Abstract

Pumping fluids recovered in a marine oil spill cleanup can be problematic, particularly in cold temperatures. The high viscosity and high pour point of weathered crude oils and emulsions can lead to difficulties in pumping operations and impose a severe bottleneck in an ongoing operation.

In a series of projects over the past seven years, various aspects of dealing with cold, viscous oils and emulsions have been investigated. Specifically, individual tests have demonstrated the following:

1. Annular water injection to reduce line pressures, to facilitate pumping at higher rates and over longer distances than would otherwise be possible,
2. Viscosity reduction through the use of emulsion-breaking chemicals,
3. Steam heating to warm the contents of a mini-barge to facilitate flow,
4. Small portable pumps vs. large positive displacement pumps, and
5. The flow properties of weathered oils at temperatures significantly below their pour points.

1 Background

The tests described in this paper were initiated by a broader planning study by Alaska Clean Seas on the handling and disposal of oil recovered in a spill (SL Ross, 2000). The underlying issue under investigation was the ability to transfer cold, weathered, and possibly emulsified crude oil that had been recovered in a marine spill cleanup. In particular, the ability to pump the recovered product from a marine barge to shore-side storage in a timely manner was important to the overall effectiveness of a marine response scenario.

1.1 Procedures common to all tests

The field tests were carried out in Deadhorse, Alaska in the Alaska Clean Seas (ACS) Warehouse Annex. This facility has an open area of approximately 800 m² (approximately 55 by 15 metres), which allowed ample room in which to assemble and operate the required equipment. Performing the tests within the Annex allowed some control over the ambient temperature during the tests and test preparations. Laboratory tests were performed in the SL Ross laboratory in Ottawa.

A variety of North Slope crude oils were used in these tests. In general, oils were weathered by placing the oil in an uncovered tank, heating it with steam to approximately 82°C (180°F), and bubbling compressed air through it. The oil was weathered to increase its viscosity, to increase its emulsification tendency and stability, and to rid the oil of its most volatile components, making it safer and more stable for the tests. Seawater for making emulsions was obtained from the Seawater Treatment Plant, which draws from the Beaufort Sea. Because salt concentration
affects the stability of an emulsion, the salinity of the water was increased to 3.5% by adding powdered sodium chloride.

2 Annular Water Injection System (October 2000)

If spilled in open water or light ice conditions, most Alaskan oils will eventually form stable emulsions. Pumping weathered emulsions could result in significant pressure drops, and could limit the distance over which the oil could be pumped while respecting the pressure limits for standard discharge hose. The use of annular water injection (AWI) was thought to offer great potential for reducing the pressure drops. This work was done in conjunction with the U.S. Coast Guard (USCG), which had completed initial tests with an AWI system and was interested in additional tests with a more viscous fluid (GPC, 1999).

2.1 Test Procedures

The equipment used in the tests included: a Desmi DOP 250 submersible positive displacement pump; a 100-metre loop of 6-inch hose; 1000-kPa Hydrasearch hose fittings; and a Desmi Rotan gear pump for fluid injection.

Four different liquids were used as the injection fluid in the AWI system: fresh water, glycol, diesel, and diesel with emulsion breaker added. The glycol tests were done with a 50/50 mixture of propylene glycol and fresh water, which resisted freezing at temperatures down to -33°C (-28°F). The diesel tests were done with Arctic-grade diesel acquired locally. The emulsion breaker was EC2085, produced by Exxon-Nalco and stockpiled on the North Slope in considerable quantities for production operations. For tests with the emulsion breaker, the chemical was mixed with the diesel in a concentration that corresponded to 1000 ppm (chemical volume to total emulsion volume).

The test plan was to evaluate the effect of annular water injection with three different viscosities and five product flow rates up to the maximum pumping rate of 100 m³/h (440 gpm). For each of the three viscosities, the system was run and measurements taken both with and without water injection to demonstrate the change in line pressure. These tests were followed by a set of tests using alternatives to water as the injection fluid: first a glycol solution and then diesel. In a final test, a mixture of diesel and chemical emulsion breaker was added to the oil stream through the injection flange.

