Interspill 2004
Presentation no. 425

Positive Displacement Archimedes' Screw Pumps and Flow Enhancing Techniques. Essential Tools in Response to Spills of Heavy Oil and Bitumen.

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Abstract

The perspective of this paper is to provide responders and authorities with a broader understanding of the most advanced pumping technologies and techniques that are available for one of the most difficult tasks in mechanical response to spills of heavy and extreme viscosity oil: Extreme viscosity transfer pumping.

The so-called positive displacement Archimedes' screw (PDAS) pumps have within the oil spill industry for several years been considered superior to other pumps as regards the transfer of debris laden and often very viscous and difficult-to-deal-with oil or water-in-oil emulsions. Their ability to handle viscous oils, solids, to cut debris, and to pump oil and water without causing the creation of emulsion has together with relatively low weight and small dimensions - when compared to the performance - cemented the position of these pumps in the market.

There are presently four PDAS pump brands on the oil spill response market, which all have their origin in a patent, which was taken by Goodyear in 1955.

This presentation will describe their historical development and provide insight to the technology: From the design of the original Goodyear pump, based on a gear box principle, to the DESMI and GT cooperation on the first Destroil screw pump. It will cover their split-up following GT's design of its own version, and DESMI's reaction with the launch of the DOP pump type. It will go through FOILEX' special variant, and will complete the picture with the new Lamor GT-A. The technical differences between the pumps, their capacities, pressure ratings, availability of performance curves, and selection of materials will be discussed.

Increased awareness of the need to respond to spills of high and extreme viscosity oil, has led to the development of new flow enhancing water injection techniques, which enable the PDAS pumps to transfer even the most extreme viscosity oils and emulsions at operational pumping rates over operational distances. Summary results from full scale tests of the new techniques will include testing at manufacturers, at the Canadian Coast Guard / Environment Canada in Ottawa, February 2002, and at the Joint US and Canadian Coast Guard and Industry Viscous Oil Pumping System testing in the US December 2003.

1 Introduction

The so-called Positive Displacement Archimedes' Screw (PDAS) pumps have within the oil spill industry for several years been considered superior to other pumps as regards the transfer of debris laden and often very viscous and difficult-to-deal-with oil or water-in-oil emulsions. The pumps are able to handle viscous oils, solids, to cut debris, and to pump oil and water without causing the creation of emulsion. This has together with low weight and relatively small dimensions - when compared to their performance - cemented the position of these pumps in the market.

Despite the good performance on heavy oil the PDAS pumps will be severely challenged on extreme viscosity oil like for instance bitumen or very cold heavy oil. The oil will not freely flow into the pump and even if it does get into the pump the friction inside the pump and in the discharge line may be more than the pump can handle without causing damage to itself, its hydraulic motor, or the discharge hose. It is therefore in such situations necessary to use a flow enhancing technique in order to pump the product over an operational distance at an operational rate.

2 The History of Positive Displacement Archimedes' Screw Pumps

There are presently four positive displacement Archimedes' screw pumps on the oil spill response market; DESMI, FOILEX, GT, and LAMOR, which all (although there are variations) have their origin in a patent, which was taken by Goodyear in 1955, for the so-called Goodyear pump. The patent expired in 1975.

2.1 The Goodyear pump – from gear to pump

This pump was in made by modifying a globoid worm gear (in earlier years used in high performance worm gear boxes for the automotive industry) to a positive displacement pump. Opposite a traditional worm gear, which incorporates a linear screw or worm, which interlocks with the larger gear wheel and only has full contact (or in pump terminology: total seal) between screw and wheel in one single position, the globoid worm gear involves a screw and wheel with geometries, which enable them to have full contact between the screw and gear wheel flanks over the full extent of the engagement. This means that the load induced forces are distributed over a much larger surface, thus allowing for the transfer of more power.

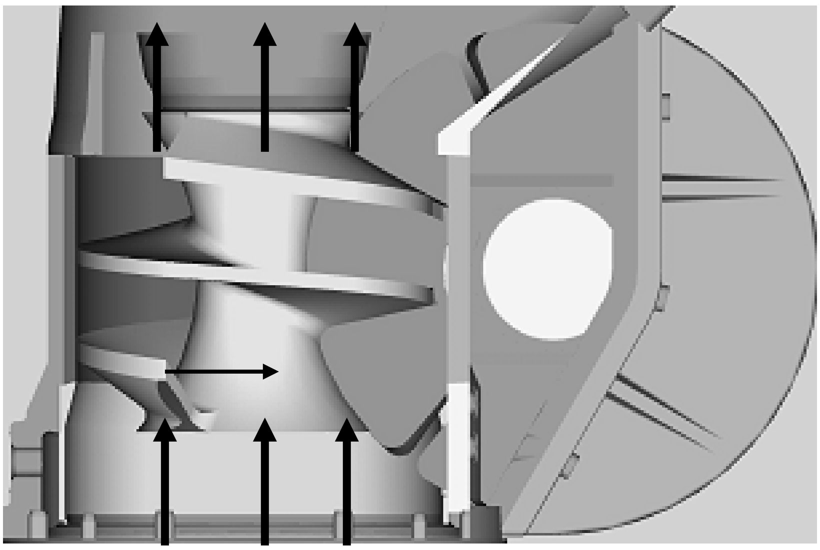


Figure 1 Goodyear Geometry with Directions of Flow and Screw Rotation

Goodyear's trick was to transform the gear to a pump by providing a casing with a sealing ring around the screw, and by constructing the large gear wheel with sealing material on the "teeth" so that they, once engaging with the screw, would enclose a volume that could not escape back to the pump inlet (Fig. 1). One volume per tooth or disk, and one new disk per screw revolution. The gear wheel, which in the pump version of the geometry is called the plate wheel, had in the pump design been placed in a casing of its own. This configuration would provide a seal against back-flow through the plate wheel arrangement and would provide support for the plate wheel bearings. A new positive displacement pump had been developed.

