Research Proposal to Syncrude Canada

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I. INTRODUCTION

The research proposal is for continued funding of research on froth lubrication which was started under liaison with Ken Sury in Oct. 1995. That research was an important positive factor in the decision of Syncrude's management to build the Aurora-Lake Mildred pipeline. I am going to specify projects for continuous research which I think are required not only for understanding but for design features and emergency procedures involved in start up and restart after shut down.

II. SUMMARY OF PREVIOUS CONTRIBUTIONS

- Established that long term self-lubricated pipelining was possible without pressure build-up.
- Found the procedures to start-up self-lubricated pipelining and wrote Syncrude's pre-patent application for these procedures.
- Identified the mechanisms of self-lubrication associated with clay covering of bitumen which prevent bitumen from sticking to itself, promoting the coalescence of clay water into lubricating sheets. I also prepared the pre-patent for this technology.
- The two patents are:
  - *NS305. Technique to promote lubrication of bitumen through the addition of colloidal particles in the water by D.D. Joseph, K.N. Sury and C. Grant.*
  - *NS306. Method for establishing self-lubricated flow of bitumen froth or heavy oil in a pipeline by D.D. Joseph, R. Bai, O. Neiman, K. Sury and C. Grant.*
- We verified that restart was easy after short shut downs and showed theoretically that a stopped line could always be restarted and experimentally that the pipeline could be cleaned by running clay water, without pigging. <u>There are no show stoppers</u>.
- We collected pressure gradient vs. flow speed data and recently added pressure gradient vs. temperature, highlighting the important role of frictional heating.
- Our results motivated the construction of the 24" pilot loop in Fort McMurray. We reduced this data, Neiman's two-inch pipeline data and our 1" data and found the

scale-up law; the pressure gradient is proportional to $U^{7/4}/R_o^{3/4}$ where U is the flow velocity and R_o the pipe radius and the constant of proportionality is 10 or 20 times greater than water, depending on the temperature.

- We have shown in our one-inch pipe that a lubrication result more favorable than the one above occurs spontaneously at high velocities (larger than 1.6 m/sec in our 1" line). This better lubrication appears to be associated with the temperature rise associated with frictional heating.
- We collaborated with Sean Sanders in the construction of the new 4" test loop in Edmonton. Of course, we hope to be able to think about how the data from this loop impacts our understandings of self-lubrication and to consider the implications of their data for the Aurora project.

III. MODIFICATION OF OUR PIPELINE TO MEET SYNCRUDE'S OBJECTIVES

We have already modified our 1" test loop to meet Syncrude's test objectives. We changed the stator in the Moyno pump and the sealing package. We arranged for mechanized loading and unloading of froth and covered the top of the supply tank. These changes must be done for environmental health and safety, but they can also reduce the waste of froth. We added a cooling system to control the temperature of the test system and an additional tank for storing ice or cold water. If the temperature in the system is too high, we turn off the head and pump cold water through the system. Our pipeline is now easy to run and the procedures for collecting data are very efficient.

IV. OVERVIEW OF PROJECTS RELATED TO SELF-LUBRICATION OF BITUMEN FROTH.

Here I will list the projects we propose to study in 1998. In the next section I will give the justification for each problem on this list, emphasizing their relation to Syncrude's objectives, specifying a projected date of completion.

1. Effect of water addition on self-lubrication

- application to restart of filled pipeline

2. Critical shear rates - rotating cylinder viscometer study

3. Water Release Studies; relationship between pressure drop, temperature, holdup, thickness of lubricating layer

4. Observing the development of self-lubrication in the critical region near the pump discharge

5. Pipeline hydraulics in lined pipes

6. Theory of turbulent self-lubrication and frictional heating in self-lubricated pipelines

V. DESCRIPTION AND JUSTIFICATION OF RESEARCH PROJECTS

1. Effects of water addition on self-lubrication (Completion Date Oct. 1998)

The study of water addition to enhance restart after shutdown and to improve start up at the pipe line entrance is important for the design and placement of injectors and procedures of water addition to relieve plug ups in real lines. Water addition is the control parameter for lubricated pipelines, but its impact on self-lubricated systems, using produced clay-water released from the froth is not well understood.

2. Critical shear rates - rotating cylinder viscometer study (Completion date Dec. 1998. We expect to issue an interim report on Aug. 1998).

