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Evaluation of Pumps and Separators for Arctic Oil Spill Cleanup

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EVALUATION OF PUMPS AND SEPARATORS FOR ARCTIC OIL SPILL CLEANUP

by

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for the

Research and Development Division
Environmental Emergency Branch
Environmental Impact Control Directorate
Environmental Protection Service
Departmental of the Environment
Ottawa, Ontario

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April 1979

REVIEW NOTICE

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ABSTRACT

Commercially available positive displacement pumps were evaluated for use in handling oil, water and ice mixtures during possible arctic oil spill cleanup operations. Pumps were assessed on the basis of weight, capacity, debris tolerance, self-priming capability and ability to operate in sub-freezing temperatures.

The LFE Mildand and the Moyno progressive cavity pumps were found most suitable for the project purpose. A Moyno pump was tested at temperatures down to -15°C and was found to perform satisfactorily. The Offshore Devices Ltd.'s double-acting diaphragm pump was also tested to -15°C but was considered to have design faults. This pump should be considered for the purpose when lightness of weight is a predominant factor.

Commercially available oil separators were evaluated for use in similar arctic cleanup conditions. None of the separators currently on the market were considered adequate for the project purpose. An A.P.I. design separator was constructed and tested in cold room conditions with satisfactory results.

RÉSUMÉ

Dans l'éventualité d'un déversement dans les régions arctiques, on a évalué l'efficacité de différentes sortes de pompes volumétriques, présentement sur le marché, utilisées pour pomper des mélanges d'eau, d'hydrocarbures et de glace. L'évaluation tenait compte du poids et de la capacité des appareils, de l'effet des déchets sur leur rendement, de leur propriété d'auto-amorçage et de leur fonctionnement à des températures inférieurs au point de congélation. Les pompes à vis Midland et Moyno ont démontré une efficacité supérieure. La Moyno, testée à des températures atteignant - 15°C, a donné des résultants satisfaisants. Un appareil à membrane à double effet de l'Offshore Devices Ltd a subi des essais identiques, mais a montré des défauts de conception. Elle ne devrait être utilisée que si l'on recherche une pompe légère.

Des séparateurs d'hydrocarbures, également sur le marché, ont été mis à l'essai dans des conditions identiques, mais aucun ne s'est révélé suffisamment efficace. On a construit un séparateur, conçu par l'A.P.I., et on en a fait l'essai dans une chambre froide. Les résultats on été satisfaisants.

FOREWORD

The work described in this report was performed by Western Canada Hydraulic Laboratories Ltd. under contract to the Environmental Emergency Branch. Mr. Kenneth Meikle, Environmental Protection Service, Ottawa, acted as scientific authority for the project.

The assistance of the numerous persons in the oil and pump industries who contributed advice and comments on field performance during the course of this study is appreciated.

In particular, the cooperation and assistance of Ms. E.C. Swett, Offshore Devices Inc., and Mr. W.H. Woods, Robbins and Myers, who made pumps available on loan for cold room testing, is gratefully acknowledged.

Additionally, Mr. D.J. Morrow, Canguard Consultants Ltd., provided considerable assistance in the oil separator assessment and was responsible for the design of the A.P.I. separator that was tested in the cold room.

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1 INTRODUCTION

The Arctic Marine Oilspill Program (AMOP) has been undertaken by the Government of Canada since 1977 to develop countermeasures for handling oil spills in arctic waters. The major concern of the program is the handling of uncontrolled oil well blowouts, and tanker or submarine pipeline accidents which could lead to major spills.

As part of this program, the Environmental Protection Service of the Department of the Environment has undertaken development of suitable equipment to contain and recover oil from ice-infested waters. Recovery equipment has included oil spill recovery devices such as surface skimmers; pumps and piping required to discharge oil from the skimmers; oil separators to eliminate water from the collected oil and so reduce its volume; containers for transporting oil to disposal sites elsewhere; and incinerators for on-site disposal.

The anticipated situation for use of pumps and separators to be used in arctic oil spill cleanup operations is as follows:

- The oil recovery devices, or surface skimmers, will collect the oil from the partially ice-covered sea surface and bring it in their reservoirs to a nearby barge or other clearing point. The reservoir mixture will consist of oil and seawater, with ice or other solid debris probably mixed in; if cleanup operations are taking place near shore, the mixture may include stones.
- The oil/water/ice mixture will be pumped out of the skimmer revervoir into either another containment vessel for transport and disposal elsewhere, or, preferably, into a separator. The separator will reduce the water content of the mixture by returning water to the sea, while the oil will be retained for transport and disposal elsewhere. The use of a separator will considerably reduce transportation costs and logistic requirements for handling the collected material.

2 PUMP ASSESSMENT

2.1 Project Evaluation

2.1.1 **Pump Specifications.** Basic criteria governing selection of equipment suitable for arctic oil spill cleanup operations were set out by the Department of the Environment. The criteria are as follows.

2.1.1.1 **Portability.** Equipment must be air-portable by helicopter either as internal cargo or as an externally slung load. Units must not weigh more than 1800 kg each; and preferably, they will not weigh more than 450 kg each.

2.1.1.2 **Cold-weather performance.** Equipment must operate efficiently and continuously at temperatures from -15 to +10°C without shelter in exposed locations. Controls must be readily operative by personnel wearing arctic clothing. The equipment must also be able to operate intermittently under extended continuous exposure to an ambient air temperature of -15°C.

2.1.1.3 **Durability.** Equipment must be able to withstand rough usage and operate for extended periods with little or no maintenance. The equipment should be readily maintainable in the field without the need for special tools or skills.

2.1.1.4 **Performance.** The minimum flow rate should not be less than 275 litres per minute of a reference oil specified by the Environmental Protection Service. The equipment must be salt-water corrosion resistant. The pump must be able to handle an oil/water/frazil ice mixture in which the oil content is as low as 75 percent by volume. All equipment must conform to Canadian industrial safety codes.

2.1.1.5 **Emulsification.** A positive displacement pumping was considered necessary to minimize emulsification prior to the oil being introduced to the separator. The positive displacement class of pumps includes both reciprocating pumps, of which the diaphragm type is an example, and rotary pumps. Both pump types utilize the principle of pushing the pumped fluid down the discharge line rather than throwing it, as occurs with centrifugal pumps. The pushing action induces considerably less fluid shear and turbulent mixing than does the centrifugal pumping process. As a result, positive displacement pumps induce less emulsification in the pumped fluid than do other pump types.

2.1.1.6 **Debris tolerance.** The pumps should be capable of handling stones, ice or other solids up to 1.9 cm. This maximum size limit for ice or debris was established after consideration of trash racks on existing skimmers, equipment usage, likelihood of ice formation in the screens, and screen blockage. It was assumed that skimmer manufacturers would have no difficulty in incorporating whatever size trash screens were specified in their equipment.

2.1.1.7 Suction lift. The pump had to be capable of lifting the design discharge against a 3 m static suction head and 3 m discharge head plus pipe losses. Pipe losses likely to be incurred during pumping of 275 l/min of oil with a viscosity of 1500 centistokes through 20 m of 10.2 cm diameter pipe were calculated to be 5.2 m.

2.1.1.8 Self-priming capability. Once started, the pumps had to be self-priming in the event of loss of prime due to wave action. No consideration was given to the use of strainers or non-return valves at the foot of the suction line, due to likelihood of screen blockage or ice formation in the valve.

2.1.1.9 Further criteria. Pumps that met the above-mentioned criteria were further judged on the basis of the criteria that follow:

- ability to operate under cold conditions,
- ease of disassembly for clean out or repair,
- ability to operate over long periods with minimal supervision or maintenance,
- ease of handling and operation, and
- capability of being run dry without damage.

Consideration was not given in this study to the size or design of suction and discharge ports, or to the source of pumping power. Pumps were to be assessed on their pumping capabilities only. It was concluded that sufficient hydraulic or electrical power would be made available on site for pump operation purposes. Prior to transport to site, the suction and discharge ports of available pumps can be modified through the use of commercial adaptors to suit whatever hose or piping arrangement is to be used on site.

In assessing commercially available pumps, air-operated diaphragm pumps were downrated because of previous experience in which moisture freezing in the supply lines had resulted in pump failure. These pumps were not downrated because of any contemplated difficulty in obtaining compressed air.

2.1.2 Market Assessment. Contacts were established with persons in the oil industry, both in Canada and the U.S.A.; persons connected with oil cleanup operations; Canadian and U.S. Coast Guards; Canadian Armed Forces; U.S. Navy; Department of the

Environment; and with manufacturers and suppliers of pumps, oil separators and oil cleanup equipment.

Reports on studies investigating equipment for similar purposes, but which generally disregarded the low temperature and ice aspects of the problem, were considered.

Appendix A lists 20 positive displacement pumps that were considered during the study. Remarks regarding their suitability for the project purpose are included.

Only 10 of the listed pumps had the capacity to handle 1.9 cm solids. These pumps are described briefly in the following sections.

2.2 Diaphragm Pumps

2.2.1 Principle of Diaphragm Pumps. Diaphram pumps have a circular, flexible diaphragm in the pump cavity which is fixed around the edge to the pump casing and which is attached to a drive rod at the centre. Reciprocating movement of the shaft bends the diaphragm, enlarging and decreasing the pump cavity. Fluid is sucked in when the cavity is enlarged and discharged on the opposing stroke. The pumping action is strongly pulsatory in nature. Flow direction is controlled by check valves.

Diaphragm pumps generally require no priming, are simple to operate and can pass solids up to the size limited by the check valves. Desirable characteristics of diaphragm pumps are their ability to handle large solids if flap valves, and not ball valves, are used to check flow, and their abilities to self-prime and to run dry. The flexible diaphragm is generally more resistant to wear from solids in slurry pumping than are the driving parts of all-metal pumps.

A single-acting diaphragm pumps passes fluid on only one side of the diaphragm. A double-acting diaphragm pump has two chambers affected by the same diaphragm: it sucks flow in on one side while discharging from the other. This reduces the pulsating nature of flow in the pipeline and increases the pumping capacity for a given stroke rate over that achieved by the single-acting pump.

When comparing double-acting diaphragm pumps with single-acting diaphragm pumps, preference was given to the double-acting pumps, as the reduced pulsating action was considered less likely to result in any plating or build-up of cold, coagulated oil on the inside of pipe lines under extreme operating conditions. Oil build-up on the inside of the pipe would result in partial pipe blockage, increased head losses and a greater load on the pump.

2.2.2 Diaphragm Pumps Considered. This section briefly describes diaphragm pumps that were considered for the project. The name of their main Canadian or North American supplier is listed.

2.2.2.1 Gorman-Rupp 4DX-3. Supplier: Gorman-Rupp of Canada Ltd., St. Thomas, Ontario. This pump is a single-acting diaphragm pump driven by an explosion-proof, three-phase motor. It weighs 185 kg and comes mounted with wheels and a handle. The pump is also available with an attached gasoline or diesel engine.

Pump capacity is 375 l/min of water at the design head. However, the pump is not recommended by the supplier for regular use with fluids having a viscosity greater than 80 centistokes. The pump has flap valves for flow control and will pass solids. The pump casing is bolted together, which should allow easy disassembly. The pump has a water-filled, surge-reducing chamber (called a suction accumulator by the manufacturer) on the suction side of the pump. Although some vertical motion of fluid within the chamber would occur, little circulation takes place between fluid in the chamber and that passing through the pipe during operation. Freezing of water contained in the chamber would likely lead to casing fracture.

2.2.2.2 Homelite 111-DP3-1. Supplier: Textron Canada Ltd., Pointe Claire, Quebec. The Homelite is a single-acting diaphragm pump driven by a gasoline motor. This pump is normally used for dewatering and general construction purposes. The pump and motor comes as a 50 kg unit mounted on skids.

Though this pump could pass the required solids, it has been considered unsuitable for cold weather operation as the surge reducing "priming chamber" has no drain, is not part of the normal pump circulating system, and is prone to freezing. Its advertised capacity of 260 l/min of water for a 3 m suction head is slightly below that required for the project.

2.2.2.3 Midland 33-4028. Supplier: LFE Canada Ltd., Mississauga, Ontario. The Midland single-acting diaphragm pump weighs approximately 135 kg, including explosion-proof motor, and comes mounted on wheels with towing handle. The pump is 71 cm high, 70 m long, and 73 cm wide; it has 7.6 cm threaded suction and discharge ports.

The pump has an advertised capacity of 285 l/min against a 3 m suction lift. The Midland pump is normally used in industrial or construction applications for continuous pumping of sludge, slurries and debris-laden materials. This pump will pass solids of sufficient size. Disassembly is simple, with only four bolts to remove in order to replace the diaphragm. It is anticipated that a larger motor than the 1.1 kw motor normally supplied will be required to maintain the design discharge with high viscosity oil. Single or three-phase motors are available. This pump has a suction chamber with no bottom drain; this would be susceptible to freezing.

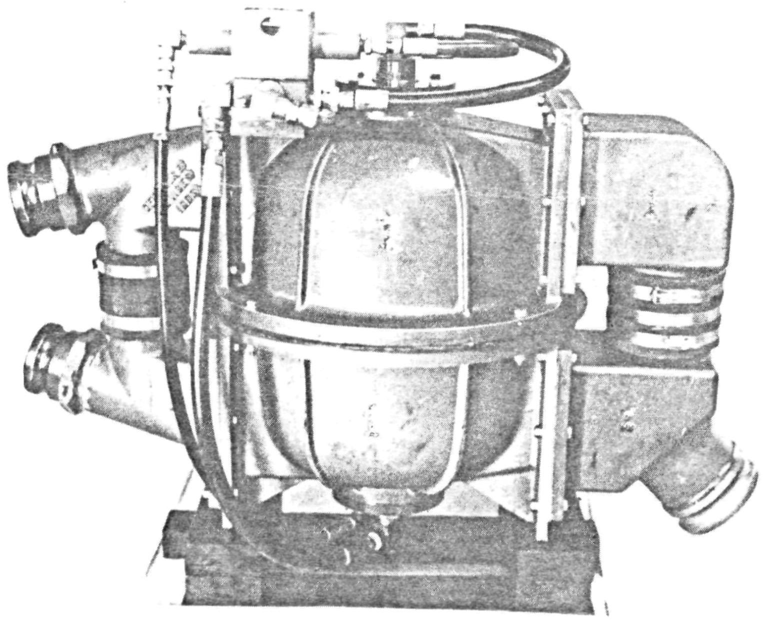
2.2.2.4 Offshore Devices Ltd. double-acting diaphragm. Supplier: Offshore Devices Inc., Peabody, Mass., U.S.A. This pump is a lightweight, hydraulically driven, double-acting diaphragm pump specifically developed for the purpose of handling moderate volumes of oil/water/solids mixtures over low heads during oil cleanup operations (Figure 1). The pump is approximately 43 cm wide, 50 cm high, and 81 cm wide. The manufacturer claims a weight of 36 kg for the basic pump. The unit supplied for testing weighed 70 kg; this weight included the mounting base with control valves but not the hydraulic supply unit.