2.2 Destroil – the first positive displacement Archimedes' screw pump

Already in the late seventies, Capt. Erling Blomberg – at that time harbour master in Gothenburg, Sweden – had realized that a major factor in response to oil spills at sea is the ability to handle viscous oil. He saw the traditional linear Archimedes' screw as a way to overcome high viscosity pumping problems. Teaming up with a local machine manufacturer, Gustav Terling AB, he contacted DESMI in Denmark who in those days had a production of Archimedes' screw pumps for sewage treatment plants. DESMI caught interest in the project of making a pump and skimmer for oil spill recovery, but it was soon realized that an Archimedes' screw pump in itself would not be the answer. Its capability is solely to transport sludge from one end of the screw to the other. It is not a positive displacement pump and cannot build up pressure.

Figure 2 Destroil DS-210 Pump (left) and Blomberg (right) w. 1st Prototype

However, at that time in 1978, DESMI had the representation of Goodyear pumps in Denmark, and one of its design engineers developed a combination of the Archimedes' screw and the Goodyear pump geometry. The linear screw would transport or feed product from a skimmer's hopper to the positive displacement section (the Goodyear pump geometry), which would be able to deliver sufficient pressure to send the recovered product through a discharge hose to a reception tank onboard a response vessel or a barge. The linear screw was designed so that its geometry gradually changed to that of a globoid worm gear as it reached the pumping section. The so-called positive displacement Archimedes' screw pump had been developed (Fig. 2).

2.3 DESMI and GT

DESMI formed a cooperation with Gustav Terling AB. Desmi manufactured the Destroil weir skimmer with the new pump and Gustav Terling AB made the diesel hydraulic power packs and hose reels, and a joint sales effort was established. Three Destroil Skimmer Systems system sizes were developed, the 150, 210, and 310 series, where the figure refers to the diameter of the pump screw.

After two years the cooperation fell apart. Gustav Terling AB had started production of a weir skimmer of their own with a similar type pump as the one DESMI manufactured, namely the GT-185 pump (Fig. 3). The GT pump was a second-generation pump. The DESMI pump still required manual forging of the very complex pump screw geometry, where the GT pump screw was cast in stainless steel and partly machined.

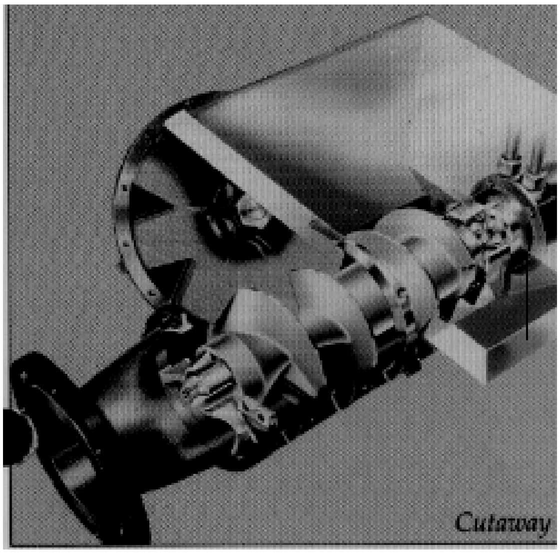


Figure 3 GT-185 Pump Cutaway with Inlet Hopper for Weir Skimmer

An intense competition between the two companies started and in 1984 DESMI decided to modernize its pumps and skimmers. In 1987 a new skimmer was launched to the market: The DESMI-250. It incorporated the DS-250 pump, which is the skimmer version of the DOP-250 off-loading pump that was launched in 1988/89.

2.4 3rd generation

Desmi's new pump consisted of the Goodyear pump geometry section only. The feeding screw had been excluded, and the pump had no more anything to do with an Archimedes' screw, even though it as of today still is described as a vertical positive displacement Archimedes' screw pump.

The pump had bearings at the motor end of the pump only, which in the DOP version meant direct end suction access to the pump screw and no obstructions in the inlet region caused by traverses to hold bearings. The design of the bearing arrangement and the pump discharge further made it possible also to avoid traverses and other obstructions at the discharge side. The pump had been designed with as few moving parts as possible and easy access to most commonly replaced wear parts. Lessons learned in the first years of oil spill response, and brought forth in literature prepared by Capt. Blomberg, had been adopted, namely that small inertia mass is essential for a free floating skimmer's wave following ability. The new DESMI pump had small outer dimensions, a weight of 75 kg, and was able to deliver up to 100 m^3/hour and a pressure up to 10 bar. The old horizontal DESMI pump that it replaced (DS-210) could deliver 25-50 m^3/h and a pressure of 7 bar. Its weight was 140 kg.

