8.0 DISPOSAL OF TEST PRODUCT AND DECONTAMINATION

Execution of the primary JVOPS Workshop test goals had progressed well during the Test Week. By Friday 12 December, Master and Long Distance testing for the DOP-250 and GT-185 had been completed. However, prior to the weekend, it had been determined by the JVOPS Workgroup that Monday 15 December would necessarily be the final test day. This decision was largely driven by continued on-site costs of the decontamination contractor, and it was estimated that the required decontamination procedures, product disposal, and preparation of equipment for return shipment might take as long as 5 days. Additional considerations included the impending holiday season.

8.1 Decontamination of Test Hoses

Test hoses had been decontaminated on a continuous basis throughout the test week, and this work continued after testing. All oil was removed from test hoses applying the compressed air / pigging / diesel flushing / detergent washing technique developed in the first days of the test week.

Throughout the period, the contracted decontamination crew continued “fine” hose cleaning (detergent washing of interior and exterior, Figure 60) following GPC pigging and flushing operations. The ”fine” cleaning progressed more slowly than expected and considering that there was over 2,000 ft of oiled test hose, there was a backlog of contaminated hoses by the completion of testing. However, Asco were able to concentrate solely on hoses for the final few days and completed all hose fine decontamination by the end of Friday 19 December.

Figure 60 Final Hose Decon in Progress by the ASCO Crew.

8.2 Decontamination of Equipment

The contracted decontamination crew continued throughout the testing to clean the various salient equipment items (Figure 61). This work continued during the test site breakdown with aid from USCG personnel that had been called in. By Friday 19 December only the larger components, such as the oil tanks and oil / water receiving tanks remained to be fine cleaned outside and inside.

Figure 61 Equipment Decontamination in Progress, here of a DOP-250 pump.

8.3 Test Infrastructure Breakdown

Workshop Test Infrastructure breakdown activities started during the last day of testing on the CCG side of the Test Complex, since the local bulk-heating test Monday morning 15 December had been moved to the USCG test line. The breakdown activities were conducted by personnel who were not assigned specific duties for the remaining tests of 15 December. These activities included removal and disassembly of wooden platforms, hose ramps, and other structures. The activities progressed well and at the debriefing at the end of the day, a goal was set to have the last elements of the breakdown personnel leave the site by Thursday 18 December. Help arrived in the form of an additional 7 personnel from the Gulf Strike Team who arrived on 16 December and were dedicated to breakdown activities.

The Cenac Towing facility was enormously generous in accepting the waste and debris resulting from the breakdown. From 15 to 18 December, they arranged to have the wood and steel from dismantled structures and waste PPE collected and removed from the test site. Even more importantly, they agreed to accept all test product and oily water.

8.4 Disposal of Test Product

The test product would be accepted by the facility into a large waste oil tank. This would require transfer of the approximately 40 barrels left in the in the CCG test tank, the approximately 50 bbl left in the USCG test tank after Test 11, and the balance of product from the 200 bbl buffer tank and the Baker backup tank. To save time and make use of existing oiled hose runs, the JVOPS Workgroup decided to use the 200 bbl buffer tank as a central collection point for the product within the test tanks and for product to be used in the remaining tests. It was arranged to have the test product from the CCG test tank pumped to the 200 barrel buffer tank. The lube water techniques that had worked so well during the test week were applied in these transfer operations.

A transfer operation was then arranged between the 200 barrel buffer tank and the waste oil tank. A DOP-250 with an inlet AWIF was submerged in the 200 bbl buffer tank and with the injection of 2% hot inlet lube water, pumped the collected product through 200 ft of 6" hose into the waste oil tank (Figure 62). Test product from testing on 15 December (Local Bulk Heating/Viscosity Verification GT185) was pumped through the 100 ft test hose and discharged directly into the 200 bbl buffer tank. The DOP-250 pump in the 200 bbl buffer tank continued the transfer for final disposal simultaneously during this final testing.

Figure 62 200 ft. 6 inch hose to waste oil tank.

Following transfers, the 200 ft hose connecting the 200 bbl buffer tank to the waste oil tank was pigged by GPC from the waste oil tank connection back into the 200 bbl buffer tank.

