Interspill 2004
Presentation no. 426

Viscous Oil Recovery and Pumping Research in Canada

D. Cooper
SAIC Canada
Ottawa, Ontario, Canada

R. MacKay
Canadian Coast Guard
Charlottetown, P.E.I., Canada

C. Brown
Environment Canada
Ottawa, Ontario, Canada

Abstract

Testing over the past five years has helped quantify improvements made to oil spill response equipment designed for the recovery of extremely viscous oils. From a prototype device designed to accelerate the natural coalescence of bitumen droplets after simulated spills of Orimulsion to the modification of skimmers currently stocked by Canadian Coast Guard bases, improvements to the operational capacity has been dramatically improved.

This paper details the development of a collaborative series of projects supported by Environment Canada and the Canadian Coast Guard over the past five years. It provides background information on the original problems or design limitations of the oil spill recovery equipment. Descriptions of the subsequent modifications are presented, along with performance information which quantifies any improvements to performance. The work has evolved to include partnerships with federal government organizations from Canada and the United States – culminating in a project which saw pumps stocked by the Canadian Coast Guard and United States Coast Guard, along with other manufacturers units tested in viscous oil during the winter of 2003/2004.

Introduction

The pumping of heavy, viscous oil remains one of the many challenges facing response efforts today. The tendency of most oils to quickly weather and form emulsions in rough seas exacerbates the situation – often resulting in extremely viscous product that can be difficult to handle. One special case, which has been undergoing investigations in recent years, involves spills of Orimulsion. Such spills can lead to the formation of pools of extremely viscous bitumen, whose properties can surpass the capabilities of commonly used pumping equipment.

Background

SAIC Canada, under contract from Environment Canada's Emergencies Engineering Technologies Office (EETO), develops and performs studies to evaluate new and existing oil spill recovery and containment equipment in order to assist in the advancement of these technologies. The Canadian Coast Guard (CCG), Environmental Response Branch, has extensive expertise in identifying, analyzing and developing the preparedness and response activities essential to an efficient and dependable response system. CCG recently initiated a program and partnered with EETO/SAIC Canada to test the viscous oil capabilities of currently stocked skimmers at CCG bases in Eastern Canada. Under this program, a number of evaluation studies were developed involving some innovative equipment that were designed to assist in the recovery of extremely viscous products.

Description of Test Facility

Most of the testing was centered around a 29 m^3 flume tank. The tank is approximately 8.5 m long, 3.0 m wide, and 1.2 m deep, with a false floor covering two drive units located at Environment Canada's Environmental Technology Centre in Ottawa, Canada. It is designed to create flows in a vertical race-track configuration. A steel walkway encircles the tank and was used as an operating platform for much of the later pumping trials. A moveable bridge straddles the width of the tank, enabling easy access to all points within the tank.

Phase 1 – Initial Testing of Equipment

The first phase of this program was initiated as Orimulsion was introduced into Canada. Spill responders quickly discovered that the behaviour of this product when spilled in water was unique when compared to traditional crude based oils. Conventional equipment stocked by responders in Canada was deemed inadequate to handle the extremely viscous bitumen that could coalesce and form slicks following a spill. Due to these factors research and testing was undertaken to identify new and innovative equipment which could be used to help remediate such a spill.

This initial set of testing incorporated a device called the PNP Refloater prototype which was constructed at Environmental Recovery Equipment (ERE) in Port Colborne, Ontario (Canada). Initial testing encompassed the refloatation of spilled Orimulsion in the flume tank. The PNP Refloater was operated in a variety of modes, simulating a small dockside spill scenario. Factors such as temperature, salinity (or lack thereof), concentration of bitumen, and time were incorporated into a testing scenario. The concentrations of bitumen remaining in the water over time were compared with baseline runs performed without the benefit of the Refloater – providing quantitative information on the Refloater effectiveness.

Preliminary data indicated that the Refloater had a noticeable affect on the water column. Fresh water test runs showed up to 34% removal of bitumen from the water column, compared to 4% which naturally refloated during the test period. During saltwater testing, the refloater was able to remove up to 90% of the Orimulsion, having an immediate impact on refloating the bitumen droplets. Naturally refloated Orimulsion in 3% saltwater resulted in a decrease of up to 37% in the water column over the same testing period.