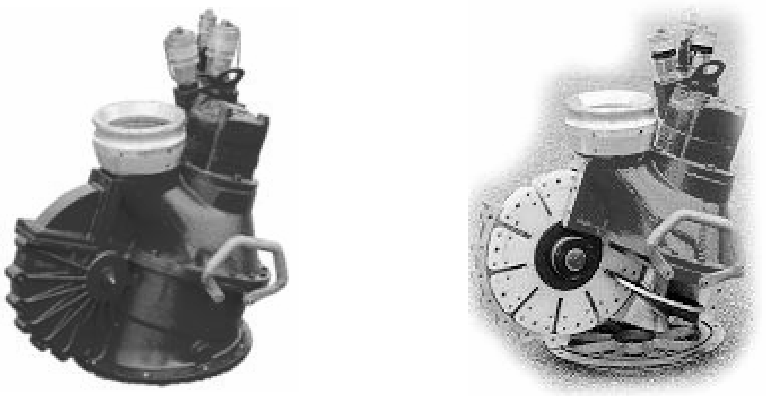
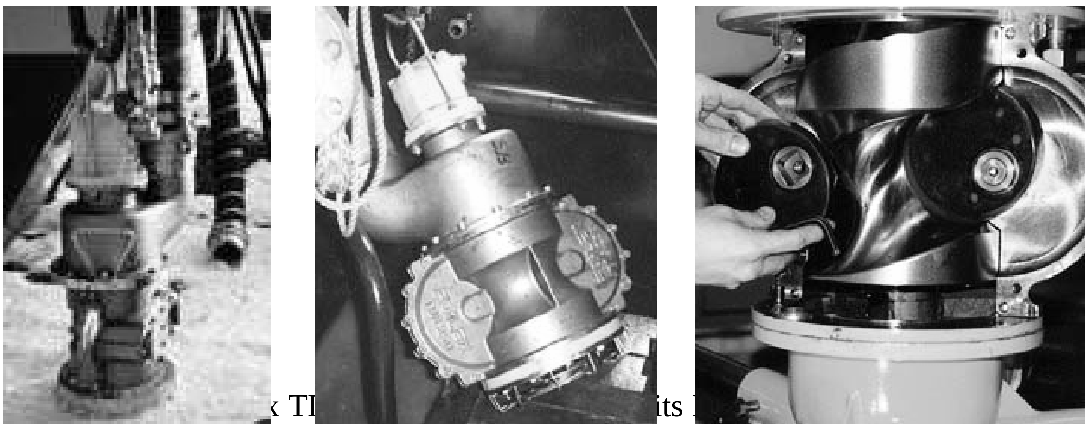


Figure 4 Desmi DOP-250 Pump with Cutaway Version to the right

Almost at the same time as the DOP-250 was launched to the market, a GT-260 pump with the same capacity as the DOP-250 was introduced. However, it was still of the old horizontal design with both feeding- and pump screw section, and its weight was 275 kg, more than three times that of the similar capacity DOP pump.

2.5 A new player

In 1993 a new player within the positive displacement Archimedes' screw pumps became significant in the market: Foilex. Foilex AB of Sweden had in 1991 been established by Anders Johansson, a former R&D engineer at GT / Pharos Marine, the company who had acquired from Gustav Terling AB its GT oil spill equipment business.



Foilex introduced its new twin disk technology which is a further development but nevertheless still a variation of the Goodyear type pump geometry (Fig. 5): Instead of one relatively big plate wheel engaging with the pump screw, the new pump had a unique new geometry incorporating two smaller circular discs made of polyurethane coated steel, placed on each side of the screw and eccentrically rotating in and out of the screw's matching geometry. The first disk, which engages with the screw, will create seal through the first 180° of a screw revolution and will simultaneously, via a transmission with 4 gear wheels, synchronize and bring the second disc into position when it must take over sealing during the next 180°, and so forth.

The Foilex principle, which has been patented, has made it possible to make a pump that is relatively less wide than the pumps with one big plate wheel (DESMI and GT), since the displacement per revolution is relatively larger than for the DESMI and GT pumps. However, this has been obtained by adding complexity and more moving parts.

2.6 Latest developments

Both FOILEX and DESMI have over the years had a continued development of their products. The GT pumps have not undergone any significant further development since their introduction in 1981/82 (GT-185) and 1989 (GT-260).

FOILEX has expanded its program to include a full range of skimmer- and off-loading pumps.

DESMI has expanded its program with the DOP-160, a smaller version of the original DOP pump. Recently DESMI introduced a so-called dual outlet version of the DOP-250 (Fig. 6). The aim is to replace the DOP-250 and DS-250 pumps with one pump provided with two outlets, which may be used dependent on configuration, off-loading, or weir skimmer, or other. Both of the newer pumps have cylindrical screws for easier inspection and repair, and have wear protection plates for the protection of the plate wheel casing.

