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Recovery Devices and Pumping Techniques for High Viscosity Oil Spills

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Abstract

Numerous spills over the years have demonstrated that mechanical response to high viscosity oil spills at sea is less than successful. After the 10,000 m^3 ERIKA Spill in France, less than 5% was recovered before the oil reached the coast. The weather played an important role, but the selection of equipment and apparent response strategy did as well. Mainly weir skimmers were used.

Weir skimmers are due to their simplicity and reliability widely used in spills at sea. Probably because some of the well known brands are equipped with heavy oil transfer pumps, they are even commonly attempted used in heavy oil spills. But also high capacity units with light oil centrifugal transfer pumps are being used on heavy oil (ERIKA). However, weir skimmers start losing their efficiency when the viscosity of the oil exceeds certain limits. It gets too difficult for the oil to pass the weir lip and flow into the hopper, so that the pump can transfer it. For very heavy oils, which barely can float, the inlet weir becomes an even larger obstruction.

A mechanical feeder skimmer lifts or drags the oil out of the water to a position above the water surface, and feeds or drops it into a collection tank or a transfer pump. The mechanical feeder principle may result in significantly increased performance regarding high viscosity, debris, and - in most cases - low water content.

Tank tests at SAIC/Environment Canada's test facility in Ottawa, Canada, sponsored by the Canadian Coast Guard, and tank tests since 1999 carried out by flemingCo, under contract with PDVSA/Bitor, have demonstrated that floating bitumen in the viscosity range of 2 to 3 million cSt could be recovered by several mechanical feeder skimmers, while a "high viscosity" weir skimmer had no effect. This puts the ERIKA Spill's viscosity of 200,000 cSt, the Baltic Carrier's 500,000 cSt, and the Prestige Spill's 320,000 cSt into perspective, and strongly point at mechanical feeder skimmers in the preparedness for heavy oil spills.

However, the same tests clearly demonstrated that the transfer pumps in the skimmers had difficulties transferring the extremely viscous product from pump inlet to pump discharge; meaning that feeding the product into the pump inlet showed difficult and/or the pressure/friction losses inside the pump itself could barely be overcome. It was therefore deemed necessary to test existing and newly developed techniques, which might improve these pumps' ability to transfer high to extreme viscosity oil.

This presentation will document that there as of today are skimming and pumping equipment and techniques available, which can be efficiently used in response to spills of even very viscous oil.

Discussion

Mechanical response to oil spills at sea has always had its limitations. Rarely has as much as 30% of the spilled volume been recovered. Overall effectiveness rates of mechanical recovery on-water generally range from 15% to 35%, depending upon incident-specific conditions (US Congress, Office of Technology Assessment, 1990). However, these percentages are according to ITOPF and other organizations too high. After the ERIKA spill, Dec. 12, 1999 off the coast of Brittany, France, where about 10,000 m^3 of heavy fuel oil spilled into the ocean, less than 5% was recovered at sea before the oil reached the coast (CEDRE/OSIR, 1999).

A best situation average of about 30% recovered at sea after an oil spill may not sound like a lot, but when compared to the costs involved in cleaning a coast line, which has been severely polluted by sticky and viscous oil emulsion, even 20-30 % do matter a lot. Cleaning, disposal, and compensation for damages to property may result in astronomic costs: In the US about USD 20,000 per m^3 heavy crude is the average figure for cleanup and disposal only, while up to about USD 94,000 per m^3, as in the case of "Exxon Valdez", can be the tab to pick up (Etkin, 2000) for cleanup and disposal. Add to this the costs of damage to property and environment!

Therefore it requires very little imagination to realize how feasible - environmentally and economically - it is to recover as much as possible before an oil spill at sea causes massive pollution of the coast lines or other environmentally sensitive areas. As the following will explain further, mechanical recovery of heavy oil spills can be more successful than past statistics and recent spill responses will let us know – provided the right equipment is being used.

Recovery of High to Extreme Viscosity Oil

Although weir skimmers with positive displacement screw pumps may have some effect as long as the heavy oil as lumps (including a large amount of water) flow into the hopper, these skimmers will face problems with larger concentrations and layers of oil when the viscosity reaches 30-40,000 cSt. The oil will have difficulties floating over the inlet weir and into the hopper (Fig. 1). Therefore a number of mechanical feeder skimmers have been tested for the recovery of high to extreme viscosity oil. Bitumen was used since the tests were carried out in relation to the special properties of spilled Orimulsion, which develops to bitumen if it is mechanically refloated after a spill in sea water (Hvidbak and Masciangioli, 2000).

A mechanical feeder skimmer lifts or drags - by means of more than just adhesion - the oil out of the water to a position above the water surface, and feeds or drops it into a collection tank or a transfer pump. The lifting/feeding can for instance be by belts, brushes, rotating net drums, counter-rotating drums, "corn elevators", or rotating toothed discs.

Common to all these methods is that they are able to drag the oil out of the water, based on combinations of adhering, grabbing, trapping, and squeezing, dependent of type in question. Adhesion is a major success factor. In some cases adhesion will positively influence performance, while strong adhesion will negatively influence the performance of others.

Mechanical Feeder Skimmers, which Have Been Tank Tested on Refloated Bitumen

Since 1999, flemingCo has tank tested a number of mechanical feeder skimmers on mechanically refloated bitumen. These tests, and tests in 1999 at SAIC/Environment Canada's test facility in

Ottawa, Canada have demonstrated that floating bitumen with a viscosity of 2 - 3 million cSt can be recovered by a number of different types of mechanical feeder skimmers.

Tested by flemingCo at manufacturers' facilities in Kalmar Sweden, June 1999 (Hvidbak, 1999):

The KLK 602 skimmer, a product of KLK in Sweden, marketed by SEAGULL ENVIRONMENT AS, Billingstad, Norway. It operates by twin counter rotating drums with positive guides, which lift and pressure-scraper feed the oil into an auger placed above water level, parallel with the drums, which further feeds into a screw pump.