Due to time constraints, the oil transfer team was unable to transfer the approximately 300 bbl of remaining test product within the Baker backup tank and the small amount of oil left in the 200 bbl buffer tank after the last pigging operation.

8.5 Final Decontamination and Removal of Tanks

In addition to accepting the used test product, the facility agreed to decontaminate both test tanks, the 200 bbl buffer tank, the Baker backup tank and the oil / water collection tanks. This relieved an enormous burden from the Workshop given the time constraints. Arrangements for the shipment of CCG, USCG and contracted equipment were made by the Logistics Section. The last member of the JVOPS Workgroup departed the site on 17 December.

Later, the various ancillary tanks rented for the project in addition to the CCG and USCG test tanks were collected from the site by the rental source following decontamination by the Cenac Towing facility. The Baker backup tank was decontaminated by the facility, modified back to its original pre-Workshop specifications by a Coast Guard work crew, and returned to its rental source.

9.0 RECOMMENDED PUMP SYSTEM IMPROVEMENTS

The tested PDAS pumps, with their respective AWI devices applied, all performed very well and way beyond expectations during the JVOPS Workshop. Where only minor modifications seem to be required on some of the basic pump systems, including their AWI devices, the ancillary equipment that provide and control the injection of lube water may require a more thorough review.

The general impression of the various pumps as to appearance, weight, and handling is different from system to system. It is critical that the pump systems are easy to handle and are as uncomplicated and compact as possible. There is no advantage of a pump system that is so bulky or difficult to handle that it will not be used in a real world scenario. Responders have in the past repeatedly preferred smaller pump systems over larger, at the calculated cost of reduced capacity. This is simply because the work environment in many cases does not allow for large pump systems.

It is therefore recommended that a VOPS system pump with AWIFs should be as sleek and compact in overall design as possible, given its basic size (Figure 63).

Figure 63 LAMOR GT-A 50 ready for Deployment. Note the compact and sleek overall concept with the fewest possible protruding parts and simple hose arrangement.

9.1 Recommended Pump/AWI Improvements

Especially the USCG DOP-250 and the CCG GT-185 VOPS pumps with their AWIFs can easily be modified to meet the following recommendations:

1. Minimal number of lube water lines (USCG and CCG)
2. No protruding fittings and other parts (USCG, CCG, LAMOR)
3. Reduce size of discharge AWIF and fit it directly to the pump (USCG)
4. Heat and pressure resistant internal sealing parts in pump (USCG, CCG)

1. Minimal amount of lube water lines (USCG and CCG)

In some cases, two or four lube water supply lines are connected to an AWI device. This should be reduced to one line. In order to do so, it should be ensured that the AWI device either contains an internal distribution channel, or that one is provided externally, that can ensure an even distribution of lube water around the core of oil. An external distribution ring, tube, or channel should not protrude from the basic pump/AWI structure.

The lube water connection to an AWI device should include a non return valve to protect the AWI device and the water line from being contaminated with oil. This non return valve should be placed parallel with, and tight against the pump body. Or even better in a natural cavity in the pump / AWI structure.

2. No protruding fittings and other parts (USCG, CCG, LAMOR)

All fittings, hoses, valves, and handles should be of the smallest possible dimension that can do the job. They should only protrude minimally from the basic footprint of the pump body (when placed in deployment mode). Hoses should be strapped tight against the pump body or be clamped on.

The USCG VOPS DOP-250 AWI flange system include several lube water hoses and protruding fittings that can conflict with structures in for instance a tank that must be unloaded. There should be one feed line only per AWIF. The discharge AWIF is rather big and is not placed on the pump, close to the pump screw.

The CCG GT-185 inlet AWI device protrudes from the pump body. This is necessary for the functionality, but it should be protected by a smooth rounded frame around, but not protruding from the opening between the AWI plates. These injection plates are fragile and with sharp corners. The protection frame could be used as water distribution ring, thus simplifying design while increasing the inlet heating area.

