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Pumps for Oil Spill Cleanup

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PUMPS FOR OIL SPILL CLEANUP

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REVIEW NOTICE

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ABSTRACT

A testing program was conducted by Arctec Canada Limited for the Environmental Protection Service whereby various commercially available pump designs were evaluated with respect to the requirements for general-purpose transfer pumping in oil spill cleanup situations. In addition to making comments about the specific units tested, effort was devoted towards the development of criteria for pumps to be utilized for this application. These criteria and the test observations led to generalizations about classes of pump designs in relation to oil spill operations.

The key performance criteria were determined to be:

- developing suction-lift and self-priming with high viscosity fluids;
- debris tolerance;
- low shear of the pumped fluid;
- ease of handling and repair; and
- reliability at below-freezing temperatures.

Eleven pumps were tested representing a range of hydrodynamic and positive displacement designs. Results indicate that a solids-tolerant positive displacement pump has application for spill cleanup use, whereas a diaphragm design shows much potential for an effective pumping system.

RESUME

La société Arctec Canada Limited a entrepris, pour le compte du Service de la protection de l'environnement, des essais de divers modèles courants de pompes de transfert sur des nappes d'hydrocarbures déversés accidentellement. La société a non seulement commenté ces essais, mais elle s'est aussi efforcée d'établir des critères pour déterminer quel genre de pompe convenait particulièrement à ce genre d'opération. Les modèles ont donc été classés d'après ces critères et d'après les observations faites au cours des expériences.

Les critères d'évaluation du rendement ont été:

- la hauteur d'aspiration et l'amorçage automatique avec des fluides de forte viscosité;
- la tolérance au débris;
- le faible indice de cisaillement du fluide pompé;
- la maniabilité et la facilité pour réparer; et
- la fiabilité à des températures au-dessous du point de congélation.

Les essais ont porté sur onze pompes représentant l'éventail des modèles hydrodynamiques et volumétriques. Les résultats ont montré qu'il faut employer une pompe volumétrique pour matières épaisses, pour les travaux de nettoyage; tandis que ce sont les modèles à membrane qui pompent le mieux.

FOREWORD

The work described in this report was performed by Arctec Canada Ltd. under contract to the Environmental Emergency Branch, with Mr. L.B. Solsberg of the Branch acting as scientific authority and Mr. W.F. Purves of Arctec as project manager. Testing was conducted between May and September, 1977 at the company's Montreal laboratory.

By its nature, this study involved assembling a large amount of equipment and materials from numerous sources. This was greatly facilitated by the much appreciated co-operation of many people including Al Cormack - BP Canada, Al Egerton - M.S.E. Engineering, Bob Gilbert - A.B.C. Rubber, Jim Huston - Robbins & Myers, Yves Leclerc - Canadian Coast Guard, and Jerry O'Donahue - R.N.G. Equipment.

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1 INTRODUCTION

1.1 Background

In 1975 a study of oil spill countermeasures with potential application to the Beaufort Sea was undertaken for the Environmental Emergency Branch. This work, summarized in report numbers EPS-3-EC-77-6 and -7 (Ref. 1) includes the identification of pumps with a capability of processing highly viscous oils. This information was then used as a basis for the selection of transfer units for comprehensive laboratory testing in 1977. The final list of pumps included the following units:

1. Homelite 121TP2-1 Trash Pump
2. Monarch BSG 2-Inch Centrifugal Pump
3. Gorman Rupp 12B-2 Centrifugal Trash Pump
4. Spate 3B
5. Homelite 111DP3-1 Diaphragm Pump
6. Gorman Rupp 3D Diaphragm Pump
7. Sandpiper SA2-A
8. Moyno 1L6
9. Blackmer NPZ
10. Rotoking K124
11. Megator L150

This report presents the findings of the laboratory study. Section 1.2 of the "Introduction" outlines the situations in which one expects to utilize pumping systems and presents brief notes on pump types and pump selection variables. Section 2 provides a summary of results in terms of pump head and capacity, suction-lift and self-priming characteristics, emulsification tendencies, solids-handling capacity, cold-weather performance and ease of repair and handling. Also included is a performance summary of the pumps examined, as well as conclusions and recommendations. Section 3 describes the laboratory evaluation procedure and apparatus used, while Section 4 details the test results.

1.2 Oil Spill Cleanup

Pumps are key components in most systems for cleaning up marine oil spills. Typically, the cleanup system will consist of a boom subsystem for containing the spill, a skimmer for picking up the oil layer from the water's surface, and various containment and disposal devices. Once the skimmer has collected a volume of oil at or slightly above the water level, pumps are commonly employed for draining the skimmer's small surge capacity; for transferring the collected oil to temporary storage; and for draining the temporary storage, delivering its contents to a disposal facility. Each step in the process - from the skimmer surge, to the temporary storage, to the disposal facility - normally involves raising the fluid volume two to six metres typical of the freeboard of a vessel or a dock at low tide. The first step in particular - from the skimmer surge to a barge or small boat - involves taking suction from very near the local water level. Unless the pump is mounted below the skimmer's waterline, this implies that the pump must provide suction-lift. Further, typical nearshore skimmers are very small vessels with low stability, and their surges are of the order of one cubic metre. Thus, any small disturbance can cause the pump to lose prime.

Experience has shown that many slicks which require skimming are in busy shipping channels or industrial harbour areas. Oil collected in these environments can be expected to contain large quantities of debris ranging from seaweed to plastic cups.

A key component of most spill cleanup operations is the "vessel of opportunity". This might be a work boat loaded with empty drums and equipped with a "pump of opportunity". Although not originally specified for oil spill cleanup, under such situations the pump:

- does not self-prime;
- has limited suction capacity;
- loses prime with every roll of the skimmer;
- drains itself on shutdown;
- loses capacity with slight increases in oil viscosity;
- cavitates if the sun warms the oil slightly; and
- blocks on the slightest suspended trash (which occurrence requires constant cleaning of the screens and intermittent dismantling for this purpose).

This is an extreme picture, but it indicates some of the deficiencies of an oil spill utility pump. Skimmers rarely collect more than a few tens of cubic metres of oil per hour and are drained to vessels with freeboard of a few metres; therefore, head and capacity are not normally serious constraints in specifying pumps for this service. Virtually any pump design is available in this head and capacity range. Far rarer, however, is a reliable self-priming suction pump with high viscosity and trash processing capability.

1.3 Pumps

The wide range of available pump designs can largely be described as fitting within three general classes: positive displacement pumps, hydrodynamic pumps, and jet eductors.

Figure 1 (taken from Ref. 1) presents a jet eductor in cross-section which functions as follows. The pumping fluid is accelerated through a venturi nozzle to create a partial vacuum, which draws the pumped fluid through the suction port where it mixes and is discharged with the pumping fluid. This is a simple and robust design, but the pumping fluid (usually water, steam or air) must itself be pressurized by some other pump, boiler or compressor. Uchida, Takeshita and Seike (Ref. 3) have recently discussed the application of jet eductors to oil spill cleanup. In this program, no jet eductor designs were considered.

The positive displacement and hydrodynamic pump categories embrace a wide variety of disparate designs, each with its performance strengths and weaknesses. In this report, a set of performance criteria is developed specific to the oil spill situation and is used to compare various common designs. On a general level, hydrodynamic designs are typically simpler and less expensive with few moving parts or precision clearances. Often available with mounted diesel or gasoline engines, these are widely used in the construction industry for de-watering excavations.