Figure 6 Desmi DOP-250 Dual Pump

In 2002 Lamor Corporation AB in Finland acquired GT Pollution Technology Ltd., who had produced and marketed the GT pumps and skimmers since 1998. Lamor decided to design a new modernized GT pump and introduced in 2003 the newest development in the family of positive displacement Archimedes' screw pumps: The GT-A series. It incorporates a full range of skimmer- and off-loading pumps in vertical design and with dual outlet function. Like the DESMI pump the GT-A uses the Goodyear geometry section only; no feeding screw. As the first PDAS pump in the market the GT-A series has 100% replaceable wear protection of the pump casing. It is expected that the original horizontal design GT pumps soon will be withdrawn from the market.

Figure 7 The Lamor GT-A Pump Series with a Cutaway Pump to the right

3 An Overview on all the PDAS Pumps in the Market

Table 1 shows the weights and capacities for the various pump sizes for manufacturers' standard pumps. Please note that the information has been extracted from the manufacturers' technical information in manuals, brochures, or web sites.

Table 1 Standard Capacities, Pressures, and Pump Weights

Manufacturer / Pump Type	Weight kg / lbs	Max. Pressure bar / psi	Max. Standard Capacity m^3/h / USGPM @ RPM	Optional Capacity m^3/h @ RPM
DESMI				
DOP/DS-250*****	75 / 165	10 / 147	100 / 440 @ 800	125@1000 w. lower torque motor
DOP-250 Dual*****	80 / 176	10 / 147	100 / 440 @ 800	125@1000 w. lower torque motor
DOP-160	31 / 68	10 / 147	30 / 132 @ 1000	
FOILEX				
TDS 250*****	120/265	10 / 147	165 / 726 @ 750	
TDS 200*****	90 / 198	10 / 147	85 / 374 @ 780	
TDS 150*****	35 / 77	10 / 147	45 / 198 @ 900	
GT				
GT-185*****	81 / 178	7 / 103	45 / 198 @ 600	
GT-260*****	275/604	7 / 103	100 / 440 @ 500	
LAMOR				
GT-A 115*****	72 / 158	12 / 176	114 / 502 @ 800	140@980 w. lower torque motor
GT-A 50	47 / 103	12 / 176	62 / 272 @ 980	
GT-A 20	25 / 55	12 / 176	20 / 88 @ 1000	30@1500 w. lower torque motor

***** Note: These pumps will require higher torque / lower RPM motor on very high or extreme viscosity oil

3.1 Pump performance curves

Performance curves, especially if they have been certified by a bureau of classification, can provide the potential pump customer as well as a pump owner with valuable information on a given pump. Normally the curves will be based on water testing, especially when each produced pump is tested to verify that it meets the requirements set forth in the manufacturers quality control system (few customers will purchase a pump, which has already been in black and sticky oil). A test curve on water cannot tell directly about heavy oil capabilities, but it can disclose tolerance errors in the various sealing mechanisms and can verify the pump's water pumping capability. The performance curve for a specific pump production number can also prove to the customer that the pump has been operated minimum for the duration of the test, which for the manufacturer would be enough to detect and correct any malfunctions.

DESMI

- Performance curves on water, flow vs. pressure, are available for DOP-160, DOP-250, and DS-250.
- Performance curves on oil of various viscosities up to 60,000 cSt, flow vs. pressure, are available for DOP-250 and DS-250

FOILEX

- No performance curves are readily available, but they can be provided upon request for all Foilex pumps. The curves are on 1000 cSt oil.

GT

- No performance curves are available

LAMOR

- Performance curve on water, flow vs. pressure, is presently available for the GT-A 50 (Will be available later in 2003 for the GT-A 20 and GT-A 115 according to the manufacturer).

3.2 Materials, seals, and wear protection

Table 2 displays the materials that the manufacturers have selected for their pumps and discloses design details related to sealing against back-flow and to wear protection.

Table 2 Materials, Sealing and Wear Protection

Pump	Casing	Pump Screw	Screw Shaft	Seal/wear protection of Screw/Casing	Seal screw/plate wheel /discs	Wear protection
DESMI	**Marine gr. aluminium** Cast steel Acid proof st.	**Ni-resist** Ni-resist Acid proof st.	**Acid proof st.** Acid proof st. Acid proof st.	**Replaceable PE-HD sealing**	**Replaceable PE-HD discs on electro galvanized steel core**	**SST inserts in plate wheel casing sides. Not on DOP-250**
FOILEX	**Stainless** Aluminium	**Ni-coated Stainless** Ni-Coated Stainless	**N/A** N/A	**None**	**PUR** or NBR on steel core	**None**
GT	**Cast Steel/ Stainless mix**	**Stainless**	**N/A**	**None**	**Nitril Rubber w. epoxy fiber support**	**None**
LAMOR	**Marine gr. aluminium**	**Acid proof st.**	**Acid proof st.**	**Replaceable PE-HD** or PTFE **sealing**	**Replaceable PE-HD** or PTFE **discs on acid proof steel core**	**SST inserts in plate wheel casing sides and rounding**

Note: **Bold text** is standard version

3.3 Flow enhancing equipment

Steam/hot/cold water injection devices are available off-the-shelf for the PDAS pumps as described in Table 3.