The LAMOR GT-A 50 with AWIFs is very compact and sleek design, but the inlet water feed line should be strapped or clamped to the pump, and the outlet feed line should be strapped to the hydraulic lines. The fitting for the single feed line to the built-in inlet AWIF could be better protected, and would protrude less, if it could be fitted on the pump casing, parallel (or at a small angle) to the pump casing center line. This would involve a minor modification to the casting of the pump casing.

3. Reduce size of discharge AWIF and fit it directly to the pump (USCG)

The USCG VOPS discharge side AWIF, with it's connecting tube to the pump, is almost of same size as the pump, and the connecting tube is so long that the discharge lubrication starts at too great a distance from the pump screw. The AWIF should be made smaller in outside dimensions, thus making it possible to fit it directly on the pump outlet, close to the pump screw.

4. Heat and pressure resistant internal sealing parts in pump (USCG, CCG)

Hot water or steam injected at the inlet of a PDAS transfer pump requires that the pump is equipped with high pressure/high temperature internal sealing parts. The CCG GT-185 and the LAMOR GT-A 50, were equipped with such internal parts.

The USCG DOP-250 was not equipped with heat resistant sealing parts, but damage was avoided by a careful injection of hot inlet lube water when operating at no or low pump rate. The USCG DOP-250 can with caution be used with hot lube water applications, but there is a great risk that the standard polyethylene sealing parts get damaged. High temperature/high pressure sealing parts are now available from the manufacturer.

During a 2 million cSt bitumen testing with the CCG GT-185/AWI pump system in Ottawa, the standard rubber/fiber glass sandwich type plate wheel degraded. Hot inlet and outlet lube water was applied (at that time the pump was only tested up to a pressure of 102 psi). This means that the hot inlet lube water cannot be used with the GT-185 pump unless it has been equipped with a high pressure/high temperature plate wheel as used in the JVOPS testing (Figure 64).

Figure 64 GT-185 High Pressure/High Temperature Plate Wheel (Left)
GT-185 Standard Plate Wheel (Right)

The LAMOR GT-A 50 was in the JVOPS testing equipped with high pressure/high temperature sealing parts, which are provided as standard.

9.2 Recommended Improvements to Water Lube Supply System (WLSS)

In the following sections it is necessary to split up the lube water application systems into three separate types. This will for the individual response organization make it possible to chose between solutions, and to find which solution best meets their operational requirements:

1. Discharge side AWI system only
2. Inlet side and discharge side AWI system
3. Inlet side AWI system only

Advantages and limitations will briefly be described, as will the required ancillary equipment.

9.2.1 Recommendations for Discharge side AWI WLSS

A Discharge side AWI system is recommended for response situations where oil of a viscosity up to maximum about 100,000 cSt must be pumped over longer distances than 100 ft. Within this viscosity range the concept will work with all the tested PDAS pumps and with a number of other pump types.

Recommended Improvements to Existing USCG VOPS and new Outlet AWI WLSS:

- High pressure feed pump, preferably submersible.
  - Pressure requirement: Max. main system pressure plus 30 to 50 psi.
  - Capacity: Minimum 5% to maximum 10% of total product pump maximum flow rate.
- WLCS with bleed-off of not used lube water and return to tank function, using adjustable relief valve pressure. Same principle as the WLCS for JVOPS Workshop, but with one inlet with bleed off, and one outlet only. Should have pressure gauge, flow gauge, and thermometer on outlet.
- Optional portable hot water source and (possibly) pump/hoses for hot water

9.2.2 Recommendations for Inlet side and Discharge side AWI WLSS

An Inlet and Discharge side AWI system, which incorporates hot water injection minimum at the inlet of the pump, is recommended for response situations where oil of a viscosity over 200,000 cSt and up to 2 or 3 million cSt must be pumped over any operational distance. Within this viscosity range the concept will work with all the tested PDAS pumps.