The Unisep skimmer, a product of Unisep AB, Kalmar, Sweden. It works (larger versions) by a rotating expanded metal net drum, a "snail's shell", which for each revolution grabs a rectangular section of the in-flowing oil, and feeds it – by the concentrating geometry of the expanded metal drum and a scraper – into an auger placed above water level, parallel with the drum, which further feeds the oil into a pump. The water escapes via the holes in the stretch metal.

Tested at SAIC/Environment Canada's test facility in Ottawa with flemingCo participation November 1999 (Cooper and Hvidbak, 2000):

The ERE skimmer, a Product of Environment Recovery Equipment, Inc., Port Colborne, Ontario, Canada. The ERE Oriliminator skimmer incorporates an open meshed stainless steel belt with a square honey-comb structure. As the belt rotates, oil is forced down at the oil/water interface and is trapped between the belt and a polyethylene support plate, which effectively squeezes the oil into the mesh structure. The belt rests on this plate until it meets a roller inside the belt bank, which has protruding knobs that match the openings in the mesh. As the oil saturated belt moves up and rotates past the roller, the knobs force the oil out of the mesh and a scraping mechanism carries the oil away from the belt.

The Axiom HOBS, Heavy Oil Belt Skimmer, a special one-design by the Canadian Coast Guard. The HOBS unit incorporates an inclined conveyor type belt with short 10 mm long bristles on its upper surface to collect oil at the water/oil interface. The skimmer is large and extends to overall dimensions of approximately 5.2m x 1.7m x 2.0m (LWH) and weighs approximately 770kg. The belt lifts the oil up off the surface and carries it to the top of the unit, where a scraper with a relatively soft rubber edge forces the oil to drop off. The oil collects in a trough, which diverts the oil to an opening, gravity feeding into a final container or a pump.

The KLK 602 Twin Drum Skimmer as described earlier.

Tested by flemingCo at manufacturer's facility in Aalborg, Denmark, February 2001 (Hvidbak, 2001):

The DESMI Belt Skimmer, marketed by Ro-Clean DESMI A/S, Odense, Denmark. This inclined belt skimmer incorporates a conveyor belt type consisting of many small fiber plastic links with catch plates. It has like the ERE a support plate beneath the belt, which holds the oil at the belt on its way to the scraper. On high to extreme viscosity oil the belt rotation must be reversed so that the belt rotates down water an up, thus bringing the oil up on its upper surface.

Tested by flemingCo at manufacturer's facility in Porvoo, Finland, June 2002 (Hvidbak, 2002):

The LAMOR/LORI Brush Belt Skimmer, manufactured by LAMOR, Porvoo, Finland. This brush belt skimmer incorporated a 1.6 m long brush belt bank with 5 separate brush belts, each. approx. 100 mm wide. The belt bank was manufactured specially for the test, i.e. with brackets for mounting on the end wall of the test tank, and with no floats mounted. No transfer pump was mounted, the recovered product was scraped off the brushes and delivered back into the test tank. In a later test the skimmer had been equipped with a heated hopper, which guided the recovered bitumen from the scraper into the Lamor GT-175 transfer pump with inlet side steam injection.
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In addition to these tests, a Tar Hawg Inclined Belt Skimmer (same as Grizzly), USA, was tested at an offshore Orimulsion spill test in Venezuela in 1996 by PDVSA/Bitor with CCG and USCG in attendance (Deis, et. al., 1997).

All the tests have been carried out under almost the same conditions with a product temperature of 15 °C, except for the Kalmar test where the temperature was about 18 °C. The bitumen layer was 30 mm thick and the skimmers were used in static mode except for the SAIC/Environment Canada tests, where a flow could be induced towards the skimmers. It was in all tests visually observed how well each skimmer could grab and lift the bitumen off the water surface and how efficiently it could scrape it off.

Despite differences in performance, all the tested skimmers could recover the extremely viscous bitumen. Nearly all skimmers had to have minor modifications made in order to handle the extremely viscous and sticky product (mainly higher torque hydraulic motors). All seven skimmers are shown in Figure 2 and the viscosity vs. temperature curve for refloated bitumen is shown in Figure 3.

Mechanical Feeder Skimmers with Potential, Not Yet Tested on Bitumen[1]

Based on the results of the bitumen skimming tests and many years experience from within the "oil spill recovery industry" the following skimmer types are expected to have potential in response to spills of high to extreme viscosity oil (Fig. 4):

- MARCO Filterbelt Skimmer. Product of MARCO Pollution Control, Seattle, USA.
- Egmopol "corn elevator type" skimmer. Product of S.E.P. Egmo, Brest, France.
- Sea Devil toothed disc skimmer. Product of Vikoma Ltd., Isle of Wight, UK.
- Sea Wolf, toothed disc clamshell type skimmer. Product of Vikoma Ltd., Isle of Wight, UK (not shown).
- Hiwax, twin drum skimmer w. dynamic driving plates. Product of Frank Mohn, Bergen, Norway.

Important Efficiency Parameters for a Mechanical Feeder Skimmer

The skimmer must be able to grab the oil and actively bring it to a position above the water surface. So the grabbing capability is a very important parameter. But once the oil is above water, it is as

[1] Disclaimer: This selection has been made based on the authors general knowledge to the market and the equipment listed, but it does not necessarily present a complete picture of the equipment types, which could have this potential.

important that it can be scraped off and be directed into a transfer pump or a storage tank. Several parameters will influence the skimmer's ability to grab the oil:

- ?? Wave action
- ?? The presence of debris
- ?? The viscous oil's access to the skimming device
- ?? The direction of rotation of the belt, brush, drum, or disc
- ?? The vertical extent of the active grabbing zone
- ?? Open or closed structure of skimming device
- ?? Device fixed to a barge or a vessel, device free-floating, or device built into the hull of a vessel
- ?? Inertia mass and buoyancy arrangement (free-floating)

The weather – and thereby the waves – plays an important role in response to oil spills at open sea. The before mentioned tests were all tank tests with no wave action and no advancing mode. It is therefore strongly recommended that further testing on high to extreme viscosity oil be continued in a testing environment, which, with advancing mode in waves, better will resemble real world conditions.