2.2 Test Results

The annular water injection system was found to significantly reduce the line pressures for a Desmi 250 pumping a 60% water-in-oil emulsion with a viscosity of 50,000 mPa.s. The pressure reduction was sufficient to allow the pump to operate at its maximum pumping rate of 100 m³/h (600 bbl/h) through 150 metres (500 feet) or more of 6-inch hose.

Glycol was an effective alternative to water as the injected fluid. A 50/50 glycol/water solution was used, which resists freezing down to -33°C.

Diesel was ineffective as an alternative to water as the injected fluid, although it does have some pressure-reducing effect because it dilutes the emulsion.

Injection of emulsion breaker into the flowing oil at a concentration of 1000 ppm quickly broke the emulsion and reduced the viscosity to its initial un-emulsified value. Adding emulsion breaker to a storage tank of emulsion, but without additional
mixing or recirculation, was not effective in breaking the emulsion although the viscosity of the emulsion was reduced somewhat. The use of chemicals to break emulsions and reduce fluid viscosity showed great promise based on the limited testing in this study. Although a comprehensive test was not done, its relative ease of use and potential promise led to further laboratory tests, described below.

2.3 Conclusions

Annular water injection is an effective and relatively simple method of reducing line pressures when pumping viscous fluids. Its main application is when the fluid must be pumped over a long distance. In Arctic conditions glycol or glycol/water mixtures should be considered as an alternative to water as the injected fluid. The use of emulsion breaker showed promise and should be investigated further.

3 Emulsion Breaking Chemicals (March 2001)

The concept under investigation was to add small amounts of emulsion-breaking chemical at the skimmer collection sump or skimmer discharge pump, which would have the effect of reducing fluid viscosities and simplify each subsequent transfer (i.e., from skimmer to storage barge and from storage barge to land-based storage). Adding small amounts of emulsion breaker to oil at ambient temperature may not completely break the emulsion, but there is evidence that it will reduce the apparent viscosity of the fluid and enhance the flow rate (Peigne and Cessou, 1989). Depending on the specific oil and emulsion-breaker, chemical is generally added at rates up to 0.2 to 1% of the volumetric flow of oil.

There is a great deal of knowledge on the Alaska North Slope on the application of chemical products, and their dosages from everyday production operations. Exxon-Nalco supplies demulsifying chemical on the Slope, and reports it has performed thousands of lab-scale tests with various chemical products on North Slope oils. Exxon-Nalco determined that EC2085a provides adequate results for a range of oils. EC2085a is therefore stockpiled on the Slope in considerable quantities for production operations.

3.1 Test Procedures

Five North Slope crude oils were selected for testing: Flow Station 1, Lisburne, Endicott, Milne Point, and Kuparuk. The oils were weathered, and then emulsions prepared by recirculating oil through a small gear pump (10 gpm at 1750 rpm) while gradually bleeding in salt water with a salinity of 3.5%. The gear pump technique produces emulsions that are more stable than those formed using the rotating flask technique, one accepted test for emulsion formation and stability. The results of the emulsion breaker effectiveness and viscosity reduction tests can therefore be considered as conservative.

The emulsion-breaking effectiveness of Exxon-Nalco EC2085a was tested on emulsions made with the weathered crude oil samples. The tests were performed in a temperature controlled chamber at 0 and 5°C. Additional tests were conducted with Endicott and Milne Point emulsions at 10°C because these oils were found to produce the most viscous and hard to break emulsions. Two dosage ratios of demulsifier to emulsion were used: 1 to 500 and 1 to 5000. The IKU Petroleum Research (Sintef Group) demulsifier test procedure that was presented at the MSRC-sponsored workshop on the formation and breaking of water-in-oil emulsions was used
The procedure is similar to the Mackay and Zagorski emulsion formation test, and involves rotating flasks containing water, emulsion and demulsifier, and then monitoring the breakage of the emulsion during a defined settling period.

The effectiveness of each demulsifier was characterized by the achieved dehydration, which is the reduction in the amount of water in the emulsion expressed as a percentage of the initial water content. The dehydration was determined two minutes after adding the demulsifier and after a twenty-four hour settling period.