Recommended Improvements to Prototype Inlet side and Discharge side AWI WLSS:

- High pressure feed pump, preferably submersible, discharge side:
    - Pressure requirement: Max. main system pressure plus 30 to 50 psi
    - Capacity: Minimum 4% to maximum 8% of total product pump maximum flow rate.
- Centrifugal feed pumps, preferably submersible, inlet side:
    - Pressure requirement: Minimum 100 psi.
    - Capacity: Minimum 4% to maximum 8% of total product pump maximum flow rate.
- Feed pumps for discharge side should be for hot water, if this option is selected.
- Feed pumps for inlet side must be for hot water.
- Revised design WLCS to incorporate more reliable adjustable relief valves than on the prototype WLCS. Should have pressure gauge, flow gauge, and thermometer at both outlets. The WLCS may be simplified to have three inlets only if only hot water is selected for inlet AWI. The number of inlets may be reduced to two if only hot inlet water and one only of cold or hot outlet lube water are desired.
- Portable hot water source. The hot water source may incorporate the supply pump(s), in which case the hot water feed pump(s) may be excluded.
- Lube water supply and return hoses for hot water

9.2.3 Recommendations for Inlet side AWI WLSS

An Inlet side AWI system, which incorporates hot water injection at the inlet of the pump only, will be the most cost efficient option. If the choice is between inlet side or outlet side lubrication, it should be considered that inlet lubrication is the most versatile option.

An inlet side only AWI system with hot water has the benefit of some degree of local bulk heating, thus being able to enhance inflow of extreme viscosity oil to the pump, while simultaneously providing lube water for the pump and the discharge line. It is a very simple system that only includes one hot water capable low pressure feed pump compared to as many as three or four pumps for the maximum range inlet/discharge side lube water system. Cold water may be used for the inlet only AWI system in the lower viscosity range up to 100,000 cSt and maybe even up to 200,000 cSt, dependent on type of oil in question.

The Hot Water Inlet side AWI System is recommended for response situations where oil of a viscosity over 100,000 cSt and up to 2 or 3 million cSt must be pumped over any operational distance. Within this viscosity range the concept will work with the end suction PDAS pumps. The concept will not work with the GT-185 pump on the higher viscosities (> 250,000 cSt), since lack of internal sealing will back-flush inlet lube water.

Recommended Inlet side AWI WLSS:

- Centrifugal feed pump for hot water, preferably submersible:
  - Pressure requirement: Minimum 100 psi.
  - Capacity: Minimum 4% to maximum 8% of total product pump maximum flow rate.
- Simplified design WLCS to incorporate only one inlet and return connection, and only one outlet. The unit should have a more reliable adjustable relief valve than on the prototype WLCS. Should have pressure gauge, flow gauge, and thermometer on outlet.
- Portable hot water source. The hot water source may incorporate the supply pump, in which case the hot water feed pump may be excluded.
- Lube water supply and return hoses (from the WLCS) for hot water

9.3 Recommendations for all Viscous Oil Pumping Systems (VOPS)

- All VOPS should have a pressure sensor built into the pump outlet (or minimum an analog gauge connected to the pump outlet). The sensor could provide a signal to a digital display for manual control.

- The sensor could, as a better option, communicate with the hydraulic motor flow control. The system should work on 12 of 24 Volt from a battery, and should be in explosion proof design at the pump. This arrangement will prevent the pump and hoses from excessive pressures that may cause injuries, environmental and equipment damage, and that may shut down operation.

- Optional advanced digital WL control: Electronic control of lube water flow via input from data on hydraulic flow to transfer pump. To include variable WL % settings. This concept has the advantage of always delivering the pre set percentage of lube water to the AWIFs, no matter the pump capacity. The WL settings may be adjusted while pumping.

- Hose Grounding Continuity Kits. Should be retro fitted on existing systems. For new systems: Discharge hoses with built in anti static/grounding wire that connects pump, hose, and ground.

- High torque motors on transfer pumps. None of the JVOPS Workshop PDAS pumps could have completed baseline test or baseline-like test runs without the fitted high torque motor. Too little torque may lead to inability to re-start after a planned or unintended pump stop.

- A VOPS should include an appropriate and safe hose cleaning system that preferably can be used in-line and in-situ. This will make it possible to remove oil from "above deck" transfer hoses after an intended or unintended pump stop without removing any hoses. The application will facilitate a rapid re-start of the water lubricated pumping process with very long transfer hoses. The hose cleaning system should further be used in the post operation hose cleaning process.