The idea is to use cheap devices to get good information batch testing. These devices can be used to study water release and loss of lubrication in a more controlled, much cheaper and more easily understood setting than pipelines.

- We have constructed a rotating cylinder apparatus, with froth in the annular space between the cylinders, to measure the torque vs. angular velocity when the inner cylinder rotate). We control the ambient temperature by immersing the apparatus in a water bath. The instrument can be regarded as a froth rheometer.
- The froth temperature increases with angular velocity even when the water bath temperature is fixed. The torque begins to oscillate when the temperature rises to about 36^{o}C. This marks a transition to lubrication which is probably associated with a stick-

slip regime. At higher RPM the froth enters into a fully lubricated regime characterized by a precipitous drop of torque to values close to those for water alone. The temperature then slowly decreases to values only modestly larger than the temperature (26^{o}) of the water bath.

- The froth rheometer may also be used to find values of the torque, angular velocity and temperature for the loss of lubrication. The data for these studies are the torque curves for decreasing RPM. Self-lubrication is abruptly lost at a critical RPM not more than the critical value for the start up of self-lubrication.
- So far the results are splendid. We get an increase of torque with angular velocity until a critical value for the sample of froth is reached. Then the torque drops abruptly to almost zero signaling the start of lubrication. When we lower the torque, the lubrication effect is lost. These events are in excellent correspondence with observations in pipelines though the critical values are different.
- We have to do more testing. The froth rheometer could be the standard instrument (like a Fann) at pipeline stations. We are preparing a video and a report. Syncrude should consider whether they want to patent this rheometer. As usual, the plan proposed may and probably will be changed as dead ends and good opportunities come into evidence.

3. Water release studies (Feb. - Sept. 1998)

We want to create an extensive data base giving pressure drops, flow rates, froth temperature and froth hold ups for lubricated froth flow in our one-inch pipe. The temperature data is critical for understanding frictional heating to predict froth temperature for different froths (by composition). The prediction of temperatures in the Aurora-Mildred pipeline is an important design and operation consideration.

We need to know how the free water correlates with flow speed to get a handle on the mechanism of water release under shear. We believe that the wave structure is important here and we want to create data in which the flow speed, free water and wave length and structure are measured for each value of the pressure. The wave parameters can be measured with our high-speed video system. It would be desirable to create this data for high and low temperatures, at least, and for relatively dry and we froths.

- We are going to repeat these experiments again; this time we will add a hold-up measurement to each data point; that is, stepping up the velocity we collect the pressure gradient, the temperature and the free water at each step. We cannot understand the basic mechanisms for self-lubrication without knowing the free water, or hold-up.

4. Observing the development of self-lubrication in the critical region near the pump discharge (June-Aug. 1998)

We want to equip our pipeline with an observation section at the pipe inlet where the lubrication is formed. The formation of lubrication is still not perfectly understood and it would be beneficial to see the event. In addition, such studies might impact procedures for introductory froth in the commercial line. This is a low priority project.

5. Pipeline hydraulics in lined corrosion-resistant pipes (Sept. - Dec. 1998)

We have studied cement-line pipe for lubricated pipelines but we did not look at cement-lined pipes for self-lubrication. I understand that corrosion is an issue and cement linings are a cheap remedy. But I think that synergies between cement and clay water could give rise to desirable hydrodynamic effects of self-lubrication.

6. Theory of turbulent self-lubrication (k-ε model) and frictional heating in self-lubricated pipelines (Feb. - Dec. 1998)

It is necessary to carry out theoretical studies of frictional heating to correlate the temperature data being taken in experiments. This frictional heating could be a major factor controlling froth temperature in the Aurora line.

We are developing the theory of self-lubrication which was initiated in the paper "Self-lubrication of bitumen froth" by Joseph, Bai, Mata, Sury and Grant. We developed an idea to explain the observed increase of 10 or 20 times the friction of water. It is based on analysis of hold in turbulent flow of water. Now we have done a κ-ε calculation of turbulent flow; if you use the observed pressure gradient you find that the thickness of the turbulent water layer is consistent with our measurements of free water. The κ-ε code could enter as a theoretical tool to support the pipeline project.

The mechanisms that control self-lubrication need to be explained. It is not convenient to set theoretical results as a deliverable with a date of completion. It is more honest to say that I have a deep interest and will be working on theoretical aspects.