Debris is an often overseen problem in oil spill response. The skimming device must be designed so that most floating debris immediately will be brought away from the recovery zone and be removed manually or be automatically separated and disposed of. Only in this way free in-flow of viscous oil to the recovery device can be secured.

The skimming device must be designed so that the construction itself does not form an obstruction for the oil's free in-flow.

The direction of rotation of a skimming device can either be down into the water, picking up the oil on its way up, or down into the oil, moving the oil down water and up. The first type of rotation creates a water pumping effect, which will tend to push the oil away from the skimming device, while the second actively will drag the oil towards the device.

The vertical extent of the active recovery zone is very important in waves. If the zone is too short, the oil may part of the time be either above or under the recovery zone of the skimming device.

An open structure of the skimming device will facilitate water and oil in-flow to the skimming device and will reduce the negative influence of wave action provided the active recovery zone is high enough. A closed structure (for instance a solid belt) will tend to work against nature by pushing or splashing the oil away from the skimming device when being moved up and down by waves. Further it will not allow for a free in-flow of oil and water, especially not if the direction of rotation further complicates this.

A skimming device can be brought to use in many ways. It may seem convenient to mount it on the bow of a vessel or a barge, but then the vessel's movements in the waves will force the device in and out of the oil/water causing severe disturbance to the in-flow of oil. This effect can be somewhat reduced by mounting the skimmer on the side of the vessel, amidships. The device can also be free-floating, having its own buoyancy, which may be a convenient solution for lighter oils and in relatively calm sea, but in bad weather and/or heavy oil it may be difficult to operate and there may be a safety problem involved in deployment and recovery of the unit. Thrusters mounted on the skimmer may to some extent facilitate the ability of this skimmer type to move to and into the oil. However, the most optimal solution with respect to sweeping speed, waves, and safety is to circulate the collected oil through a wide and unobstructed channel inside the response vessel where the skimming device can operate in a protected and controlled environment (Fig. 5).

The inertia mass and buoyancy arrangement of a free-floating skimming device are other important success factors. The inertia mass must be as low as possible and the center of gravity must be kept as close as possible to the center of the skimmer. The buoyancy must be sufficient and be placed so that the device rapidly will follow the wave movements. For free-floating mechanical feeder skimmers it is extremely important that the reserve buoyancy is big enough to handle both the wave action and the weight of the recovered product, while it is on its way to be scraped off and be pump transferred to the response vessel.

Other approaches to recovery of high to extreme viscosity oil

Crane grabs and backhoes

These types of equipment are conveniently located in many countries since they are very common within the construction industry. They have in many cases been the solution when most of the dedicated oil spill response equipment failed on heavy oil (Baltic Carrier spill), and especially when the heavy oil is severely debris-laden (Natuna Sea spill). Their downside is that they will only work under calm conditions and that the recovery rate may be relatively small, severely decreasing with increasing adhesiveness of the oil.

Oil trawls

Oil trawls are used for recovery of floating tar balls, slicks of heavy fuel oil, oil contaminated debris, residual tar after oil burns, and bitumen residues from Orimulsion spills.

Oil trawls have, like mechanical feeder skimmers in tests and incidents (Erika and Natuna Sea spills), proved to be able to recover even very viscous oils. In tests (Clement et al., 1997) the oil trawls have demonstrated recovery of extremely viscous floating bitumen. But there may be logistical problems in terms of handling and emptying the full recovery socks and an issue relating to cost as to whether they should be regarded as “disposable”. In the Erika spill, two fishing vessels using nets recovered about 8 m3 of the very viscous oil in two days, but the nets were too difficult to empty and clean and had to be disposed of.

An oil trawl system consists of the guide booms, the entrance net, and the detachable trawl bags. It can be very rapidly deployed with only small work boats. No hydraulic power or heavy mechanical equipment is required - only a simple air blower for inflation of the guide booms, or even less if foam filled booms are used.

Two of the more well known brands are the ScanTrawl and the Jackson Trawl.

High Viscosity Pump Transfer

No skimmer is better than its transfer pump, unless it can scrape off the recovered oil directly into a tank. So, it is in most cases not enough to evaluate the skimming device itself. The transfer pump or transfer system must be evaluated as well.

Two of the most widely used heavy oil transfer pumps in the oil spill industry – the DOP-250 and the GT-185 – were tested in two of the previously mentioned tests on 2-3 million cSt bitumen and both had difficulties transferring the extremely viscous product from pump inlet to pump discharge. It was therefore deemed necessary to test existing and new flow enhancing techniques which might improve the ability of these pumps to transfer bitumen. Unless the problems could be overcome, a large number of otherwise capable mechanical feeder skimmers could be considered unsuitable in the preparedness for spills of high to extreme viscosity oil. Heating was an obvious option, but might not always apply, or might not in itself be sufficient. Various methods of water injection lubrication of bitumen had to be tested.

The ongoing series (since 1999) of high viscosity oil pumping tests, sponsored by the US Coast Guard and the US Navy (Moffat, 1999), and from 2002 also the Canadian Coast Guard, aim to develop methods of efficient emergency high viscosity pumping and to prepare educational material for responders, so that there finally can be put an end to the long history of spill response difficulties due to problems with high viscosity oil transfer. Results available as of January, 2003, show <u>a factor 10 - 12 reduction in pressure drop</u>, when pumping 13,000 to 27,000 cSt heavy fuel oil through a 400 m long 6” transfer hose, aided by water lubrication via an annulus water injection flange (AWIF) on the discharge side of the pump.