The pump has a maximum capacity of 1325 l/min. A hydraulic source capable of delivering 19 l/min of fluid at 10 300 kPa is required to power the unit. The pump has a cast aluminum housing, stainless steel hydraulic cylinder and rods, and a woven, nylon-reinforced neoprene diaphragm (Figure 2). The cylinder rod is hollow, with a single blockage at its midpoint; the rod passes completely through the pump. The hydraulic cylinder, to which the diaphragm is attached, reciprocates while the rod remains stationary. Hydraulic fluid is supplied to and from each side of the hydraulic cylinder via the cylinder rod, using cross-holes. The diaphragm displaces 7.6 l/stroke.[1] Quick-connect hose fittings are provided for the suction and 10 cm discharge lines. Either single 10 cm or double 7.6 cm suction connections are available so that the pump can operate from more than one source at a time.

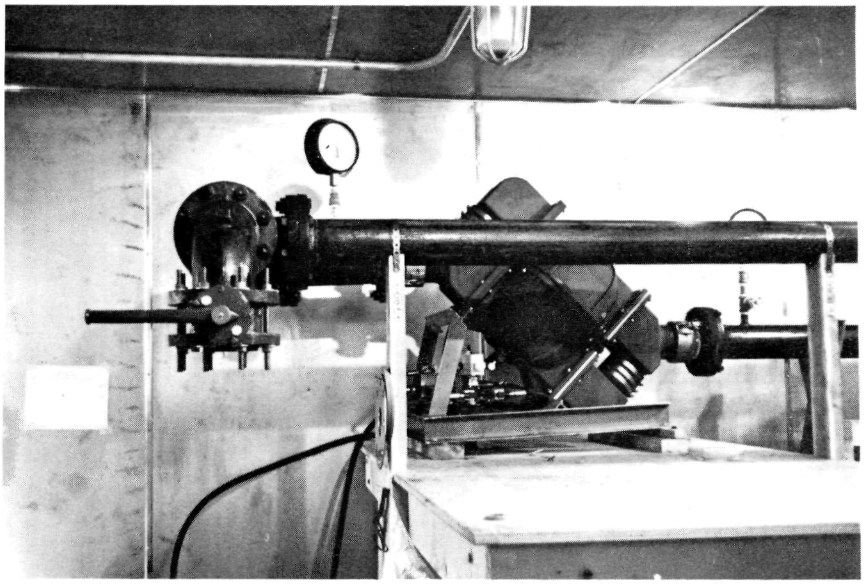
This pump is new to the market and has not yet been thoroughly tested or tried in the field. It was selected for cold room testing. Test results are discussed in Section 3.3.

2.2.2.5 Oliver diaphragm ODS 4F. Supplier: Dorr-Oliver, Stamford, Conn., U.S.A. The ODS 4F is a compressed-air driven, single-acting diaphragm pump weighing 275 kg.

The pump has a rated capacity of 340 l/min of water at 15 strokes per minute. This slow stroke rate would provide a more gentle pumping action than the faster-acting diaphragm pumps previously listed. However, the effect of the slow stroke rate on minimizing emulsification will likely be offset by the 90^{o} change in flow direction and the flow reversal required for the fluid to enter and leave the pump through the same tee in the off-line installation.

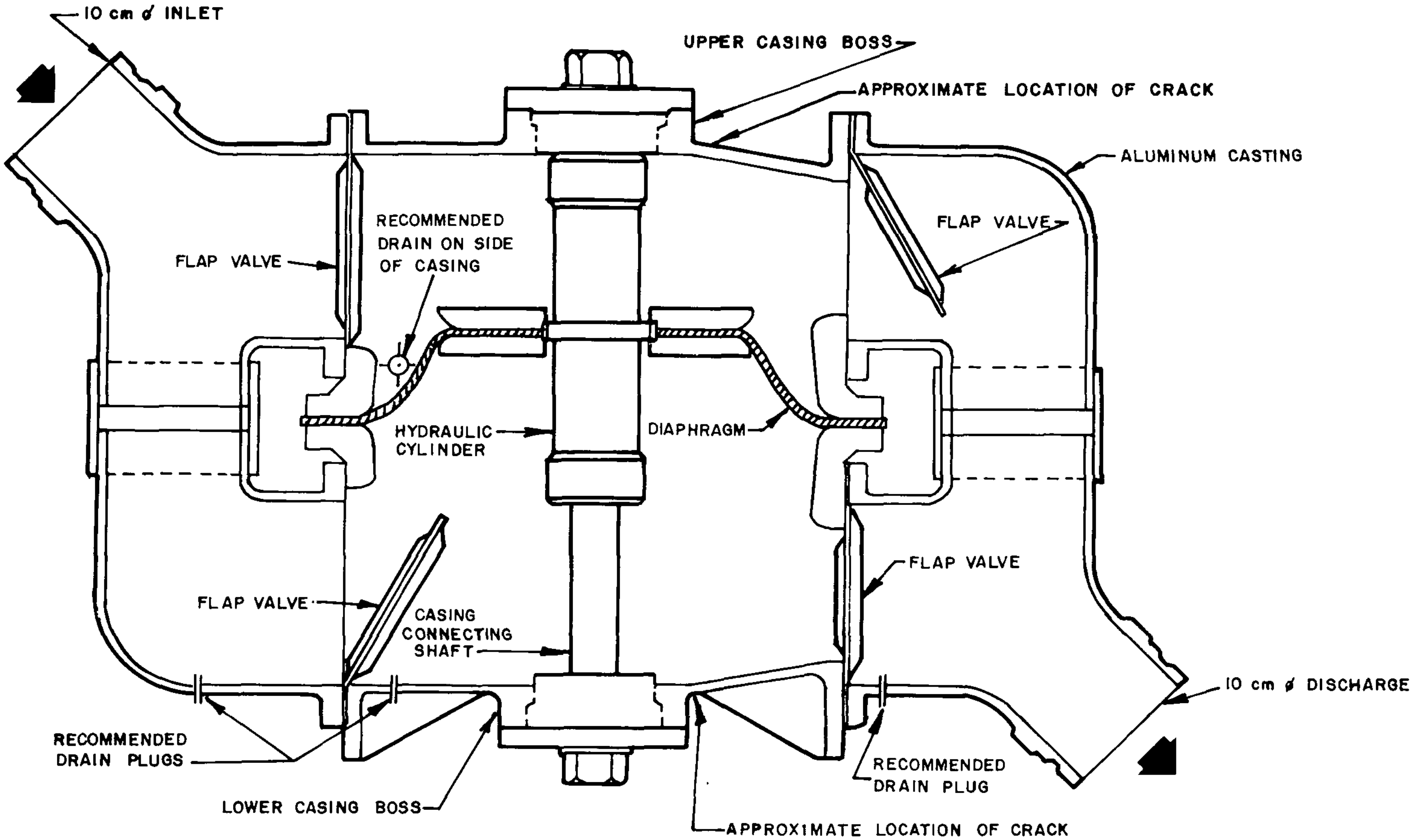


1(A) Pump Equipped with Suction Inlets



1(B) Pump Installed in Cold Room

FIGURE 1 OFFSHORE DEVICES LTD. DOUBLE-ACTING DIAPHRAGM PUMP



SECTIONAL VIEW OF PUMP

Approx. Scale 1:5

FIGURE 2 OFFSHORE DEVICES LTD. PUMP: SECTIONAL VIEW

The pump has no priming chamber and could be easily drained by pumping dry. Although no operating experience with this pump in sub-freezing conditions is available, other air-powered pumps have been subject to failure by moisture freezing in the supply line and drive cylinder. The heavy weight, compressed-air driving principle, and single-acting pulsating flow from the pump are the disadvantages of this pump.

2.2.2.6 SA3-A Sandpiper. Supplier: Warren Rupp Co., Mansfield, Ohio, U.S.A. The Sandpiper is a compressed-air powered diaphragm pump weighing 110 kg; it can handle solids up to 7.5 cm. It uses two single-acting diaphragms acting in concert in separate chambers to give a double-acting effect.

Viscous fluids can be handled by the Sandpiper, which has been used in the oil cleanup industry to discharge oil/water/debris mixtures. However, as a compressed-air driven pump, the air distribution valve is prone to failure by freezing of airborne moisture through adiabatic cooling action of air expanding into the drive chamber.

2.3 Progressive Cavity Pumps

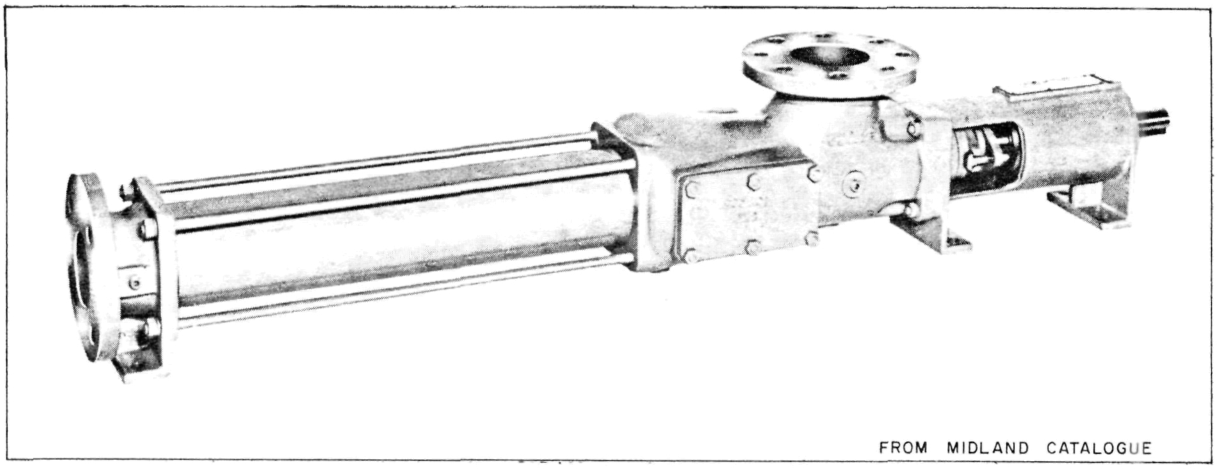
2.3.1 Principle of Progressive Cavity Pumps. Progressive cavity pumps are a special design of single-screw rotary pumps in which a spiraled rotor turns eccentrically in an internal-helix stator. As the shaft turns, pockets, which are continuously formed between the rotor and stator walls, fill with fluid at the inlet end and are pushed continuously along the stator to the oulet. The most suitable rotor for oil cleanup operations is made of chrome-plated steel with a stator of Buna-N, or other oil-resistant synthetic rubber.

The pumps have good suction lift and self-priming capabilities and deliver a uniform discharge without pulsation. Very high discharge pressures may be developed.

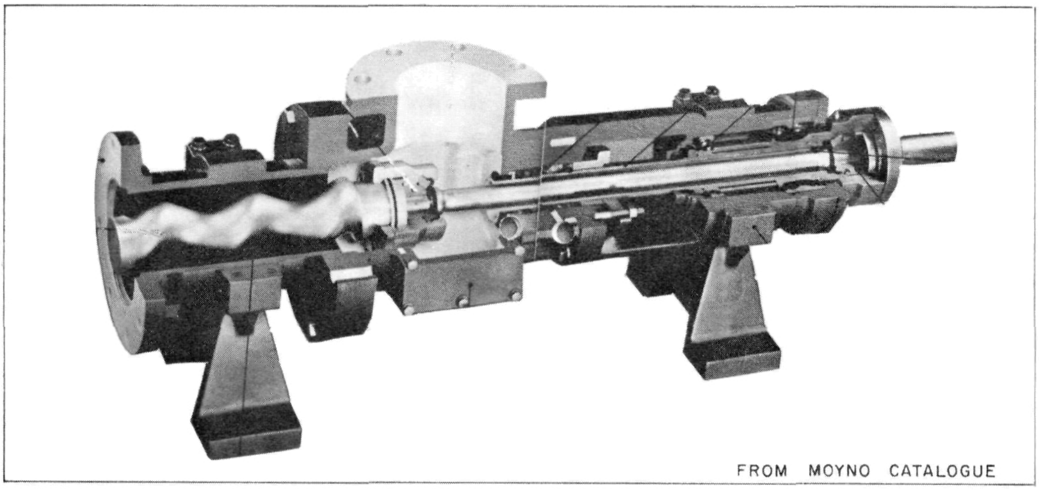
These pumps do not have the same degree of solids capability as do diaphragm pumps. However, slightly larger solids than those recommended by the manufacturers may be passed with little damage to the soft rubber stator. The pumps may be run continuously with as little as 10 percent fluid in them; but due to the effect of friction by the rotor on the stator, they should not be run dry for extended periods of time.

2.3.2 Progressive Cavity Pumps Considered. The three brands of progressive cavity pumps which were investigated are described in this Section.