Testing of a qualitative nature was performed with the suite of skimmers, to determine if any would be able to process the refloated bitumen. The ERE belt skimmer was able to process the refloated bitumen, having a wide range of influence within the test tank. The scraping mechanism was able to remove most of the bitumen, although some build-up of bitumen was noticed at the leading edge of the belt, which was partially submerged in the tank.

The KLK drum skimmer had initial difficulty processing the thin layer of refloated bitumen. As the non-symmetrical drum (one drum only was operated during testing) rotated in the water, it created small waves that caused the trail of bitumen to "break" and be pushed away from the skimmer. Operating the drum at slower speeds solved most of this problem.

The GT 185 skimmer was not able to process the refloated bitumen by itself since the bitumen would take too long to “flow” into the weir mechanism. Manually pulling the refloated bitumen into the weir was attempted in order to determine the pumping capabilities of the unit. Testing showed that pumping through the approximately 4 metres of 10.2 cm (4") hose attached to the skimmer would be a taxing chore for the pump, as flow rates during testing were extremely low.

The Hobs belt skimmer was able to pick up and process the refloated bitumen, although some build-up was noticed on the belt support rollers. The diverter at the end of the unit which directed the recovered oil to a chute cause some build-up of oil, but the retained amount was not considered substantial enough to warrant any design changes.

Although some units were able to process limited quantities of recovered product, it was felt that modifications would be warranted in order to actually move the recovered product from their respective holding reservoirs through a recovery hose. It was these considerations that led to the development of the next phase of testing.

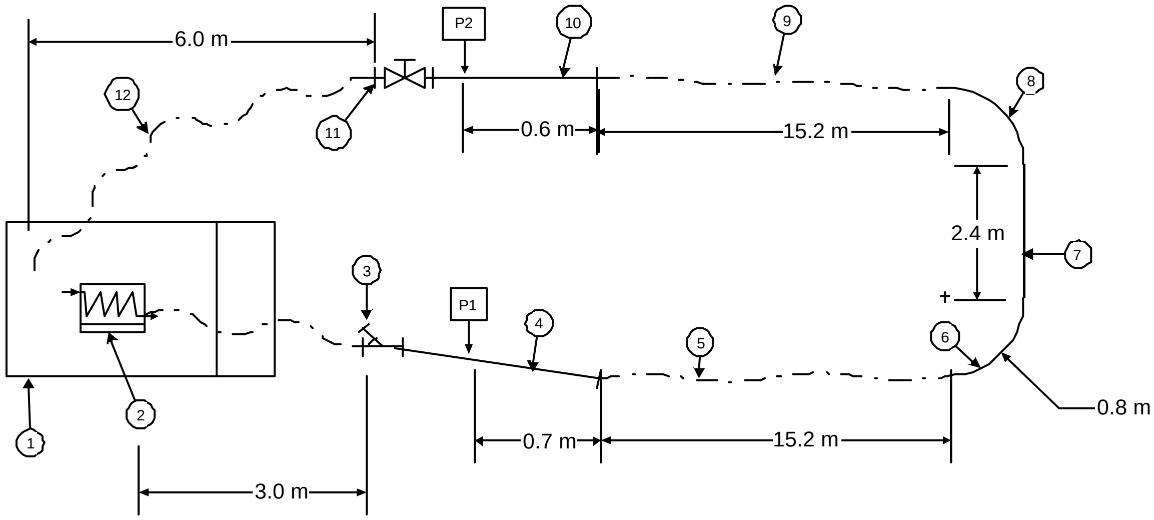
Phase 2 – Testing of Initial Modifications

The performance results of the initial phase of testing were a bit disappointing. All of the equipment had some difficulties in processing recovered bitumen. Two primary problems include difficulties in collecting or recovering the extremely viscous product, and the very slow rate of actual pumping. One of the easiest modifications considered and ultimately tested was the installation of higher torque motors. Even with this modification, however, the flowrates generated by the skimmers remained disappointedly low. Additional modifications were warranted.

The next step in the research related to the recovery and pumping of viscous oil centered on the performance enhancement developed by the addition of annular water injection at the discharge end of stocked Canadian Coast Guard pumps – the GT185 and GT260. Two sizes of Annular Water Injection rings were used in this study. The two aluminium rings created for flow in 10.2 cm (4”) and 15.2 cm (6”) diameter hose were designed to bolt onto the flanged end of a flow straightening section. They provide a means of injecting water into the flow of oil being pumped in such a way as to create a “ring” of water surrounding the oil flowing in the hose.