No results were available detailing the effect of water lubrication applied either at the pump inlet, or both before and after the pump. The history behind positioning the AWIF after the pump is that mainly centrifugal pump transfer systems have been used in the emergency offloading industry. These pumps observe, at a relatively small increase in viscosity, a severe decrease in efficiency. Water lubrication has been able to enhance the efficiency of these pumps, but only by placing the AWIF after and a little away from the pump, because turbulence would otherwise mix the oil and water. This mixing could emulsify the added water into the oil, hence creating higher viscosity emulsion and further decreasing efficiency.

Positive displacement Archimedes’ screw pumps like the DESMI, Foilex, and GT are far less sensitive to higher viscosity oil. But when the pressure drop – due to friction in the discharge line – eventually exceeds the maximum pressure of the pump, these pumps must decrease transfer capacity to avoid damage to hoses, pump, or hydraulic motor. Therefore the screw pumps will also benefit from water lubrication. But for these pumps the above mentioned reasons for positioning the AWIF after the pump do not apply; there is no turbulence after the pump, and there will be no emulsification inside the pump if water is added before the pump.

On very high viscosity oil - and especially on bitumen of extreme viscosity - the friction losses inside the screw pump will significantly influence its overall performance. There will be limited benefit of water lubrication after the pump if the pump itself is the obstruction. By applying the water injection before the pump, some of these difficulties might be overcome while still maintaining the benefit of the water lubrication in the discharge line.

An inlet lube flange – for injection of both cold water and steam/hot water into the DESMI DOP-250 pump intake – was designed as a consequence of these considerations.

Extreme Viscosity Pump Transfer Tests

In a test at DESMI's test facility in Aalborg, Denmark in 2001, sponsored by PDVSA/Bitor (Hvidbak, 2001), cold bitumen with a bulk temperature of 14 – 15°C (> 3 million cSt) was transferred, using a DOP-250 pump equipped with a flemingCo designed inlet side steam / hot water injection system (Figures 6 and 7). The product was pumped through a 20 m (66 ft) long 6" hose at a rate of 45 m3/h (198 USgpm). The injection system incorporates an injection flange (AWIF), distribution hoses, a distribution manifold, and hook-up for a steam cleaner (Figure 8).

This was a break-through in extreme viscosity pumping, which was further cemented when a similar test was carried out at SAIC Canada/Environment Canada's test facility in Ottawa, where a GT-185 transfer pump was tested with flemingCo designed inlet- and outlet steam/hot water lubrication devices (Figure 8) (Cooper, et. al., 2002).

The test, which was sponsored by the Canadian Coast Guard, demonstrated that the modified GT pump could transfer 2-3 million cSt bitumen at a rate of 13.9 m^3/h (61 USgpm) through 12 m (40 ft) of 4" hose. This was a 40 times performance improvement when compared to the baseline test, where only 1.07 m3/h (4.7 USgpm) could be pumped through 3.6 m (12 ft) of 4" hose without any steam or hot water injection.

It was at the Danish test further observed that heating the bitumen from 15 to 30 °C was sufficient for an operational pumping capacity without the aid of water lubrication.

Since these tests were carried out, a new positive displacement Archimedes' screw pump has been developed. As a result of LAMOR's acquisition of GT Pollution Control in 2002 it was decided to design a pump to replace the old GT-185 design from 1981. The new pump is in vertical design like a DOP pump but develops a slightly higher pressure and has as standard a built in flemingCo type inlet side steam/hot water injection system. This pump and its steam injection system has been tested on bitumen in-house at LAMOR in Finland as transfer pump on a brush belt skimmer. The viscosity was about 3 million cSt and the pump could match up with the skimmer and transfer the recovered product through the discharge hose – fully water lubricated.

The new flow enhancing techniques for the pump transfer of extremely viscous bitumen have not only made bitumen emergency transfer pumping operational, but have also already been incorporated into several applications of emergency pump transfer of conventional high viscosity oil. In 2002 it was used in the unloading of highly viscous oil from the sunken world war 2 vessel Luckenbach off the coast of California. In 2003 the inlet side injection system will be tested at the next Joint US and Canadian Coast Guard Viscous Oil Pumping System (JVOPS) workshop in USA. Oils of 200,000 cSt and 500,000 - 1 million cSt will be the targets for long distance testing. All the positive displacement Archimedes' screw pump in the market will be tested with their respective flow enhancing techniques.

Both ERE, LAMOR, and DESMI deliver off-the-shelf mechanical feeder skimmers, where the transfer pump is equipped with inlet or outlet side steam/hot water injection, and ERE and LAMOR have optional heating of all surfaces leading the viscous oil to the pump.

Conclusion

It was a surprise to the author that so many existing mechanical feeder skimmer designs were able to pick up and scrape off the extremely viscous bitumen of 2 – 3 million cSt, with no or only few modifications required to the equipment. Some even had an impressive performance. This is promising for the potentially capable skimmers that have not yet been tested at these high viscosities.

When the development and implementation of the new flow enhancing techniques are added in, it is safe to conclude that as of today there are known and tested techniques and equipment available for responders, which can be applied in response to high and extreme viscosity oil spills.

Tests have shown that there are standard off-the-shelf equipment available that can recover even very viscous oil and that the oil can be transferred at an operational rate once it has been recovered. Response organizations, which could face responding to spills of high viscosity oil, should therefore consider acquiring the necessary equipment besides what they already have and should make the necessary modifications to existing equipment. In this way – and by carrying out the necessary training – the preparedness for coming spills of high viscosity oil may result in significantly better overall effectiveness rates than we have witnessed in the past few years.