- A VOPS should include one or more SHAS devices, each consisting of one “through” valve and one “down” valve. The ability to add on an additional hose section “on the fly” may become very useful when pumping to temporary storage tanks. Once a tank is close to full, an additional hose length to the next tank can be added on without stopping the pumping process. The SHAS is installed on the end of the first continuous length of hose. While discharging into one tank, using the “down” valve (“through” valve closed), the additional hose length to the next tank can be added on. When tank one is full, the horizontal “through” valve is opened first, and then the “down” valve is closed. The flow will continue discharging into tank two, where one more “Single SHAS” may have been fitted to the hose end.

10.0 LESSONS LEARNED – RECOMMENDATIONS FOR FUTURE TESTING

The Joint Viscous Oil Pumping Workshop was truly pioneering work. There have been many theories developed and conference presentations made over the years on the subject Core Annular Flow. Only in few cases, however, have the proposed theories been tested. The few tests that actually were carried out were under small scale laboratory conditions, and with oil of a relatively low viscosity.

Within the oil spill response community some larger scale tests have been conducted, but these have been either on low viscosity oil over long pumping distances or with extremely high viscosity oil over short distances.

High viscosity oil is a “bad” word within the oil industry. Therefore this industry already in 1959 initiated some research that should investigate potential transfer of viscous oil through pipelines. But the technique never became the standard approach. Within the oil industry the “solution” to viscous oil remains heating.

Experience with high viscosity oil is limited. There existed before the JVOPS Workshop no available experience on how to chill high viscosity oil. Who would want to do that? There existed no or limited experience on pumping high viscosity oil in pipelines or hoses over long distances. This would instead be carried out with the viscous oil heated to a temperature where it would flow easily.

These and many other issues were unknown factors when the big jigsaw puzzle of preparing for the JVOPS Workshop was put together.

The limited experience that was available was used to the largest possible extend, but still left the JVOPS Workgroup with many questions that could not be answered.

10.1 Test Oil

The problem obtaining a suitable oil for the project was unexpected. The JVOPS Workgroup members that were assigned to locate and obtain oil for the test had an extremely difficult time locating a product that would provide the target range of viscosity under the climate conditions expected at the test location. High viscosity heavy fuel oil (HFO or #6 oil) is available from domestic suppliers of residual oil, but this oil type must still be cooled down (and maintained) at 40 F or less in order to reach and exceed 200,000 cSt. This of course, is the situation when a ship is grounded or sinks in cold waters where the cargos and bunkers can quickly reach ocean temperatures in the 35 to 45 F range. HFO that would meet the JVOPS Workshop requirements could have been obtained from Russia and China, but costs and logistics ruled this out.

Therefore other sources had to be investigated, and the final choice was the bitumen crude oil from Japan Canada Oil Sands in Alberta. Prior to acquisition, initial sample analysis by the US Navy SUPSALV prime contractor GPC indicated that this product would meet the test requirements very well. It was found that the viscosity would be the correct range for USCG testing at approximately the expected ambient temperatures at the test site and should be cooled only a few degrees C to meet the higher viscosity required for the CCG testing. The product was found to have similar characteristics to residuals oils in that it was pseudo plastic (viscosity was inversely proportional to shear rate) but that the viscosity would increase slightly under constant RPM conditions. This was found very positive since this would be an additional challenge. However, only the actual oil behavior under testing would reveal how well the planned test procedures would work.

During the workshop and data analysis period, the extremely efficient pumping and lubrication performance caused some concern that the initial sample analysis may not have been correct. It appeared that the JVOPS Test Oil might have the characteristic of being shear thinning. This means that stirring and pump action, that can cause internal movement between the oil particles, will result in the oil flowing more easily, or that it has a lower viscosity than when it is left untouched.
However, samples of test oil taken prior to the start of each test were professionally analyzed and confirm the findings of the original pre-test analysis of the test oil behavior:

1. The JVOPS Test Oil has normal pseudo plastic characteristics (It's viscosity decreases proportionally to an increase in shear rate)

2. The JVOPS Test Oil does not display any thixotropic characteristics (it does not decrease viscosity at constant shear rate)

3. The JVOPS Test Oil shows only marginal rheopectic characteristics (it increases viscosity marginally over time when subjected to constant shear rate)

As would be expected for most oils, the oil became less viscous as shear rate increased and then stabilized at the new shear rate. In other words, as pump speed increases, the oil will reduce in viscosity to a slightly lower level but will then maintain that viscosity so long as the pump rpm is constant. See Appendix G, Test Product Specifications, for more information on the properties of the JVOPS Test Oil.