The viscosity reducing effect of Exxon-Nalco EC2085 was also tested. The tests were performed using 60% water-content emulsions. A Brookfield RV DV-II+ cone and plate viscometer with a temperature-controlled bath was used to measure the viscosity of the emulsions. The viscometer requires a 0.5 mL sample of emulsion.

An initial curve of viscosity vs. time was generated at a constant shear rate by taking 1000 readings over 33 minutes (i.e., one reading every two seconds). Varying dosages of emulsion breaker were then added to samples in the viscometer, and the decrease in viscosity was measured over the same time period as the initial reading. Three dosage rates of emulsion breaker were tested: 1 to 1000, 1 to 500 and 1 to 250. The 1:1000 test was repeated three times because of the potential for experimental error related to the measurement of such small volumes of demulsifier (0.5 µL). All tests were done at 0 and 5°C, with additional tests at 10°C with the more viscous Endicott and Milne Point emulsions.

3.2 Test Results

In general, the dehydration achieved by the Exxon-Nalco EC2085a was very low (in the range of 5 to 15%), and for many of the tests no separation was seen. There was little difference in effectiveness after waiting for 24 hours. There was no significant difference when the dosage rate was increased (from 1 to 5000 or to 1 to 500), or when the temperature was increased from 0 to 5 or 10°C.

Viscosity reduction was much more promising, as summarized in the tables below. For the Flow Station 1, Lisburne, and Endicott oils (Tables 1, 2, and 3), viscosity reduction was particularly impressive, in the range of 95+% for most conditions tested. In each case, the viscosity reduction occurred quickly, with most of the decrease taking place in the first 10 to 15 minutes of the test.

In the case of the Milne Point and Kuparuk oils (Tables 4 and 5), the emulsions were very stable at the colder temperatures and only modest viscosity reductions were achieved.
Table 1: Results of viscosity reduction tests with Flow Station 1 emulsions

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Initial Viscosity(^v) (mPa.s)</th>
<th>Dosage</th>
<th>End Viscosity(^v) (mPa.s)</th>
<th>Viscosity Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>358300</td>
<td>1:1000</td>
<td>14127</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>6007</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>21983</td>
<td>94</td>
</tr>
<tr>
<td>5°C</td>
<td>76900</td>
<td>1:1000</td>
<td>1298</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>2348</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>1136</td>
<td>99</td>
</tr>
</tbody>
</table>

\(^v\) rpm = 0.3, shear rate = 0.6 s\(^{-1}\)

Table 2: Results of viscosity reduction tests with Lisburne emulsions

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Initial Viscosity(^v) (mPa.s)</th>
<th>Dosage</th>
<th>End Viscosity(^v) (mPa.s)</th>
<th>Viscosity Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>233300</td>
<td>1:1000</td>
<td>12743</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>16059</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>8558</td>
<td>96</td>
</tr>
<tr>
<td>5°C</td>
<td>27000</td>
<td>1:1000</td>
<td>1345</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>474</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>541</td>
<td>98</td>
</tr>
</tbody>
</table>

\(^v\)0°C, rpm = 0.3, shear rate = 0.6 s\(^{-1}\); at 5°C, rpm = 2.5, shear rate = 5 s\(^{-1}\)

Table 3: Results of viscosity reduction tests with Endicott emulsions

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Initial Viscosity(^v) (mPa.s)</th>
<th>Dosage</th>
<th>End Viscosity(^v) (mPa.s)</th>
<th>Viscosity Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>379200</td>
<td>1:1000</td>
<td>66405</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>38779</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>19597</td>
<td>95</td>
</tr>
<tr>
<td>5°C</td>
<td>325000</td>
<td>1:1000</td>
<td>117582</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>56333</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>10°C</td>
<td>28700</td>
<td>1:1000</td>
<td>463</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>158</td>
<td>99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>236</td>
<td>99</td>
</tr>
</tbody>
</table>

\(^v\)0 and 5°C rpm = 0.3, shear rate = 0.6 s\(^{-1}\); 10°C rpm = 3, shear rate = 6 s\(^{-1}\)

