PROVISIONAL PATENT APPLICATION NS306

Method for Establishing Self-Lubricated Flow of Bitumen Froth or Heavy Oil in a Pipeline

D.D. Joseph[*] , R. Bai[*], O. Neiman[‡] , K. Sury[‡], C. Grant[‡]

Background

When heavy viscous oil is transported through a pipeline, significant energy savings can be achieved by lubricating the oil flow with water as in core-annular flow. The conventional method for establishing core-annular flow is to inject water and oil simultaneously with the water in the annulus encapsulating oil. The design of injection nozzles and control of the flow rates impacts on the formation of a lubricated layer and on the time and downstream distance necessary to establish lubricated flow. Establishing lubricated flow in conventional applications is a manageable problem which can usually be controlled by varying the rate of water and oil injection. In fact, different flow types, with different pressure gradients can be achieved by varying the injection rates (see, for example, Joseph & Renardy, [1992])

The context for our invention is the need to pipeline bitumen froth economically over long distances (35km). Bitumen froth is produced from the oil sands of Athabasca using the Clark's Hot Extraction process; the froth contains about 20% to 40% by volume of dispersed water in which colloidal clay particles are well dispersed. Bitumen froth self-lubricates in a sheet of produced water; water injection is not required. In the usual oil-water mixture, dispersions of 20-40% water in oil are very stable and very viscous with viscosities even higher than the oil alone. However, the froth is unstable to faster shearing which causes produced water droplets to coalesce and form a self-lubricating layer of free produced water.

---

[*] University of Minnesota
[‡] Syncrude, Canada

Conventional methods for start-up of lubricated core flow are impractical or impossible for the start-up of core flow of bitumen froth in real pipelines. A process for restarting core flow with very viscous oils after a long standstill period by controlled injection of water was described in a patent by Zagustin, Guevara and Núñez [1988]. Their method was applied to restart an experimental one inch pipeline filled with bitumen froth at the University of Minnesota. The addition of water led to very erratic pressure readings and to achieve the restart so much water was added that the froth core broke up. The addition of water is in general not desirable; the froth contains 20 to 40% water by volume in its natural state and more water makes the separation of bitumen from water in subsequent processing more difficult.

A second method for starting self-lubricated flow of water in oil emulsions (5 to 60% water by weight) was described in a patent by V Kruka [1977]. This patent documents startup of self-lubrication of emulsions of water in Midway-Sunset crude oils by creating a certain shear rate for a certain length of time in a pipe flow to break the emulsion and create a water rich zone near the pipe wall. Kruka’s experiments were in a 1" diameter, 53.5" long pipe. He achieved the shear rates required to break the emulsion by slow increases in pressure. In the experiments with Syncrude bitumen froth at the University of Minnesota, it was not possible to start self-lubricated core flow by slow increase of pressure in a 1" by 236" long pipe. It is believed that the condition for self-lubrication can be achieved by slow increase of pressure in short pipes, but in long pipes the pressure drop required to produce the critical shear rates are too large. The method of slow increase of pressure will not work in long commercial lines. The breaking of oil-in-water emulsions is similar to, but different than the breaking of emulsions of dispersed water with colloidal clay particles in Syncrude’s bitumen froth, because the clay covering protects the bitumen from coalescing, thus promoting the coalescence of clay water under shear.

The method of startup by slow increase of pressure (Kruka 1977) differs from the method of fast froth injection behind moving water or air in a water wet pipe described below. The prior art runs through laminar flow whereas in the present invention the water is always in turbulent flow. The prior art specifies that the "...shear rate must not approach or exceed the value beyond which emulsification of the viscous and less viscous liquid will occur..." whereas no upper limit of shear rates has been found in the case of self-lubrication of bitumen froth. The long-term durability against fouling was not claimed by the prior art but is claimed for froths protected by colloidal particles (see patent application NS 305). The beneficial effects of protection of bitumen by coverings of colloidal solids, inhibiting the fouling of pipe walls and preventing the bitumen from sticking to itself does not apply to the prior art but is believed to be essential for the present invention.

The present application describes a new procedure appropriate for start up of self-lubrication of Syncrude's bitumen froth, in which the froth is injected behind water moving at a speed faster than that required to break the emulsion (the order of 1 m/sec). This method of start-up will not work for conventional heavy oils for which water addition, undesirable for froth, is required.

The claims made for self-lubrication of Syncrude's bitumen froth are believed to apply more generally to emulsions of mobile immiscible liquids in a relatively immobile viscous phase at stable volume fractions (10% to 40%) with the additional caveat that the viscous phase is stabilized against coalescence by colloidal particles in the mobile liquid.