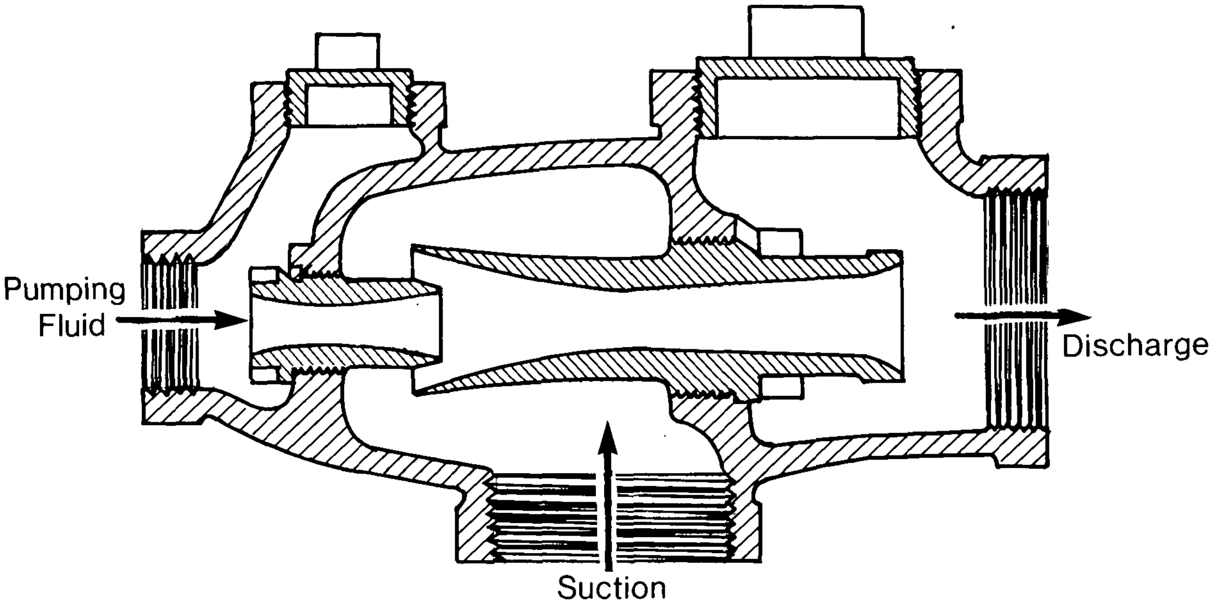


Fig.1 - A Jet Eductor in cross-section

Positive displacement pumps, on the other hand, are often precision designs for fixed installation in chemical processes. They typically move high viscosity fluids very well and self-prime readily. However, many types are designed for pumping "clean" fluids, and their valves and precision clearances are usually intolerant of suspended solids. Prior work (Refs. 5,6) has shown that positive displacement pumps generally shear the pumped fluid less than hydrodynamic designs, and thus form less emulsion when pumping oil/water mixtures.

1.4 Pump Selection Variables

The hydraulic work available from a given pump can be expressed as:

$$W = hV\rho \qquad (1)$$

where W = hydraulic work available (kgm/sec)
h = pumping head (metres)
V = flow rate (m^3/sec)
ρ = fluid density (kg/m^3)

Information on this performance index for any given pump design and size is normally available from the manufacturer, but in the form of a characteristic curve as is shown in Figure 2a (Gorman Rupp centrifugal model). Figure 2b, taken from a Moyno pump catalogue, shows a tabular presentation. In both cases the data are presented for clear 21.1°C (70°F) water at sea level. All of these ratings are seriously affected by changes in the liquid viscosity from that of 21°C water. Pumps such as the Moyno and Waukesha are often specified for paste service so viscosity correction tables are made available by the manufacturer. Figure 2c presents an example of such a table, this one offering correction factors for 11 Moyno pumps. On the other hand, many pumps are designed principally for water service so that appropriate viscosity corrections to the capacity curves must be developed experimentally.

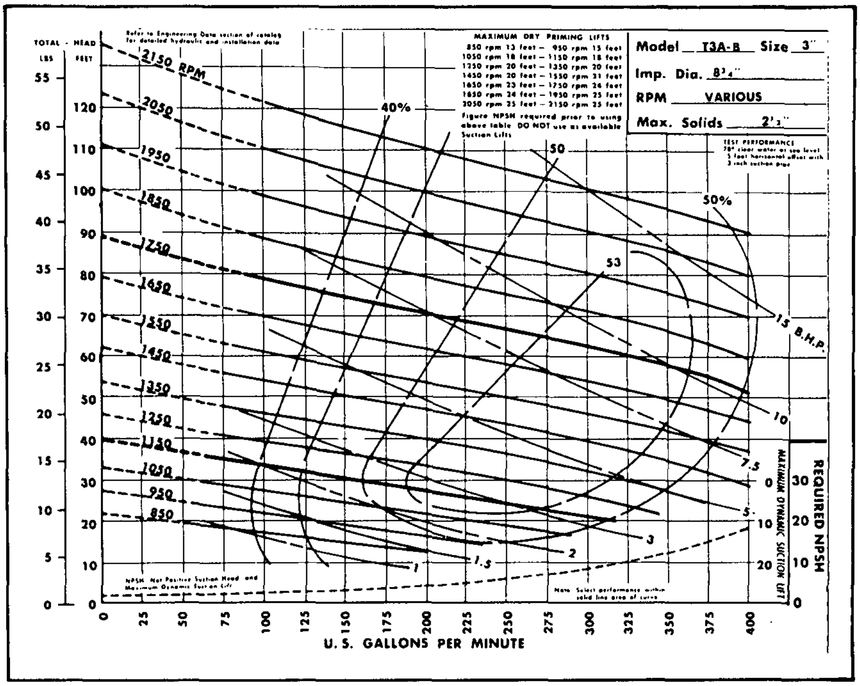
Head, capacity and viscosity response can be described as the functional variables in pump selection. It is clear that a pump which will not move No. 6 fuel at 189 ℓ/min (50 gpm) through 2-6 metres of head cannot be effective in many common spill applications and must be judged unsuitable. Beyond this first selection, pumps can be compared against a complementary set of dysfunctional criteria.

The first of these criteria is emulsification. At some spill sites, facilities and storage capacity may be available for processing emulsions. When they are not, however, the problems are enormous. Many stable emulsions are 50% water or more, so the disposal system must deal with disposing of a mass of water at least equivalent to the collected oil. Since the density of the emulsion is much less than that of either component alone, the storage and handling problems on a volume basis are even more serious. Not all spilled materials form stable emulsions easily, but the possibility of this should be taken into consideration when selecting pumps.

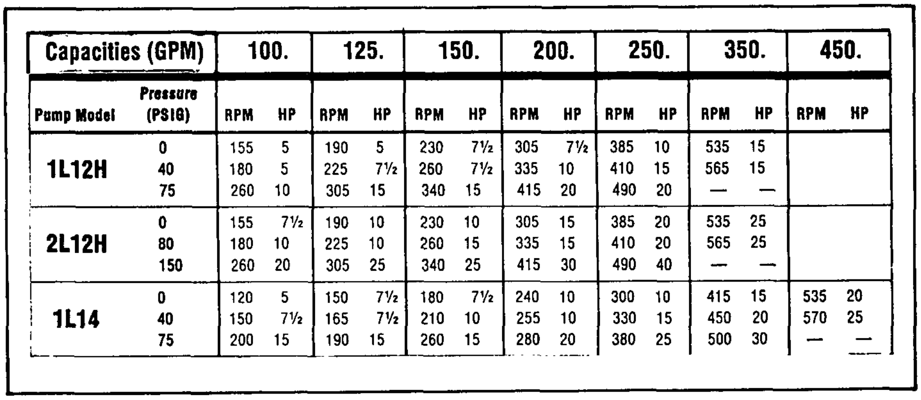
Harvey et al (Ref. 5) discuss the various emulsion-forming processes within a pump, and Fruman et al (Ref. 6) present a parametric analysis of various pump types in terms of the Weber and Reynolds numbers of the flow. These studies concur that hydrodynamic designs, with their vigorous acceleration of the fluid, generally emulsify more than positive displacement types. In positive displacement designs, high-speed flow through constricted passages or sudden, large pressure drops are key emulsifying processes. In polymer and food processing, for example, emulsification seriously degrades many products and pumps are especially designed for these industries which move even high viscosity fluids gently. The Moyno pump is one example that was tested in this program.

Solid "debris" is present in most spilled materials. Ice is a particular form of debris and is important in the Canadian situation as its presence is widespread; it exists in very high concentrations and is of every shape and size. An ability to pass solids such as ice chips is thus an important qualification. This requirement is commonly found in construction applications where pumps are widely used to de-water excavations. These pumps routinely ingest stones, mud and ice without clogging or breaking down. Sewage treatment is a similar case. In both applications, centrifugal pumps are widely used.