Table 4: Results of viscosity reduction tests with Milne Point emulsions

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Initial Viscosity(^v) (mPa.s)</th>
<th>Dosage</th>
<th>End Viscosity(^v) (mPa.s)</th>
<th>Viscosity Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>238900</td>
<td>1:1000</td>
<td>148339</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>93458</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>105964</td>
<td>67</td>
</tr>
<tr>
<td>5°C</td>
<td>83846</td>
<td>1:1000</td>
<td>27729</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>45310</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>22194</td>
<td>74</td>
</tr>
<tr>
<td>10°C</td>
<td>12871</td>
<td>1:1000</td>
<td>831</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>366</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>426</td>
<td>97</td>
</tr>
</tbody>
</table>

\(^v\)0°C, rpm = 0.3, shear rate = 0.6 s\(^{-1}\); 5°C, rpm = 1, shear rate = 2 s\(^{-1}\); 10°C, rpm = 3, shear rate = 6 s\(^{-1}\)
### Table 5: Results of viscosity reduction tests with Kuparuk emulsions

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Initial Viscosity (mPa.s)</th>
<th>Dosage</th>
<th>End Viscosity (mPa.s)</th>
<th>Viscosity Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
<td>140000</td>
<td>1:1000</td>
<td>82264</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>128654</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>68437</td>
<td>51</td>
</tr>
<tr>
<td>5°C</td>
<td>57100</td>
<td>1:1000</td>
<td>49529</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:500</td>
<td>44597</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1:250</td>
<td>23503</td>
<td>59</td>
</tr>
</tbody>
</table>

1°0°C, rpm = 0.6, shear rate = 1.2 s⁻¹; at 5°C, rpm = 1.5, shear rate = 3 s⁻¹

### 3.3 Conclusions

The addition of demulsifier at a dosage rate of 1 to 1000, coupled with moderate mixing was successful at reducing the viscosity of emulsions formed from several North Slope crude oils at 0 and 5°C within 30 minutes. For two oils, the emulsions proved to be more stable and resistant to the effects of the demulsifier even at elevated dosage rates. Additional tests at an elevated temperature indicated that heating the emulsion to 10°C would result in an acceptable viscosity reduction.

It was concluded that mixing emulsion-breaking chemical into stored emulsion would be an effective means of rendering the product more pumpable for some crude oils.

### 4 Pumping a Cold, Weathered, Emulsion (October 2001)

The objective of this study was to demonstrate offloading using the worst-case parameters of hose length and elevation head, while pumping an emulsion at 0°C (32°F) with a viscosity representative of what would be expected from an oil spill recovery operation.

#### 4.1 Test Procedures

The test plan was to prepare the emulsion at a temperature just above its pour point and perform the pumping demonstration at as cold a temperature as possible. Prior to the test, a sample of emulsion was pumped from a steel tank to an overpack drum. This smaller volume could be more readily cooled to demonstrate the gelling characteristics of the emulsion at near-freezing temperatures.

#### 4.2 Test Results

Two pumping tests were performed with an emulsion temperature of 15°C (59°F) and between 10°C and 14°C (50°F and 57°F). In each case, the emulsion was fluid enough to flow to the pump suction. This would appear to be at odds with the pour point of the oil, which was measured to be 19°C (66°F), and of the emulsion prepared in the lab, which had a pour point of 46°C (115°F). It should be noted that the pour point, while providing an indication of the temperature at which a fluid will gel, is estimated with a test performed in a small-diameter test jar and is not totally applicable to the pumping scenario demonstrated in these tests. (This was investigated more thoroughly later, as described in section 7 of this paper.)

The final test was a qualitative demonstration of pumping an emulsion well below its pour point. Prior to the first test, a 270-litre sample (72-gallon) was pumped from the steel tank to an open-top drum. Since that time, it had cooled for 44 hours while sitting within the warehouse. To cool it further, the drum was set outside on a
pallet. After 4.5 hours the emulsion had cooled somewhat but not equally through the drum; the temperature was -3°C (27°F) at a point 8 cm (3 in) in from the wall of the drum, +3°C some 15 cm (6 in) in, and +7°C in the middle (all measurements taken at a depth of about 20 cm).

The Desmi pump was lowered into the drum of oil with the suction positioned just below the surface. As in the previous two tests, the pump was lowered periodically such that the pump suction was in the upper surface of the emulsion. The pump was started at low speed.