This ruled out the possibility that a shear thinning test oil was the reason for the extremely good test results.

The post-test analysis of the test oil samples also revealed increasing water content in the test oil throughout testing. Before the first test the total water content (free water and emulsified water) was between 0.8 and 1.6% and towards the end of the tests this had increased to 3 to 3.5% at the CCG test line and 8 to 9% at the USCG test line. Obviously some limited amount of lubrication water may not have been separated from the used test oil by the separating belt skimmers, but the majority of the water content as per the post test analysis would probably be for the following reasons:

1. The oil samples were taken from the top layers in the test tanks where the water concentration would be highest due to the test oil density that is higher than that of water.

2. Free water was from the AWIFs released into the test tanks before the start of each test. Some of this water may not have been pumped away during testing, but may instead have surfaced or have been entrained in the upper oil layer.

3. Heavy rain prior to the Workshop had left several inches of water on top of the oil in the CCG test tank and the USCG buffer tank. The water was removed by the USCG Gulf Strike Team and the tank covers were re-arranged to avoid any repetition. But even though all rain water apparently had been removed, some may still have been "hidden" within the upper oil layers.

The post test analysis of the JVOPS Test Oil (See Appendix G) reveals that despite the presence of some free and emulsified water, the pump transfer during testing was not made easier. On the contrary: Any emulsified water would add to the difficulties by increasing the viscosity of the test oil.

It is recommended for future VOPS testing with clean oil that the test oil is 100% protected from rain water and that lube water is applied to the least possible extend prior to pump start, however, without compromising it's desired effect.

Since many disasters with HFO or heavy crude oil cause spillages that eventually develop into extremely viscous water-in-oil emulsions, it is recommended that future VOPS testing also will be carried out on a high to extreme viscosity emulsified HFO.

It is not known exactly to what extent the oil/water separating skimmers were able to separate oil and lube water. Visually performance seemed good. Very little water discharge into the oil reservoirs could be observed and significant amounts of water were observed entering the water receiving tanks. It is nevertheless for future testing required that the efficiency of the belt skimmer oil/water separating principle is investigated or that other techniques are developed and tested.

It is recommended for future VOPS testing that properly tested oil/water separating techniques be used to separate test oil and lube water before re-use of the test oil.

10.2 Testing

Test Run Time

As mentioned above, only testing could reveal how the test oil would behave. Likewise, only testing could reveal if the rapid test procedure, as developed in the Test Plan to reduce oil consumption, hose length and decontamination costs, would produce reliable results from the very short test runs for each individual lube water setting. The Test Plan had assumed, that to test a lube water combination or the settings of lube water percentages, it would be enough to apply each new combination or setting for a little longer than the time it would take to pump the oil and lube water through the test hose. This appeared not to be right. Once very efficient core annular flow had been established, the test team could do almost anything with the lube water settings. The results, at least on clean test hoses, remained very stable and impressive.

> Therefore it is recommended for future testing either to test each new lube water setting or combination with a new clean test hose (which may not be realistic). Alternatively the test run time with any new setting or combination should be extended to the equivalent to pumping through a two to three times longer test hose.

The latter will require much more test oil and some more time, but may be the realistic approach that will also best resemble a real world scenario with adjustments to the settings.

Test Hoses

An approach that also could be considered is to test on contaminated hoses only. The work that the JVOPS Workshop carried out had the primary purpose of enhancing the real world pumping capabilities. In the real world clean hoses can rarely be expected available.