A hydraulically driven water pump with an operating capacity of up to 106 lpm (28 gpm) at 11 bar (160 psi) was used to supply water to the annular water injection ring. This pump, supplied by Hyde Marine Services, is capable of long-term operation using a hydraulic drive common to spill response operations.

Test loops were designed for each of the skimmers, based in part upon previous test loop designs that pumped oil with viscosities approaching 30,000 cP (Moffat, 2000, Loesch et al, 2000). The loops consisted of flow straightening sections with pressure sensors, piping curves, and hose segments that allowed the overall length of the circuits to be changed when desired during testing.



Legend:

1) holding tank and GT185 skimmer location
2) 10.2 cm (4") diameter discharge positive displacement Archimedean screw pump (with hydraulic drive)
3) Water injection port
4) 10.2 cm (4") diameter steel pipe
5) 10.2 cm (4") diameter flexible hose
6) wide 90° bend PVC pipe, 10.2 cm (4") diameter
7) 10.2 cm (4") diameter PVC pipe
8) wide 90° bend PCV pipe, 10.2 cm (4") diameter
9) 10.2 cm (4") diameter flexible hose
10) 10.2 cm (4") steel pipe
11) 10.2 cm (4") gate valves (with flanges)
12) 10.2 cm (4") flexible pipe

P1 &P2: Pressure measurement ports.

Figure 1 Testing Loop (10.2 cm - 4")

GT 185 in Bunker C

The full length of the 10.2 cm (4") loop was used for the Bunker C (a heavy fuel oil) tests. This loop consisted of flow straighteners (1.3 m), hose lengths (30.4 m), and a rigid return loop (4.0 m). Oil was pumped into the hopper of the skimmer, which was run at a slow speed while the test loop filled with oil. Excess oil was poured into the holding tank and the system was left to stabilize for approximately 10 minutes. The data logger was activated and after a short period of type (typically 2 minutes) pressure readings from the gauges were obtained. The time required to pump the liquid into a container of known volume was then measured, and the flowrate was calculated. Once this measurement was obtained, the datalogger was stopped, and the datafile was saved. The speed of the skimmer was then changed, and the system was again left to stabilize for approximately 10-15 minutes. This scenario was repeated until four speeds were recorded. Data from this series of runs is presented in Table 1, while a picture of the GT 185 is presented in Figure 2.

Figure 2: GT 185 pumps

Table 1 Bunker C in 10.2 cm (4") loop (GT 185)*

Test Run	Q (m^3/hr)	V (m/s)	Inlet Pressure bar (psig)	Loop Pressure Drop bar (psig)
1	3.74	0.129	2.72 (39.5)	2.23 (32.3)
2	3.13	0.107	2.27 (33)	1.86 (27)
3	4.61	0.158	3.10 (45)	2.55 (37)
4	6.19	0.212	4.00 (58)	3.31 (48)

*Measured viscosity: 17,000 cP

As expected, loop pressure drop and inlet pressures increased as the flowrate was increased.

Testing with the annular water injection ring produced an interesting result. The system was run without water injection up to an inlet pressure of approximately 4 bar (60 psi) and left to stabilize. The skimmer was then momentarily stopped and the water injection ring was engaged. The skimmer was then brought back online and the system was left to stabilize. As the system stabilized, the pressure drop was dramatic. A reduction of over 90% of the pressure was observed indicating a significant contribution from the water ring.

GT 185 in Bitumen

A shortened section of the 10.2 cm (4”) loop was used for the bitumen runs. This loop consisted of the same flow straighteners (1.3 m) and rigid return loop (4.0 m), however the hose length was reduced to an overall measurement of 13.7 m to account for the limited quantity of bitumen on hand, and the expected high resistance to flow throughout the test loop.

Bitumen was poured from the open top drums into the hopper of the skimmer, which was run at a slow speed while the test loop filled with bitumen. Once bitumen filled the test loop, the system was left to circulate and stabilize for approximately 25 minutes to ensure a homogeneous liquid. The test runs were performed in a similar fashion to the Bunker C runs, with pressure and flowrates being measured and recorded. This scenario was also repeated until four speeds were recorded. Data from this series of runs is presented in Table 2.