Unfortunately, the positive displacement pumps which handle high viscosity fluids and pump gently, tend to be intolerant of suspended solids. One possible solution to this problem is to fit a well-designed screen in the pump suction. In view of this, solids tolerance should be considered a second-order dysfunctional criterion; neither solids processing nor screen design was explicitly studied in this program.

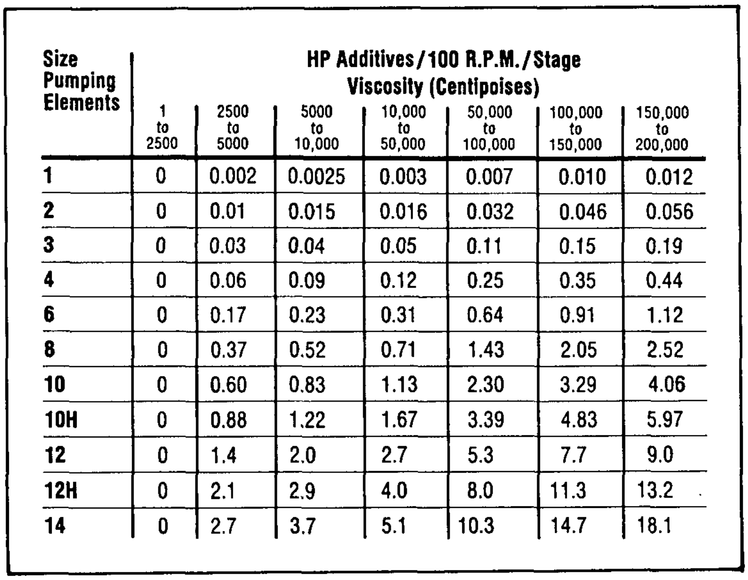


a) Characteristic curves for Gorman-Rupp centrifugal



Capacities (GPM)		100.		125.		150.		200.		250.		350.		450.	
Pump Model	Pressure (PSIG)	RPM	HP	RPM	HP	RPM	HP	RPM	HP	RPM	HP	RPM	HP	RPM	HP
1L12H	0	155	5	190	5	230	7½	305	7½	385	10	535	15		
	40	180	5	225	7½	260	7½	335	10	410	15	565	15		
	75	260	10	305	15	340	15	415	20	490	20	—	—		
2L12H	0	155	7½	190	10	230	10	305	15	385	20	535	25		
	80	180	10	225	10	260	15	335	15	410	20	565	25		
	150	260	20	305	25	340	25	415	30	490	40	—	—		
1L14	0	120	5	150	7½	180	7½	240	10	300	10	415	15	535	20
	40	150	7½	165	7½	210	10	255	10	330	15	450	20	570	25
	75	200	15	190	15	260	15	280	20	380	25	500	30	—	—

b) Tabular presentation for Moyno "progressing cavity"



Size Pumping Elements	HP Additives/100 R.P.M./Stage Viscosity (Centipoises)						
	1 to 2500	2500 to 5000	5000 to 10,000	10,000 to 50,000	50,000 to 100,000	100,000 to 150,000	150,000 to 200,000
1	0	0.002	0.0025	0.003	0.007	0.010	0.012
2	0	0.01	0.015	0.016	0.032	0.046	0.056
3	0	0.03	0.04	0.05	0.11	0.15	0.19
4	0	0.06	0.09	0.12	0.25	0.35	0.44
6	0	0.17	0.23	0.31	0.64	0.91	1.12
8	0	0.37	0.52	0.71	1.43	2.05	2.52
10	0	0.60	0.83	1.13	2.30	3.29	4.06
10H	0	0.88	1.22	1.67	3.39	4.83	5.97
12	0	1.4	2.0	2.7	5.3	7.7	9.0
12H	0	2.1	2.9	4.0	8.0	11.3	13.2
14	0	2.7	3.7	5.1	10.3	14.7	18.1

c) Viscosity correction factors for Moyno units

Fig.2 - Typical presentations of performance data

Finally, a spill cleanup pump should be judged on its ease of handling, ease of repair, and operational safety. Many positive displacement pumps, for example, have check valves which, situated up and downstream of the pumping chamber, rely on gravity to close them on each stroke. If the pump is not mounted upright, the check valves will not seat properly. This is a constraint which should be avoided in pump selection or compensated for in the design of the rest of the pumping system.

In this program, 11 common pumps were operated in the laboratory in a test loop designed to represent some of the demands of a spill cleanup situation. Three fluids were pumped, and the performance of the pumps was evaluated in terms of both the functional and dysfunctional criteria.

2 PRINCIPAL FINDINGS AND RECOMMENDATIONS

2.1 Principal Findings

It is unlikely that the "best possible" pump configuration for spill cleanup was studied in these tests. Undoubtedly better variants or different pumping concepts could be proposed for study. Nevertheless, these test observations provide both general inferences and specific guidance with reference to the requirements discussed in Section 1, "Introduction". The laboratory test findings appear as Table 1; conclusions and recommendations complete the section.

2.1.1 Head and capacity. Two centrifugal pumps (the Monarch and the Gorman Rupp 12B-2) had difficulty establishing a flow at 5.8 m total head. Otherwise, all the pumps tested were satisfactory in terms of head developed and delivery rate. The Spate, in fact, had to be throttled as it exceeded the capacity of our rate measuring system.

It is important to note that not all units delivered a steady stream. The diaphragm pumps, Gorman Rupp 3D, Homelite 111DP3-1 and Sandpiper, delivered a pulsing flow. In most transfer pumping operations this is not a serious problem, but some skimmers (e.g. the SLURP) require steady, gentle offloading, and diaphragm pumps would not be suitable. The Sandpiper is a double-acting diaphragm design which delivered smaller, faster pulses, better approximating a smooth flow. Milgram and Griffiths (Ref. 4) have discussed such double-acting designs. The Blackmer rotary pump delivered similar small, fast pulses.

Some centrifugal pumps showed serious capacity reduction in pumping higher viscosity materials. The Homelite 121TP2-1 centrifugal maintained similar pumping rates when presented with both crude and lubricating oil, but the Gorman Rupp and Monarch centrifugals were seriously affected. The Monarch could not pump the bunker fuel with which it was tested, despite flooded suction.

The Spate (a non-centrifugal hydrodynamic design) and the positive displacement pumps were less affected by viscosity. This fact led to their selection by previous authors (e.g. Refs. 3,4) in the design of many skimming systems.

2.1.2 Suction-lift and self-priming. The centrifugal pumps tested were preselected for their self-priming ability. All were equipped with a priming chamber to

TABLE 1 PERFORMANCE SUMMARY

	Viscosity Tolerance	Lift & Priming	Emulsion Formation	Trash Tolerance	Cold Tolerance	Ease of Repair	Ease of Handling	Comments
Positive Displacement								
Blackmer	G	P	G	P	P	A	P	
Gorman Rupp Diaphragm	G	G	G	A	P	A	G	Surging Flow
Homelite Diaphragm	G	G	G	A	P	A	A	Surging Flow
Megator	G	G	A	P	G	G	G	
Moyno	G	G	G	P	A	P	P	
Rotoking	G	A	A	P	P	G	P	
Sandpiper	G	G	G	A	P	A	P	Compressor Required
Hydrodynamic								
Gorman Rupp Centrifugal	A	P	P	G	G	G	G	
Homelite Centrifugal	G	G	P	A	A	A	G	
Monarch	P	P	P	G	A	P	A	Inexpensive
Spate	G	G	P	P	A	A	A	Hose Fittings

Key: G = Good, A = Acceptable, P = Poor

"pump" air from the feed line by suspending it as bubbles in the pumped fluid. Through 1 m of suction-lift, the Homelite centrifugal self-primed promptly, but the Gorman Rupp and Monarch centrifugals had difficulty when pumping lubricating oil. The Spate self-primed easily.

Positive displacement pumps, with their valves or close tolerances, draw a vacuum in the feed line by pumping air. All of the positive displacement designs evaluated in this test self-primed effectively except the Blackmer which operated with difficulty at low speed. Uchida, Takeshita and Seike (Ref. 3) report self-priming difficulties with a diaphragm pump equipped with ball-type check valves. All diaphragm pumps tested in this program had flap valves and difficulties were not encountered.