Table 3 Steam/hot/cold Water Injection Flanges

Pump	Inlet side injection	Discharge side injection
DESMI, all pumps	yes	yes
FOILEX, all pumps	no	yes
GT, all pumps	yes	yes
LAMOR, all pumps	yes, standard, integrated in pump	yes

3.4 Common properties

Despite differences in design, performance, and selection of materials the four pump brands have a number of common properties:

- No or limited emulsification of water and oil. Most other pump types will create the very viscous and difficult-to-deal-with water-in-oil emulsion if oil and water are pumped simultaneously. But the PDAS pumps will in principle for each revolution cut a segment of "thread" out of the pumped product and push it through the pump in a very gentle manner. It might be better explained by thinking about pumping children's toothpaste with stripes: There would still be stripes after the pump; but no mixing or emulsification.
- Good debris handling. All four pumps have cutting knife systems, which chop up lots of the debris that could seize the operation for many other pump types. Furthermore the open structure plays an important role when the chopped debris must be brought forward through the pump.
- Good solids handling is due to the very open structure of these pumps. It should, however, be noted that solids (stones, pieces of steel, etc.), which happen to be hit by the knives may not pass through the pumps unless the knives can chop them up. It is quite random whether a solid, that would otherwise pass through the pump, will be hit by the knives and - if strong enough - thereby cause the pump to stop instantaneously. It could therefore seem that fewer knives would result in a higher chance that the solid passes through
- Good performance on heavy oil or high viscosity oil is really what the pumps are famous for. Once again the open structure plays an important role, as does the gentle treatment of the oil. A relatively small portion of the pump power is used for sliding, squeezing, and attempting to compress the oil, which is very power demanding with higher viscosity oil. This leaves more for the task to move the product forward. Or in other terms: The pumps have an overall high efficiency on high viscosity oil.
- Mobility: All the PDAS pumps are made for mobile use, and especially the smaller pumps offer the important combination of portability and heavy oil performance.
- Wear may be a problem due to the fundamental design of the PDAS pumps where the moving parts slide against each other and the pump casing. This is especially the case when pumping abrasive media. The problem has caused two of the manufacturers to place relatively inexpensive wear (and sealing) parts at critical locations to protect mainly the pump casing (Table 2).

4 PDAS Pump Limitations on very High and Extreme Viscosity Oil

Despite the good performance on heavy oil, the PDAS pumps will be severely challenged on extreme viscosity oil like for instance bitumen or very cold heavy oil. Consider that the viscosity may be in the 500,000 to more than 3 million cSt range. The oil will not freely flow into the pump and even if it does get into the pump the friction inside the pump and in the discharge line may be more than the pump can handle without causing damage to itself, its hydraulic motor, or the discharge hose. It is therefore in such situations necessary to use a flow enhancing technique in order to pump the product over an operational distance at an operational rate.

5 Flow enhancing techniques

Since 1999, BITOR, the Orimulsion producer, has tank-tested a number of mechanical feeder skimmers on mechanically refloated bitumen (Hvidbak, 1999, 2001 and 2002).

These tests, and tests in 1999 at SAIC/Environment Canada's test facility in Ottawa, Canada, sponsored by EC and the Canadian Coast Guard (Cooper and Hvidbak, 2000), 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. But as will be described in further detail in section 6 it also became obvious that some means of flow enhancing technique would be required if the transfer pumps should be able to transfer the recovered product.

A series of full scale tests, carried out by the US Coast Guard since 1999, has seriously brought focus on flow enhancing techniques and has also been the cradle for the thinking that led to the development of the inlet side injection technique. The USCG tests have involved PDAS pumps, a double screw pump and a centrifugal pump. The most important USCG discharge side water lubrication test result has been an impressive factor 10 to 12 reduction in pressure drop, while pumping oils over long distances at viscosities not exceeding 50,000 cSt with a DOP-250 PDAS pump (Moffat, 1999).

The Canadian Coast Guard and Environment Canada have supported this work by carrying out tests of inlet side steam/hot water injection and combinations of inlet- and discharge side lubrication. The Canadian Coast Guard used a GT PDAS pump and demonstrated that the application of inlet- and outlet side steam/hot water injection in combination could increase performance of this pump more than 40 times on a bitumen of about 2 million cSt.

The four main flow enhancing techniques are discussed in the following sections.

5.1 Bulk heating

Bulk heating involves the heating of the entire volume of oil in a storage tank, for instance, using heating coils. There may be a limited temperature increase required to convert the extreme viscosity product to something that is pumpable. Bitumen may as an example go from 2 million cSt and down to 200,000 cSt by increasing the temperature from 20 to 30 °C. This would be enough for a PDAS pump to transfer it at an operational rate, and further heating would enable several other pump types to be useable. However, most oil recovery skimmers do not have an on-board tank. They must be able to transfer the recovered product instantly. By transfer of cold heavy oil from sunken vessels it may likewise be impossible, or to the best very difficult and expensive, to heat up the entire tank.

5.2 Local bulk heating

Local bulk heating involves a heating coil wrapped around the transfer pump or placed in front of its intake. A steam/hot water source heats up the coils, which heat up the oil adjacent to the pump, thus reducing viscosity and facilitating in-flow. Even though the oil outside the local heating area will remain extremely viscous, it will nevertheless gradually sink in and compensate for the oil that is being removed by the pump, so that the transfer process can keep going. Instead of heating coils, other types of heat exchangers may be used, as long as they can be placed in the vicinity of the pump. A steam heated inlet hopper to the transfer pump in a mechanical feeder skimmer may in some cases be enough to change failure to success.

