologies.

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We did three phases of pilot work to address the technical concerns.

First some small scale pipeloop work at the Alberta Research Council on naphtha froth, next a pilot program at the University of Minnesota on core annular flow; and finally some commercial scale tests on core annular flow.

Step 3 Naph

Naph-Concern...

As I mentioned the concern with the naphtha froth option was the impact of pipelining on froth separability.

The pipeline was operated at different velocities and with froth of various properties in order to simulate the shear regime in the commercial pipeline.

By shear regime I refer to
- shear at the pipewall
- peak shear rate occurring in the pump
- the impact of the flow regime
- the pipeline duration
- and temperature or naphtha to bitumen ratio which both affect froth properties

We simulated the impact of pipelining on froth treatment plant performance by conducting batch centrifuge tests on froth samples before and during pipeloop circulation. The water content remaining in the hydrocarbon phase indicated the separability of the product, - high water, poor separability

Centrifugal

We began the testing at a flow velocity of 1.5 m/s. This corresponds to an impeller speed of 2300 rpm on the centrifugal pump used in the pipeloop. The results are shown on the top line in red.

From centrifuge testing we found that the fluid separability was being damaged shortly after the loop was started. The water content at time zero is 3 % which represents the potential product quality without pipelining.

We can see from this plot that even for the first sample at the thirty minute mark that the water content of the hydrocarbon product was 11 % which is clearly unacceptable to upgrading.

However in subsequent tests at lower rpm we found that the separability was not affected as shown on the green and yellow lines.

The question that remained is "Was the fluid damaged by the pipewall shear at a given velocity, or by the peak shear at a given pump speed"?

Progressive

In order to answer this question, we changed out the pump to an inherently lower shear progressive cavity pump, and ran the pipeloop at similar conditions.

This time, as is shown on the red line, we found no fluid damage therefore we knew that the separability was being affected by the peak shear in the centrifugal pump not the shear occurring at the pipewall.

In some other tests we found that at low temperature, the fluid was damaged even using the progressive cavity pump, this is shown on the rising yellow curve. (Similarly we found that lower naphtha to bitumen ratios also caused a problem).

Next we explored the effectiveness of demulsifiers. We found that mixing demulsifier with the damaged fluid after pipelining had no benefit, however mixing demulsifier before pipelining had significant benefits.

Demulsifier

Once again the top line in red is the centrifugal pump results. We found that under the same conditions the addition of about 70 ppm of demulsifier eliminated the separability problem as shown on the yellow line. We found similar results for the tests at low temperature.

Conclusion

In conclusion:
- High shear or high viscosity conditions results in emulsion formation and poor froth separability.
- Low shear pumping to avoid emulsion is feasible
- The addition of demulsifier prior to shearing eliminates emulsion for high shear, low temperature and low N/B ratio conditions

In summary there are no show stoppers for the naphtha diluted froth option.

Given this result, we turned our focus to the technology that has the most promising economics.

Step 3 CAF

CAF - Key

As I mentioned the key issues for core annular flow are pipeline fouling and the ability to re-start the pipeline.

Our objective was to investigate those issues as well as to establish an operating envelope and the mechanism for core annular flow in order to derive scaling parameters

Results

- Froth pumped in core flow mode for periods of up to 100 hours
- No requirement for external water addition
- No indication of pressure drop increase. (Venezuelans saw fouling within a few hours which lead to S/D in three days).
- reasonable operating envelope from 0.7 to 2.5 m/s (max vel. was limited by equipment not tech).
- Shutdowns less than three minutes were re-started without water injection and at peak pressures less than 3 times operating pressure.
- Longer shutdowns required water addition equivalent to 20 wt % lubricating water

Insights

Core annular flow has always referred to a pipelining process requiring a dedicated water addition to form the annulus. One of the insights we gained in Minnesota in that froth is self lubricating, shear liberates approx. 5% of the water tied up in the froth emulsion. Free water migrates to the point of highest shear- at the pipe wall. Therefore, self lubricating flow or natural froth lubricity, is probably a better description of the technology.

Second, fouling appears to be inhibited by the liberated water. Bench scale tests show that even carbon steel fouled by the Venezuelans' Zuata crude can be cleaned by liberated water from Syncrude froth.

Third a minimum velocity of 0.7 m/s is required. Below this velocity, the froth core would begin to separate into slugs of lubricated froth between sections of water. This core separation would continue slowly over time until enough water left the annulus that a plug of froth would become unlubricated. At this point pipeline pressures would increase dramatically.

Mechanism

Proposed mechanism of self-lubrication of bitumen froth:

We know that froth is highly viscous and offers resistance to *low rates* of shearing. Our proposed mechanism for self lubrication depends on the fact that froth is unstable to *higher shearing rates*, resulting in the coalescence of water droplets to form a lubricating layer of free water. The unique property of bitumen froth that promotes the coalescence of water droplets arises from the dispersion of clay particles in the water.

The clay present in the water inhibits the coalescence of bitumen droplets and promotes the coalescence of the water droplets through a mechanism we refer to as "powdering the dough". Anyone who has baked bread will appreciate Professor Joseph's analogy.