> In this case, testing should be with hoses that have been pigged once only. No further cleaning should be applied prior to using the hose again. This would probably produce less impressive test results, but would much better correlate with a real world response scenario

Available Time for Testing

Compared to the amount of work and funds that had been invested in the JVOPS Workshop prior to testing, there was a limited time available for actual testing and a number of planned tests had to be cancelled.

> It is for future testing recommended that relatively more time should be allocated for testing.

Radio Communication

The JVOPS Lead Engineer is not an experienced user of portable radio equipment. Training should have been planned for in order to ensure a better communication and more clear messages to all stations.

It was for some of the manually recorded data a problem that not all manual data and manual backup data recorders had a radio of their own.

> It is for future testing recommended that proper training in the use of radios, including signal and instruction phrasing, are carried out and that all recorders of manual data and manual backup data are equipped with radios.

10.3 Data Acquisition

The Data Acquisition system and procedure was an essential part of the Workshop testing. A tremendous amount of valuable data was recorded, which has formed the basis for the test analysis in this report.

It has in the analysis work been extremely convenient that all primary data was recorded by the data logger systems and later processed on a PC with the MAS 3000 software. This developed graphs for each sensor function.

Manual data and manual backup data were recorded by a massive effort by many responders and observes and were recorded on pre assigned sheets. There are, however, a few data sets that could have been slightly more reliable:

Inlet Oil Temperature Sensors

The temperature sensors (primary and backup), that measured the temperature of the test oil as it entered the test pump, were placed on one or more brackets 8" in front of the inlet openings of the pumps. However, the brackets were fabricated differently from pump to pump. Only the two manufacturers' pumps had brackets that met the requirements of the Test Plan and that were placed correctly. For these pumps there was a difference between the two inlet oil temperatures of only 0.5 F for the LAMOR pump and almost 2.0 F for the FRAMO pump. For the CCG GT-185 pump the temperatures differed from 2.0 F in one test to about 10.0 F in another. For the USCG DOP-250 pump the temperatures differed from 5.0 to 12.0 F in one test and from 10.0 to 16.0 F in another.

The significant differences were a problem for proper analysis of some of the test results. When one sensor failed, it would further be unknown whether it was the one with the high or the low readings that had worked.

> It is recommended for future testing that the inlet oil temperature sensors (primary and backup) are placed and fitted exactly in the same way relative to the pump intake. Proper calibration should be verified in connection with oil pre testing.

Test Tank Bulk Oil Temperatures

The electronic recording of bulk oil temperature was based on two sensors in each test tank. In the USCG test tank were placed one "high" and one "low" sensor, but in the CCG test tank the sensors had been placed only 6 inches apart. The position of the CCG bulk oil temperature sensors were due to a misunderstanding, but in general the Test Plan should have required several more sensors placed throughout the tanks, and their exact positioning should have been clearly stated. The very viscous oil would over time tend to stratify, thus being of lower viscosity in the upper layers and of higher viscosity in the lower layers.

The inlet oil temperature sensors would have been of great value in this in the interpretation of the test oil temperature, but in several tests they were, as mentioned above, not reliable.

This reduced the accuracy of the recorded data and of the results derived from the data.

> It is recommended that for future testing a more representative distribution of bulk oil temperature sensors be placed in the test tanks.

Manual Data and Manual Backup Data

The data sheets that the responders and observers had to use during testing left in some cases doubt as to the frequency and timing of recorded data. This was in some test a problem when primary data failed.

> It is recommended that for future testing the manual and manual backup data are recorded on test sheets that clearly indicate what is recorded, when synchronized timing starts, when data is marked (for specific Mark Data points), and at which frequency data are recorded.

Gauges on the WLCS

Especially the lube water temperature gauges on the water lubrication control stand seemed less than reliable. As per available information, they had been calibrated with the electronic sensors. However, during some tests the recorded temperatures differed significantly from electronic data and from data from the source tanks. This caused some concern as to the reliability of recorded lube water temperatures in some tests.

> It is recommended for future testing that the lube water temperature sensors be properly calibrated and be checked in the full temperature range for the test. Calibration should be carried out in a scenario that resembles the testing procedure, switching from hot to cold lube water and back, and involving starts and stops.