The suction-lift results correspond with these observations. Each pump was tested under two conditions of equivalent total head where in one case the suction was flooded, while in the other the total head included about 2 m of suction-lift. The Blackmer, Gorman Rupp 12B-2 and Monarch pumps had subtantially reduced delivery rates in the suction-lift condition. The other pumps showed slight reductions or maintained the pumping rate.

On the basis of suction-lift and self-priming, it is possible to select an acceptable hydrodynamic pump (e.g. the Spate) or even an acceptable centrifugal design (e.g. the Homelite) but positive displacement pumps in general gave superior performance.

2.1.3 Emulsification. The emulsifying tendencies of the various designs were not studied per se, but the temperature and viscosity of the pumped fluid was measured every 5-10 minutes throughout a 60-90 minute series of tests. With the fluid initially at room temperature, any heating or thinning of the liquid was attributed to shear in the pump which would tend to emulsify oil/water mixtures. The total oil volume was about 91 ℓ (20 gal); therefore, the total oil inventory was circulated at least once per minute in most tests.

The centrifugal pumps caused substantial heating in the fluid. Some rotary positive displacement designs caused slight heating, while the diaphragm (positive displacement) pumps, the Moyno and Blackmer, caused the least heating. This agrees with more detailed studies that have been reported by others (Refs. 5, 6) using oil/water mixtures. The Spate was run at low flow rates and showed no heating, although it had previously displayed emulsifying tendencies (Ref. 6).

2.1.4 Solids handling. The solids capacity of each pump was not tested, but was evaluated on the basis of manufacturer's claims and the pump design. The Blackmer and Rotoking are rated for clean feed only, and this restriction is typical of many rotating positive displacement pumps. The Spate and Megator are designed to pass particles of sand, while the Moyno handles solids to 0.4". The diaphragm and centrifugal designs are the only ones claimed to handle substantial solids. The centrifugal designs will pass stones, weed and most bodies which pass through the suction line. The diaphragm pumps can tear a diaphragm on large stones, and long items (e.g. a pencil) can jam the check valves and stop the flow. Of the pumps tested, only the centrifugals could be installed with no strainer in the suction. The only positive displacement designs tolerant of significant solids were the Moyno and the diaphragm pumps.

2.1.5 **Cold-weather performance.** The suitability of each pump for cold-weather use was estimated on two bases. The more important basis was the ease with which the pump was drained for overnight storage. This operation was facilitated by the accessibility of the fill and drain plugs; the design of the latter permits complete drainage. A secondary basis was the ease with which the pump could be operated using insulated rubber mittens. Both factors were estimated on the basis of warm-weather laboratory operation.

The centrifugal pumps were generally better designed from these points of view. The Blackmer, Moyno and Rotoking appeared to be designed primarily for plant use with little regard for drainage at night. The others were better designed for draining, but it was thought that the flap valves on the diaphragm pumps would likely ice up even after draining. Only the centrifugals, the Spate and the Megator seemed well designed from the cold-weather point of view. All are portable pumps designed for construction and mining applications.

2.1.6 **Ease of repair and handling.** As discussed above, certain of the pumps were explicitly designed for mobile field use. The plant process pumps - the Rotoking, Moyno and Blackmer - were deemed to be less satisfactory in this regard. The Sandpiper air-driven pump was also felt to be inconvenient for spill cleanup use in light of its requirement for compressed air.

Throughout testing of each pump, various observations were recorded with respect to design features which contributed to operational ease.

2.1.7 **Composite evaluation.** With respect to such items as viscosity, suction and self-priming, some pumps of each type perform well, but when emulsification is considered, positive displacement designs demonstrate their ability in terms of spill cleanup application.

Many of the positive displacement units tested were not primarily designed for field use; only the Megator and the diaphragm pumps were well designed from this point of view. The Megator is limited in its solids-handling capacity, while the check valves of diaphragm pumps are known to block with solids such as weeds and ice (Ref. 3). In addition, the diaphragm pumps deliver a pulsing flow.

No ideal oil spill utility pump was identified in these tests, but the results do focus attention on design-types of potential interest. The ideal pump will be of a semi-positive displacement design so as to provide positive suction yet accommodate solids in the flow. The diaphragm designs show promise, but their valves require study to minimize the possibility of blockage by debris or cold-weather malfunctions. In addition, strainer design requires closer study to identify reliable self-flushing strainers for use in oil spill situations.

2.2 Conclusions

1. Positive displacement designs are the pumps best suited to oil spill cleanup applications.

2. Positive displacement pumps designed for field use should normally be selected in designing spill cleanup systems.

3. Multi-chambered semi-positive displacement designs are preferable to single-chambered units.

4. Of the pumps tested, the Megator L150 and Gorman Rupp 3D-BKND were best suited for spill cleanup.

5. None of the pumps tested in this program completely met the requirements of oil spill cleanup.

6. Pumps or pump variants are available which will perform better than any pump studied in this program.

2.3 Recommendations

1. A study should be pursued to identify pumps or pump variants that will outperform any particular unit tested in this program. Further testing is probably not required at this stage. Following the general principles developed during this study, preferable designs can be identified through study of catalogue options and discussions with manufacturers.

2. Starting with the performance data from this study, the total strainer-hose-pump-control-receiver system should be examined. Proper upstream and downstream equipment can often compensate for the defects of an imperfect pump.

3. Further study should focus on diaphragm pumps and the design details offered by various manufacturers.

3 TEST PROCEDURE

3.1 General

A test loop was assembled in a covered but unheated warehouse in the Port of Montreal. The functional performance of each pump was evaluated by pumping fluids of different viscosity through various conditions of suction and discharge head and by observing the flow rates. The tests provided hands-on experience and allowed assessment of each design with respect to the dysfunctional criteria.

Figure 3 shows the test apparatus, while Figure 4 displays the apparatus in operation; two parallel versions of Figure 3 are visible in the photographs of Figure 4. Each unit was tested with a separate fluid.

Suction-lift, measured as the distance between the level in the feed drum and the pump centerline, was varied by raising and lowering the pump on a chain hoist. Discharge head was varied by inserting the discharge hose into the various arms of the downspout, and this was measured from the high point of the discharge hose to the pump centerline.