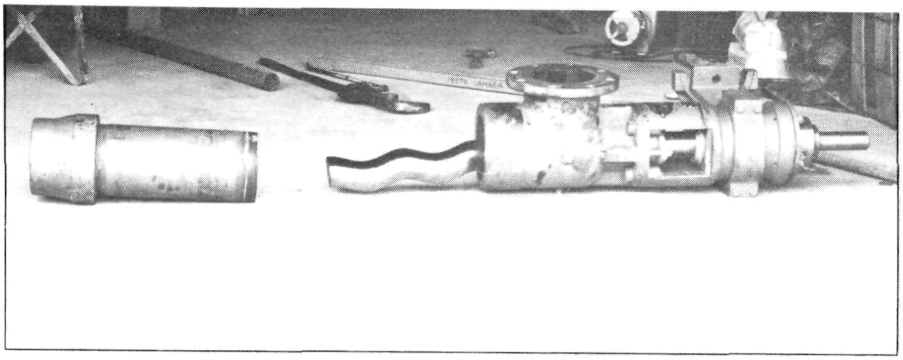
2.3.2.1 Midland-Bornemann 1600/360 EH. Supplier: LFE Canada, Ltd., Mississauga, Ontario. This pump weighs 175 kg, plus motor. Its dimensions are: length, 157.5 cm; height, 30.5 cm; and width, 25.4 cm (Figure 3A). The 12.7 cm diameter suction flange may be aligned either vertically or horizontally. Drain plugs are suitable for all suction



3(A) Midland Progressive Cavity Pump



3(B) Cutaway View of a Typical Moyno SWG Progressive Cavity Pump



3(C) Moyno 1L10H Pump with Stator Removed and Rotor Exposed Following Test

FIGURE 3 PROGRESSIVE CAVITY PUMPS

orientations. Two large, bolted cleanout openings are provided at the input end of the rotor for both cleanout of pump blockages and for easy removal of the pump rotor. The stator may be removed by removing four bolts and lifting the barrel straight out; disassembly of pipework is not required. Solids up to 3 cm can be passed.

The Midland-Bornemann pump is the lightest of the progressive cavity pumps investigated which had the required discharge capacity. Manufacturer's information on this pump was received too late in the program for the pump to be considered for testing. However, the advantage of having easily accessible cleanout ports, relatively large solids capacity and the lighter weight give it some advantage over the other pumps of its type which are discussed below. The pump is considered by at least one oil skimmer manufacturing company that uses it in their equipment to be the equivalent in design and performance to the Moyno pump.

2.3.2.2 Moyno 1SWG10H. Supplier: Robbins and Myers, Brantford, Ontario. The Moyno progressive cavity pump is a well-proven design of long-standing. There is a wide variation in models and assembly options for numerous industrial purposes. The 1SWG10H model is suitable for handling oil, slurries, sewage and viscous fluids containing debris. It weighs 225 kg, plus motor; its dimension are: length, 142 cm; height, 42 cm; width, 29 cm (Figure 3B).

The 15.2 cm suction port may be oriented either horizontally or vertically. The pump has cleanout ports (23 cm x 23 cm) on two sides and a single drain plus below suction port. When the suction port is aligned horizontally, the single drain plug is ineffective. The stator barrel is flanged to the main assembly and must be removed to allow access to the rotor. This arrangement does not appear difficult to disassemble but does require a clear space of 80 cm length in front of the pump, which may require removal of some piping. The pump has an advertised capacity for a maximum solid size of 2 cm.

Moyno pumps were recommended or suggested for oil cleanup purposes by 60 percent of the oil industry personnel contacted in the early stages of the study. These pumps have a reputation for reliability and have continued operating satisfactorily in the field despite considerable damage to the stator caused by oversize solids.

2.3.2.3 Roper 71228. Supplier: Roper Pump Co., Commerce, Ga., U.S.A. The Roper pump is very similar to the Moyno L series of pumps, which are used for clear water pumping and which do not have side cleanout ports. Parts are interchangeable between the two brands of pumps. No further consideration was given to the Roper pump because the Moyno designs, the originals on which the Roper designs were based, were already being investigated for the project.

2.4 Other Positive Displacement Pump Designs

Progressive cavity pumps are one type of rotary pump having a capacity to pass moderate solids. Other designs of rotary pump use rotary lobes, gears or other devices which create rotating pockets inside the pump casing to discharge flow. Reciprocating pumps utilize pistons and plungers to discharge liquid during each stroke.

Both rotary and reciprocating pumps normally have closer tolerances and have generally less capacity to handle ice and stones than progressive cavity pumps. However, rotary and reciprocating pumps may be lighter in weight and may have as good suction lift and self-priming characteristics as the progressive cavity pumps. In addition, they can be run dry.

Rotary and reciprocating pumps which either met the solids capacity criteria for the project or which had been used previously for oil cleanup are discussed as follows.

2.4.1 MD Lobe-Line 4540L. Supplier: MD Pneumatic Ltd., Springfield, Mo., U.S.A. The Lobe-Line pump uses non-meshing rotating lobes that will pass solids up to 4.8 cm. The pump weighs 9.1 kg. It will pass 290 l/min at 200 rpm. However, due to clearance between the lobes and casing wall, the pump is not self-priming and was therefore considered unacceptable for inclusion in this study.

2.4.2 Spate Four Inch. Supplier: Peacock Bros. Ltd., Mississauga, Ontario. The Spate pump is a British-manufactured reciprocating pump. The manufacturer claims that this pump works on a revolutionary new pumping principle; however, this is not clearly explained in their literature.

The Spate pump has been used in handling oil and was suggested or recommended by 33 percent of industry personnel contacted at the start of the study. In addition, it is being recommended and widely used by the Canadian Coast Guard for cleanup operations on the Pacific Coast.

Because of its previous wide usage and reputation, the pump is briefly mentioned in this study. However, although used for slurries and viscous fluids, the pump cannot handle solids in excess of 1.2 cm; therefore, it does not meet the project criteria. The pump has been found to have strong emulsifying characteristics due to its rapid reciprocating action.

2.4.3 Tuthill Pump Ulrich 330. Supplier: Tuthill Pump Co., Chicago, Ill., U.S.A. The Tuthill pump uses two non-meshing rotating lobes in similar fashion to the Lobe-Line pump which was discussed previously. The pump is self-priming and can be run dry.

In previous tests (2) the Tuthill pump has successfully discharged oil/water mixtures containing ice or other crushable materials. However, the pump does not have the clearance to pass 1.9 cm stones or other non-shearable objects.

3 PUMP TESTING

3.1 Selection of Pumps

Only 10 pumps passed the requirement to handle 1.9 cm solids. Six of these pumps were considered unsuitable for the project purpose for the following reasons:

- the Gorman-Rupp pump was not considered by the supplier to be suitable for handling fluids with viscosities above 80 centistokes;
- the Homelite motor-driven diaphragm pump did not meet the required minimum discharge capacity;
- the Midland single-acting diaphragm pump was not considered as suitable a design as the double-acting diaphragm pump that was selected for testing;
- the Dorr Oliver diaphragm pump had the disadvantages of being both single-acting and compressed-air driven;
- the Warren-Rupp air-powered diaphragm pump's previous cold weather usage had resulted in pump failure due to moisture condensation and freezing in the air supply lines; and
- the M.D. Lobe-Line pump was not self-priming.

Of the other four pumps, the Roper and Moyno progressive cavity pumps were almost identical; their parts were interchangeable. The Moyno pump was selected over the Roper for testing under cold conditions because it had been widely used and recommended by industry personnel.

The Midland progressive cavity pump also seemed to be suitable for the purpose. It appeared to be easier to disassemble than the Moyno, had large ports, would handle larger solids, and was lighter than the Moyno pump. However, product information on this pump was not received until too late in the program to arrange its loan for test purposes.

The two pumps selected for cold room testing were the Moyno 1SWG10H and the Offshore Devices Ltd.'s double-acting hydraulically driven diaphragm pump. However, due to unavailability of the 1SWG10H pump for loan purposes on short notice, a Moyno 1L10H pump (Figure 3C) was made available by the suppliers. The only differences between the two Moyno models are those incorporated in the casing design.

3.2 Test Arrangement

3.2.1 Test Oil. The physical characteristics of the reference oil were supplied by the Environmental Protection Service and are given in Table 1. The reference oil was to represent Alberta Fenn-Big Valley medium crude oil that had weathered for two days on the sea surface at 0°C.

TABLE 1 CHARACTERISTICS OF OILS USED

	A.P.I. Gravity (15.5°C)	Specific Gravity (15.5°C)	Pour Point (0°C)	Viscosity, cSt.			
				37.7°C	15.5°C	0°C	-15°C
Reference oil, fresh	32.9	0.861	-12	7.8	16.4		
Reference oil, two days weathered	23.4	0.914	+1	26.8	170		
Gulf Alberta, fresh	36.4	0.843	-21	7.7	10.6	38.0	
Gulf Alberta, after first heating	36.1	0.844	-23	6.5	9.8	33.0	86
Gulf Alberta, after second heating	33.0	0.860	-16	8.1	16.9	83.5	1895
Oil sampled from Offshore Device pump tests	32.0	0.865	-15			122	3330
Oil sampled from Moyno pump tests		0.871	-17		26	256	4362
Separator test mix	23.7	0.912	-29.4		106	407	3080

The characteristics were to be achieved by heating the crude oil for three hours at 50°C.

Nine drums of Gulf Alberta Crude were heated to over 50°C in an outdoor heated distillation tank. Water temperatures were read and controlled at 15 minute intervals. Comparison of oil viscosities and specific gravities sampled randomly from three drums following the first heating of nine drums showed litle change from the initial characteristics.

It was decided to reheat six drums for a further period of three hours at temperatues in excess of 55°C while bubbling compressed air up through the oil to stir it during heating. The viscosities and specific gravities of the reheated oil are also given in Table 1.

It can be seen that there was an appreciable change in characteristics between the first and second heatings. The reheated oil had characteristics similar to the fresh reference oil and was lighter and less viscous than the anticipated weathered oil. A plot of test oil viscosities is shown in Figure 4.

3.2.2 Test Facility. Testing of the two selected pumps was carried out in a cold room of the following dimensions: length, 6 m; width, 3.6 m; and height, 2.4 m. The pumps were mounted on a table 1.2 m above the floor.

The test oil and oil/water mixtures were circulated from covered tanks through 10 cm cast iron pipe (Figure 5). Rigid steel pipe of 10 cm diameter was used in the tests to minimize any variation in test conditions between the two pumps being studied.

Head on the pumps was varied by throttling the suction and discharge lines. A gate valve was used to establish suction head when pumping with water. This valve was left fully open during all tests involving oil pumping. A squeeze valve was fabricated on a 76 cm length of flexible hose to establish pressures in the discharge line without providing any abrupt flow constriction.

Bourdon pressure gauges located within 30 cm of the pump inlet and discharge ports were used to measure positive pressure on the discharge side and vacuum on the suction side of the pumps. Discharge was established by measuring the weight of fluid pumped into a 65 l container during a measured time period.

3.2.3 Test Program. The basic pump test program's six objectives were to:

- establish that the pump would discharge a minimum of 275 l/min against a total head of 11.2 m, including a minimum of 3.0 m suction lift;
- confirm the pump's ability to pass 1.9 cm solids without damage;
- confirm self-priming capabilities;
- assess the comparative emulsification effects of pumping an oil/water mixture at two temperatures;
- confirm that the pump would operate continuously for an extended period of several days at temperatures to -15°C without failure; and