VI. DELIVERABLES

I work directly with Syncrude people so that we have ongoing and collaborative interactions. This mode of operation is the right one for doing the work that Syncrude wants done. Formerly, I collaborated with Ken Sury, Chris Grant and Peter Stapleton; now I work with Pat Dougan and Sean Sanders.

We also have been diligent about writing research reports summarizing all of our results. I think that one of these is in your file and a second comprehensive report of our results in the period Oct-Jan is being prepared. You have the informal preliminary versions.

We will prepare an interim in August 1998 and a final report in Jan. 1999.

VII. BUDGET JUSTIFICATION

The following people work on our Syncrude project:

D.D. Joseph (10%)
R. Bai, lab manager (30%)
Taehwon Ko - grad student (50%)
Clara Mata - grad student (5%)
Travis Smieja - undergraduate student (40%)
Shop time & clerical workers

The amount of money we get from Syncrude is perhaps 40% of what it costs to do the work. The Syncrude research is in fact being subsidized by research grants I get from the U.S. Department of Energy. I believe that the budget set down here is justified by the utility of the results we obtain for Syncrude.

The three projects listed below are submitted to Syncrude for consideration for the first year's work.

1. *Modification and improvement of the test system for the 1" pipeline (3 months)*

- Maintenance of Moyno pump: change the stator (maybe rotor) and the sealing package.
- Modify test system for loading and unloading froth, clean the pipeline and cover the top of the supply tank. These changes must be done for environmental health and safety, but they can also reduce the waste of froth.
- Add a cooling system to control the temperature of the test system. We need an additional tank for storing ice or cold water. If the temperature in the system is too high, we turn off the heat and pump cold water through the system.
- Equip the pipeline with glass or plastic glass sections at the pipe inlet where lubrication is formed and the conditions are most severe. We will examine viewing sections at different locations for each fixed flow speed.

  – ***All the proposed modifications to our 1" pipeline except the viewing section at the inlet were done. It is now easy to download froth and we have the means to control and accurately measure temperatures.***

2. *Study the critical shear rate for water release between rotating cylinders and rotating parallel plates.*

- We would like to build something inexpensive to do this kind of batch testing. The idea is to determine if and what kind of useful data can be obtained from modest equipment. We may evolve a froth tester from this work and it should serve us well in our study of the mechanism of water release.

3. ***Experiments to correlate the pressure gradient, flow rate, free water and wave structure of lubricated flows in the one-inch line (9 months)***

– ***We have generated the curve of critical velocities for loss of lubrication as a function of temperature . We don't yet now if this value is identical with the minimum critical value for starting self-lubrication.***

- Importance, relevance of proposed research.
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- The studies will be carried out in our 1-inch pipeline. We need information on scale up. We want to consider setting up a 2-inch and 1/2-inch pipeline for scale up studies. Perhaps a small facility could be set up in Canada.
- We intend to equip our pipeline with an observation sector at the pipe inlet where lubrication is formed and the conditions of lubrication are most severe. It would be useful to examine viewing sections at different locations.

I am sure that Syncrude recognizes the significant investment we made to modify our pipeline loop to meet Syncrude's test objectives. In view of this and ongoing contributions beyond the scope of the work agreement, I am requesting additional funding.

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- We know that there is a critical velocity for water release leading to lubricated flows. We have conjectured that the release is related to critical shear stress. The underlying fundamentals for water release leading to self-lubrication need further study.
- It is necessary to vary froth speed, composition, temperature and pipe diameter at the border between lubricated and non-lubricated flows. These factors, which should enter to understanding of the fundamentals are just the parameters which enter into control of start and restart and are basic to the operation of froth pipelines.

- The effective thickness of the lubricating layer is related to the amount of free water released. We need to know how the amount of free water varies with froth speed, composition, temperature and pipe diameter. We propose to create a database for free water from experimental measurements on our 1-inch pipe. The free water studies are important for understanding of shear induced release and for the determination of optimal conditions for lubricated transport.

The waves (Tiger waves) on the froth depend on the flow speed and the amount of free water. The wavelength is shorter when the wave speed is larger and when more free water is liberated. Maybe we can find a way to predict the amount of free water from observations of the speed an amplitude of waves.