Biography

Flemming Hvidbak is an oil spill consultant who has been in the industry for 19 years. He has specialized in developing and testing response techniques and equipment for spills of heavy and extreme viscosity oil. Presently he serves as technical director for the coming joint US Coast Guard, Canadian Coast Guard, and Industry viscous oil pumping system tests in the United States, 2003.

References

(in order of appearance)

US Congress, Office of Technology Assessment, 1990. *"Coping With an Oiled Sea: An Analysis of Oil Spill Response Technologies"*. OTA-BP-O-63. US Government Printing Office, Washington DC., 70p., 1990.

OSIR (Oil Spill Intelligence Report), citing CEDRE 1999. (Center of Documentation, Research, and Experimentation on Accidental Water Pollution) Vol. XXII, Nos. 50 and 51, 1999.

Etkin, D.S., Environmental Research Consulting, 2000. *"Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors"*, Proceedings of the 23rd Arctic and Marine Oilspill Program Technical Seminar, AMOP 2000, Environment Canada, Ottawa, Ontario, Canada, 2000, pp. 161-174.

Hvidbak, F., flemingCo, Masciangioli, P., INTEVEP, 2000 *"The Development and Test of Equipment for Rapid Reflotation of Spilled Orimulsion®"*. Proceedings of the AMOP 2000 technical seminar.

Hvidbak, F., flemingCo, 1999. *"Projects for the Detection and Recovery of Spilled Orimulsion®, Evaluation of the UNISEP and KLK Skimmers"*, Bitor America Corporation report, 1999.

Cooper, D., SAIC Canada, Hvidbak, F., flemingCo, 2000. *"Evaluation of Mechanical Recovery Devices for Spills of Orimulsion®"*, SAIC Technical Report, 2000.

Moffatt, C., GPC, US Coast Guard and US Navy, 1999. *"Testing of the U. S. Coast Guard Viscous Oil Pumping System (VOPS Prototype) at the MMS OHMSETT Test Facility, Earle, NJ, November 1999"*.

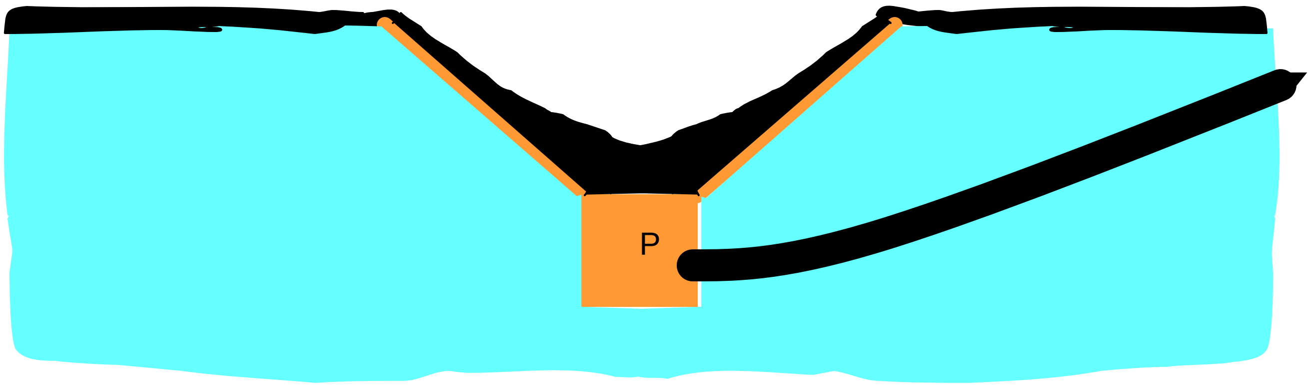
Hvidbak, F. flemingCo, 2001, *"The Development and Test of Techniques for Emergency Transfer of Extreme Viscosity Oil",* Proceedings of the AMOP 2001 technical seminar.

Hvidbak, F., flemingCo, 2002. *"Test and Evaluation of the LAMOR Brush Belt Skimmer on 3+ million cSt Bitumen"*, Bitor technical report, 2002

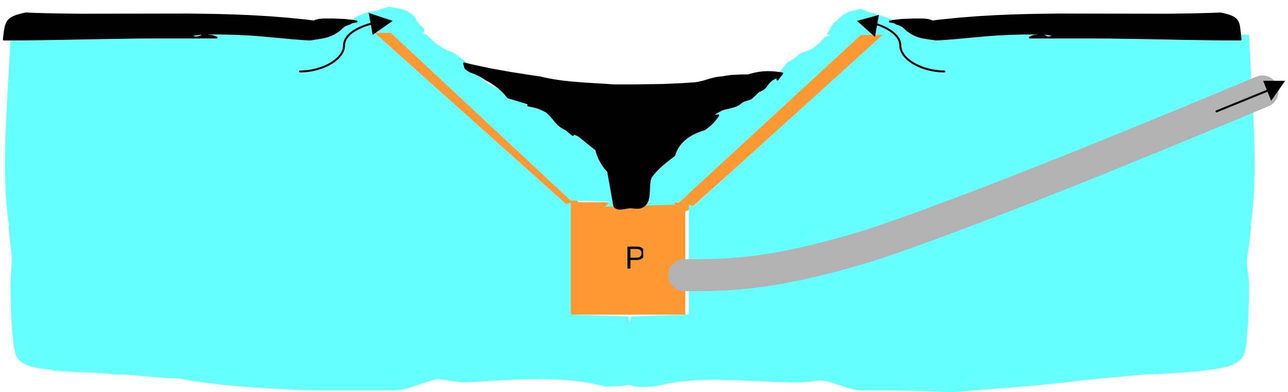
Deis, D.R., Garcia, N.G., Masciangioli, P., Villoria, C., Jones, M.A., Ortega, G.F., Lee, G.R., 1997, *"Orimulsion® Research and Testing and Open Water Containment and Recovery Trials"*, Proceedings of the 1997 International Oil Spill Conference.