Critical conditions for self-lubrication

The results of the 1985-1986 experiments of Neiman at Syncrude, the 1996 experiments at the University of Minnesota, and the pilot tests in a 24-inch (0.6m) diameter, 1000m long pipeloop at Syncrude, Canada, indicate that a lubricating layer of water will not form unless the flow speed is large enough. The Neiman experiments in 2" pipes do not mention this point explicitly but data for self-lubrication is given only for flow velocities greater than critical where the critical is of the order of 0.3 m/s. It is believed that the critical velocity is a function of the temperature, lower for high temperatures.

The University of Minnesota experiments using the 1" diameter pipeloop addressed this point explicitly and they showed that self-lubrication was lost when the flow velocity was reduced below 0.3-0.9 m/s, depending on the froth temperature (figure 1). They also were unable to re-establish self-lubrication by increasing the speed of the froth trough during non-lubricated slug flow regimes. In these regimes, the froth is weak but the pressure gradients are an order of magnitude greater than the value in self-lubricated flows. It is believed that if the flow velocity could be increased through the non-lubricated slugging regimes, a critical speed would be found. This experiment could not be done because of the high pressures needed to raise the flow speed are beyond capacity of the Moyno pump used in the 1" diameter pipeloop experiment.

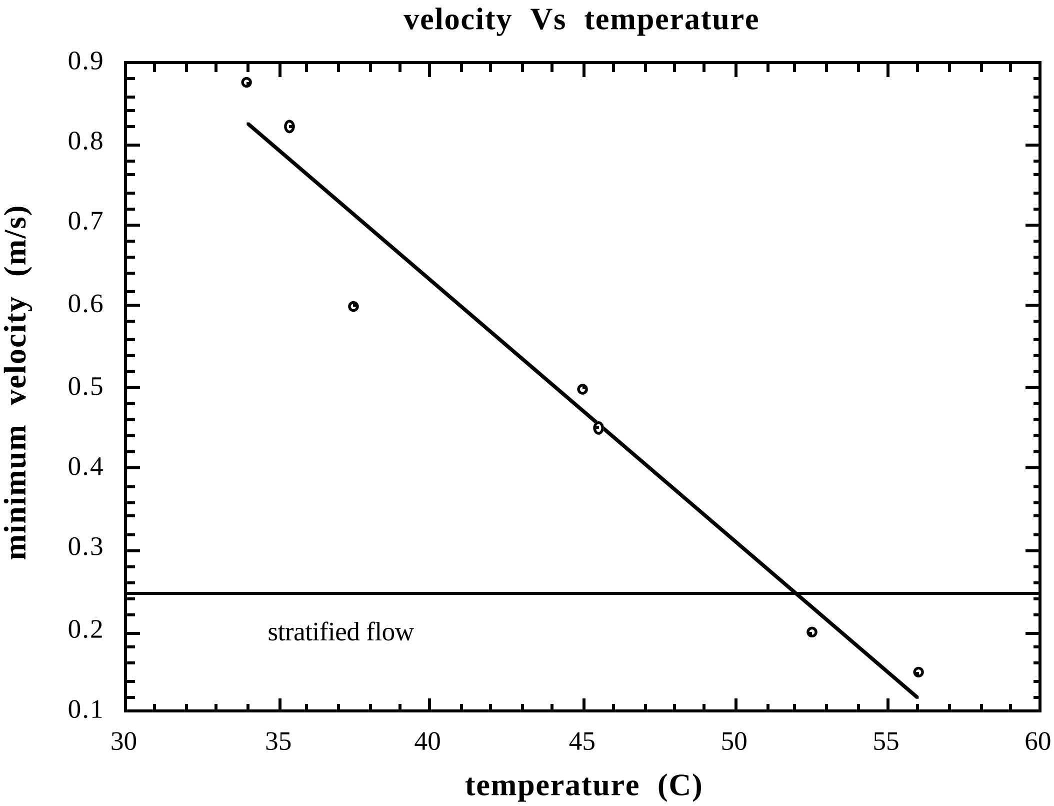

Figure 1: (University of Minnesota, 1" pipeline, July 1997) Minimum velocity for self-lubrication in a one-inch pipe as a function of temperature.

In principle there are two critical velocities for self-lubrication; the minimum velocity at which core flow can be started and the minimum at which core flow can be maintained; the latter value is easily measured and is given in figure 1. The two critical values may be the same or nearly the same.