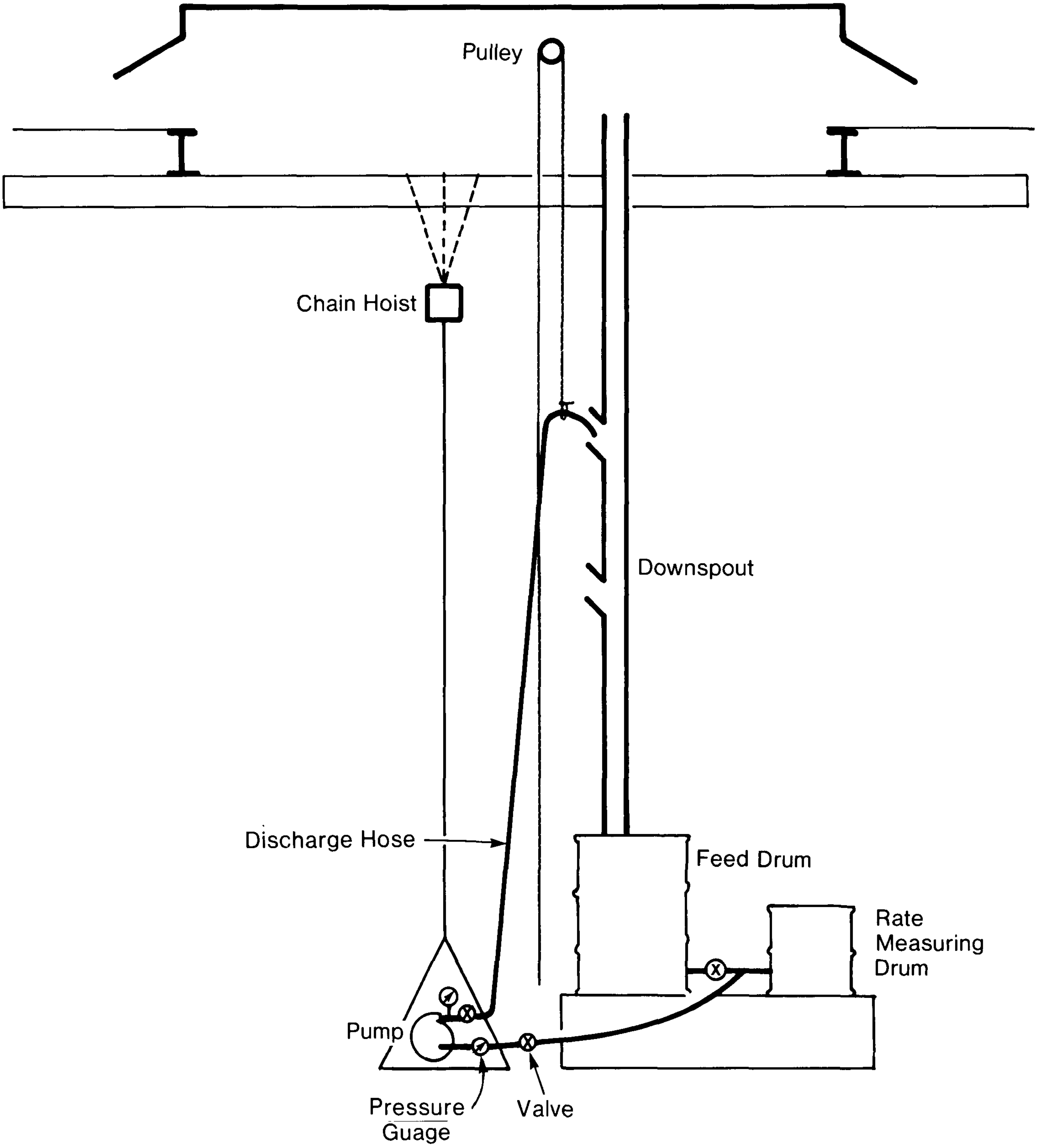
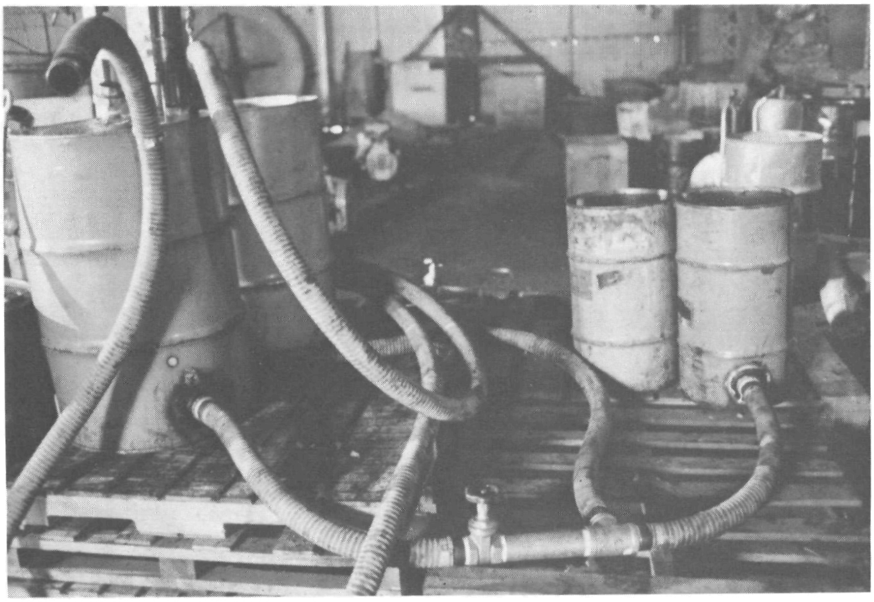


Fig.3 - The Test Loop



a) Feed and Rate-measuring Drums

b) Downspout with Sidearms

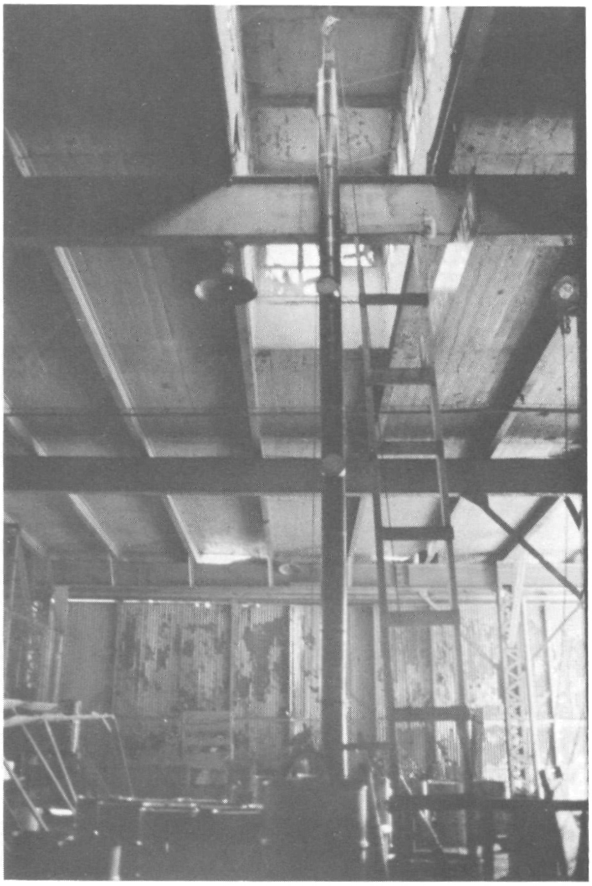


Fig.4 - The Test Apparatus

Once the flow in a test had been well established, the delivery rate was measured by valving off the main feed drum and drawing exclusively from the small drum. A level gauge was a fixed to the inner wall of the drum and the drop in level was timed with a stopwatch.

Pressures were recorded at the pump suction and discharge. The accessibility of rotating parts on some pumps enabled rpm measurements by tachometer. This was not the case, however, with 5 of the 11 pumps tested. Near the end of each test, oil viscosity and temperature were measured with a Zahn viscometer and glass thermometer in the oil reservoir.

Table 2 presents the test conditions applied to each pump. The actual heads were dependent upon the centerline height of each pump and were measured before each run. Under test E, a self-priming test, the system was pumped empty by closing the valve at the feed drum, and then the time was recorded from the moment the valve was opened until the flow emerged from the downspout.

TABLE 2 TEST CONDITIONS

TEST	DISCHARGE CONDITIONS (Placing of Discharge Hose)	SUCTION CONDITION (Pump Centerline Relative to Level in Drum)	COMMENTS
A	Hole 1	Pump on Floor	
B	Top	Pump on Floor	
C	Direct to Drum	0	
D	Hole 1	0	Feed line pumped dry at end of test
E	Hole 2	+ 1 metre	Priming timed to first flow and full rate
F	Hole 2	+ 1 metre	
G	Top	+ 3 metres	

For each pump, the tests described in Table 2 were repeated with two oils of different viscosities: Tia Juana Venezuelan crude oil (31.4 API) and BP Energol 125 lubricating oil (29.0 API). These tests, along with the published curves representative of cold-water service by some of the pumps, provide pressure and flow rate data at two or three different viscosities. The original intention was to conduct tests at two temperatures for the purpose of obtaining additional viscosity values. This proved impractical, however, as the daily temperature range during the test period averaged about 6°C. Instead, additional tests were performed on some of the pumps with a thixotropic No. 6 fuel oil (17 API gravity with a 50°F pour point). These were qualitative tests in which the No. 6 fuel was pumped from one drum to another under flooded suction (20-80 cm head) against 20-80 cm discharge head. Pumping rate was measured by weighing the drums and timing with a stopwatch.

These suction and pressure arrangements were designed to provide a realistic simulation of the physical arrangements typical of spill cleanup operations. The lines were 2" in diameter and fittings were minimized in an effort to reduce frictional losses through the system so that changes in suction and pressure arrangements could be observable in the flow rate data. Table 3 presents average frictional head losses for each pump with each fluid. The array of lines and fittings was identical for all pumps, so variations in these figures are attributable to the flow rate developed by the particular pump and the viscosities measured on that test day. Expressed in centimetres of frictional head loss per centimetre of flow path, these contributions are substantial, but do not overwhelm the effect of changes in suction and discharge arrangements.