Table 2 Bitumen in 10.2 cm (4”) diameter loop (GT 185)*

Test Run	Q (m^3/hr)	V (m/s)	Inlet Pressure bar (psig)	Loop Pressure Drop bar (psig)
5	1.15	0.039	4.07 (59)	3.31 (48)
6	1.30	0.044	4.41 (64)	3.42 (49.6)
7	0.79	0.027	2.83 (41)	2.14 (31)
8	1.44	0.050	4.48 (66)	3.45 (50)

*Measured viscosity: 200,000 cP

Again, as expected, inlet and loop pressures increased as flowrates increased.

Testing with the annular water injection ring produced also provided interesting results. The system was run up to an inlet pressure of approximately 4.4 bar (64 psi) and left to stabilize. The skimmer was then momentarily stopped and the water injection ring was engaged. The skimmer was then brought back online and the system was left to stabilize (see Figure 3). As the system stabilized, the pressure drop was slower to stabilize, but levelled off within minutes. A flowrate measurement was performed and flows were recorded as shown in Table 3.

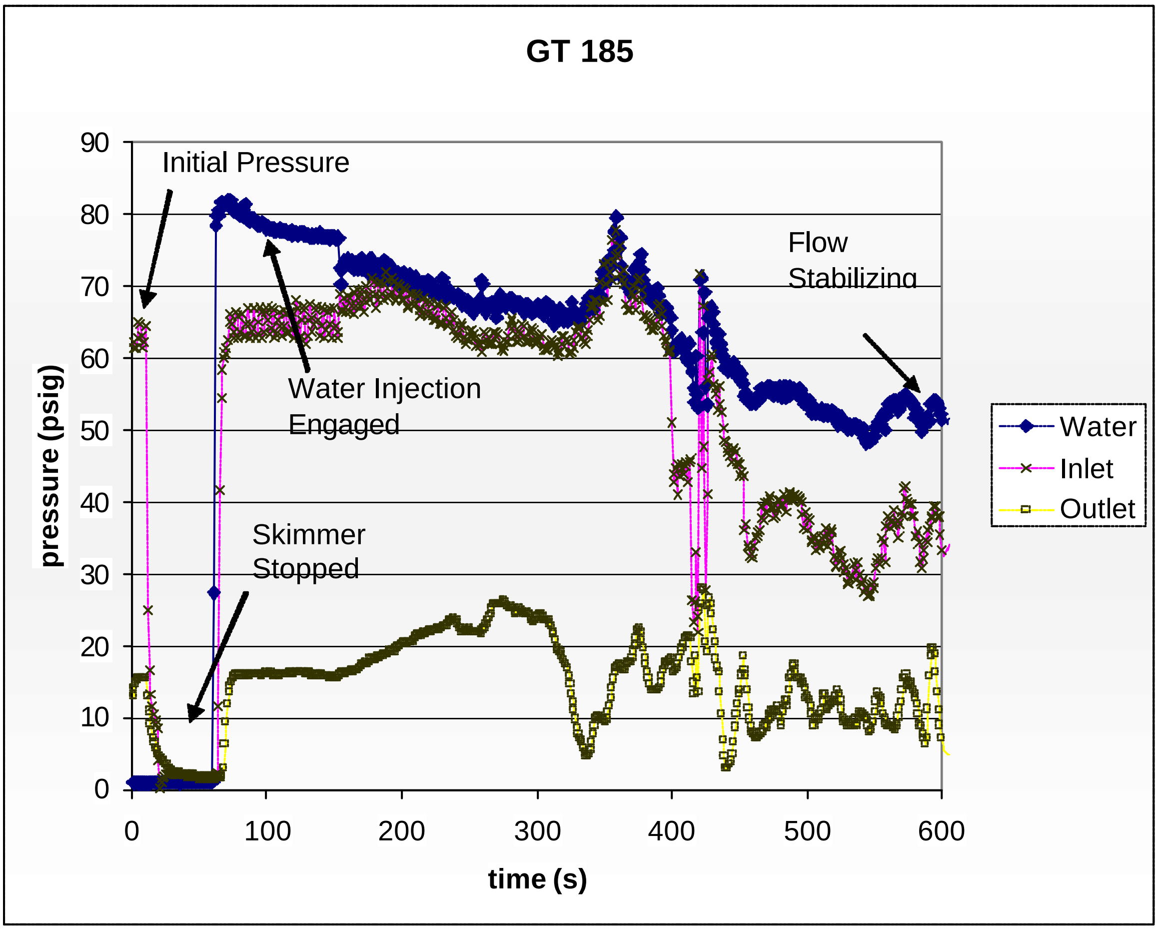


Figure 3 Testing Bitumen with Annular Ring 10.2 cm (4")