The pump drew emulsion into its suction, but only from the immediate periphery of the pump. As the pump was lowered into the drum it continued to pump, but gelled emulsion was left clinging to the walls of the drum.

4.3 Conclusions
Of particular interest was that the pump could draw in and pump oil that was semi-solid although the oil was gelled to the extent that it could not flow to the pump suction to maintain flow. In other words, the ability of the fluid to flow to the pump suction, rather than the pump itself, was the limiting factor.

5 Use of Steam Heat to Facilitate Pumping (December 2002)
The objective of this study was to demonstrate that an oil spill emulsion at 0°C could be heated using readily available steam-generating equipment, such that the emulsion could be pumped off.

5.1 Test Procedures
Oil was weathered and an emulsion formed, then placed in a 3.7 x 3.7 x 1.5 metre (12 x 12 x 5-foot) deep open-top steel tank, approximately 20 m³ (125 barrels). Thermocouples were positioned within the tank to provide measurements of the fluid temperature while it was cooled and subsequently when it was heated.

The heating procedure was simply to apply steam using two simple “injection” lances. Each of the two lances was a 1-1/4 inch aluminum pipe fitted to the discharge hose from the steam boiler. Each pipe was intentionally bent to form a gentle curve. This was done so that the flow of steam would create a circulation within the tank and enhance the transfer of heat from steam to emulsion. The steam lances were inserted through the “deck hatch” and positioned such that they were discharging steam across the bottom of the tank.

5.2 Test Results
Steam heat was applied to the tank of emulsion starting at 0845h and ending at 2350h, for a total of 15 hours. The steam unit had to be operated at a reduced capacity for the first eight hours of the test, and was operating at an estimated 25% capacity for the first seven of those hours. This was done to reduce splashing of the heated emulsion, and associated leaking of oil from the junction of the joists supporting the deck and the steel tank. Had the steam unit been run at full capacity from the outset, it would have taken an estimated 9.5 hours to heat the tank.
5.3 Conclusions
Steam can facilitate pumping cold emulsion. However, given the time required, it would likely only be considered as a last resort if no other method were feasible.

6 Use of Small Portable Pumps (2004)
The objective of the study was to demonstrate the feasibility, determine realistic rates, and identify possible limitations of 3-inch and 4-inch portable diaphragm and trash pumps. The demonstration was performed using representative parameters of hose length and elevation head, while pumping a cold, weathered oil that had a pour point in excess of ambient temperatures.

The test addressed two major uncertainties with the feasibility of the pumping scenario that was being simulated: the ability of the cold, weathered oil to flow to the pump suction, and the limitation on the pumping rate associated with the viscosity of the oil (and its effect on the backpressure developed in the transfer hose).

6.1 Test Procedures
Three candidate oils were tested in the lab, resulting in the selection of Pt. McIntyre as the test oil. Its pour point, when weathered 20% by volume, was estimated to be 9°C (50°F). Unfortunately, the oil that was received for testing was more fluid than expected; although weathered to 22% by volume, its pour point was estimated to be 0.7°C (33°F).

The oil was weathered, placed in 60-cm (2-foot) deep portable tanks, and allowed to cool in preparation for the tests. Tests were performed with three trash pumps and one diaphragm pump. A hose loop was formed, with oil discharged back into the holding tank. Instrumentation in the hose loop monitored line pressures and flow rates.

To test the ability of a pump to self-prime, it was important to use “undisturbed” oil, that is, oil that has cooled in the tank and not disturbed, such that the wax crystalline structure remains intact. It is this wax structure that causes it to gel, and that causes difficulties for pumping.

A brief test was performed with each of the pumps to determine their ability to prime from a “dry” condition, i.e., the pump casing and suction hose empty. The test was brief, on the order of time to prime plus 10 seconds, just long enough to determine that prime was established and flow started. For each test, the suction hose was inserted in an undisturbed section of the tank. The discharge hose was directed to a separate tank so that the flow of pumped oil did not disturb the test oil for subsequent tests.