Bread dough is sticky, but when a layer of flour is sprinkled on top, the dough will no longer stick to itself or other surfaces. The fine solids surrounding a droplet tend to act as a barrier protecting the oil droplets from coalescing with one another.

Photo of SLF

This is a high speed photo of lubricated froth occurring in a glass section of pipe at Minnesota. You can see what we call tiger waves from the froth core protruding through the milky white annulus water containing suspended clay.

Although you could spend years studying this phenomenon, I can point out that the levitation takes place due to a hydrodynamic lifting action caused by the waves sculpted on the core surface.

Step 3 Commercial

Given the encouraging results at Minnesota we decided to continue with self lubricating flow as a base case for further development.

Our intent for the commercial test was to run the equivalent of 110 000 BPD of bitumen as froth through a 24" by 1 km pipeline to duplicate the commercial conditions at full scale with respect to line diameter. We were less concerned about line length.

Objectives

Our first objective for the commercial program was to understand whether or not we could establish self lubricating flow given the shear regime that would exist in a large diameter pipe.

As an aside, we know that the surface area to volume ratio drops as you go up in pipe diameter, so a simple approach might assume that we may not have enough shear to establish self lubricating flow. However, Professor Joseph proposed that the shear required to generate a lubricated water layer can only penetrate a certain depth into the froth. A simplified model assumes that the critical shear rate for self-lubrication **is constant** for all pipe diameters and that the depth of penetration increases linearly with the flow velocity. This approach appears to be validated by the small scale test results.

If we go back to the slide for the second point, it wasn't obvious how to scale-up the re-start results from a 1 inch line diameter to a 24" line diameter.

And third we simply wanted to gain some confidence that the technology would work by seeing it a full scale.

A hurdle to overcome for commercial tests was to understand whether or not we could use a centrifugal pump. Centrifugal pumps are inexpensive and have high capacity but will not operate with fluid viscosity's higher than about 3000 cP. (The viscosity of froth at 50 C is closer to 10000 cP).
Positive displacement pumps can operate at much higher viscosities, but we would have required three pumps operating in parallel for the commercial tests, and each pump would have been among the largest in the world.

However, if our insights about self lubrication were correct than a centrifugal pump could also work in this service. Therefore we went back to Minnesota for some quick tests with a centrifugal pump and verified that it could indeed work.

Pump Photo

Pipeline Photo

I have a couple of photos of the commercial pilot to give you a feel for the scale of the plant. On the left is the main pipeline pump (in blue) with an 800 HP diesel drive (in yellow), this is a rental dredge pump. You can see part of the froth surge tank which is normally used for bitumen offloading. On the right is a 500 meter section of the pipeloop with the return elbow in the distance, this piping was borrowed from tailings.

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Prelim. Results

The preliminary results from the commercial pilot are:
- successfully established lubricated flow in a a large diameter pipeline.
- able to use a centrifugal pump to do it
- we tested pipeline shutdowns from 1 minute to 6 hours
- Successful re-starts- no high pressure water required.

Finally, we saw pressure drops on the order of 10 times the pressure drop of water which is higher than expected. However, I think its important to put this in perspective, because we would expect pressure drops on the order of 5 to 10,000 times the pressure drop of water based on conventional froth viscosity measurements.

Final Sel.

Next Steps

In order to make a final technology selection we need to complete the analysis of the commercial scale data, update the economics based on pilot learnings, and conduct a decision analysis based on the updated economics and risks.

Summary

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I'd like to wrap up my presentation with a summary of what you've heard:

First we verified that froth is the right form of product to ship from Aurora because it has the lowest supply cost for Syncrude.

Second, we did a screening study of the available froth transport technologies and identified diluted froth and core annular flow for further study.

Next, we did some pilot work to show that the diluted froth option could work by managing the separability problem with demulsifier or low shear pumps. For core annular flow we investigated the potential show stoppers and proved that pipeline fouling and re-start were manageable.

This has opened the door for us to implement a step change in technology for Aurora.

Finally, a decision analysis is in progress to make the final selection.

Acknowledgments

I would like to thank my co-authors

Ken Sury has been key part of the development program since day one, he has a very broad base of knowledge, and has always been willing to mentor me .

Peter Stapleton for his creative efforts leading the design and operation of the commercial scale pilot

Professor Dan Joseph led the Minnesota testing and provided important insight into the self lubrication mechanism and scale-up.

For the naphtha froth work; Rod Ridley and the Alberta Research Council

Ted Kizior, Mark Jamieson and Derek Cookson for helping us to understand the issues behind separability.

Ack' cont'd

For the core flow work

Owen Neiman's research in 1985 which gave us the confidence to seriously consider core annular flow
Dr. Runyan Bai for his tireless efforts at the University of Minn.
and finally, Russell Hillier, Doris Saxton, and Jeff Buckles for their efforts in the rapid and cost effective construction of the commercial scale self lubricating flow pilot.

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Thank You