An observed inlet pressure reduction of approximately 45% was recorded with the annular water ring operating. It should be noted, however, flowrates remained relatively low, and that no annular flow was observed to have developed through the outlet. It was expected that a larger drop in initial and loop pressure would be observed if the annular water ring was established.

Table 3 Bitumen with Annular Water Injection (GT 185)*

Test Run	Q (total) (m^3/hr)	V (m/s)	Inlet Pressure (psig)	Loop Pressure Drop (psig)
Mix	9.32	0.320	2.48 (36)	1.65 (24)
Bitumen	2.23			
Water	7.09		3.65 (53)	

*Measured viscosity: 200,000 cP

Testing with Bunker C provided baseline data for comparison with the bitumen pumping.

The annular water injection ring was successful in reducing the pressure requirements during pumping with the GT185, however it could not be confirmed that the water ring successfully formed within the test loop. Output from the hose seemed to indicate some mixing of the oil and water was occurring but readily separated once discharged. The reduction in pressure requirements could be attributed to two phased flow within the test loop, as opposed to the formation of an annular ring.

Based upon the results obtained from this series of tests, the annular water injection ring did have a strong effect on the bunker C results; however the results for pumping the bitumen were inconclusive. The relatively slow velocities generated in the test loops may not have been sufficient to support the full development of the annular ring. Further testing using pumps capable of higher flowrates is recommended to determine if the minimum flowrate required to sustain the formation of the annular ring can be attained with bitumen.

Additional areas of study were also identified as a result of this series of tests. These topics include:

- development of water injection devices which could attach directly to the discharge outlet of a skimmer head (inlet to the pump). Such a device would reduce the pressure losses the system would endure when pumping pure bitumen from the skimmer head to the current remote water injection ring.
- study of possible alternatives to water for pumping in cold climates (sub-freezing conditions). Freezing of water in the piping system would limit the operation of the injection ring.
- research other methods for affecting viscosity of recovered bitumen to enable pumping (re-emulsification) using stock skimmers.

These tests have demonstrated that the water ring did have an affect on the heavy bunker C, however additional research is required to enable the effective pumping of recovered bitumen.

Phase 3 – Testing of Refined Modifications

Testing during the third phase was performed using bunker C), a viscous oil (bitumen) and water for baseline testing. Two loops were used during the testing. The first consisted of approximately 4 metres (12 feet) of hose, connected to a 2 metre (6 foot) pipe with pressure sensors, a valve to regulate backpressure, and a return 45° angle plus hose approximately 4.5 metres (14 feet) long. The bitumen tests were run using a 8 metre (25 foot) section of hose.
Two "working tanks" were installed and acted as the staging areas for all test runs. The first tank had a capacity of approximately 1.6 m^3. This was used as the working tank for all of the water runs. A second tank, dedicated for oil use, had a capacity of approximately 2.4 m^3. Both tanks were constructed of high density polyethylene with an external supplemental metal support framework on the outside. The GT 185 pumps were placed in the working tanks and pumped testing liquid through the loops in a recirculating fashion. Pressure and temperature sensors were attached to a datalogger, with manual readings being measured as a backup once each run had stabilized.

Figure 4: Test Loop

The test liquids used in this study included water which was used for baseline testing, a heavy heating oil (bunker C) which was used as a commonly available product for comparison purposes, and an extremely viscous bitumen product recovered from a simulated spill of Orimulsion®.

Table 4: Test Liquid Viscosities

Test Liquid	Viscosity, cP	Temperature, °C
Bunker C	8,700	21.3
Bitumen	930,000	20.0
Bitumen	700,000	23.4
Bitumen	200,000	30.0

Testing in bunker C was performed to determine the performance levels obtainable while pumping a common product. Again reading all hydraulic system and pumping parameters for each measured flowrate, typically starting at 0 psi system pressure then working up by 10 psi per run until the pump reaches its maximum operating pressure, or 100 psi.