6.2 Test Results
Each of the four pumps was able to self-prime from a dry condition drawing from undisturbed oil at an oil temperature of -13°C (9°F). Note that the pumps were able to self-prime with viscous oil that was 13°C (24°F) below the pour point, as measured in the laboratory.

Samples of the oil were taken during the tests and subsequently analyzed in the SL Ross laboratory. Seven samples were taken and the results averaged, as shown below in Table 6. Care was taken to obtain representative samples: the oil was taken
during the test, from an area in the tank that was well mixed with oil from the discharge hose.

<table>
<thead>
<tr>
<th>Table 6: Viscosity of oils sampled during testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity @ 32°F (0°C)</td>
</tr>
<tr>
<td>shear rate 10 s⁻¹</td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

It was intended to measure pumping rates and pressures at increasing pump speeds, starting at a low setting and gradually increasing the throttle. However, this proved difficult as all of the pumps tested were essentially “on-off”, and performed poorly until the throttle was increased to “full” or nearly so. Table 7 shows the measured rates and pressures at full-throttle pump speeds.

<table>
<thead>
<tr>
<th>Table 7: Measured pumping rates and pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil temperature °C (°F)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>3-in. diaphragm</td>
</tr>
<tr>
<td>3-in. trash</td>
</tr>
<tr>
<td>3-in. Sykes</td>
</tr>
<tr>
<td>4-in. trash</td>
</tr>
</tbody>
</table>

1. Limited data due to diaphragm failure.
2. Pressure readings fluctuated between 69 and 520 kPa (10 and 75 psi).

When pumping viscous fluids, backpressure within the hose may be of concern, and may limit the distance that the fluid may be pumped. In these tests, pressures for the 3-inch pumps were in the range of 240 to 310 kPa (35 to 45 psi) with 54 metres of hose. For a maximum operating pressure of 520 kPa (75 psi, typical for standard camlock fittings), this means that the maximum hose length would be in the range of 100 metres. If the limit were 690 kPa (100 psi), the maximum distance that could be pumped would be 120 metres.

Pressure is less of a concern for the 4-inch pump and hose: maximum pressure was only 110 kPa (16 psi). This translates to a maximum hose length of 270 metres for a 520 kPa limit, and 370 metres for a 690 kPa limit.

When pumping viscous fluids over considerable distance, the line pressures may be of concern; in such situations the pressure should be monitored close to the pump discharge, i.e., the point of maximum backpressure. Rupture discs may also be used to provide pressure relief to prevent damage to hoses and related spills.

6.3 Conclusions

The diaphragm pump is unsuitable for pumping cold, viscous crude oil, experiencing failure at the diaphragm in two separate tests within 10 minutes of operation.

In a test of the ability to self-prime, the trash pumps performed well, establishing prime within 15 seconds with two 3-inch pumps and one 4-inch pump.
The highest pumping rate was with the 4-inch trash pump, achieving a rate of 348 L/min. The 3-inch Sykes pump was only slightly less at 320 L/min.

Backpressure in the hoses was not a concern, with a maximum pressure of 310 kPa with the 3-inch pumping system, which included 54 metres of hose. With the weathered crude oil at a temperature of -13°C (9°F), the maximum distance that could be pumped would be in the range of 100 metres if the maximum allowable pressure were 520 kPa, and 120 metres if it were 690 kPa. With a 4-inch hose system, and the oil and temperatures used in these tests, backpressures would not be of concern unless pumping distances exceeded 300 metres.

The test proved the ability to pump a cold, weathered crude oil that was at a temperature 12°C (22°F) below its pour point as measured in standard laboratory tests.

7 Investigation of Flow Properties Below the Pour Point (2006)

The objective of the work was to determine whether weathered Endicott oil would flow at a temperature of 0°C, a temperature that is well below the oil’s pour point.

Anecdotal accounts of pumping problems with high pour point oils include observations of “drilling holes” into a cargo of weathered oil or emulsion. Modern positive-displacement pumps are capable of pumping weathered oils and emulsion with viscosities of 100,000 mPa.s and greater, if oil is presented to the pump suction. However, the flow of oil to a pump suction may be greatly slowed or stopped with high pour point oils.