Experiments have established that there is a critical speed for self-lubrication; below this speed the pressure gradient required is very high and depends on the froth rather than water viscosity. When the froth is injected behind fast moving water or air in a water-wet pipe, it is sheared at the wall where spherical drops of water stretch into elongated water fingers which coalesce; the bitumen does not close off the water fingers because it is protected from sticking to itself by a layer of absorbed clay. The fingers coalesce into water sheets which lubricate the flow.

The critical criterion can be possibly expressed by a critical shear stress for water release which depends on the froth, on its composition and temperature. Whenever and wherever this stress is exceeded, water will be released; the maximum stress in the froth is where it is most sheared, at the water-froth interface. The shear stress is continuous across the interface and in the water it scales with the shear rate. Hence, the critical shear stress is equivalent to a critical shear rate.

A critical speed for lubrication of Syncrude’s froth has been established in experiments in 1", 2" and 24" diameter pipes. The critical speed may be related to a critical shear stress for water, but the relation has yet to be established.

Summary:

The start-up procedure for establishing self-lubrication of bitumen froth is to introduce the froth behind a water flow at speeds greater than critical. Lubrication is established immediately by this method and the water is then diverted from the pipeline to allow continuous self-lubricated froth flow. It is important to introduce the froth at speeds high enough to promote coalescence of the bitumen drops into a film of lubricating water. Speeds of the order of 1 m/s have been repeatedly successful in 1", 2" and 24"

pipes, though somewhat lower speeds may also work. It is believed that the success of this method of start-up is due to the fact that the walls of the pipe are wet by running water prior to the introduction of the froth; the froth enters the pipe as a plug flow at speeds large enough so that even the small annular gaps of water are in turbulent flow. All these factors are favorable to the generation of high shear rates promoting the coalescence of clay water drops required for self-lubrication. Start-up procedures using fast froth injection behind moving water or air in a water-wet pipe do not generate high pressure surges or the high pressure required in start from rest procedures used in the prior art (Kruka 1977). The method of fast froth injection behind moving water also circumvents the need to add water during start up (see Zagustin et al. 1988) which has undesirable consequences for maintaining froth integrity and dewatering after pipelining. Pure water or clay water can be used for the water flow prior to froth injection.

Description of Specific Embodiment

Example 1. *Control devices for injecting froth behind moving water.*

A view of the test facility used in the Minnesota tests is shown in figure 2. Two loops (*main* and *secondary*) are connected in this facility. Froth circulates through the main loop; which principal components are a supply tank, a three stage Moyno pump, and 1” (25mm) diameter, 6m long pipeline. The supply tank is made of cast steel with a conical bottom, which promotes the flow of froth to the Moyno pump. This tank is provided with a two-marine-blade mixer, used to homogenize the froth. The Moyno pump draws the froth from the supply tank, passes it through the test pipeline, either returns to the supply tank or to the pump inlet, by-passing the supply tank. The Moyno pump is driven by a variable speed (0-1100 rpm) motor. Since the Moyno pump is a positive displacement pump, the flow rate or the speed of the froth in the pipeline is easily determined from the pump’s rpm and the pressure discharge in the pump. The test section is a 1” (25mm) diameter carbon steel pipe set in a horizontal “U” configuration.

Special attention has to be paid to the sampling system shown in the detail of figure 2. It is composed of a removable section and a bypass pipe. The removable section is a glass pipe straightway connected to the main test pipeline by means of two rubber unions tightly attached to the cast iron pipe. The principal parts of the secondary loop are a small tank (provided with and electrical resistance), a gear pump, a 1/4" diameter pipeline and a copper tube. This loop provides the main loop with water for flushing, establishing a slug or fast moving behind which we can restart froth flow. It is also to control the temperature of the flowing froth. Water can be heated by electrical resistance and kept at a certain temperature in the small tank, before it is pumped through the copper tubes rolled inside the supply tank, around the Moyno pump and around part of the pipeline.

Test Procedures. Warm froth is loaded into the supply tank and the mixer is turned on. Meanwhile, warm water is circulated in the main loop driven by the Moyno pump. This flushing and warming ensures that the pipe is clean and warm enough to receive the pre-heated and pre-homogenized froth. Once the froth is homogeneous, it is injected through the Moyno pump to the main loop. The injection points and froth preparation should be designed to prevent preferential pumping of water. Simultaneously the water is diverted. When the froth entirely replaces the water, it is circulated by the Moyno pump without further water addition. The shut-down procedure is the reverse of the start-up. The froth flow through the Moyno pump is stopped and water is injected to the line, completely diverting the remaining froth to the head tank, leaving only water circulating in the line.