5.3 Discharge side annulus ring water injection

This technique dates back to 1959 where it for the first time was used by the heavy oil industry who wanted to facilitate the pumping of very viscous crude oil through pipelines.

The principle of a so-called annulus water injection flange (AWIF), which injects water as a low viscosity “coating” between the oil and the hose or tube, can be seen in Fig. 8.

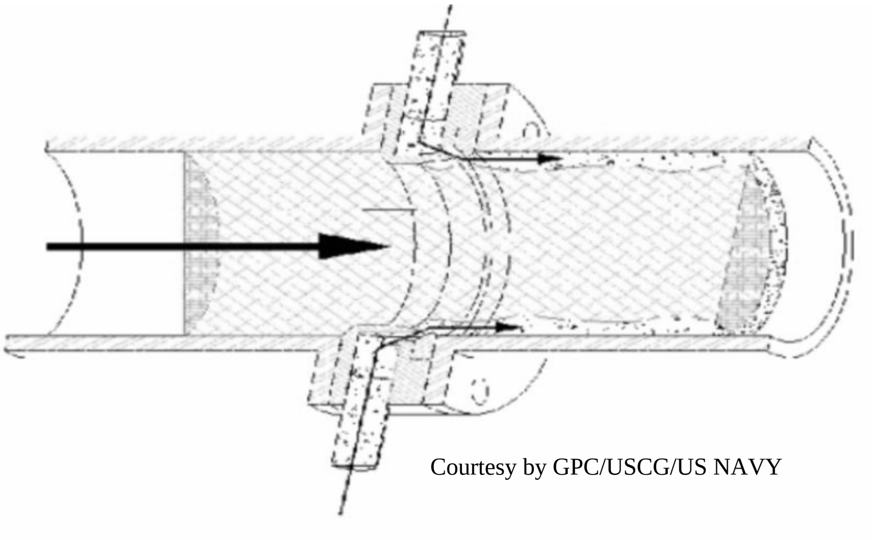


Figure 8 Discharge Annulus Water Injection Flange Cutaway Sketch

Later on the technique was adopted by the emergency off-loading industry. In both cases mainly centrifugal pumps have been used, which is the reason for having the point of injection after the pump. These pump types have a severe decrease in efficiency, at a relatively small increase in viscosity,. Water lubrication has been able to enhance the efficiency of these pumps, but only by placing the injection flange after and a little away from the pump, because turbulence inside the pump would otherwise mix the oil and water, hence creating higher viscosity emulsion and further decreasing pump efficiency. For the PDAS pumps these reasons for positioning the flange after the pump do not apply; there is no turbulence after the pump, and there will be no or little emulsification inside the pump if water is added before the pump.

Traditionally water at ambient temperature has been used for discharge side water lubrication. As it has been tested by the Canadian Coast Guard, the injection of hot water may further enhance the flow when pumping extremely viscous oil. But the results are not conclusive

5.4 Inlet side annulus ring steam/hot water injection

Inlet side annulus ring steam/hot water injection is an option to local bulk heating that only requires that the pump itself be fitted with an injection flange on its intake (Fig. 9). This is a more portable and compact solution, which, besides the hydraulic power lines, only requires hook-up to a steam source like a standard mobile steam cleaner. The injected steam heats up the pump intake and gradually the entire pump, thus heating up the oil near the pump and creating almost similar conditions as for local bulk heating. The used steam condenses to hot water and is via a circular slot injected to the inside of the pump where it has two functions:

1. It heats up the inner surfaces – including the moving parts – so that the oil touching the surfaces – locally, in a very thin layer – gets heated up. This reduces the viscosity of the thin oil layer, thus significantly reducing friction inside the pump.

2. Friction is further reduced by the lubricating effect of the injected hot water, which in turn also lubricates the discharge line and facilitates the overall transfer of the oil.

6 Extreme Viscosity Pumping Test Results

Two of the most widely used PDAS pumps (GT-185 and DOP-250) in the spill response market were tested in two of the skimmer tests, mentioned in section 5, on 2-3 million cSt bitumen. They both had difficulties transferring the extremely viscous product from pump inlet to pump discharge, meaning that feeding the product into the pump inlet was difficult and/or the pressure/friction losses inside the pump itself could barely be overcome.

It was therefore deemed necessary to test existing and new techniques which might improve the pumps' ability to transfer bitumen. Unless the problems could be overcome, a large number of otherwise capable mechanical feeder skimmers could be considered unsuitable for the recovery of extreme viscosity oil. Only designs where the recovered product could be dumped directly into a tank would be suitable.

6.1 Test at DESMI in Denmark

In a Bitor and Ro-Clean DESMI sponsored test at DESMI's test facility in Aalborg, Denmark in 2001 (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 type inlet side steam / hot water injection system - through a 20 m long 6" hose at a rate of 45 m^3/h. The system incorporates an injection flange, distribution hoses, a distribution manifold, and steam cleaner hook-up (Fig. 9).