On the other hand, it is likely that the standard test for measuring pour point is somewhat conservative as a measure of an oil’s fluidity in contrast to pumping oil from a large container, such as a barge. Pour point is measured according to a procedure described in ASTM D97, Standard Test Method for Pour Point of Petroleum Oils. There are three main reasons why the pour point test may be conservative. First, the way the test is performed and the results reported add a “safety factor” of up to 3°C (5.4°F). Second, the small size of the test container (a 1.25-inch diameter beaker) introduces an edge effect that would not be present with a large pool of oil that is, say, several feet deep and several feet wide. Finally, in the pour point test, there is almost negligible force applied to the oil to cause it to flow. The beaker is tipped sideways, so the only applied force is the 1.25-inch head of oil. In a barge-pumping scenario, there would be several feet of head to cause the oil to flow, and the expectation would be that the weight of the oil would cause it to slump towards a pump suction. Once initiated, oil would slowly flow towards the pump.

Indeed, in a pumping test performed for Alaska Clean Seas (SL Ross, 2005), tests with several smaller, portable pumps demonstrated that a weathered oil was pumpable at a temperature some 12°C below its pour point, as measured by the standardized laboratory test.

7.1 Empirical Slump Tests

The investigation involved the development of an empirical test to measure the limiting flow condition. In preparation for this, a search was done of existing standard methodology to determine if a relevant test already existed, or more likely, if procedures could be adapted for this purpose. Although no standards were found to directly relate to the proposed test, several important issues were noted:
Several methods involve establishing and supporting a height of fluid, then removing the support to determine slump. It was thought that this would be very difficult to achieve and replicate with a viscous and sticky crude oil.

For some materials, the temperature history as well as the temperature at the time of the test may be important. Specifically, it will be important when cooling a specimen to not overshoot the desired temperature for any significant length of time. The risk is that internal structure to the fluid might be established that is not diminished prior to the test.

On the other hand, it is known that the gelling or solidification of weathered crude oils involves some sort of crystallization of wax compounds. Therefore, as specified in the ASTM test for pour point, it is important that the waxes be dissolved prior to each test. This involves heating the oil to a minimum of 30°C above its pour point, and mixing to produce homogeneity.

A test apparatus was devised to demonstrate the fluidity of weathered oil at various temperatures. A 38-cm (15-inch) diameter cylinder was fitted to a base, and two openings cut in the side of the cylinder, one near the bottom, and one at mid-height (Figure 1). The openings were covered with a gasket and sheet metal, held in place with removable band clamps.

Figure 1: Test cylinders and heating coils (at left) used to re-heat oil between tests
Oil was weathered 6.5% and 11.6% by volume. The oil was heated to ensure that the waxes within the oil were dissolved, and then mixed to ensure their distribution. The oil was then placed into the two cylinders, which were positioned within the SL Ross wind/wave tank emptied of water (Figure 2). The tank was covered, and cold air circulated through it to cool the cylinders of oil. Thermocouples were positioned within the cylinders so that the oil temperature could be monitored continuously. Care was taken to not go below the target temperature.

Figure 2: Wind/wave tank, insulated and emptied of water

Two tests were envisioned. The first preliminary test would involve using an ordinary ladle to scoop oil out of the top of the cylinder, thereby creating a hole, and then observing how deep the hole had to be before slump occurred. This would be adequate to determine slump up to a height of about 30 cm (12 in). If the oil did not slump into a 30-cm hole, a second test was performed. This involved removing the covers on the openings in the side of the cylinder, and observing if slump occurred through the openings.

The plan involved performing these tests at successively colder temperatures, in 5°C increments, starting at 0°C. Between each set of tests, the oil was re-heated to re-dissolve the waxes, mixed, and then cooled to the next test temperature. While the oil was being cooled, a process that took between seven and fourteen days, the
cylinders were covered to minimize any loss in light ends and concomitant change in oil properties.

7.2 Test Results

In initial ladle tests at 0°C and at -5°C, the 6% weathered oil slumped readily when a hole depth of a 10 cm was created. At the lower temperature, the 11% weathered oil maintained a hole scooped out of the middle to a depth of 30 cm. As this was the maximum depth that could be created with the ladle, the openings on the side of the cylinder were then uncovered. When the hole at two-foot depth was opened, the 11% oil flowed very slowly at first, but after a brief delay, flowed readily and emptied the cylinder to the bottom of the hole.