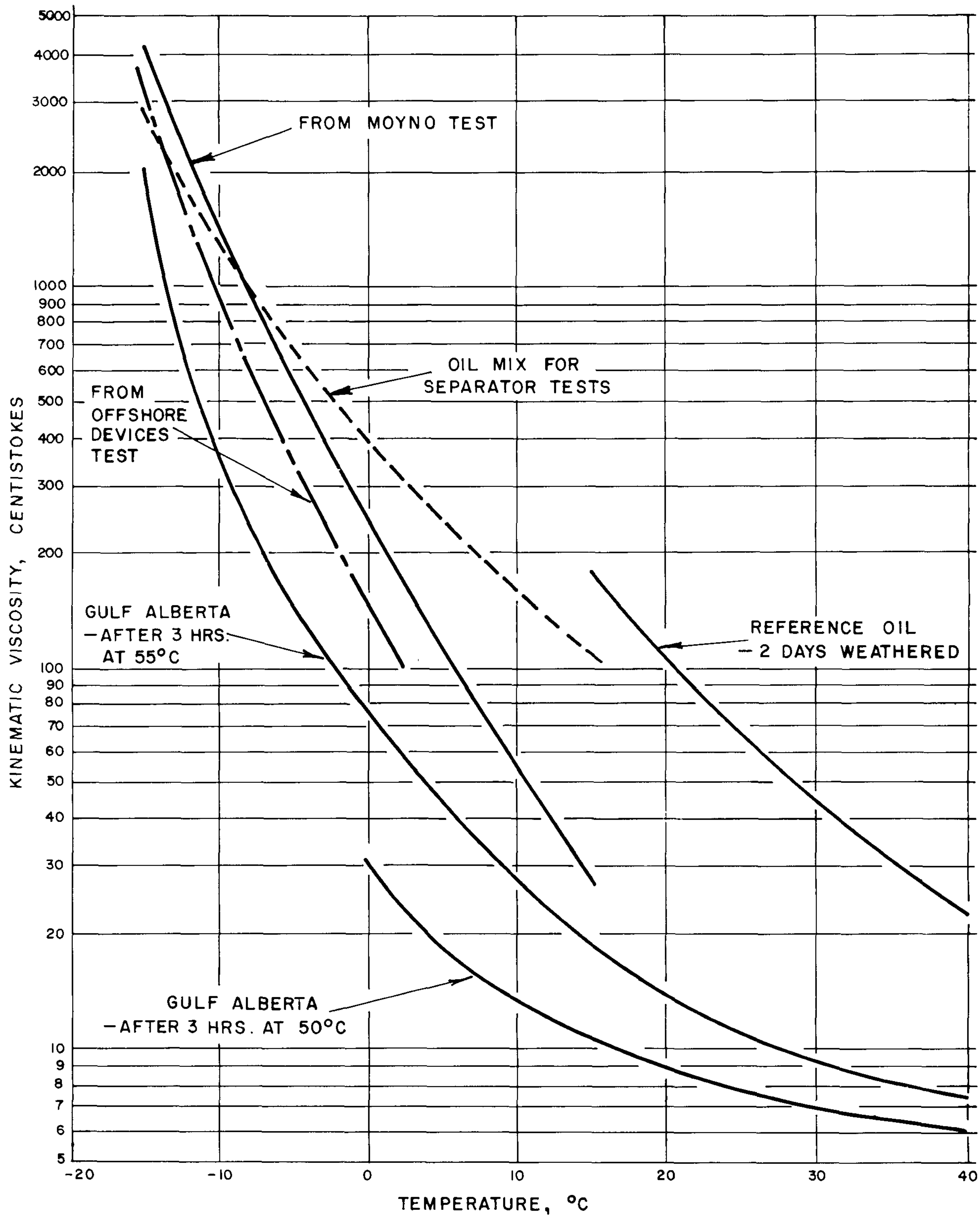
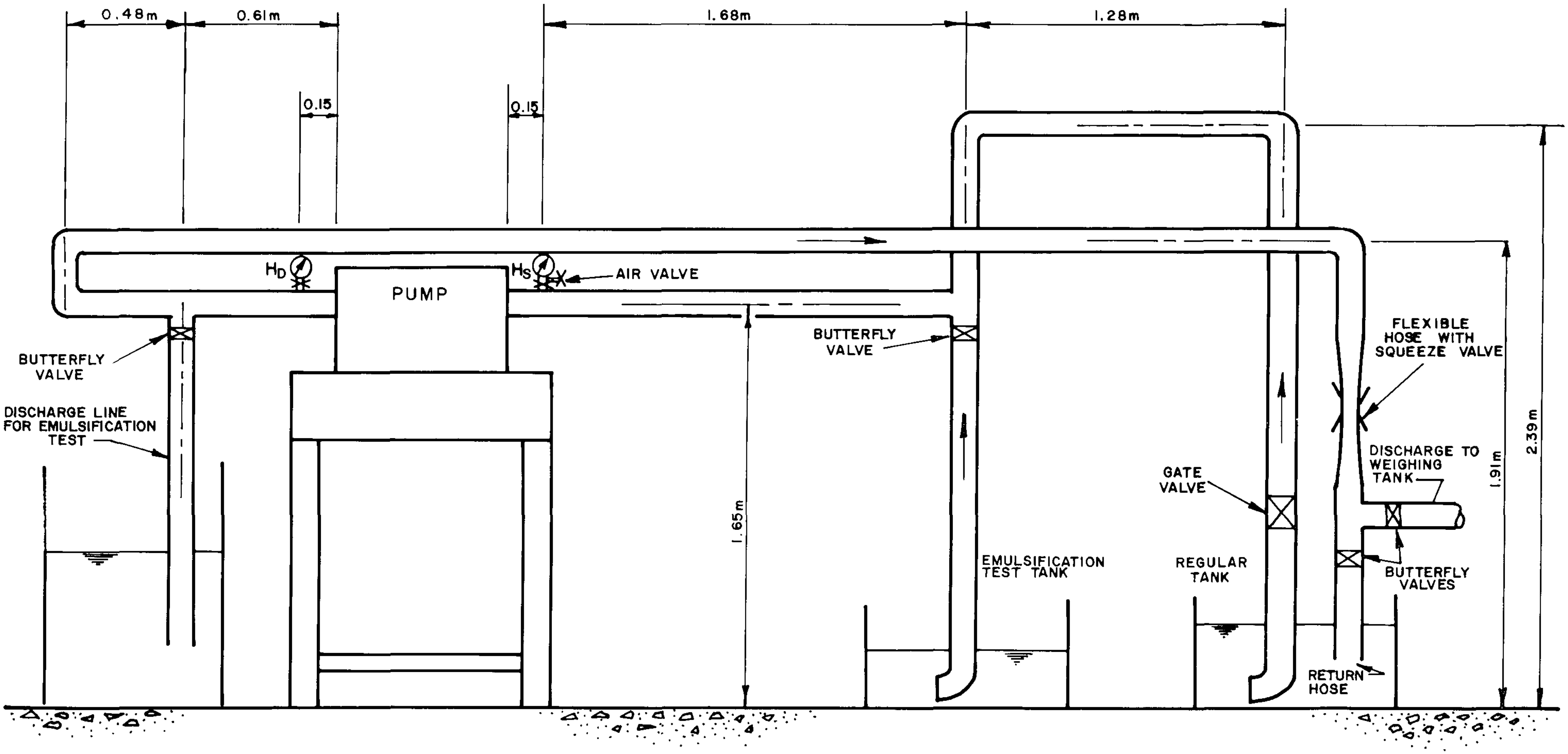


FIGURE 4 OIL VISCOSITIES USED



NOTE : Pipework of 10.4 cm diameter

SCALE = 1:25

FIGURE 5 TYPICAL PUMP TEST LAYOUT

- provide actual cold temperature assessment of pump operation, maintenance requirements and ease of repair.

The test programs followed for the two pumps are set out in Table 2. Self-priming tests and brief runs with the suction line open to air were run during the Test 4 endurance trials.

3.2.4 Test Procedures. Discharge performance tests were run using only water in order to establish that the pumps would handle over 275 l/min against the required suction and total heads. Flow was recycled from the regular tank through the pump and back into the tank (Figure 5). With the pumps operating, the gate valve on the suction line and the squeeze valve on the discharge line were operated to develop the pump heads. Flow was diverted into the weighing tank for known time intervals by simultaneous operation of the butterfly valves on the pump discharge line. The samples were weighed to determine pump discharge rate. Pressures were read directly from the dial gauges. To minimize pipeline pressure fluctuations with the diaphragm pump, a small air chamber with throttle valve was built into the air line leading to the pressure valves.

Tests to examine solids capacity were run by adding 1.9 cm chunks of crushed ice and 1.9 cm lengths of 1.9 cm diameter wooden dowelling to the regular tank and by ensuring their continued entry into the pump suction pipe. Solids tests were run for a minimal period of three hours.

A second tank of 350 l capacity was used on a separate suction line for emulsification tests. The suction line drew through a horizontal 10 cm diameter elbow located approximated 4 cm above the tank floor. The tank was filled to a depth of 9 cm with salt water and a further 9 cm of oil was added on top.

For the emulsification tests, the pump was initially set to circulate normally through the regular tank after which it was switched to draw from the emulsification test tank by simultaneous operation of valves. An eight-second interval was allowed to pass the remaining regular tank oil through the pump and piping before withdrawing a discharge at the butterfly valve immediatley downstream of the pump. After allowing the withdrawn discharge to stand 15 minutes for separation of free water from the oil to take place, a sample of approximately 75 cm^3 was taken from the oil surface for free and suspended water analysis at an independent laboratory.

An endurance test of approximately 96 hours continuous operation was run with each pump to determine if it would stand up to extended cold weather use during cleanup operations. The period of 96 hours was selected arbitrarily as sufficient to reveal

TABLE 2 PUMP TEST PROGRAMS

Test No.	Fluid Pumped	Temperatures (°C) Air	Fluid	Pump Heads (m) Suction	Discharge	Duration (h)	Test Objective
Offshore Devices Ltd. Diaphragm Pump							
1	Water	+10	+11	1.5 to 2.7	0.6 to 7.6	2 1/2	discharge performance
2	Brine and solids	-15	-2	1.5	neg.	3 1/4	solids passage
3A	50% oil; 50% brine	+2	+10	1.5	0.6	1/4	emulsification
3B	50% oil; 50% brine	+5	+3	1.5	0.6	1/4	emulsification
4A	75% oil; 25% brine	+5 to (-) 10	+10 to 0	1.5 to 3.0	3.0 - 4.9	70 1/2	endurance
4B	Water	+20	+20	2.1	4.3	25	endurance
Moyno 1L10H Progressive Cavity Pump							
1	Water	+20	+20	1.5 - 7.0	0.6 - 5.53	3	discharge performance
2	Water and solids	+10	+10	1.5	neg.	3	solids passage
3A	50% oil; 50% brine	-1	+10	1.5	0.6	1/4	emulsification
3B	50% oil; 50% brine	-5	+5	1.5	0.6	1/4	emulsification
4	95% oil; 5% brine	+4 to (-) 17	+7 to (-) 6	1.5 to 3.0	5.5 - 9.8	96 1/2	endurance

any major faults. During this period, a mixture of oil and salt water was recirculated through the normal tank to maximize the likelihood of corrosion.

During the endurance tests, suction on each pump was periodically broken by opening an air valve on the suction line during normal operation. The pump was left to run dry for periods of up to 15 minutes to assess the likelihood of damage due to a break in the suction line or to inattention while pumping out a skimmer. After closing the air valve, the self-priming capabilities of both pumps were noted.

Following the endurance tests, both pumps were dismantled as far as was required: e.g., to change the diaphragm for the Offshore Devices pump; to replace the stator for the Moyno pump. Disassembly provided an opportunity to determine the need for any special tools or expertise required in the event of pump blockage. Disassembly was carried out at normal room temperature; however, consideration was given to the probability of having to wear gloves in the field.

3.3 Offshore Devices Ltd. Pump

3.3.1 Test Results. The Offshore Devices double-acting diaphragm pump has been specifically designed to handle oil/water/debris mixtures during oil spill cleanup operations. The pump is still in the developmental stage and has not yet been thoroughly tried or tested in the field.

With an operating hydraulic fluid pressure of 10 300 kPa, the pump was found capable of easily handling 415 l/min of water against a total pressure of 10kPa. Pump discharge could be varied against a given head by control of the rate of hydraulic fluid to the pump. The pump self-primed quickly against the maximum suction test head of 2.4 m. Ice cubes and 1.9 cm wooden blocks were pumped without blockage. Results of the discharge performance tests on this pump are shown in Table 3.

After pumping the wood blocks for a period of 2 3/4 hours at -15°C air temperature, the upper pump casing developed a crack around the foot of the top boss (Figure 2), which permitted considerable leakage. The crack was temporarily sealed with fibreglass resin for the duration of the test program.

Later examination of the casing showed that improper casting had left a slight groove in the 0.6 cm thick metal at the foot of the boss. This casting flaw in an area of high stress was presumed to have been the major cause of the casting failure. However, the pump is designed so that movement of the hydraulic cylinder driving the diaphragm is stopped at each end of its travel by impact against the inside of the casing under the boss.

TABLE 3 OFFSHORE DEVICES LTD. DIAPHRAGM PUMP PERFORMANCE

Run No.	Fluid	Visc. (cSt) (+10°C)	Suction Head (m)	Discharge Head (m)	Total Head (m)	Discharge (l/min)	Stroke/ min	Hydraulic Pressure (kPa)
1	Brine		2.7	7.6	10.3	413	30	10 350
2	Brine		1.7	7.3	9.0	367	35	10 350
3	Brine		1.2	3.5	4.7	553	40	10 350
4	Brine		1.2	2.4	3.6	598	42	10 350
5	Brine		1.5	1.2	2.7	454	29	10 350
6	Oil & Water	40	1.5	0.6	2.7	435	32	6 900
7	Oil & Water	100	2.7	1.2	3.9	495	54	6 900

It is not known whether entrapment of a wooden block between the moving hydraulic cylinder and the casting locally increased the stresses produced by this action and precipitated the crack. A similar crack developed in the lower casing after the pump had been operating for a further 21 hours.

Tests were run with fluid temperatures of +11 and +3°C to assess emulsification produced in pumping an oil/water mixture. Samples taken after the pumped mixture had been allowed to stand for 15 minutes contained approximately 10 percent water in the surface oil at both temperatures.

The pump was run almost continuously for a period of 96 hours. During the first 63 hours, a mixture of 75 percent oil, salt water and ice was pumped. Air temperatures ranged between +5 and -10°C. Fluid temperatures ranged from +10 to 0°C, as work done in circulating the mixture kept the fluid temperature generally six to eight degrees warmer than the room air temperature. After running for 70 1/2 hours, the oil/water mixture was replaced with pure water for a further 25 hours of pumping. Air temperatures were about 20°C during this period.

During the continuous operation test, the crack in the top casing became extended and the bottom casing cracked. Differential movement across the crack around the boss in the top casing was observed during each stroke. Also, a rubber seal in the control valve unit broke, but this was easily repaired. Despite the casing damage, however, the pump kept operating and successfully pumped the fluid for the full period of testing.

Following the 96-hour test, the pump was disassembled and the casings were replaced. Lack of time and the request that the pump be returned to the manufacturer prevented any further testing with the new casing.

Generally, the pump was found to be easy to operate and to disassemble. Its performance characteristics met the study criteria. However, it had a noisy, jarring action. The design flaws are discussed below.

3.3.2 Recommended Pump Improvements. As previously mentioned, this pump is still in the developmental stage. It was found during testing to have several design faults which may easily be rectified. The design improvements listed have been discussed with Offshore Devices Ltd. and could be incorporated into the design.

1. The lightweight casing cracked during testing near the foot of the top and bottom bosses supporting the interconnecting hydraulic cylinder shaft (Figure 2). The boss should be enlarged and, more important, the short-radius curve around the foot of the bosses should be replaced with a more gradual transition into the casing. The manufacturer has advised that this modification has since been incorporated in the design.
   The 0.6 cm thin casting walls of both pump casing and suction/discharge elbows appeared prone to damage if dropped or from collision with other equipment. No test to determine casing durability was undertaken. However, for situations where weight is not of prime importance, a casing thickness of approximately 0.95 cm would give increased safety against breakage.
2. There were no drain plugs in any of the pump compartments. Without drains, ice may form in the pump when it is not in operation. Draining of the pump could only be accomplished through disconnection of suction and delivery pipes and tipping the pump to pour the contained fluid through the flap valves. This is an awkward, two-man operation unless the mounting base, control valves and hydraulic fluid lines are also removed. Provision for drain plugs should be built into the pump casing, above and below the diaphragm, as well as in the inlet and outlet connecting elbows (Figure 2).
3. The travel of the hydraulic cylinder in both directions will stop if a solid blockage is trapped between the moving cylinder and the casing boss. This could produce a sudden shock to the casing which may be reduced through the introduction of a shock absorbent cushion of neoprene, Buna-N or similar material just inside the casing bosses. A cushion at these points should be bevelled to reduce the likelihood of solid materials becoming caught between the cylinder and casing.