Pilot Tests. The pilot scale tests were carried out in a closed loop at Syncrude, Canada. A 24" (0.6m) diameter and 1000 m long pipeline was used. The bitumen froth was recirculated in the loop, driven by a centrifugal pump. Flow rate and pressure drop were measured using an ultrasonic flowmeter and pressure transducers. The data was automatically collected and recorded. Before and after each test, the loop was flushed with tap water. Pressure drop measurement as a function of flow rate were also carried out on produced water.

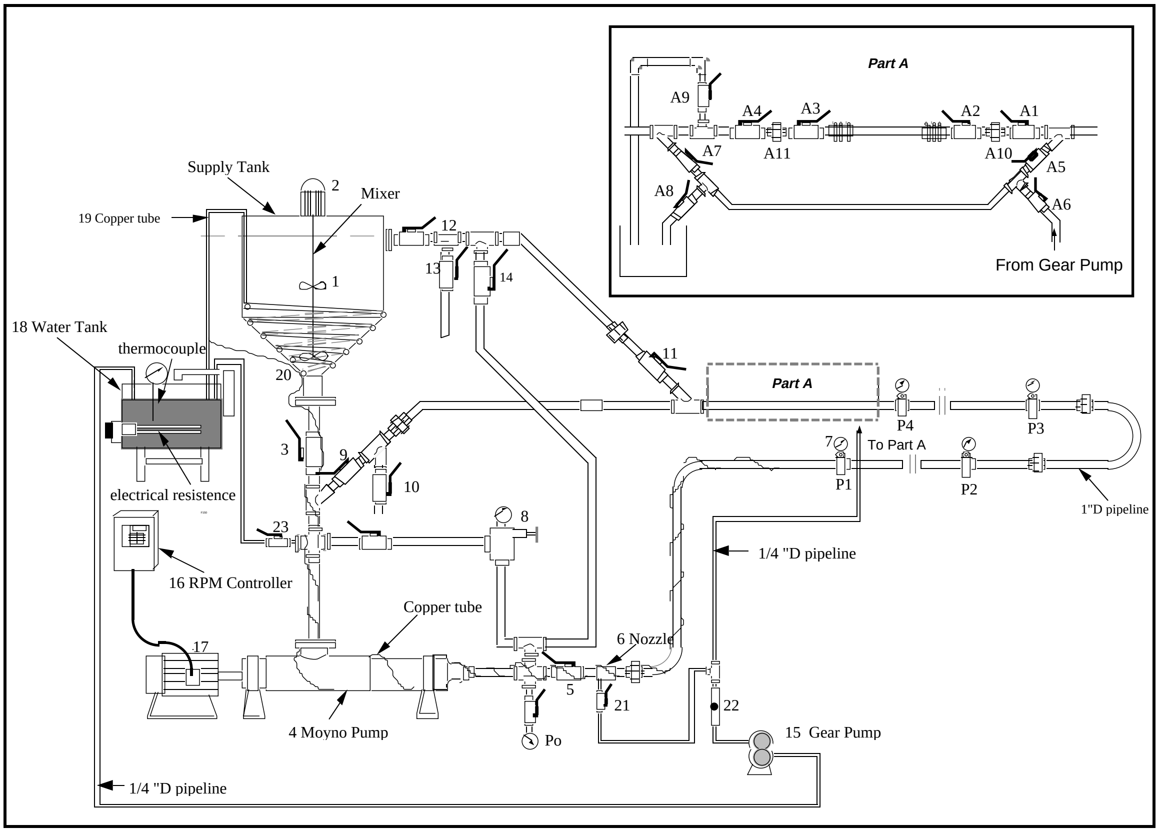

Figure 2. Test facility schematic. Two interconnected loops can be easily identified. First, a main loop, which principal components are a supply tank, a three stage Moyno pump and a 1”(25mm) diameter.- 6m long pipeline. Also a secondary or water loop which principal components a water tank, a 1/4”(6.25mm) pipeline, copper tube and a gear pump. Bitumen Froth circulates through the main loop. Pressure taps are labeled as P_o, P_1, P_2, P_3, and P_4. The distances between them are: 3.86m (P_o-P_1), 3.96m (P_1-P_2 and P_3-P_4), and 4.37m (P_2-P_3). The sampling system (Part A) is shown in detail.

Example 2.

Self-lubricated core flow of Syncrude’s bitumen froth was established in the 1" pipeline experiments at the University of Minnesota, and in the 24" pipeline experiment at Syncrude’s pilot by the method of fast froth injection behind moving water in each and every test and never by any other method.