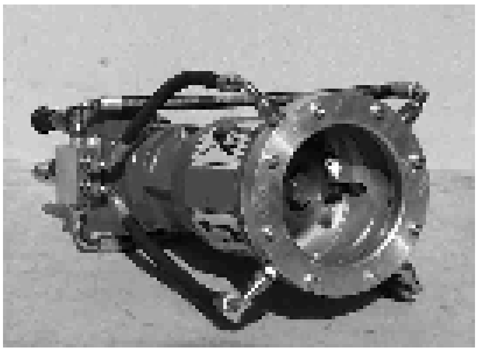



Figure 9 flemingCo Inlet Side Steam Injection System and Bitumen Test

It was at this test observed that the DOP-250 pump had to be equipped with a higher torque / lower RPM hydraulic motor in order to efficiently deal with the extremely viscous product. It was further observed that heating the bulk of the bitumen from 15 to 30 °C, thus reducing the viscosity from above 3 million cSt to about 200,000 cSt, was sufficient for an operational pumping capacity without the aid from other flow enhancing technique than the bulk heating.

6.2 Test at SAIC Canada/Environment Canada

The Danish test was a break-through in extreme viscosity pumping, which was verified when a similar test, sponsored by the Canadian Coast Guard and Environment Canada was carried out at SAIC Canada/Environment Canada's test facility in Ottawa. A GT-185 transfer pump was tested with flemingCo type inlet- and discharge side steam/hot water lubrication devices (Cooper, et. al., 2002)(Fig. 10). This test demonstrated that the modified GT pump could transfer about 2 million cSt bitumen at a rate of 13.9 m^3/h through 12 m of 4” hose. This was more than a 40 times performance improvement when compared to the baseline test, where only 1.07 m^3/h could be pumped through 3.6 m of 4” hose without any steam or hot water injection.

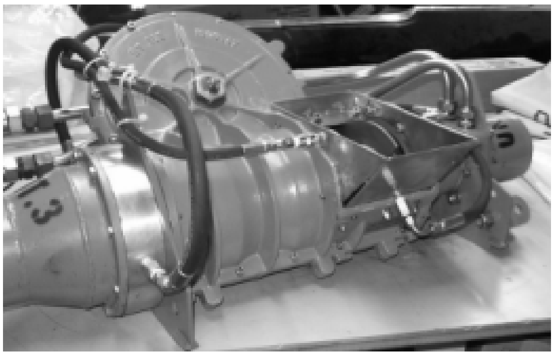


Figure 10 GT-185 w. Inlet/Outlet Steam Injection and Discharge from Test

It should be noted that the GT-185 by purpose had been equipped with steam injection devices on both inlet- and discharge side, since it was the expectation that the many inner leaks in the pump would cause a backflow of the steam/water injected at the inlet, which would result in too little water left for further lubrication through the remaining part of the pump and the discharge hose.

It was at this test observed that the GT-185 pump had to be equipped with a higher torque / lower RPM hydraulic motor in order to efficiently deal with the extremely viscous product.

6.3 Test at Environment Recovery Equipment (ERE), Canada

The FOILEX TSD 150 pump with injection flanges on inlet- and discharge side was tested on bitumen at Environment Recovery Equipment (ERE), Canada in spring 2002 (Hines, 2002). The test was witnessed by representatives from the US and Canadian Coast Guards. The ERE skimmer recovered the about 3 million cSt (16 °C) bitumen to a small buffer tank from where the TDS 150 pumped it through 30 m of 4” hose, back to the test tank in front of the skimmer (Fig. 11).

Cited from the skimmer manufacturer’s report: “The steam arrangement consisted of an intake and discharge flange mounted on the pump with a heat exchange chamber secured to the bottom of the incline tray of the skimmer. It was noted that the intake flange was of little use as the steam pressure built an air pocket and prevented oil from flowing to the pump. The steam flow to the intake flange was shut off and pumping continued with the discharge side of pump receiving steam injection. The TDS150 pump worked well, producing a steady flow.”

Figure 11 ERE Skimmer and Discharge from TSD 150 Pump

A test report has only been prepared by the skimmer manufacturer. Evaluation of performance was visual only. But it nevertheless adds to the picture of PDAS pumps in combination with flow enhancing techniques; they can handle extreme viscosity oil at operational rates. Even though – in this case – there seemed to be a problem with backflow from the pump of steam/water injected at the inlet, which can happen if the positioning of the injection device is not close enough to the active pumping section of the pump or if the pump has too many inner leaks.

6.4 Test at LAMOR, Finland

The GT-A 50 pump and its built-in steam injection system was tested in early 2003 under flemingCo supervision on bitumen in-house at LAMOR in Finland as a transfer pump on a brush belt skimmer. The skimmer scraped off the bitumen into a steam heated hopper, which guided it into the inlet of the pump. The viscosity was about 3 million cSt (15 °C) and the pump could match up with the skimmer and instantly transfer the recovered product through the discharge hose – fully water lubricated (Fig. 12).

Figure 12 Steam Lubricated Bitumen Discharge at Lamor in-house Test

The test was not "official", a test report has not been prepared, and evaluation of performance was visual only. But it nevertheless adds to the picture of PDAS pumps in combination with flow enhancing techniques; they can handle extreme viscosity oil at operational rates.