Clement, F., CEDRE, Gunter, P., Bitor Europe Ltd., Oland, D., OSRL, 1997. *"Trials of Recovery and Cleanup Techniques on Bitumen Derived from Orimulsion®"*, Proceedings of the 1997 International Oil Spill Conference, pp. 89-93, IOSC, Washington, DC, 1997.

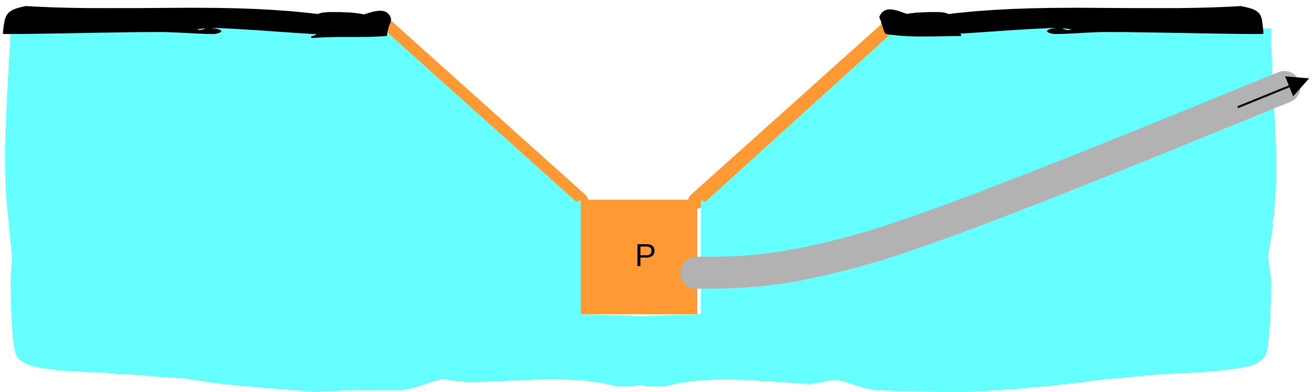
Cooper, D., SAIC Canada, Hvidbak, F., flemingCo, Mitchell, T., Breco Innovation, 2000, *"Pumping Extremely Viscous Oil Using a Modified GT-185"*, SAIC Technical Report, 2000.