4. The support base, which in this case was assembled at relatively short notice by the manufacturer specifically for these tests, should be designed with synthetic rubber pads. These would cushion the jarring pump action and firmly seat the hydraulic valve controls.
5. During pump disassembly, it was found that both 0.79 and 0.95 cm bolts were used for similar purposes; however, these bolts had both hexagon and Allen heads. A single, standard-size bolt with a hexagon head should be adopted for ease of maintenance where only a few basic tools are available.

3.4 Moyno 1L10H Test Results

A Moyno 1SWG10H was not available for testing during the time allocated for the project. A Moyno 1L10H pump, which had similar pumping characteristics but a lighter casing design without cleanout ports, was made available by the Canadian supplier, Robbins and Myers Ltd. This pump was installed in the cold room with a 3.75 kw electric drive motor. The pump was subjected to a test program similar to that used for the Offshore Devices pump. Table 4 shows the discharges pumped at varying head conditions.

TABLE 4 MOYNO 1L10H PROGRESSIVE CAVITY PUMP PERFORMANCE (3.7 kw Motor at 315 rpm)

Run No.	Fluid	Viscosity (cSt)	Suction Head (m)	Discharge Head (m)	Total Head (m)	Discharge (l/min)
1	Brine	1	1.8	5.5	7.3	332
2	Brine	1	3.5	4.9	8.4	291
3	Brine	1	5.2	4.7	9.9	284
4	Brine	1	6.9	3.0	9.9	207
5	Crude oil	55	4.8	3.5	8.3	263
6	Crude oil	120	4.8	3.3	8.3	204
7	Oil mix	200	1.8	0.6	2.4	325
8	Oil mix	200	5.2	0.6	5.8	307

No problems were experienced in pumping 1.9 cm lengths of wooden dowel for a total period of three hours. During part of the test, the pump handled congealed crushed ice chunks up to 5 cm by 2.5 cm by 1.9 cm without damage to rotor or stator. The pump self-primed speedily against a suction head of 2.2 m.

Although the manufacturer strongly warns that the pump should not run dry due to the possible effect of friction on the stator, no sign of wear was found following continuous dry runs of 10 and 15 minute durations, and the pump reprimed quickly at the end of these tests.

Discharge from positive displacement pumps is mainly a function of operating speed rather than pump head. The Moyno pump, when operating at a speed of 320 rpm, discharged 325 l/min of oil of 200 centistokes viscosity against a suction head of 1.8 m plus 0.6 m discharge head; it discharged 397 l/min against 5.2 m suction head plus 0.6 m discharge head. These figures compare closely with the 328 l/min and 325 l/min claimed by the manufacturer for this pump and motor speed when handling water at these respective heads.

A suction head of 9.8 m of water developed on the pressure gauge with the suction line closed off. With crude oil, minor cavitation commenced at suction lifts in excess of approximately 6.1 m. Pump discharge dropped to 207 l/min of brine against a suction lift of 6.9 m and a total lift of 9.8 m, possibly due to air leakage through the stuffing box. As the suction lift was well in excess of that anticipated in the field, no attempt was made to tighten the stuffing box seal; and the situation was not investigated further.

Two tests were run at +10 and +5°C to assess emulsification of an oil/water mixture during pumping. At 10°C, there was five percent by weight of suspended water in the oil sample after it had been left to stand for 15 minutes. There was three percent water in the oil sample pumped at +5°C.

A mixture of approximately 95 percent crude oil and five percent water, added in the form of crushed ice, was used for the endurance test. The pump ran smoothly and quietly for the full test period of 96 1/2 hours. Air temperatures were down to -17°C and oil temperatures ranged between -2 and -6°C for most of the test. The oil viscosity was about 500 centistokes at these temperatures.

Following completion of these trials, the pump was used in the testing of an oil separator (Section 6). Following this test, the stator was removed and the rotor and the stator were examined. Both were in good condition, with only a single, faint scratch visible on the rotor.

Removal of the stator involved application of approximately 700 ft-lb of torque on the end of a 120 cm pipe wrench. As the stator simply screws into the main pump casing, there appears to be no need for this tightness of joint. The rotational force imparted to the stator by the rotor should be resisted by either lugs or friction at the cradle mounting and not by excessive tightening of threaded joints. However, it is noted that the pump recommended for the project by the manufacturer, Model 1SWG10H, has a flanged joint, instead of threads, between the stator and the main casing. Therefore, it would not experience this problem.

3.4.2 Possible Pump Improvements. In comparison with the 70 kg Offshore Devices pump, the 192 kg Moyno 1L10H was found to have a major disadvantage in weight. Discussion with Robbins and Myers Ltd. indicated that they are considering development of a lighter weight pump, which will use an alloy for the casting. However, a very large part of the pump weight is in the rotor and bearing assembly, and this would not be affected by casting changes.

The Moyno 1L10H pump had the additional disadvantage of being difficult to disassemble. This fault may be overcome by use of the recommended Moyno 1SWG10H model in the field. However, no opportunity was available during the study to disassemble the 1SWG10H model pump to verify this.

Other minor improvements in the design of the Moyno pump would be: installation of drain plugs for use when the central suction port is in the horizontal position; and development of a connection between the rotor and drive rod that would permit removal of the rotor, if necessary, without having to completely disassemble the entire shaft system. (This feature has been incorporated into the design of the Midland progressive cavity pump.)

3.5 Comparison of Pumps

During testing, both the Offshore Devices and Moyno pumps were found easy to operate and capable of meeting the requirements set out in Section 2.1.1. Discussion with users, sales agents and manufacturers indicated that the Midland 1600/630EH progressive cavity pump has similar performance characteristics to the Moyno pump.

The important differences of these three pumps are:

1. The diaphragm pump is considerably lighter, at 70 kg, than either the 225 kg Moyno 1SWG10H or the 175 kg Midland 1600/630EH progressive cavity pumps. However, the progressive cavity pumps have a less awkward shape, which partially offsets the weight difference. Three men could move the 192 kg Moyno 1L10H pump into position on a 1.2 m high platform, as compared to two men needed to move the diaphragm pump. The weights of prime movers for both types of pump are not

included in the above figures, as these would have to be determined for each situation; however, they may be considered as approximately equal.

2. The diaphragm pump was easier to disassemble and repair than the Moyno 1L10H pump. However, the Moyno 1SWG10H and Midland progressive cavity pumps discussed in Section 4.3.2 both appear easier to disassemble than the diaphragm pump. In addition, both pumps have cleanout ports for relieving blockage without major disassembly of the unit.
3. Draining of the Offshore Devices pump for overnight, outdoor storage would be laborious and incomplete, even with the installation of several recommended drains as indicated in Figure 2. Some fluid is likely to remain behind the flap valves. This fluid could freeze and impede start-up on the following day. Complete draining of the Midland pump would be a simple matter of running the pump dry and opening the bottom drain. This process would also apply to the Moyno pump if the bottom drain were installed for the horizontal suction position. As the Offshore Devices light-weight pump casing appears considerably more susceptible to cracking due to internal pressures resulting from ice formation, it is considered that the progressive cavity pumps would be the more suitable design for cold-exposed operation.
4. The diaphragm pump could handle 7.6 cm solids, while the Moyno pump was limited to 1.9 cm, and the Midland pump to 3.0 cm solids. This factor would be important if the pump were to be used for purposes other than off-loading skimmers and no provision had been made in the system for screening of large debris.
5. The steadier flow rate provided by progressive cavity pumps results in lower and more regular pipeline pressure than the pulsating flow from the diaphragm pump. The more regular flow conditions would induce less wear on the system and may decrease the chance of oil congealing on the inside pipe walls, leading to flow constriction and eventual partial blockage.
6. The progressive cavity pumps are quieter and smoother runnning, which results in better working conditions in their proximity.
7. The smooth, regular flow of the progressive cavity pump tested produced less emulsification in the oil/water mixture than did the pulsating flow of the diaphragm pump.
8. The Midland 1600/630EH is considerably lighter than the Moyno 1SWG10H. In the unlikely event of rotor replacement on either of these pumps, the Midland rotor can be disconnected through the inspection port and removed with the stator, whereas

replacement of the Moyno rotor involves a major dismantling of the pump and connecting piping.

It was concluded from this study that the Midland 1600/630EH pump best met the requirements of the project. The Moyno 1SWG10H was also considered to be a suitable pump for arctic oil spill cleanup purposes. The Offshore Devices Ltd. double-acting diaphragm pump should be considered for the purpose if pump weight is a dominant factor in pump selection.

4 OIL/WATER SEPARATORS

4.1 Separator Specifications

Separator weight and capacity specifications were similar to those required for the pumps, i.e., a preferred weight of less than 450 kg; a maximum possible weight of 1800 kg; and a capacity to handle 275 l/min of oil/water mixture at temperatures between +10 and -15^{o}C. No definite performance specifications were stipulated. It was considered desirable, however, that there be no more than 10 ppm of oil in the effluent water returned to the sea, and that the separated oil have no more than 15 percent water content. A specific gravity of 0.92 and a viscosity of 1500 centistokes were assumed for the reference oil at +1^{o}C.

Ice particles of 1.9 cm size were assumed to be present in the oil/water mix pumped into the separator and some freezing along the walls and any exposed pipework in the separator was considered possible during operation. Large pieces of ice were anticipated to form along the separator walls during overnight periods when the system was not in operation. Any separator using a filter process could be assumed to become blocked by ice and debris. In order to minimize problems of ice formation, blockage, and operational difficulties due to freezing of mechanical devices, a separator design with no moving parts was preferred.

Following assessment of the various oil/water separation techniques currently in use, it was decided that gravity separators would be the most suitable design type for arctic cleanup purposes. Gravity separators utilizing closely spaced corrugated plates and/or having narrow passageways were considered more prone to icing problems than those using a straight gravity concept.

4.2 Separators Evaluated

Manufacturers' information on 30 separators of varying sizes and types was examined during the study. A list of separators and their relevant specifications is given in Appendix B.

The gravity separators found capable of handling 275 l/min are mentioned briefly below.

4.2.1 AFL 100-25A. Supplier: AFL Industries Inc., Chicago, Ill., U.S.A. This gravity separator is 9.1 m long, 2.0 m wide, and 2.0 m high; it weighs 1700 kg.

The unit is designed to handle 380 l/min in a permanent installation. The unit uses baffles with narrow slots to distribute flow across the tank. The slots and baffle arrangement would be prone to blockage by floating or accumulating ice. The float-controlled inlet valve, which would be an advantageous feature in ordinary conditions, would also be prone to malfunction through ice formation.

4.2.2 **Butterworth C-14.** Supplier: Butterworth Systems Inc., Florham Park, N.J., U.S.A. This gravity separator is a 2.2 m high by 1.4 m diameter vertical cylindrical tank divided by interior, fixed baffles and passageways into three recovery stages. It is imported to North America from Europe for both shore-based and shipboard purposes. The empty separator weighs 1100 kg.

This separator is designed to handle 665 l/min of mixture but the supplier recommends that it only be run at one-third to one-half capacity if installed on a floating barge. Floating ice and viscous oil would present serious problems to flow in the internal passageways. The supplier recommends installation of heating coils or hot air blowers with the unit to minimize this problem. No dimensions on internal passageways were available from the supplier but dimensions scaled from drawings indicated that some flow-ways are less than 1.9 cm across. This unit is considered unsuitable due to likely icing effects.

4.2.3 **EWD-75-A.** Supplier: Edens Equipment Co., Chicago, Ill., U.S.A. This is a gravity separator with double-baffle flow distribution system. The baffle system is considered prone to ice blockage. The unit is 4.5 m long by 1.5 m wide by 1.5 m high. It weighs approximately 2050 kg, which exceeds the weight criterion. Its rated capacity is 284 l/min.

4.2.4 **General Electric OPL 75.** Supplier: General Electric Co., Philadelphia, Pa., U.S.A. The OPL 75 is a corrugated plate gravity separator. The manufacturer would not recommend it for oil concentrations greater than 25 percent. The corrugated plates are spaced at 0.6 cm intervals and would quickly foul with ice.

4.2.5 **Heil 600-5 BPR.** Supplier: Heil Process Eqpt. Corp., Cleveland, Ohio, U.S.A. The Heil is a corrugated plate separator. The manufacturer considers that screens and/or heaters should be placed in the inlet line to remove any ice and reduce the oil viscosities. Without pretreatment of the oil, the separator would quickly foul with ice.

4.2.6 **Hydro-gard.** Supplier: Grotnes Machines Works Inc., Chicago, Ill., U.S.A. This is a 6.0 m long by 1.4 m diameter gravity separator which can handle 265 l/min of mixture at 21^{o}C. The unit weighs 2090 kg, exceeding the weight criterion, and requires additional pumps, which would further increase its total weight.

4.2.7 **Josam GNC110.** Supplier: Josam Manufacturing Canada Ltd., Scarborough, Ontario. The Josam is a small (1.2 m long by 0.8 m wide by 0.7 m high) gravity separator weighing 200 kg. Its flow distribution baffles would likely plug with ice. The manufacturer claims an unacceptable performance of 10 percent oil left in the water discharge.

4.2.8 **Offshore Devices.** Supplier: Offshore Devices Inc., Peabody, Mass., U.S.A. This is a 160 kg lightweight polypropylene gravity separator. The unit is 1.4 m long by 1.1 m wide by 1.2 m high.

The unit is divided by internal baffling to give a flow-through passage of approximately 4.0 m long by 0.3 m wide. Cross-baffles with 5 cm wide slots could clog with ice and are likely to produce some emulsification in the flow. A single, linked discharge valve is used to control outflow of both oil and water. This arrangement could produce operating problems with viscous oils near the pour point. The manufacturer suggests that efficiency for the unit would leave an unacceptable 5,000 ppm oil in the water outflow.