The pilot tests were in a 24"(0.6m) diameter, 1000m long pipeloop at Syncrude, Canada. A narrative of tests results will now be given. The pump drive speed was initially set at 650 rpm to obtain a froth flow velocity of about 1.0 m/s. As the froth displaced the water in the pipeline, the pump discharge pressure increased. It took about

10 minutes to displace completely and to establish the core-annular flow. To ensure stable flow, the pump drive speed was gradually increased to 800 rpm. As the pump speed increased, the pump discharge head was well below that required for pumping water at similar flow rates. This operational setting was continued without change for 24 hours. During this period, the pressure and flow readings were monitored. There was no increase of the pressure drop and other bitumen fouling related problems. However, both froth temperature (43°C vs. 47°C) and velocity (1.10-1.14 m/s vs. 0.90 m/s) decreased for a fixed pressure drop across the loop as the night approached.

In the next test, core annular flow at a temperature of about 55°C was readily and predictably established in 10 minutes. The initial pump drive speed was set at 650 rpm and the froth flow velocity was maintained at about 0.9 m/s for 2 hours of steady operation. Then the pump drive speed was raised and lowered gradually from 650 rpm to 1000 rpm and back in steps of 50 rpm. At each speed, pressure and flow readings were monitored for about 10 minutes and test ran for 2 hours. There was no hysteresis observed either in the velocity of pressure. The average of the two sets of data at a given speed was used for further analysis.

Example 3. *The minimum speed for which core flow of bitumen can be obtained.*

The critical velocity required by the method of fast froth flow behind moving water is difficult to measure precisely. It is easier to measure the smallest velocity for which self-lubricated core flow can be maintained; this value is obtained by monitoring the pressure drop as the flow is sequentially decreased. It is believed that this value is the same as or close to the critical value required to establish self-lubricated flow. Tests at the University of Minnesota’s 1" pipeline facility established that self-lubricated flow could be maintained at velocities exceeding 0.3 to 0.9 m/sec, depending on the temperature, with smaller critical values at large temperatures (see figure 2). Tests at Syncrude’s 24" pilot pipeline showed that self-lubricated flow could be maintained at values as slow as 0.33 m/sec, but systematic data on the minimum velocity was not taken. Neimans [1985] experiments in 2" pipes do not mention critical values for self-lubrication explicitly, but data for self-lubrication is given only for flow velocities greater than 0.3 m/s.

Claims:

The following claims are for a process to establish self-lubricated core of bitumen or heavy oil in a mobile liquid containing a dispersion of colloidal particles which stick to the surface of bitumen or oil and protect it from sticking to itself. The specific embodiment of this process is the tested process for establishing self-lubricated core flow of Syncrude's bitumen froth in the produced water which is saturated with colloidal clay.

1. A process for starting a self-lubricated core flow of bitumen froth is to inject froth behind water or behind air in a water-wet pipe moving at a speed greater than the critical one required for self-lubrication.
2. A critical velocity greater than 0.3 m/s is required to establish self-lubrication.
3. The critical velocity decreases as the froth temperature increases between 35° to 51°C.
4. It is desirable to use a heated froth for start-up since the hotter froth has a lower critical velocity.
5. The process for establishing self-lubricated core flow of bitumen froth will not work for other heavy oils or bitumen with no dispersed water.

Advantages

The procedure for establishing self-lubricated flows of bitumen froth by injecting the froth in a wet pipe at speeds in excess of those required for self-lubrication is practical alternative to other methods for establishing core flow: (1) it is superior to the method of controlled injection of water which dilutes and may decompose the froth. The addition of water also increases the difficulty of final separation of water and oil. (2) It is superior to the method of slow increase of the pressure, which requires impractical high pressures to reach critical velocity in long pipelines. No other methods of establishing self-lubricated flows are known.

References

Joseph, D.D. & Renardy, Y.Y., (1992), Fundamentals of Two-fluid Dynamics, Part II: Lubricated Transport, Drops and Miscible Liquids. Springer, New York.

Zagustin, K., Guevara, E. & Nuñez, G.A., (1988), Process for restarting core flow with very viscous oils after a long standstill period. U.S. Patent 4,745,937.

Kruka, Vitold R., (1977), "Method for Establishing Core-Flow in Water-in-Oil Emulsions or Dispersions", Canadian Patent granted to Shell Canada Limited, No. 1008108.

Joseph, D.D., Bai, R., Neiman, O., Sury, K., and Grant, C., Method for Establishing Self-Lubricated Flow of Bitumen Froth or Heavy Oil in a Pipeline. Patent application NS 305.

Nieman O., (1986) Froth pipelining tests. *Syncrude Canada Research and Development Progress Report*,. **15**(1):373-407.