TABLE 3 AVERAGE FRICTION LOSSES IN CM OF HEAD PER CM OF HOSE

	FRICTION LOSS	
Pump	Crude Oil	Lubricating Oil
Gorman Rupp Diaphragm	0.11	.35
Gorman Rupp Centrifugal	0.11	0.54
Spate	0.11	0.11
Homelite Diaphragm	0.11	0.49
Homelite Centrifugal	0.22	1.16
Sandpiper	0	0.51
Moyno	0.35	0.05
Blackmer		0.27-0.16
Rotoking	0.11	0.06
Megator	0.40	0.11
Monarch	0	0

3.2 Test Rig Details

For testing purposes, each pump was mounted on a 121 x 183 cm platform 10 cm high suspended by a chain hoist with 3 m lift (see Figure 3).

Suction was bushed to 5.1 cm (2") then connected through a 5.1 cm (2") union, a 5.1 x 10.2 cm (2 x 4") nipple, a 5.1 cm (2") gate valve, a 5.1 x 15.2 cm (2 x 6") nipple, the run of a 5.1 x 5.1 x 5.1 cm (2 x 2 x 2") tee, a hose nipple, 3.44 m of 5.1 cm (2") suction hose, and another hose nipple to the arm of a 5.1 x 5.1 x 5.1 cm (2 x 2 x 2") tee. Feed could then be taken from either the main feed drum through a 5.1 x 22.9 cm (2 x 9") nipple, a 5.1 cm (2") gate valve, a hose nipple and 93 cm of 5.1 cm (2") hose from a coupling welded at its midpoint into the wall of the drum, or from a smaller rate-measuring drum.

The main feed drum was a standard 170 ℓ (45 gal.) drum 59 x 88 cm modified by cutting off the top and welding in the bottom outlet. The alternate feed source was a smaller drum which was also run from the tee in the feed line with 93 cm of 5.1 cm (2") suction hose, terminated with hose nipples to enter the drum through a 5.1 cm (2") coupling. This branch was not valved, however, and the rate drum was only 36 cm in diameter by 65 cm high. This smaller drum was used for measuring the pumping rate as discussed in Section 3. For this purpose, a level gauge was affixed up the inner wall of the drum. This consisted of a 65 cm length of 3 cm dowel with nails protruding every 4 cm.

The pump discharge was bushed to 5.1 cm (2") and connected through a 5.1 cm (2") union, a 5.1 x 28 cm (2 x 11") nipple, the run of a 5.1 cm (2") tee, another 5.1 x 28 cm (2 x 11") nipple, a 5.1 cm (2") gate valve and a 5.1 cm (2") hose nipple to 6.7 m of 5.1 cm (2") suction hose terminating in an open hose nipple.

The feed drum, open-topped as previously described, was mounted on a stack of 4 pallets so that its bottom was 48 cm off the floor. A 5.4 m length of 15 cm stovepipe was hung vertically above the feed drum. The stovepipe had side branches 3.2 m and 4.2 m above the floor. The discharge hose was suspended by a pulley with its open end in one of these side branches. The discharge was directed by the stovepipe back into the feed drum.

4 TEST RESULTS

Earlier in the report, Table 1 summarizes the results for each pump design; this section provides more detailed information on individual pumps.

4.1 Hydrodynamic Designs

Hydrodynamic pumps are simple and rugged with few precision clearances; they pass debris well and are relatively inexpensive.

4.1.1 Homelite 121TP2-1 Trash Pump - Homelite-Terry Division, Textron Inc., Pointe Claire, Quebec

Homelite's smallest centrifugal, a "construction pump", is advertised for its light weight [33.4 kg (74 lbs)] and ability to handle "muck, mud, and high percentages of solids" though not solid debris. It is ruggedly constructed, has two handles for lifting and is spring mounted on a pair of steel skids. It comes with 5.1 cm (2") female pipefittings and is rated (for cold water) at 662 ℓ/min (175 gpm) with 8.5 m (28') total lift or 39 m (123') total head.

The pump is driven by a 2237 watt (3 hp) Briggs & Stratton gasoline motor with spring-loaded pull-cord starting. The total unit measures 50 x 40 cm x 45 cm high (20 x 25 x 40 for the pump alone) and weighs 36.4 kg (80 lbs) fueled and primed. The pump and drive are direct-coupled with no clutch, so the only control is achieved by the engine speed or alternatively, by throttling the suction. This is inconvenient for small stop-and-start pumping jobs.

The pump, however, seems well designed for cleaning and repair. The drain plug and priming cap are both accessible and easy to fill and empty. This would be essential in cold weather as the pump retains a charge for self-priming. The pump could be run with gloved hands, although the engine throttle -- the only control -- would be a bit difficult to manipulate. The gasoline engine would, of course, be a significant hazard at many spills, and no option is offered.

Table 4 presents the test data on the Homelite centrifugal. Significant results are the substantial pumping rates developed by this relatively small pump and the fact that the rates were maintained with both crude and lubricating oil. This constancy indicates that the pump's performance is relatively insensitive to fluid viscosity. The tests are tabulated in the order in which they were performed. The temperature data thus show that this pump does substantial shearing work in the fluid. With oil/water mixtures, this pump would form emulsions.

4.1.2 Monarch BSG 2-Inch Centrifugal - Monarch Industries, Winnipeg, Manitoba

The Monarch is small (36 x 41 cm x 39 cm high) and light [30.7 kg (67.5 lbs) with a prime] and is of one piece cast iron (or bronze) construction. The pump is widely sold in hardware stores for farm and cottage use and is known to be relatively inexpensive. Monarch does not publish head and capacity data, but claims self-priming and suction-lifts to 7.6 m (25').

The pump comes mounted on two small skids of channel stock and has a single, small lifting handle. Both base and handle are adequate for the pump alone, but the pump has 5.1 cm (2") female fittings, and once any substantial 5.1 cm (2") hose is attached, neither the base nor handle is very serviceable. The pump is secured directly to its base, and unless bolted down or restrained by the piping, will "walk" across a smooth floor.

The Monarch, driven by a 2237 watt (3 hp) Briggs & Stratton 4-cycle gasoline engine at 3600 rpm, is also available with electric drive. The pump and motor are directly coupled with no clutch or speed control, thus eliminating the unit's use for intermittent operation due to necessary stop-and-start procedures. The engine supplied, however, does have a spring-loaded cord starter. The self-adjusting mechanical seal must not be run dry.

TABLE 4 TEST DATA - HOMELITE CENTRIFUGAL

Crude Test	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
B	+38	+614	576	46	27		68.2	4	11
A	+38	+300	262	30	31		85.7	6	8
C	0	+97	97	32	34	Not Measurable	111.1	8	7
D	0	+262	262	30	35		73.2	7	8
E	-100	+258	358	26	38		96.8	8	9
F	-100	+258	358				(10.0 seconds to prime)		
G	-202	+374	576	26	40		75	10	8
Lube Test									
B	+41	+614	573	101	33		40.0	2	7
A	+41	+300	259	90	35		71.4	5	7
C	0	+108	108	90	38		85.7	9	6
D	0	+259	259	68	40.5		96.8	7	8
E	-100	+255	355	59	42		93.8	9	6
F	-100	+255	355	59	42		(10.8 seconds to prime)		
G	-195	+378	573	70	39		73.2	9.5	7

During operation the pump will pass substantial debris without causing damage. The usual necessity for line removal does permit easy cleaning. However, the process, which is essential in cold weather because the pump retains a priming charge, is carried out with ease due to accessible drain and fill plugs. As it has no controls, the pump was easily operated with gloved hands.

The gasoline or standard electric motors offered with this pump make its operation hazardous in many spill situations. The pump is available without drive, but bronze construction for saltwater exposure is the only feature which would make this pump applicable for use in oil spill cleanup.