Bitumen tests were run for three time periods (3 hours, 5 hours, 9 hours) with water baseline tests being performed after each run. Bitumen runs were setup to recirculate bitumen through a loop while monitoring all hydraulic system and pumping parameters.

Flowrates of the system were calculated based upon a mass of liquid pumped within a known time period, while temperature measurements were recorded via thermocouples connected to a datalogger, or manually with a handheld unit. Temperature measurements of the bulk liquids were taken before each run. In the instances where long-term runs were performed, temperature measurement of the pumping product were taken at the discharge side of the pump and logged.

This preliminary series of tests identified a possible sealing problem with the Prototype #1 plate wheel. The designers of the plate wheel decided to perform modifications to obtain better sealing with a second prototype, which was ultimately tested at a later date.

The results of the stock GT 185 system "1153-1" using a new plate wheel were very good. At this time, the original plate wheel that came in the stock GT 185 (GT185-01-90) was installed and given a designation of "1153-2". This would allow data to be generated on equipment that matched the condition of equipment in CCG inventory.

The next set of tests was performed to form the actual baseline tests for the degradation portion of the project (long term testing in very viscous oil). A second GT 185 was included in this round of testing while the prototype system was redesigned. This second stock GT 185 (GT185-03-90) was identified as "1165" and had a slightly used plate wheel, given the designation "1165-1". Test runs were performed with these stock systems, with the results listed below in Table 5.

Table 5: Initial Baseline Testing

Test Number	Plate Wheel ID	Hydraulic Flow Rate (lpm)	Flow ate 0 psi (m^3/hr)	Flow ate 0.69 bar 10 psi (m^3/hr)	Flow ate 1.38 bar 20 psi (m^3/hr)	Flow ate 2.07 bar 30 psi (m^3/hr)	Flow ate 2.76 bar 40 psi (m^3/hr)	Flow ate 3.45 bar 50 psi (m^3/hr)	Flow ate 4.14 bar 60 psi (m^3/hr)	Flow ate 4.83 bar 70 psi (m^3/hr)	Flow ate 5.52 bar 80 psi (m^3/hr)	Flow ate 6.21 bar 90 psi (m^3/hr)	Flow ate 6.89 bar 100 psi (m^3/hr)	Max pressure bar (psi)
9.	1165-1	68.5	30.2	16.7	10.3	4.7								2.90 (42)
10.	1153-2	68.5	34.9	26.8	22.3	18.5	15.6	12.1	9.5					6.00 (87)
11.	1165-2	68.5	31.1	21.5	16.0	12.2	7.8	4.6						4.34 (63)

Figure 5: #1153-2 plate wheel after 3 hours

The second plate wheel prototype and modified GT 185 casing with enhanced backing plate were tested using the 3-hour bitumen protocol. Testing in bitumen for a 3-hour period did not seem to have caused any problems for the new disk and backing plate design. The unit was able to attain pressures in excess of 6.9 bar (100 psi) which was the upper limit imposed by the test plan due to limitation of the test loop at which point the test runs were stopped.

The measured values did not seem to correlate with the apparent wear that was being caused by the pumping of extremely viscous product over the test periods. Upon detailed examination, however, evidence shows that wear is occurring not only upon the seals but also on the support structure. The impact of this damage on the lifespan of the disk wheel is not known, but the damage seemed to occur early in the testing which is cause for concern. The damage may also be due to the 'break in' period for this pump, and may reach a steady state during extended use. The new prototype was able to provide impressive results, surpassing stock equipment for maximum pressures attained during baseline water testing.

The new prototype plate wheel and backing plate combination was able to provide impressive results, surpassing stock equipment for maximum pressures attained during baseline water testing. After hot water "degradation" testing the prototype system did not show any appreciable drop in performance – which is impressive when compared to the failure of the stock disk wheel which jammed within the GT 185 casing shortly after the hot water "degradation" testing began.

Additional testing of the larger GT 260 was performed more recently. Again, the stock plate wheel and backing plates were replace with prototype upgrades. Testing with the new components showed that the pump was able to attain upwards of 6.6 bar (95 psi) pressure using a test water loop which compares favourably to the stock set-up.

Degradation testing in a hot water tank had a small impact on performance. The GT 260 was able to attain 5.9 bar (86 psi) following the hot water testing.