4.2.9 **Pielkenroad.** Supplier: Pielkenroad Separator Co., Houston, Texas, U.S.A. This is a corrugated plate pack separator similar to the Heil separator discussed previously. It would have problems of ice fouling in the narrow passages between the corrugated plates.

4.3 Evaluation Conclusions

Two conclusions were drawn from the evalution: none of the separators presently on the market are suitable for oil spill cleanup operations in icy waters; and the most suitable method of handling oil-covered lumps of ice is to pass the ice through the separator and to remove it with the discharged oil.

4.4 American Petroleum Institute

4.4.1 **Separator Design.** An A.P.I. (American Petroleum Institute) design gravity oil separator is basically a large-volume tank in which oil, being lighter than water, rises to the surface as flow passes through the tank. A deep lateral baffle near the discharge end of the tank dams the separated oil layer on one side, and allows only the clean water at depth to pass underneath and reach the water oulet (Figure 6).

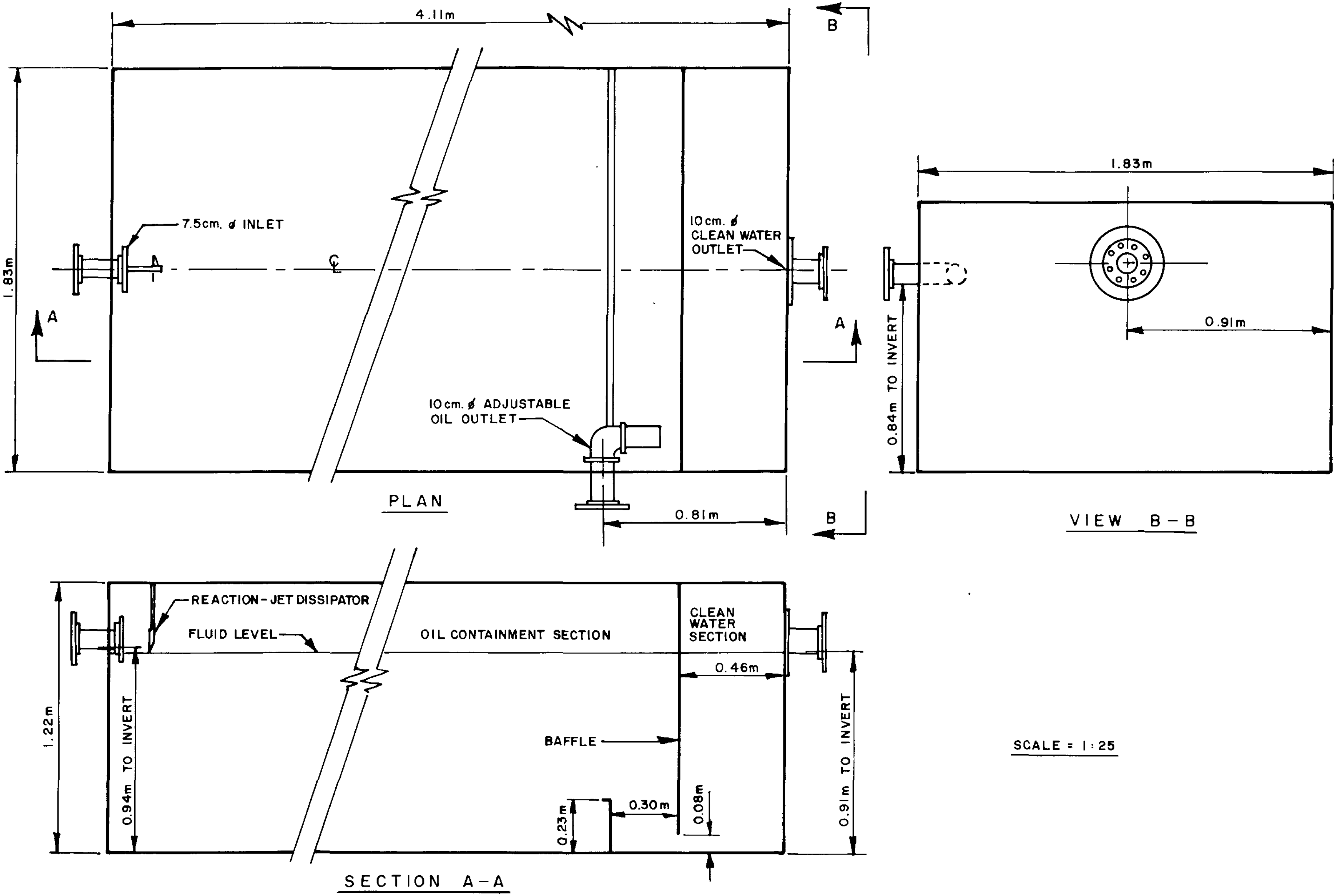


FIGURE 6 AMERICAN PETROLEUM INSTITUTE DESIGN SEPARATOR

An outlet pipe with adjustable invert elevation skims oil from the front of the baffle. A glass viewing window allows observation of the oil layer thickness.

A.P.I. separators are often designed for a specific installation and are constructed of reinforced concrete in-situ.

The efficiency of the A.P.I. separator is a function of fluid "residence time" in the separator tank, and the rise velocity of oil droplets. The major factors affecting rise velocity of oil droplets are the droplet size, which is a function of viscosity and is therefore temperature-dependent; the fluid viscosities; and the relative specific gravities of the oil and water.

Although some of the manufacturers discussed above have used the A.P.I. settling tank concept for their separator designs, none have produced a unit suitable for project purposes, i.e., one which would eliminate problems with ice blockage of baffles or valving. It was decided that an A.P.I. separator should be fabricated of steel and tested in the cold room in order to obtain first-hand experience of separator operation and performance using viscous oil and icy water. A reaction jet dissipator was to be used in the design to spread the inflow across the tank width without inducing likely ice blockage problems.

Design and construction of an A.P.I. separator was carried out in March 1978. The separator was designed to remove oil droplets larger than 150 microns in diameter, with specific gravity of 0.91 and viscosity of 1500 centistokes. Design oil layer thickness was 15 cm. The separator was 4.1 m long by 1.8m wide by 1.2 m deep (Figure 6) and weighed 1050 kg. The steel separator was constructed as a single unit in the interest of saving time. However, it could have been designed for partial dismantling or constructed of a lighter weight material to reduce component weight. No longitudinal baffles were installed in the test model but these would be necessary to stop lateral wave action developing in the oil tank when operating on a floating vessel.

4.4.2 **Test Program.** The objectives of the test program were to assess:

- the separator's ability to handle ice;
- separator efficiency with respect to the amount of oil in the discharged water; and
- separator efficiency with respect to amount of water in the discharged oil.

The test runs were made under the following conditions:

Separator Test Conditions

Run No.	Air Temp (^oC)	Fluid Temp (^oC)	Oil/Water Concentrations 3:1	1:1	Ice Added
1	+5	+8.0	Yes	No	Yes
2	+4	+1.4	Yes	Yes	No
3	+2	+8.5	Yes	Yes	No

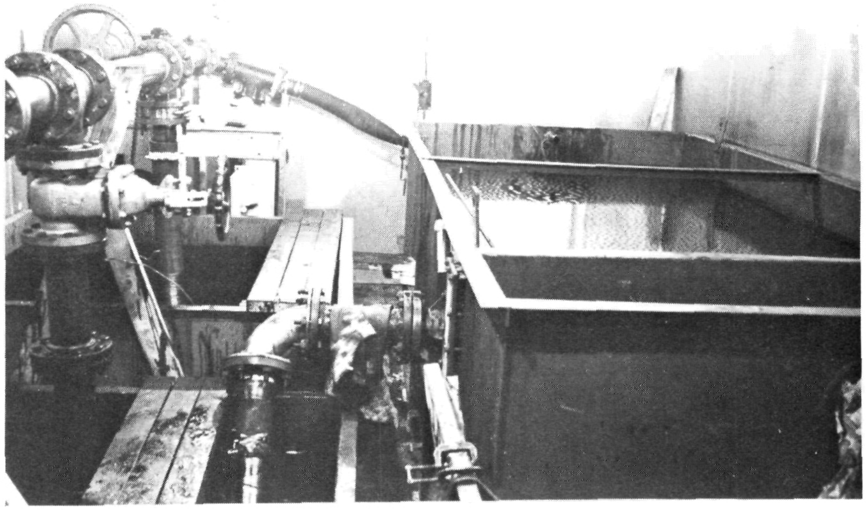
The first run was made to assess the effects of ice on inlet or outlet blockage during operation. Ice was added in both block and small-chunk form at the separator inlet in large quantities over a short period of time. Excessive emulsification of the oil/water mixture during recirculation of the fluid through the piping system outside of the separator prevented useful information on separator efficiencies being obtained during this run.

The second test run assessed separator performance at near 0^oC fluid temperatures. Samples were taken at regular time intervals at both oil and water outlets. Both 3:1 and 1:1 concentrations of a reference oil/water mixture were used to assess the effect of input concentration on efficiency.

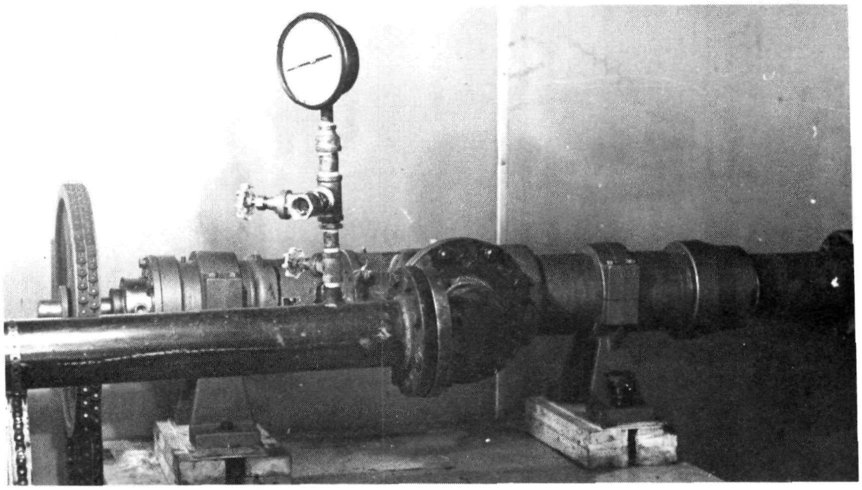
The third run assessed separator efficiencies using both 3:1 and 1:1 oil/water mixes at a warmer temperature, near the upper project limit of 10^oC.

An oil mixture of 46 percent L.S. diesel oil and 54 percent bunker C was prepared for use in the tests. This mixture closely reproduced the specific gravity of two days' weathered Alberta Fenn-Big Valley crude oil and had similar viscosity at cold temperatures. Properties of the mixture are given in Table 1. The viscosity curve of the oil mixture is shown in Figure 4.

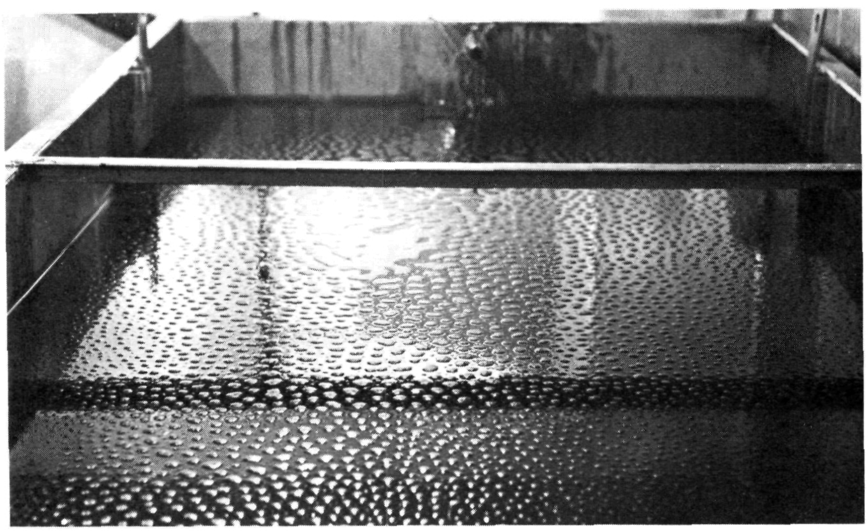
4.4.3 Test Procedure. The separator was installed in the cold room facility as shown in Figure 7. The Moyno pump, running at 275 rpm and discharging approximately 285 l/min, was used to circulate the oil/water mixture for the tests. The separator was cleaned prior to each test run, and filled with water to within 15 cm of the water outlet. Commerial salt was added to the separator and stirred by pumping to give a salinity of 24 ppt, equivalent to a specific gravity of approximately 1.02 at 0^oC. A 15 cm layer of reference oil mix was slowly added to the containment section of the separator. Tanks of 1000 and 1500 l capacities were filled with the oil/water concentrations to be tested and a 275 l tank was filled with brine.



7(A) Separator Test Arrangement in Cold Room



7(B) Moyno 1L10H Pump Mounted for Separator Test



7(C) Contained Oil Surface After 60 Minutes Operation

FIGURE 7 SEPARATOR TEST FACILITY

Testing commenced with recirculation through the separator to initiate appropriate turbulence and flow circulation likely to be generated in the separator by continuous prototype operation. This was followed by pumping the reference oil mixes through the separator for set time periods.

Sampling of surface fluid at the oil inlet and oil outlet ports was done at set time intervals. Samples were also taken regularly from just below the water surface at the water outlet port. Any surface oil slick at the water outlet was excluded from these samples to eliminate misleading effects of any oil buildup between sampling.

Oil and water outflow from the separator were both returned to the 1000 l tank and recirculated through the separator after the test mixes had been emptied from their respective tanks.

Analysis of all oil and water samples were carried out at an independent laboratory following completion of the test run.