Table 5 presents the Monarch test results. Comparing tests B and G with each fluid highlights the effect of suction-lift on the performance of each pump. As can be seen, total heads were the same, but in the "G" tests, the total head was largely suction-lift and the pump was barely able to maintain a flow. This suction performance makes the Monarch unsuitable for most spill cleanup applications.

Table 5 also shows a severe viscosity effect on the pump's delivery rate. The pump would not move Bunker C at 15°C despite flooded suction.

The temperature data of Table 5 show that the Monarch does substantial shearing work on the fluid. With an oil/water mixture, emulsion would result.

Overall, the Monarch is not well suited to spill cleanup service.

4.1.3 Gorman Rupp 12B-2 Centrifugal Trash Pump - Gorman Rupp Canada Ltd., St. Thomas, Ontario

This pump is designed and advertised for handling solids to 3.8 cm (1.5"). Figure 5 shows the dogged cover designed for quick access and cleaning. Mounted on wheels with a towing handling, the pump is designed for construction sites; it is widely rented and has an extensive distribution and service network. The fittings are 5.1 cm (2") female, with a flap valve on the suction side which might freeze shut. Mounted in this way, the unit measures 63 x 58 cm x 70 cm high (35 x 25 x 51 for the pump itself) and weighs 91 kg (200 lbs). In addition to the towing handle, the unit has a single, central lifting eye.

The unit tested was powered by a 1491 watt (2 hp) Wisconsin gasoline engine which is also designed to run on diesel or kerosene. This could be handy in cleaning up spills of light products. In fact, this engine was observed to burn a lot of fuel in comparison with others tested; however, quantitative measurements were not made. The motor was also difficult to start with the rope starter. (Gorman Rupp Canada Ltd. offers two other gasoline engines.) The motor and pump are direct-coupled with no clutch so that the throttle is the only control. The pump is designed to run between 1150 and 2600 rpm on cold water, delivering 150-250 gpm at the heads tested.

TABLE 5 TEST DATA - MONARCH

Crude Test	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
A	+35	+305	270	25	27		32	0	3.5
B	+35	+619	584	21	29.5		16.6	0	7.5
C	+5	+155	150	12	30		30.8	0	3.5
D	+5	+275	270	17	30		30	1.5	5
E	-95	+266	361	16	31	Not Measurable	4.8	2.5	4
F	0	+371	371	17	31		(4 seconds to self-prime)		
G	-196	+388	584	30			9.1	6	5
G	-196	+388	584	30			12	6	5

Initially the pump couldn't start flow under condition G; 4 was therefore started on the ground and raised while in operation. Then, after 5 minutes, G was repeated starting the test at top; this time the pump worked, but only after a delay of 3 minutes.

Lube Test	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
A	+52	+305	253	180	22		13	1	6.5
B	+52	+619	567	171	24.5		7.3	1	7.5
C	+5	+156	151	157	25.5		20.9	2	3
D	+5	+258	253	154	25.5		11.2	2	6
E	-95	+254	349	147	26		5.6	3	5
F	-95	+254	349	134	26		(Would not self-prime)		
G	-177	+385	562	121	29		1.6*	2	5.5
Bunker Test					15		(No flow)		

*Took 5 minutes to build up to this flow rate, although accelerating the motor could increase it ot 5.5 USGPM

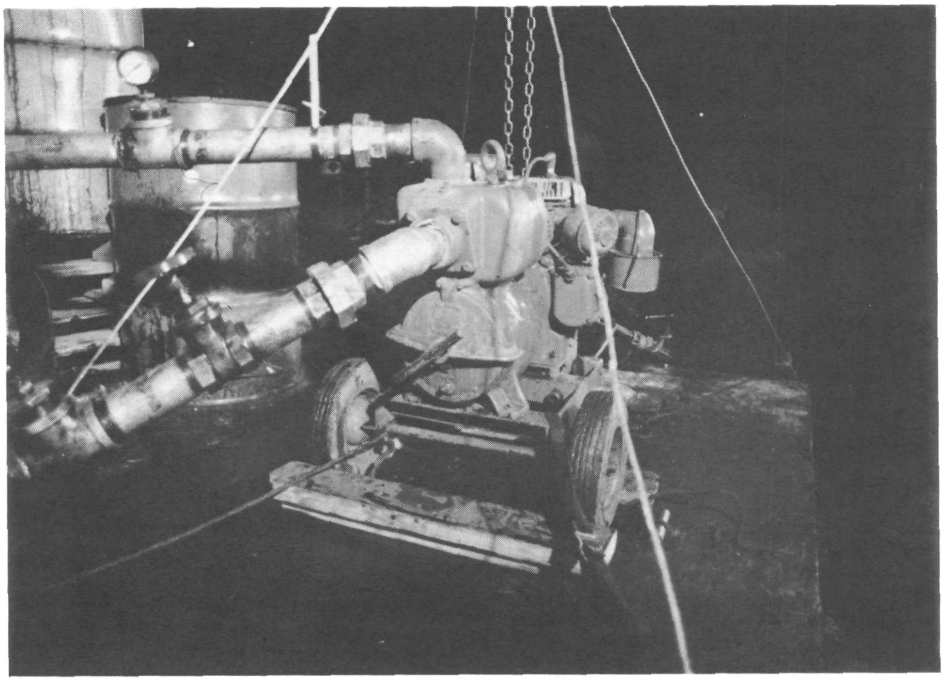


Fig.5 - The GORMAN RUPP 12B-2

The unit retains a charge for self-priming, but is well designed for easy draining and refilling. As mentioned above, the flap valve at the suction might freeze in cold weather. The design allows for easy maintainance and gloved-hand operation. The gasoline engine is a potential hazard at many spills, and the unit tested dripped gas from the carburetor. The fuel tank is very exposed to accidental damage in slinging the unit by the lifting eye. Finally, the hand-wound cord starter is an unprotected rotating hazard when the pump is running.

Table 6 shows that the very useful solids-handling design of this pump leads to a compromise of viscosity and self-priming performance. The 5 to 55 USGPM developed in the tests is well below the 114-208 ℓ/min (150-250 USGPM) rating on cold water. Tests B and G show a sharp fall in rate beyond 2 m suction-lift, and with lubricating oil the pump would not self-prime. The viscosities of lube tests A-E show that the pump is shearing the liquid, and this would form emulsion during the handling of oil/water mixtures.

TABLE 6 TEST DATA - GORMAN RUPP CENTRIFUGAL

Lube Test	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
A	+7	+270	263	185	23.5	2082	37.5	3	6
B	+7	+584	577	170	24	2082	30	3.5	9
C	0	-	-	159	26	2082	54.5	1.5	2
D	0	+263	263	133	29	2046	50	31.47	6
E	-100	+259	359	94	31	2082	44.1	2.5	3.5
F			(Would not self-prime in 3 minutes)						
G	-239	+338	577	197	26	2212	4.9	8	6
Crude Test									
A	+7*	+270	263	30	28	1934	40	2	4
A	+7	+270	263	30	28	2360	38.7	6	4
B	+7	+584	577	28	30	2034	31.2	1.5	7.5
C	0	+76.5	76.5	52	19.8	2082	54.5	1.96	2
D	0	+264	264	41	22	1956	55.8	1.96	4.75
E	-100	+260	360	34	25.5	2082	42.9	2.46	4.5
F			(82 seconds to self-prime)						
G	-228	+350	578	-	-	1863	25	3.44	5

* Suction was throttled for all crude tests

Although the Gorman Rupp centrifugal is a well-designed pump, it lacks high viscosity and suction performance and as mentioned previously, the engine supplied would be hazardous at many spill sites.

4.1.4 Spate 3B - William Selwood Ltd., Chandlers Ford, Eastleigh, Hants, U.K.

The Spate uses a hydrodynamic operating principle and although not a centrifugal pump, shares the simple, rugged design of the centrifugals with few precision clearances. It is distributed in Canada by John Brooks of LaSalle, Quebec, but is not widely known. The pump is used by British Petroleum with their skimmers and by the Canadian Cost Guard for spill cleanup. It will "pump" air well enough to inflate tires, a rubber boat or a boom.