Based upon these findings, the following conclusions were made:

The stock disk wheels did not stand up well to the testing. As a result of the these findings problems should be expected if the stock disk wheels are used while attempting to pump highly viscous product such as bitumen. Additionally, hot water injection at the inlet side of the pump which may be attempted in order to overcome some of the difficulties in moving the bitumen is not recommended due to the degradation of the stock disk wheel witnessed during our testing.

The following areas of additional research are recommended to further investigate the operating and wear characteristics of the GT (185 and 260) series:

- The new plate wheel should be tested for longer periods to ensure possible wear problems have been eliminated
- Explore new back plate retrofit on stock equipment to get better sealing. Additional testing of the new back plate design with stock disk wheel is suggested.
- Extend the wear plate testing to tens of hours of operation, with regular inspections to verify that the initial wear on the plates is solely due to the break in period.

Planned Testing for Near Future

An evaluation of five positive displacement pumps is planned for the winter of 2003/2004. A collaborative effort has been undertaken using a variety of personnel and equipment from Canada, U.S. and Europe to provide support in the development of a comprehensive testing plan in advance of any proposed testing. The purpose of this project is to perform a field evaluation of innovative water injection systems using a range of long hose lengths with extremely viscous fuels to determine the performance of the pumps. A tentative site, the CENAC facility in Houma, Louisiana, has been selected in part because of the logistical support and infrastructure for securing and storing large quantities of test liquids. Pumps from the inventory of the Canadian Coast Guard, U.S. Coast Guard, and other manufacturers with equipment designed to handle viscous product have been selected for testing.

This testing represents a natural continuation of the previous efforts to develop new and innovative products to handle extremely viscous oils. Reasonable strides have been taken in developing products which enhance the performance of currently stocked equipment. It is hoped that this planned project will demonstrate the pumps operating under simulated spill conditions and provide valuable data to validate performance enhancements.

BIOGRAPHY

Mr. Cooper is a professional Engineer with over thirteen years of experience testing and evaluating equipment and techniques used in the remediation of chemical and oil spills. He has experience performing bench and pilot scale studies in North America and Europe, and is actively involved with the development of new international standards for testing (ASTM F-20).

REFERENCES

Cooper, D., and R. MacKay, "Extended Testing of GT-185 Pumps in Bitumen" in Proceedings of the Twenty-sixth Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada, Ottawa, Ontario, 2003

Cooper, D., and R. MacKay, "Heavy Oil Pumping – A Method to the Madness?" in Proceedings of the Twenty-fifth Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada, Ottawa, Ontario, 2002.

Cooper, D., and R. MacKay, "Assisted Pumping of Extremely Viscous Oils" in Proceedings of the Twenty-fourth Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada, Ottawa, Ontario, pp 373-386. 2001.

Cooper, D, and F. Hvidbak, "Evaluation of Mechanical Recovery Devices for Spills of Orimulsion®" in Proceedings of the Twenty-Third Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada, Ottawa, Ontario, Vol. 1, pp.337-352, 2000.

Hvidbak, F., D. Hines, Oriliminator PNP Refloater - Test Trials, Canadian Coast Guard, Port Colborne, Ontario, 1999.

Jokuty, P., B. Fieldhouse, S.Whiticar, and M. Fingas, The Dynamics of Orimulsion Spills in Salt, Fresh, and Brackish Water, Manuscript Report EE-161, Environmental Protection Service, Environment Canada, Ottawa, Ontario, 37 p., 1999.

Loesch, R., C. Moffatt, and. Knutson, "Development and Testing of the U.S. Coast Guard Water Injection Enhanced Viscous Oil Pumping System (VOPS)", in Proceedings of the Twenty-Third Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Environment Canada, Ottawa, Ontario, Vol. 1, pp.385-399, 2000.

Moffatt, C., GPC, Summary of Test Data for the Testing Portion of the Northwest Viscous Oil Pumping Workshop, U.S. Coast Guard and U.S. Navy, Seattle, Washington, 64 p., 1999.

Moffatt, C., GPC, Testing of the U.S. Coast Guard Viscous Oil Pumping System (VOPS Prototype) at the MMS Ohmsett Test Facility, U.S. Coast Guard and U.S. Navy, Earle, New Jersey, 67p., 2000.