At a temperature of -10°C, both samples of oil maintained a hole scooped out to a depth of 30 cm (12 in), the maximum depth that could be created. For both the 6% and 11% weathered oils, when the covering was removed from the hole at the bottom of the cylinder, the oil flowed readily after a brief delay. With both oils, the oil had a much more fluid appearance after it had flowed out of the opening. Spot temperature measurements were taken of the oil to confirm that it was still at the test temperature of –10°C. The more fluid appearance reflected the fact that the wax crystalline structure of the chilled oil had been “broken”, and not simply a relatively warm spot within the oil.

At a temperature of -15°C (14°F), the initial ladle test was omitted given the results at –10°C. As with the test at -10°C, after a brief delay, the oil flowed readily on removal of the coverings. With the 6% weathered oil, flow essentially ceased when approximately 15 cm (6 in) of oil remained above the opening. With the 11% weathered oil, approximately 30 cm (12 in) of oil remained above the opening when flow ceased. At these temperatures, some 24°C (43°F) below the oil’s measured pour point, significant amounts of oil could be left in the bottom of a storage container unless the pump is able to move around and collect the remaining portion.

The test at -15°C was the practical limit of the test apparatus (chilling the oil to -15°C required 14 days of cooling) so the study was not able to determine the limiting temperature for flow of the weathered oil. However, for practical purposes, it was demonstrated that flow would occur at temperatures well below 0°C.

Care was taken in removing the covers from the openings, so that the adhesion of the oil against the cover did not excessively influence the initial flow of oil. Had the covers been opened haphazardly, it is possible that the oil adhering to the inside of the cover could have produced an initial flow of oil. In fact, the precaution appeared to be successful. With the two coldest tests, there was a momentary delay between the removal of the cover and the initial flow of oil.

Once flow was initiated, the oil seemed to have a more fluid appearance. This is consistent with the non-Newtonian behavior of a gelled crude oil, and specifically, shear-thinning behavior. As noted above, spot temperature measurements were taken with a probe inserted into the released oil to confirm that it was in fact as cold as initially measured.

7.3 Conclusions

Endicott crude oil, when weathered under standard laboratory conditions, has an ASTM pour point in the range of 9°C to 12°C. The weathered oil did not form a stable emulsion.
An empirical test of the flow conditions of weathered Endicott oil indicate that the oil will flow at a temperature of 27°C (49°F) below the oil’s measured pour point, when subjected to a head of oil on the order of 1.2 metres (4 feet) (SL Ross, 2006). Given a 1.2-m depth of oil, oil will flow to a pump suction at temperatures 27°C below the oil’s measured pour point.

8 Summary
A series of experiments and demonstrations since 2000 investigated various aspects of pumping cold, weathered crude oils and emulsions. The most significant of the conclusions from these tests are as follows.

• Annular water injection was useful for reducing line pressures when pumping viscous fluids. Its main application would be in transferring fluids over great distances.
• Glycol was equally effective as water as an injection fluid for annular injection.
• In an oil spill pumping application, with relatively cold emulsions and a short contact time, emulsion-breaking chemicals are unlikely to be very effective at reducing emulsion water content. Nonetheless, they do provide a relatively simple method of reducing emulsion viscosities, and may greatly facilitate pumping in many situations.
• Steam heat, provided by readily available steam generating equipment, is an option for facilitating the flow of extremely viscous oil spill fluids. It would be very time-consuming and would be considered a “last resort” option.
• Positive-displacement pumps such as the DOP-250 have the ability to draw in and pump oil that is semi-solid, even when the oil is gelled to the extent that it could not flow to the pump suction to maintain flow. The ability of the fluid to flow to the pump suction, rather than the pump itself, was the limiting factor.
• Tests determined the flow limits of weathered crude oil under conditions similar to a barge off-loading scenario. It was found that the influence of several feet of head (i.e., the depth of oil in the barge) was sufficient to initiate flow of oil to facilitate pumping at temperatures 27°C (49°F) below the oil’s pour point, as measured by a standard laboratory test.

9 References