7 JVOPS Test Summary Results

The Joint US and Canadian Coast Guard and Industry Viscous Oil Pumping System (JVOPS) testing, which had been planned for almost two years, took place at the Cenac Towing Inc. facility in Houma, Louisiana, USA in December 2003. The JVOPS project is the most comprehensive high- and extreme viscosity oil testing that has ever been carried out. The most important and rather dramatic results have been extracted after an initial study of the gathered data and are presented in the following summary. The full picture will be presented in another presentation at this conference.

A Framo TK-125 double screw pump and all the PDAS pump brands in the market (apart from Foilex) participated. The tests were carried out on oil in the 25,000, 200,000, and 500,000 cSt ranges.

The GT-185, equipped with a high torque/low RPM motor and a new re-designed high pressure/high temperature plate wheel, transferred 410,000 cSt oil through 150 m of 150 mm (6") hose at a rate of 28 m^3/h (Fig. 13). The pressure drop in the hose was 0.9 bar! This was obtained using 2% hot lube water on the inlet side and 2% cold (ambient) water on the outlet. With 4% hot water <u>on the inlet only</u> the performance was similar. The consumed power indicates that the maximum pumping distance for the GT-185 on 410,000 cSt oil might be about 225 m while maintaining nearly maximum pump capacity. These results should be compared with the fact that without water lubrication it took the pump more than one hour to fill up a 30 m long 6" hose section.

Figure 13 Discharge of 410,000 cSt oil and lube water in 150 m test with GT-185

The DESMI DOP-250, equipped with a high torque/low RPM motor, transferred 170,000 cSt oil through 450 m of 150 mm (6") hose at rates between 57 and 61 m^3/h. The pressure drop in the hose was below 3 bar. The best results were obtained with 4% hot water on the inlet and 4% cold (ambient) water on the outlet. But 6 % cold (ambient) water <u>on the inlet</u>

only also worked very well. The increase in consumed power, going from 90 to 450 m hose length, was only 13 %, and the pressure drop increased from 0.5 to 2.6 bar. This indicates that the maximum pumping distance for the DOP-250 on 170,000 cSt oil might be as far as 800 m while maintaining nearly maximum pump capacity.

The LAMOR GT-A 50, equipped with its standard motor, transferred 195,000 cSt oil through 90 m of 150 mm (6") hose at rates between 45 and 48 m^3/h. The pressure drop in the hose was 0.6 bar. The results were obtained with 4% hot water on the inlet and 4% hot water on the outlet, as well as with 4 % hot on inlet and 4 % cold (ambient) on outlet. In the 90 m hose tests the LAMOR pump consumed less power than the DOP-250, equivalent to the delivered capacity. Therefore the maximum pumping distance for the GT-A 50 pump on 195,000 cSt oil might also be up to 800 m while maintaining nearly maximum pump capacity.

The PDAS pumps all delivered 90 - 100% of their maximum nameplate capacity (limited by maximum hydraulic motor RPM) even over the longest distances. The double screw pump delivered in the 90 m hose test about 20 % of its maximum nameplate capacity in the most optimal inlet- and outlet water lubrication combination.

All pumps were in baseline testing (no lube water and heat applied) allowed to deliver at a discharge pressure up to 12 bar. The performance improvement factor (PIF) for a flow enhancing technique is defined as:

$$PIF = Pressure\ drop_{(no\ lube)}/Pressure\ drop_{(w.\ lube)}\ x\ Capacity_{(w.\ lube)}/Capacity_{(no\ lube)}$$

The best working flow enhancing techniques – applied in conjunction with the PDAS pumps – had PIF values over 150!

The tests on 30, 90, 150, and 450 m hose lengths indicated no requirement for additional lube water when increasing the pumping distance.

To save time, only one pump size of each brand was tested. Based on the obtained results there is reason to expect that other PDAS pump sizes will perform proportionally.

8 Increasing Awareness of the Flow Enhancing Techniques

The new inlet side steam/hot water injection flow enhancing technique for the PDAS pump transfer of extremely viscous oil has not only made bitumen emergency transfer pumping operational in a compact and portable way, but it has 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.

A number of skimmer manufacturers already deliver off-the-shelf mechanical feeder skimmers, where the transfer pump is equipped with inlet or outlet side steam/hot water injection, and some even have a heated hopper guiding the recovered viscous product to the pump inlet (local bulk heating).

9 Conclusion

There are with the combination of positive displacement Archimedes' screw pumps and the various flow enhancing techniques clearly means available for the difficult task of extreme viscosity pump transfer. It will be up to the individual response organization to decide on which pump type and flow enhancing technique will suit their needs and existing equipment inventory in the best possible way. Several combinations will obviously work.

It must, however, be noted that some of the PDAS pumps will need to be equipped with a higher torque / lower RPM hydraulic motor than what is standard for these pumps.
With the results from the JVOPS testing in the US it now possible to clearly quantify, for each pump type, the optimal application of heat and water injection when pumping high and extreme viscosity oil.

10 Biography

Flemming Hvidbak is an oil spill consultant who has been in the industry for 20 years. He has specialized in developing and testing recovery and pumping techniques and equipment for spills of heavy and extreme viscosity oil. He is external advisor for the establishment and operation of the largest response organization in China, Bohai Environmental Services Ltd . Most recently he planned and conducted as lead engineer the joint US Coast Guard, Canadian Coast Guard, and Industry viscous oil pumping system testing in the US.

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