4.5 Test Observations

4.5.1 Test With Ice. The initial test was run to examine separator performance with 3:1 oil/water mix and to assess any difficulties the separator would have in passing ice. Fluid temperature was $+8^{o}C$; oil viscosity was approximately 200 centistokes. Specific gravity at the start of the test was 1.02. Salinity meter observations showed a decline in salinity in the brine with time during all tests. This was believed to be due to absorption of salt into the crude oil.

Forty kg of crushed ice chunks of 1.9 to 10 cm size were added at the separator inlet at the start of the test. The ice floated to the oil surface. Smaller pieces of ice passed easily out through the oil discharge skimmer. Larger pieces jammed in the corner by the outlet pipe and impeded or totally blocked flow to the outlet. A surface circulation pattern formed in the tank, which carried flow directly along the tank, centerline away from the inlet, with a large eddy on either side, and returned flow towards the inlet, along the tank sides and back up the center. Large ice blocks which were cleared from the oil outlet were carried by the surface circulation pattern around the tank and returned to the outlet. Improved circulation could be achieved through positional adjustment of the inlet reaction jet dissipator but this condition was not optimized due to time constraints.

During an initial 30-minute period of oil/water recirculation, intended to establish prototype flow conditions in the tank, it was noted that the surface oil layer built-up steadily and increased in thickness with time despite the apparent removal of as much oil from the outlet as was supplied to the tank. The repeated circulation of the oil/water mix through the pump and separator test arrangement induced emulsification of water into the oil, which led to a considerable "bulking" of the oil layer.

The system was stopped after sufficient operation time to permit the previously mentioned ice movement observations; the system was subsequently allowed to stand overnight. No appreciable separation of the emulsified water from the oil occurred overnight.

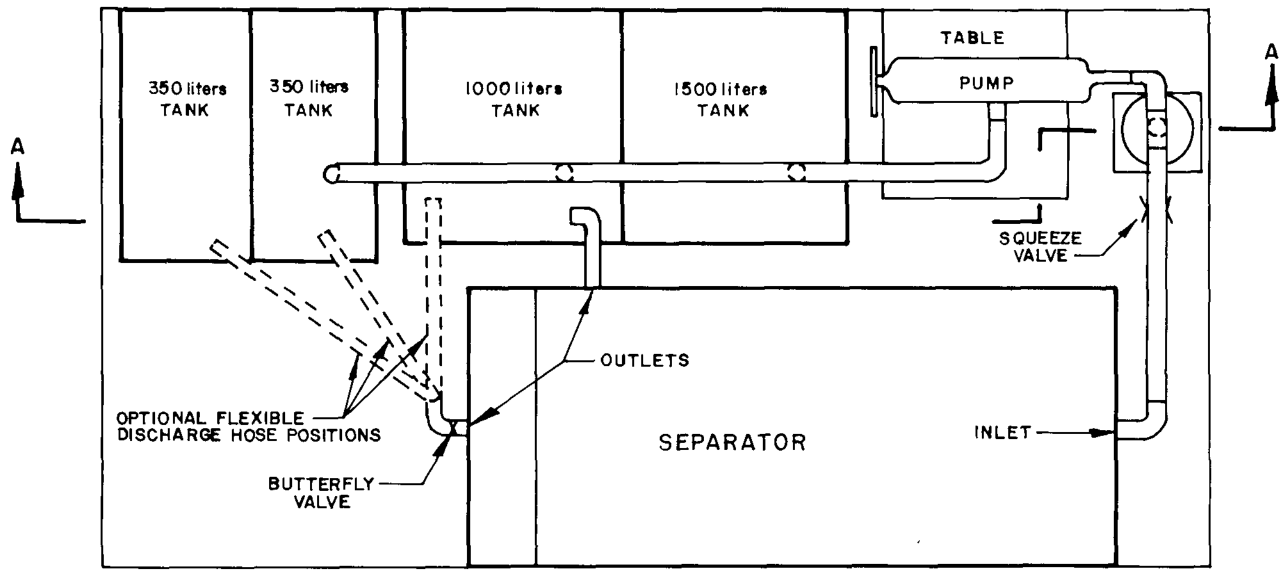
An oil outlet sample taken after one hour's recirculation through the system showed 4 percent free water and 46 percent suspended water in the oil by weight. A sample taken at the water outlet port showed a 34 ppm oil concentration, although the water was visually clean and showed no sign of a surface slick.

It was decided that an alteration to the test system was required prior to runnning further tests. The piping system was modified to that shown in Figure 8. The test procedure was changed for future runs to minimize recirculation.

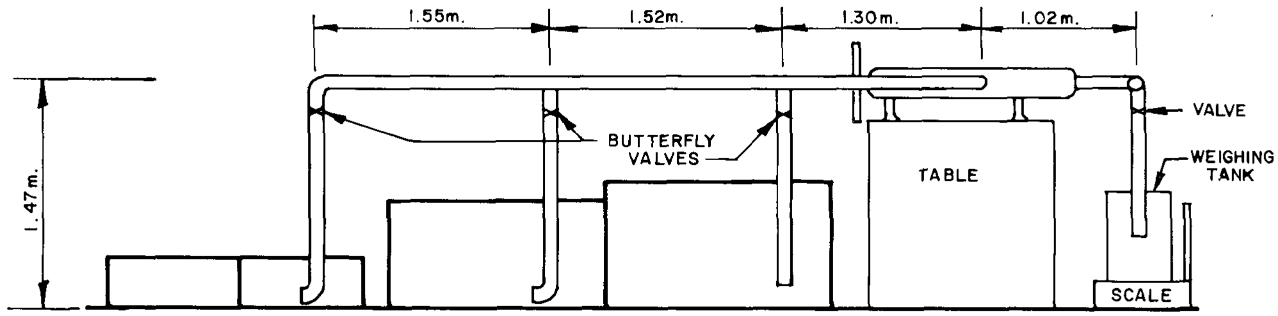
4.5.2 Test at +1.4°C. The second test was run at an air temperature of +5°C and a fluid temperature of +1.4°C, producing an oil viscosity of about 350 centistokes. Salt water alone was pumped through the tank for eight minutes to establish basic circulation. Approximately 1000 l of the 3:1 mix was then pumped into the separator and circulated for a further eight minutes. Subsequently, the 1:1 mix was introduced and recirculated for an additional 90 minutes. Results of oil and water samples taken during the test are given in Table 5.

Observation of the tank operation showed the same regular buildup of oil thickness as has previously been noted. The layer thickness increased by approximately 1 cm/min. A minor slick was noted on the water surface in the outlet water chamber after 20 minutes. After approximately 60 minutes, the oil layer was 60 cm deep; the bottom 3 cm was oil/water mousse.

Globules of mousse, oil with an appreciable water content, would gradually form from the bottom of the oil layer in the separator containment section. These globules would hang from the bottom of the layer and then slowly sink as progressively more oil separated upwards from the globule, increasing the specific gravity of the remainder. After a period of as much as 10 to 20 minutes, the globule would gradually be sucked down under the lateral baffle and would rise to the water outlet surface, where it would "burst" at the surface with rapid spreading of a local oil slick. The globules resulted from emulsification incurred during the recirculation process and only occurred



PLAN (SCALE 1:50)



VIEW (SCALE 1:50)

FIGURE 8 SEPARATOR TEST LAYOUT

TABLE 5 OIL AND WATER SAMPLE ANALYSES RESULTS

Test No. 1 Fluid Temperature +8°C

Sample Location	Time from Start (min)	Free Water (% Vol)	Suspended Water (% W+)	Free Oil (ppm)	Suspended Oil (ppm)
Oil Outlet	60	4	45.9		
Water Outlet	60			nil	34

Test No. 2 Fluid Temperature +1.4°C

Sample Location	Time from Start (min)	Free Water (% Vol)	Suspended Water (%W+)	Free Oil (ppm)	Suspended Oil (ppm)
Inlet	2	30	0.22		
	4	31	0.22		
	8	35	0.42		
	16	60	0.20		
	60	45	0.20		
	85	29	0.60		
Outlet	2	2	nil		
	5	2	0.22		
	8	nil	0.24		
	13	2	0.14		
	18	2	0.22		
	20	2	0.36		
	85	40	0.80		
Water Outlet	4			nil	nil
	15			7	12
	30			53	3
	35			42	5
	45			69	25
	60			152	16
	85			89	9

TABLE 5 OIL AND WATER SAMPLE ANALYSES RESULTS (continued)

Test No. 3 Fluid Temperature +8.5°C

Sample Location	Time from Start (min)	Free Water (% Vol)	Suspended Water (% W+)	Free Oil (ppm)	Suspended Oil (ppm)
Inlet	2	35	0.10		
	4	39	0.05		
	8	24	0.06		
	12	17	0.08		
	16	22	0.08		
Oil Outlet	5	14	0.14		
	8	20	0.04		
	13	21	0.16		
	18	19	0.08		
	24	21	0.01		
	34	6	0.10		
Water Outlet	4			nil	15
	10			nil	5
	15			nil	26
	20			nil	19
	25			nil	15
	30			nil	4
	40			nil	19
	60 Surface			270	57
	60 Subsurface			9	57

after the system had been operated for a considerable time period; they were not considered representative of prototype conditions. Care was taken to exclude globules and their resultant surface slicks from the water outlet samples.

Table 5 shows that the separator passed only two percent water in the discharged oil with both 3:1 and 1:1 mixes during the period before the effects of recirculation became apparent. The suspended water at the oil outlet is similar to that shown in the inlet samples, indicating the water that had been emulsified in the recirculation process.

The separator containment section held 5100 l of water and 1020 l of oil when the oil layer was 15 cm thick. A complete "changeover" of contained water would mathematically occur in 72 minutes for the 3:1 mix and in 36 minutes for the 1:1 mix. New oil in a 3:1 mixture would arrive at the oil outlet within five minutes of being introduced if complete replacement of the existing layer occurred. As a complete "changeover" would be the ideal situation and would not likely occur, the components of new mixtures introduced to the separator would show up at their respective outlets well within the above time frames.

The oil content in the water discharge has been plotted in Figure 9 with the calculated times shown for the inlet water to reach the outlet in an "ideal" or complete changeover situation. Allowing for the likelihood that complete changeover does not occur, it is probable that the sample taken at 30 minutes reflects operating conditions with the 3:1 mix and that the sample taken at 35 minutes represents conditions with the 1:1 mix. This would indicate that the oil content of the water outlet was approximately 55 ppm with the 3:1 mix and dropped to 47 ppm with the 1:1 mix. Figure 9 indicates that the separator will give a performance of about 40 to 60 ppm oil in the effluent for the range of operating conditions examined and will probably be more efficient with lower oil percentages in the introduced product.

4.5.3 Test at +8.5^{o}C. The viscosity of oil decreases with rising tempreature. The separation rate of water from an oil/water mixture should therefore be more efficient at higher fluid temperatures. A third test was run with a fluid temperature of +8.5^{o}C, and oil viscosity of approximately 180 centistokes, to investigate separator efficiency at higher temperatures.

Salt water was circulated through the separator for eight minutes before introducing the 3:1 oil/water mix. The oil layer was 15.2 cm thick and there was no oil/water mousse. After eight minutes of circulating the 3:1 mix, a fresh 1:1 reference

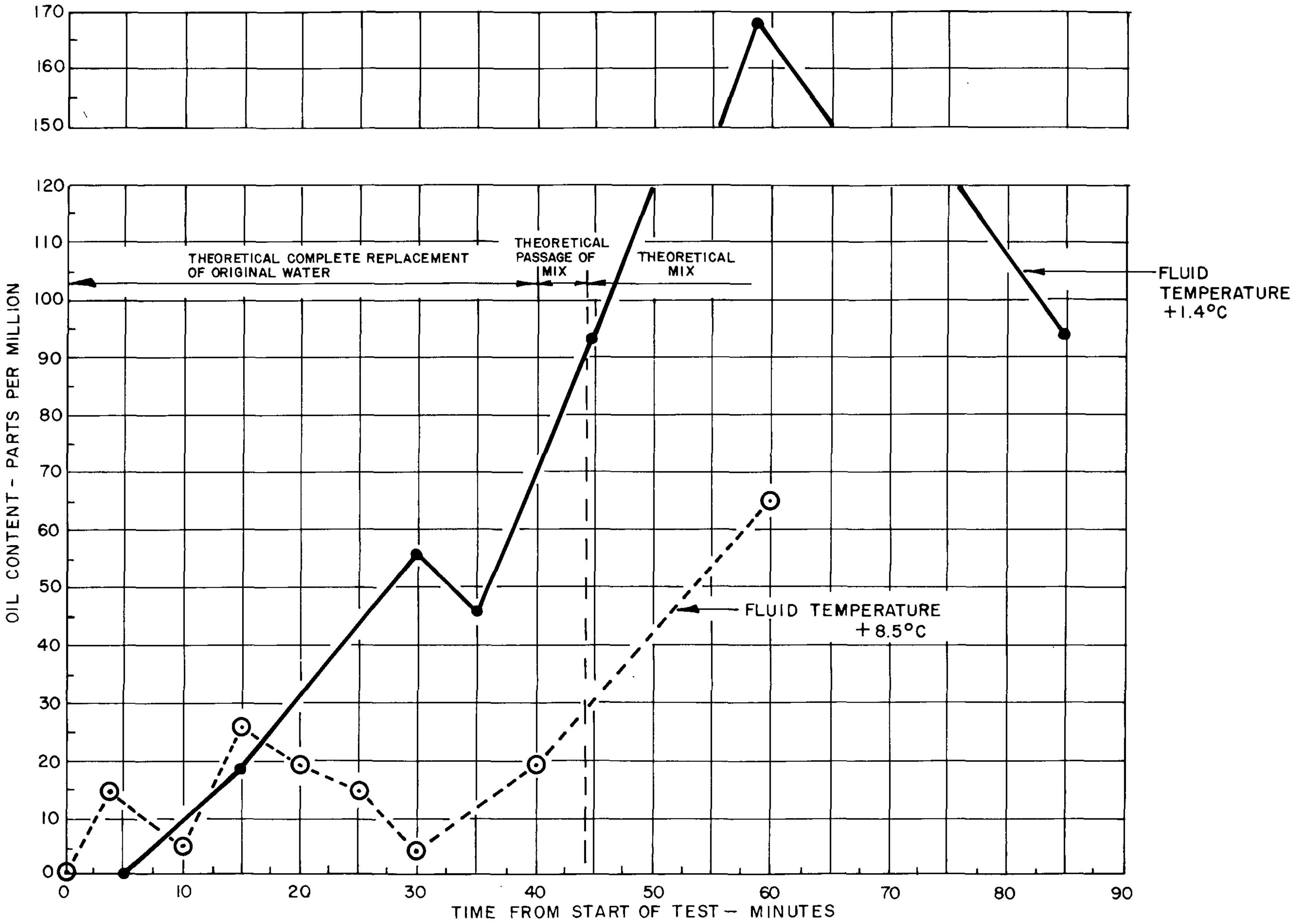


FIGURE 9 OIL CONTENT AT SEPARATOR WATER OUTLET

mix was introduced. The oil and water discharges were remixed and recirculated for 60 minutes.