Works well - Light to medium oil and weir lip in correct position



Water penetrates oil layer - Viscosity too high or pump speed too high



Weir lip stops oil - Viscosity too high or weir lip position too high

Figure 1 Free-floating Weir Skimmer and Heavy High Viscosity Oil

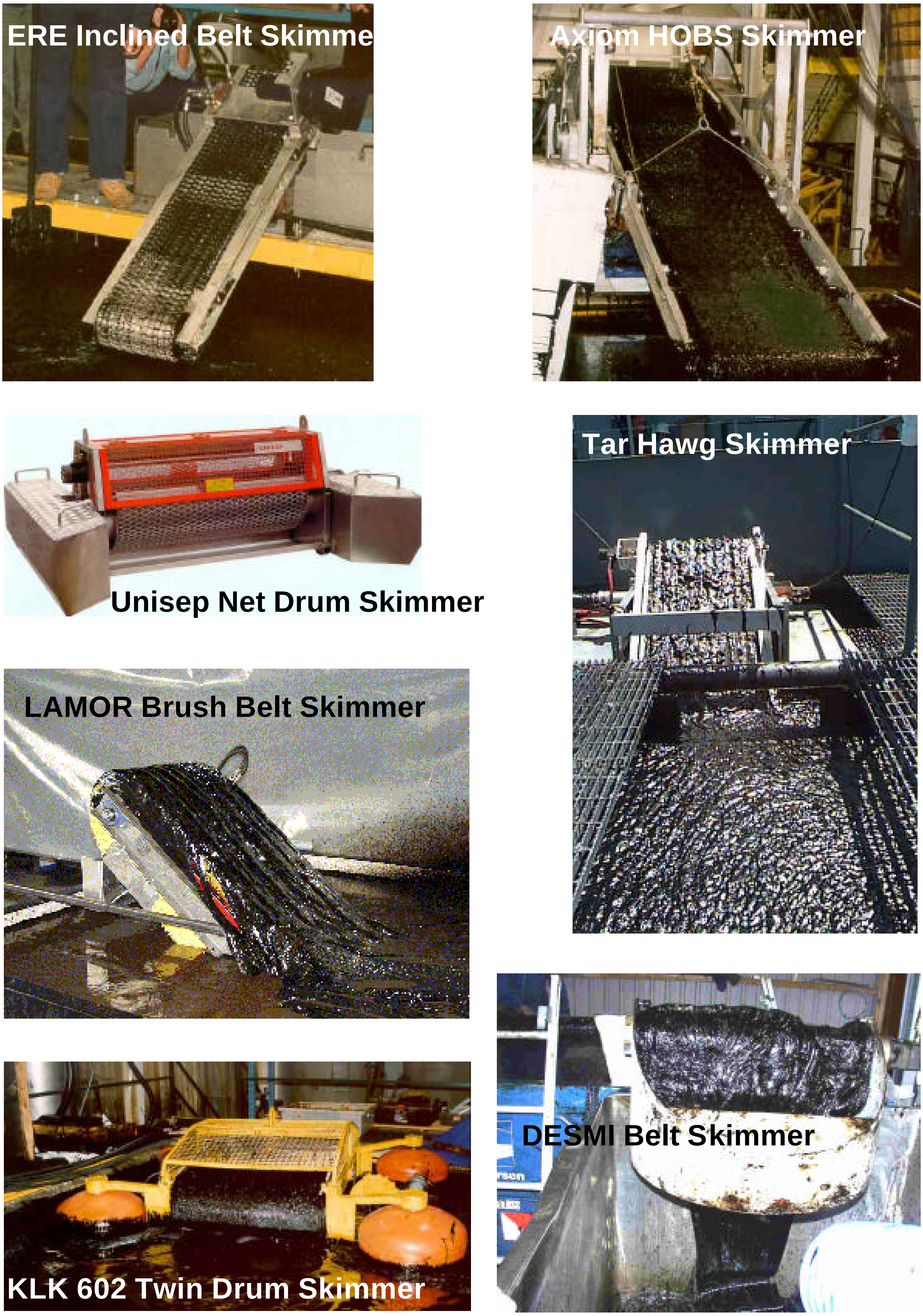
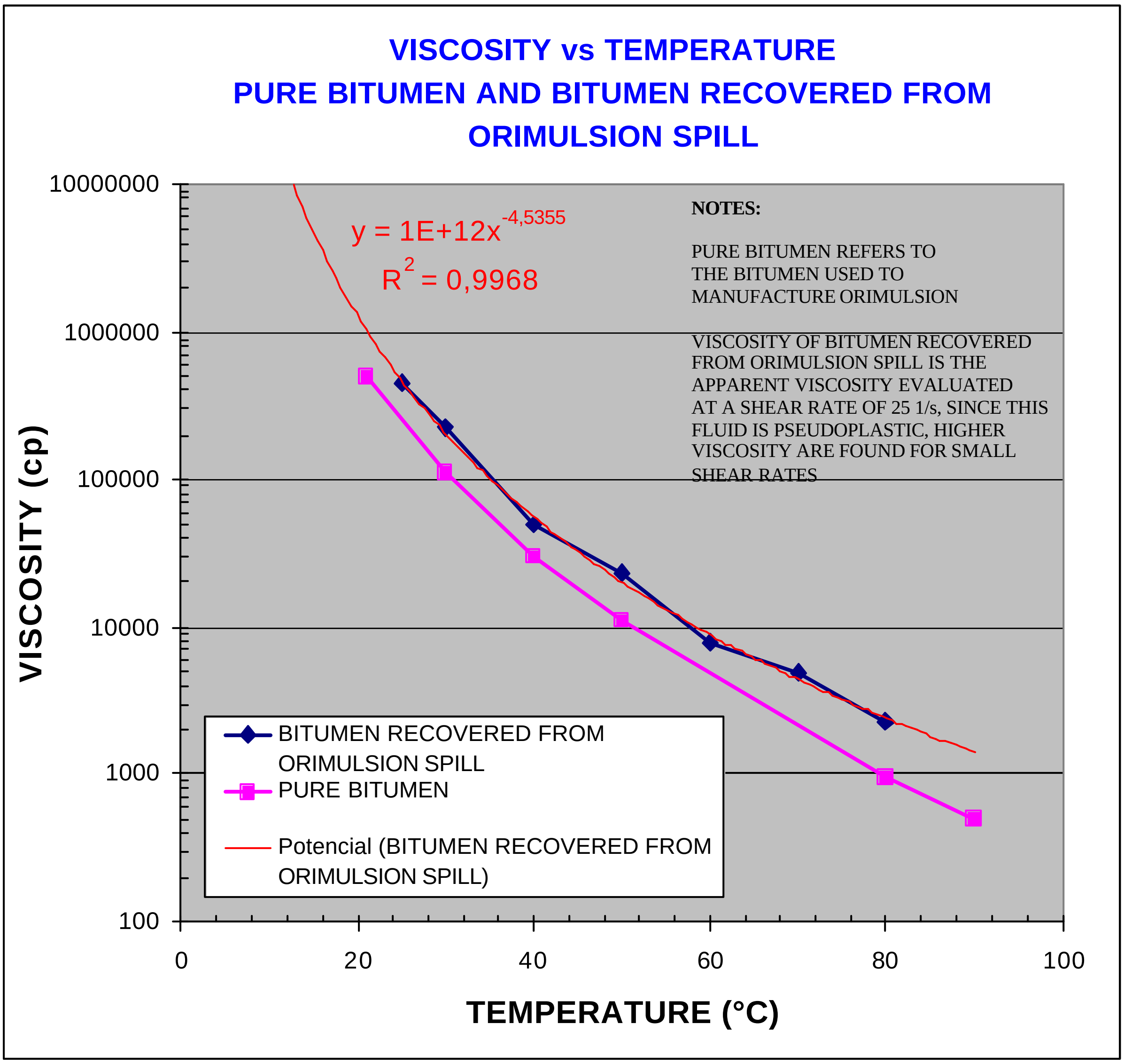


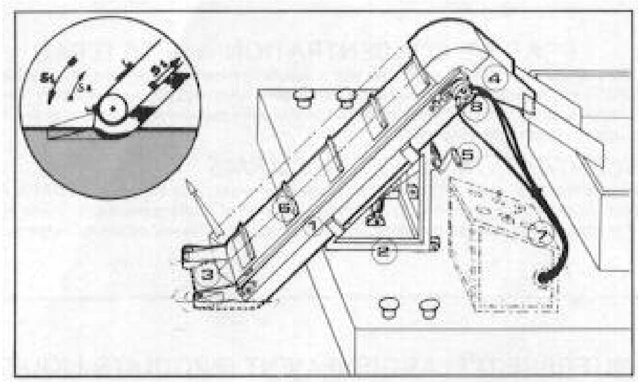
Figure 2 Mechanical Feeder Skimmers, which Have Been Tank Tested on Bitumen