Power Consumption

Manual data were recorded of hydraulic supply and return pressures that combined with data on hydraulic flow would be valuable for the estimation of pump power consumption. The pressure data were as per the Test Plan recorded at the HPU at both test lines. However, the two test lines were not alike as to control of the hydraulics. The CCG test line had a direct HPU-to-test pump connection while at the USCG test line a remote control stand were used in-line between the HPU and the test pump. The RC would return to the HPU any hydraulic oil that was not used by the pump, and adds to the pressure losses in the hydraulic lines with an unknown amount of psi. This makes it difficult to compare power consumption at the two test lines.

It is recommended that for future testing the relative power consumption, based on hydraulic flow and hydraulic differential pressure, are recorded close to the test pump.

Volumetric Control of Apparent Pump Capacity

It was at an early stage in the preparations for the Workshop discussed whether sonar sounding of the test tank level (USCG test tank) could be applied for control of the calculated pump capacity (based on hydraulic flow). The method was ruled out since previous extreme viscosity testing had revealed that a very viscous oil may not form a uniform surface level in a tank, from which oil is removed at the bottom. Instead the drum fill per time control was applied.

However, it appeared that with this oil the surface level in the test tank at all times was uniform. Tank sounding would be a more precise volumetric control than the drum fill per time method.

It is recommended that for future testing the volumetric control of apparent pump capacity is carried out by means of sonar tank sounding. The method will require that test oil is pumped from the test tank to a buffer tank, thus the oil is not to be returned to the test tank during testing.

Re-circulation of Test Oil

At the CCG test line with 500,000 cSt oil it had not been expected that the test pump would reach maximum capacity in all test runs. The GT-185 further has the lowest nominal pump capacity of all pumps in the test. A certain volume of oil had therefore been assigned to the CCG test line and the test oil was re-circulated back to the test tank via a baffle arrangement. This method was found not to be suitable for tests of a relatively long duration. The test oil, that had been subject to heat from hot lube water injection, appeared to reach the test pump again in the last test runs of a test. The results of some test runs therefore had to be disregarded.

It is recommended that for future testing the pumped oil is not returned directly to the test tank. Instead the test oil should be pumped to a buffer tank (like at the USCG test line) and should be pumped to a backup tank or back to the test tank after completion of the individual test. This method will further allow for sonar tank sounding volumetric pump capacity control.

10.4 Test Photo and Video Documentation

The video and photo documentation from the JVOPS Testing lacks to a large extend precise indication of timing relative to the Data Acquisition timing. Several tests were carried out without proper video documentation of the discharge from the test hose. Such better documentation, timed with the data timeline, could have been valuable for the analysis of the test results, since the video could have shown some of the core annular flow development process.

It is for future testing recommended that carefully planned and timed photo and video recording is an integrated part of the Test Plan.

10.5 Test Pumps

The JVOPS Test involved three out of four PDAS pump types in the market and one double screw pump.

Other pumps have a reasonable representation in response inventories, and it would have been most relevant to have such pumps included in the testing. A number of manufacturers of relevant pumps had been invited to participate in the Workshop but could for various reasons not participate. It might therefore have been a possible approach to have developed interest with some response organizations that own such pumps and in this way include them in the test program.

If ever again an opportunity arises where the most common response pumps can be tested together, it is therefore recommended to involve response organizations that own pumps that ought to be tested, if these are not available from the manufacturer.

10.6 Water Lubrication Supply System (WLSS)

The combined WLSS, including the WL supply pumps and the WLCS, had due to time constraints not been thoroughly tested prior to the JVOPS Workshop. Some WL pumps were initially not coupled right. The adjustable relief valves on the WLCS seemed not to be stable at the pre-set settings. The lube water flow control valves seemed unstable, especially at low flow rates. This caused the cancellation of the second half of Test 0/1 and caused delays in some other tests. In some tests the amount of injected lube water was not on target. It was, however, by some re-arrangements and with increased WL Operator experience, possible to overcome the problems with minimal impact on the overall result of the testing.

It is recommended for future testing that the WLCS is equipped with more stable adjustable relief valves and flow control valves and that the entire WLSS is thoroughly tested prior to any tests with oil.

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