The oil layer thickness grew at a rate of approximately 0.8 cm/min. Globules of oil and water started appearing on the water discharge side of the lateral baffle within 28 minutes from the start of the test. The globules increased in frequency to about two or three/min, then practically stopped for almost 10 minutes before resuming in frequency again. After 55 minutes from the start of the test, globules of three cm in diameter were rising to the surface approximately every five seconds. These globules formed at the bottom of the oil layer in the containment section and were carried under the lateral baffle, as described earlier.

The analysis of the oil and water outlet samples, Table 5, shows that the emulsification produced in recirculating the test mixture, as given by the percentage of suspended water in the inlet fluid, was less at the fluid temperature of $+8.5^{o}C$ than at $+1.4^{o}C$. The consistently low values of suspended water in surface oil at the oil outlet for both Tests 2 and 3 indicate that the problem of emulsification experienced in Test 1 was primarily a function of the piping arrangement and valve operating procedures and was not induced in passing through the Moyno pump.

There was considerably more free water at the oil outlet (approximately 20 percent by volume) at the warmer temperature than at $+1.4^{o}C$.

The oil content of the clean water discharge from the separator was generally less then 20 ppm during the period of complete theoretical changeover of the initially contained water. After 60 minutes of operation, the apparent surface oil layer had grown in thickness to 66 cm from the design thickness of 15 cm. This resulted from a buildup of emulsified oil/water mixture below the surface. The water content of the surface oil at the oil outlet was low, as shown by the samples. A gradation had built up in the containment section from an oil mixture with large suspended water content, and therefore relatively high specific gravity, at depth to oil with less water content and lower specific gravity at the top. The layer growth would not occur with the once-through flow process in actual field conditions. The final oil-in-outlet water reading of 66 ppm, taken after 60 minutes of operation, would therefore be unrepresentative of field conditions and sets an upper limit of what may be expected under poor operating conditions.

No appreciable difference could be noted in separator efficiency with varying oil/water input concentrations. However, examination of the inlet sample analyses indicates that the variation in mixture concentrations was neither as great nor as abruptly changed in this test as had been achieved in the second test run.

4.6 Separator Improvements

The A.P.I. design separator produced effluent qualities which were close to the desired standards. However, the following design improvements should be made before the system is used for an oil spill cleanup operation.

1. A wire mesh grid with approximately 7.5 cm wide openings should be constructed across the tank between 75 and 95 cm from the floor and at a distance of 30 cm upstream from the oil outlet port. This grid would prevent large pieces of ice, which may have formed along the separator sides overnight or have come from any other source, from hindering flow access to the outlet pipe.
2. Provision should be made on the separator floor and sides for installation of longitudinal plate baffles to break up possible lateral wave action. Determination of final baffle dimensions would require further design work. However, the baffles would extend downward from below the fluid surface and stop at some distance above the tank floor. Flow access space would be required around both ends of the baffles. The baffles could be held in position by a tubular frame and supported on legs above the tank floor. Installation would be by dropping each baffle frame into longitudinal slots at each end of the oil containment section with the support legs fitting into short pipe sections welded to the tank floor. The baffles should be held rigidly in position at the top by bolted cross members at each end.
3. A small, removable 30 cm wide cover plate should be fabricated to lie across the top of the tank above the reaction jet dissipator. This cover plate would allow adjustment of the dissipator bowl close to the inlet pipe for optimal flow dispersion without splashing outside the tank.
4. The 10 cm wide by 1.2 cm thick glass window should be replaced with 1.9 cm thick Plexiglas to better resist impacts. The Plexiglas should be located on the inside of the tank. ArmourAll or equivalent polish should be use on the Plexiglas to reduce oil adherence.
5. Although the separator as tested and including baffles was within the maximum weight restrictions of 1800 kg for the project, it was not within the preferred weight limits of 450 kg. However, this could be achieved for future designs either through compound construction of the separator in a different material such as aluminum, fibreglass or an oil-resistant plastic compound or by constructing the separator to a height of only 1.1 m, in sections. Suitable section divisions are:

- the separator floor and bottom 0.3 m would form the lower section;
- the remaining 0.8 m wall height, plus bracing to maintain shape. These two sections would be bolted together by 0.95 cm diameter bolts at 10 cm spacing through welded stiffener angle around the top and bottom of the respective sections. A neoprene strip gasket would prevent leakage at the joint; and
- the third section, also to be bolted in place in the field, would consist of a wall extension behind the inlet and an inlet cover to prevent backsplashing.

Consideration would have to be given for any particular spill condition as to whether the reduced component weight for transport outweighed the inconvenience of assembling the separator in the field.

5 CONCLUSIONS

The following conclusions have been drawn from this study:

5.1 Pumps

1. There are few pumps at present on the market which are suitable for purposes of oil spill cleanup as required by the Arctic Marine Oil Spill Program. Only five pumps passed the two basic criteria of discharge capacity and solids handling; and of these, two pumps were considered unsuitable for other reasons.
2. The most suitable pump for the purpose of arctic oil spill cleanup was considered to be the Midland 1600/630 EH (Figure 3). This progressive cavity pump weighs 175 kg, plus prime mover, and will pass 3 cm solids. Selection of this pump was made on the basis of sales information and user advice only. This pump was not tested under cold conditions.
3. The Moyno 1SWG10H (Figure 3) was also considered to be a suitable pump for the purpose. This progressive cavity pump weighs 224 kg, plus prime mover, and will pass 1.9 cm solids. This pumping mechanism with different casing, the 1L10H, was tested with water and oil at temperatures down to -15^{o}C and was found to perform satisfactorily under all conditions.
4. The Offshore Devices double-acting diaphragm pump (Figure 1) was also considered to meet the requirements for arctic oil spill cleanup if design modifications were carried out. This pump was lighter, at 70 kg, plus prime mover; had greater discharge capacity and could pass larger solids than the above-mentioned progressive cavity pumps. However, it produced more emulsification in the pumped oil/water mix than the above-mentioned progressive cavity pumps. It had a noisy, pulsating pumping action and is still in its developmental stages. Serious consideration should be given to this pump deisgn where pump weight is a dominant factor in selection.

5.2 Separators

1. None of the commercially available oil/water separators were considered to be suitable for the purpose of arctic oil spill cleanup.
2. An American Petroleum Institute design oil/water separator will function satisfactorily under cold conditions. The design of a separator suitable for arctic oil spill cleanup operations would be similar to the design shown in Figure 6. Modifications would include lower side walls, longitudinal wave-reducing baffles, and provision for transportation in sections of 450 kg maximum weight.

REFERENCES

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APPENDIX A

POSITIVE DISPLACEMENT PUMPS EVALUATED

TABLE 6 POSITIVE DISPLACEMENT PUMPS EVALUATED

Name	Model	Pumping Principle	Maximum Discharge Capacity (l/min)	Pump Speed (rpm)	Solids Capacity (cm)	Approx. Weight (kg)	Remarks
Blackmer	NPJ 2 1/2	Rotating vanes	330		No	160	Insufficient solids capacity
Dorr Oliver	ODS-4	Single-acting diaphragm	340	15	10.2	275	Freezing problems with air supply; heavy
Gorman-Rupp	4DX-3	Single-acting diaphragm	375	52	7.6	185	Not suitable for viscosities greater than 80 cSt
Granco	HHN	Rotating lobes	1135	600	No	90	Insufficient solids capacity
Homelite	11.DO3.1	Single-acting diaphragm	260		7.6	50	Insufficient pumping capacity
I.M.O.		Rotating screw			0.6		Insufficient solids capacity
LFE Midland	1600/630 EH	Rotating screw	1135	500	3.0	175	Considered suitable
LFE Midland	33E-4028	Single-acting diaphragm	290		7.6	133	Not as suitable as double-acting diaphragm pump
M.D. Lobeline	4540L	Rotating lobes	1100	750	4.7	90	Not self-priming
Megator	L300	Triplex reciprocating	340	570	0.6		Insufficient solids capacity
Moyno	ISWG10H	Rotating screw	795	750	2.0	225	Suitable - 1L10H model tested in cold conditions
Offshore Devices		Double-acting diaphragm	1325	60	7.6	70	Suitable - pump tested in cold conditions

TABLE 6 POSITIVE DISPLACEMENT PUMPS EVALUATED (Cont'd)

Name	Model	Pumping Principle	Maximum Discharge Capacity (l/min)	Pump Speed (rpm)	Solids Capacity (cm)	Approx. Weight (kg)	Remarks
Roper	71228GHL	Rotating screw	795	750	2.0	193	Copy of Moyno 1L10H
Rotoking		Rotary gear					Insufficient solids capacity
Spate	Four Inch	Oscillating impeller	885		1.2	410	Insufficient solids capacity; high emulsification
Tuthill	330	Rotating lobes	1275	450			Insufficient solids capacity
Warren Rupp	SA3-A	Double-acting diaphragm	1060	170	7.6	110	Freezing problems with air supply
Waukesha	125 D1	Rotating lobes	475	500			Insufficient solids capacity
Willden		Double-acting diaphragm	640		1.0	55	Insufficient solids capacity; air freezing problems
Worthington		Rotary gear					Insufficient solids capacity

APPENDIX B

OIL SEPARATORS EVALUATED

TABLE 7 OIL SEPARATORS EVALUATED

Name	Model	Operating Principle	Capacity (l/min)	Weight (kg)	Dimensions L,W,H(m)	Efficiency (Oil in Water)	Required Extra Eqpt.	Remarks
AFL	100-25A	Gravity	380	1700	9.1 x 2.0 x 2.0	5 ppm		Inlet valves and dispersion slots prone to clogging by ice
Bethlehem Steel	Buffalo-Morse	Gravity-weir	190	950	1.2 x 1.8 x 0.9			Not suitable for highly viscous oils
Butterworth	C-14	Gravity	665	1100	1.4 dia. x 2.2H		heaters	Inlet heating required; ice clogging in narrow passages
DeLaval	MAB 209	Centrifugal	180	1135	2.0 x 1.3 x 1.7	200 ppm	13.5 kw power	Pre-heating of fluid required; numerous moving parts; low capacity
Edens Eqpt. Co.	EWD-75-A	Gravity	280	2050	4.5 x 1.5 x 1.5			Too heavy
Electroholme		Reverse osmosis					power	Won't handle ice
Envirex		Gravity						Small units not manufactured
Envirotech	36	Air flotation	190	2270	4.3 x 1.0 x 1.4		9.0 kw power	Too heavy; centrifugal machinery
Facet		Filters					power	Filter cartridges would plug with ice; too heavy
Fram	OWS 113	Filters	430	6300	3.0 x 1.8 x 2.1			Filters would plug with ice; too heavy

TABLE 7 OIL SEPARATORS EVALUATED (cont'd)

Name	Model	Operating Principle	Capacity (l/min)	Weight (kg)	Dimensions L,W,H	Efficiency (Oil in Water)	Required Extra Eqpt.	Remarks
General Electric	OPL 75	Corrugated plates	285	820	3.3 x 1.4 x 1.1			Won't handle over 25% oil; ice would clog plates
Heil	600.5 BPR	Corrugated plates	275	680	2.5 x 1.2 x 2.3	30 ppm		Separator pack would clog with ice
Inland Environmental	Hydro-gard C-70	Gravity	265	2090	1.4 dia. x 6.9L		pumps	Too heavy
Josam	GNC110	Gravity	284	200	1.2 x 0.8 x 0.7	10%		Poor efficiency
Keene		Filter	40	425		< 8 ppm	115v	Insufficient capacity; filters would clog
Komline-Sanderson		Air dissolution					pumps	Polishing separator; needs pretreatment; too heavy
Lockheed	R 2003		760	2700				Too heavy; works as collector
Mapco	1500	Pressure filters	380	1350	4.5 x 1.1 x 2.1	10 ppm	power	Filters would plug with ice
Mapco	2000	Coalescing filters	380	3000	3.2 x 2.0 x 2.4	10 ppm		Filters would plug with ice
Marco	RDS035A	Gravity in foam drum	320	945	2.3 x 1.1 x 1.7	< 10 ppm	115 v	Maximum viscosity 540 cSt; ice wouldn't pass roller and would clog system
Midland Ross		Coalescing media						Prefiltration required; permanent installation

TABLE 7 OIL SEPARATORS EVALUATED (cont'd)

Name	Model	Operating Principle	Capacity (l/min)	Weight (kg)	Dimensions L,W,H	Efficiency (Oil in Water)	Required Extra Eqpt.	Remarks
Offshore Devices		Gravity	945	160	1.4 x 1.1 x 1.2	5%		Low efficiency
Permutit	OB10 Favair Mk 11	Air flotation	190	Heavy	1.4 x 1.1 x 1.2	20 ppm	power	Pretreatment required; permanent installation
Pielkenroad		Corrugated plate						Separator pack would clog with ice
SRS	100	filter	380	450+	2.3 x .8 x 2.0			Filters would plug with ice
U.S. Filter Corp.	Q10	Air flotation	380	2250			power	Too heavy
Velcon		Filter						Filters would plug with ice