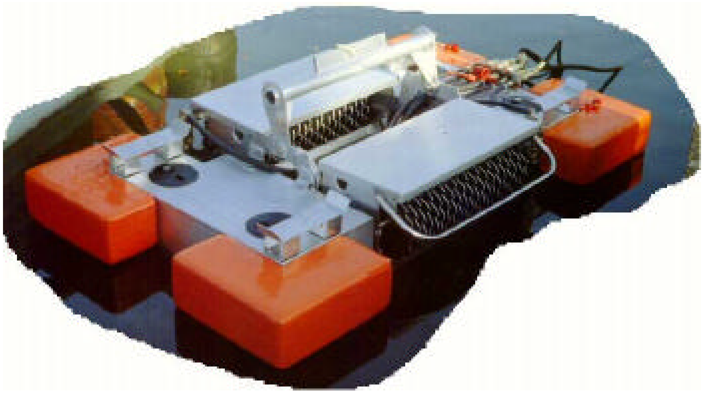
Please note that for densities close to 1, cP is approx. the same as cSt

Figure 3 Viscosity vs. Temperature for Refloated Bitumen and for Neat Bitumen

Marco Filter Belt Skimmer



Egmopol "Corn Elevator" Belt Skimmer



Vikoma Sea Devil Toothed Disc Skimmer

Framo Hiwax Twin Drum Skimmer with Dynamic Driving Plates

Figure 4 Mechanical Feeder Skimmers with Bitumen Potential, Not Yet Tested

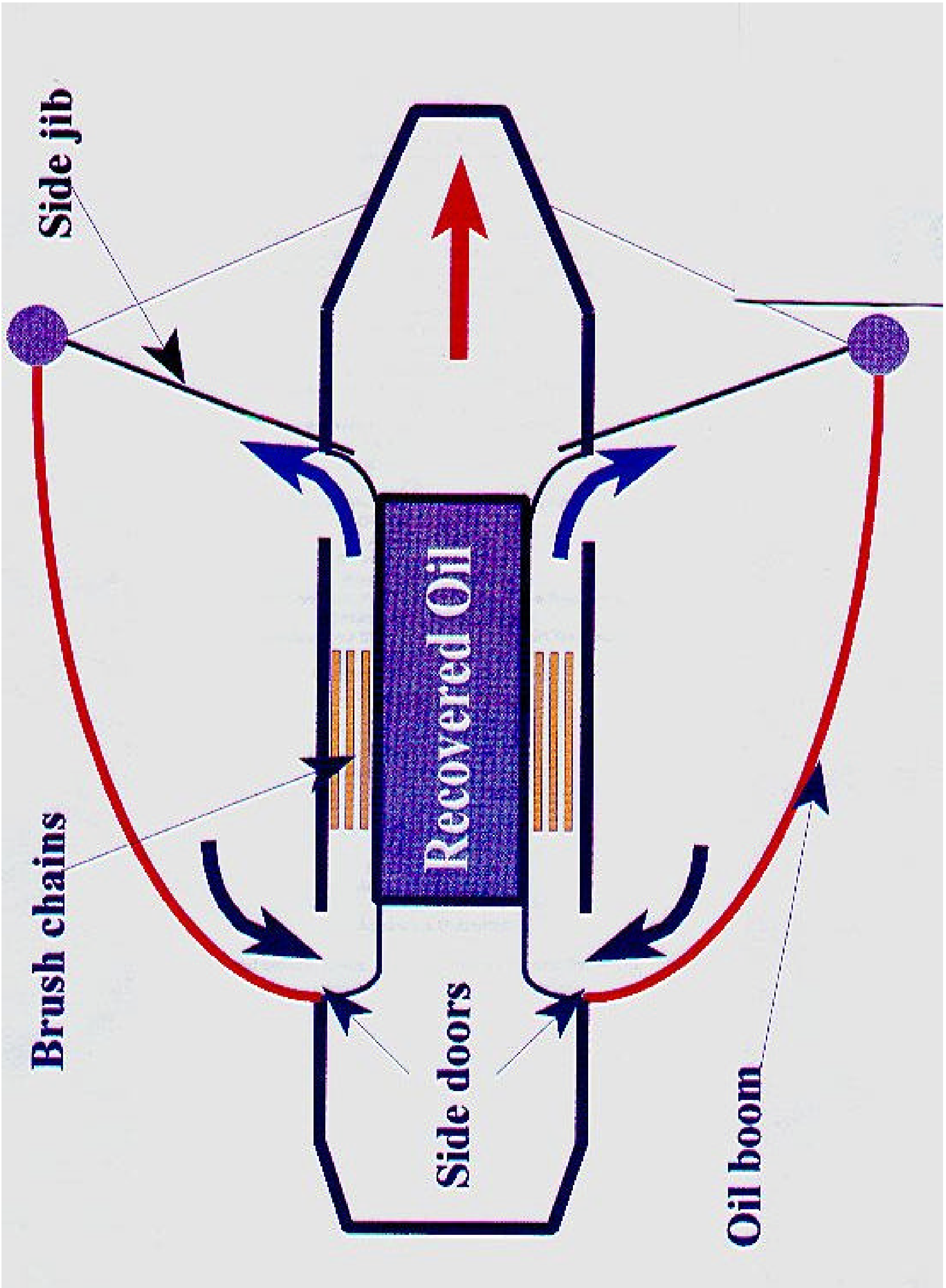


Figure 5 LAMOR/LORI In-hull Canal Skimming System

Figure 6 Cold bitumen, 33 m^3/h @ 9 bar, 20 m discharge hose, injection is on but no water lubrication yet

Figure 7, Cold bitumen, 45 m^3/h @ 2 bar, 20 m hose, water lubrication in full effect. Note the non sticky snake jumping up!

Figure 8 DOP Pump with flemingCo Inlet Side Steam/Hot Water Injection System

Figure 9 GT-185 Pump w. flemingCo Inlet- and Outlet Side Steam/Hot Water Injection System