The pump and engine come as a unit mounted on wheels with a towing handle; no other lifting point is provided. The unit measures 58 x 83 cm x 77 cm high and weighs 107 kg (235 lbs) with one-half of a tank of fuel. The fittings are 7.6 cm (3") hose nipples, and this can be a source of problems. Since normal suction-grade hose is too stiff to force over the nipples, a short length of soft hose is required to bridge the pump nipples and the nipples leading into the rest of the system. On the suction side, this hose must be just the right length, otherwise it will collapse during operation. These adaptor lengths must be kept with the pump, as suitable 3" hose is not widely available. Because either the pump or the hoses may be moved frequently in a cleanup situation, care must be exercised to prevent the friction-fitted hoses from being pulled off.

The 3B is rated at 533 ℓ/min (141 USGPM) against 40 m (130') total head. The operating principle of the pump seems to be based on the inertia of flowing fluid as is the case with a centrifugal pump. In contrast to a rotor, the Spate uses an oscillating rubber impellor which drives the fluid on the forward stroke, but bends and allows the fluid to continue flowing on the return stroke. This impellor oscillates at the full motor speed (1500-3600 rpm) but inertial flow during the return stroke leads to a flow rate greater than twice the volume displaced by the impellor.

The unit tested employed a Petter AC1 diesel engine (4847 watts (6.5 bhp) at 3600 rpm). The unit had no clutch - a drawback in intermittent operations; therefore, the only control was the throttle, which had to be tied in place because of movement during operations. The Petter has a starting crank and a 100-v electric starter - a convenience in cold weather as hand cranking is difficult when the engine is cold. In reality, the pump is too light for cranking and tends to "walk" when this start-up method is employed. Furthermore, one could easily foresee the loss, during a spill situation, of the starting crank - an item difficult to replace.

The manufacturer does not recommend use of the pump below -20°C on the basis of the flexibility required in the impellor. In fact, difficulties could be expected before the temperature would drop this low. The body has drain taps and does not require refilling to prime, but any ice forming on the rubber flaps will stop the flow. Any "long" debris, such as a 1 x 7 cm twig will have the same effect. The engine controls are also small and hard to reach with a gloved hand. The stop switch is adjacent to the muffler and this represents a safety problem.

The pump is well designed and constructed. The most frequent repair envisaged is the changing the rubber annulli; the design permits easy replacement without disconnection of the lines.

The data of Table 7 support claims that the Spate can handle high viscosities, therefore meriting its classification with the centrifugals. At about half speed, the Spate pumped crude oil at 114-190 ℓ/min (30-50 gpm) against any head. It pumped Bunker C at 13.61 kg/min and self-primed promptly.

The data show little tendency of the Spate to shear the fluid. Nevertheless, its high-speed reciprocating action should have significant emulsifying effects; this was observed in field use of the pump with oil/water mixtures (Ref. 7).

The Spate is well suited for high viscosity and high suction-lift cleanup applications. The piping arrangements require some preplanning, and the pump must be protected from debris; otherwise, the only serious drawback is emulsion formation.

4.2 Diaphragm Pumps

Diaphragm pumps are positive displacement designs in which a flexible membrane enlarges and constricts a cavity thereby forcing fluid in and out through check valves much as in the heart. Debris can puncture the diaphragm or block the valves, and the diaphragm requires occasional replacement. A simple diaphragm pump produces a "heart beat" in the flow, although double-acting designs develop a much more uniform flow.

4.2.1 Homelite 111DP3-1 - Homelite-Terry Division, Textron Canada Ltd., Pointe Claire, Quebec

This is a "construction" pump designed principally for seepage control. It is claimed to pump "mud, sludge, waste, solids and abrasive sand and silt". Widely rented, this ruggedly built device is mounted on wheels with a handle and can be slung from the base. It has 7.6 cm (3") female fittings, weighs 132 kg (290 lbs) and is rated at 303 ℓ/min (80 gpm) at 7.6 m (25') lift or 15.2 m (50') total head. Both suction and discharge have flap valves which are subject to blockage by debris or freezing. The unit measures 88 cm x 100 cm x 54 cm high.

The pump was powered by a CGE 1119 watt (1.5 hp) 1725 rpm electric motor. Although convenient for testing, this would be impractical in most spill situations. The standard Briggs & Stratton engine is direct-coupled without a clutch and is therefore inconvenient for intermittent pumping. In the electric drive configuration, the pump has no controls.

A large, easily filled priming chamber is fitted at the inlet. The pump, however, has no drain plug and the priming fluid might therefore be subject to freezing. Because the liquid in the priming chamber circulates little, it is possible for ice up to occur even during operation. The inlet and outlet flap valves would also tend to ice up even if the pump were upended and drained. Access for maintenance is good, but a spare for replacing the diaphragm must be stocked with the pump.

TABLE 7 TEST DATA - SPATE

Lube Test	Suction Head (cm)*	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
B	+31	+597	566	268	14		6.9	0	11
A	+31	+281	250	268	13		32.0	0	7.5
D	0	+252	252	268	14	Running About One-half Speed	4.3	3	7.5
C	0	+70.5	70.5	268	15		7.9	2	6
F	-100	+246	346	(8 seconds to prime - not throttled)					
E	-100	+246	346	268	14		1.5	5	7.5
G	-199	+367	566	268	14		8.9	9	9
Crude Test									
B	+25	+597	572	113			168	1.5	11.2
B	+20	+597	577	20	15.5		50	1	10.5
A	+20	+283	263	25	17		45/50	1	6.5
D	0	+263	263	25	15		45	1.5	6.5
C	0	+71	71	20	16		33	2.5	4
E	-100	+259	359	25	15		37.5	0	6.5
F	-100	+259	359	(13 seconds to prime)					
Bunker Test	+34	+88	+54		14		29,31.7 lb/min		

*The suction side was throttled for the lube tests as the pump exceeded the capacity of the rate measuring system at this viscosity

Surging in the flow made the pump difficult to use in this experimental setup; in the field it would violently rock a small dinghy or skimmer. To smooth the flow, the suction was throttled in all experiments; this did not present a serious problem, as is shown in Table 8, i.e. the pump delivered 132.5-170.3 ℓ/min (35-45 USGPM) with both oils. Self-priming was prompt and the constricting action did not tend to shear the liquid.

The Homelite diaphragm design moved the fluid well without emulsification. Its deficiencies are its gasoline (or electric) drive and its susceptibility to debris blockage and freeze-up.

4.2.2 Gorman Rupp 3D Diaphragm Pump - Gorman Rupp Canada Ltd., St. Thomas, Ontario

The Gorman Rupp 7.6 cm (3") diaphragm pump is mounted on wheels with a towing handle and a single central lifting eye. Supported by an extensive dealer and service network, this widely rented "construction" pump is a single-acting diaphragm driven by a piston with flap-style check valves. The unit measures 72.4 cm x 146 cm x 63.5 cm high (72.4 cm x 50.8 cm x 63.5 cm for the pump alone) weighs 95.5 kg (210 lbs) has 7.6 cm (3") female pipe fittings and is rated to deliver 208-303 ℓ/min (55-80 USGPM) of cold water.

The pump is available alone, but the unit tested was coupled to a Wisconsin BKND gasoline engine. With a hand-wound rope starter, this drive exposes a spinning wheel in operation and presents a fire hazard in many spill cleanup situations. The unit has no clutch, so intermittent pumping involves restarting the engine. The only control is the engine throttle.

By design, the pumping chamber sits directly on the ground; on ice it would have to be set on an insulating block of wood. In any case, cold weather would likely reveal the pump's weakest point as the flap valves and suction accumulator would tend to build up ice and thereby stop the flow. The pump does, however, have a drain plug.

The pump is well designed for diaphragm replacement, but a cold and oil-resistant spare should be stocked with the unit.

Table 9 shows the results of the test series. The pump was throttled at the suction because of the heavy surging in the flow. Nevertheless, it pumped both fluids easily with a reduction in capacity only for lubricating oil at 5.76 m total head. Suction-lift presented no problem and self-priming was prompt.

The Gorman Rupp diaphragm can move viscous fluids through suction-lift and can self-prime. In certain situations its drawbacks are violent surging flow and cold-weather and debris intolerance.

TABLE 8 TEST DATA-HOMELITE DIAPHRAGM

Crude Test	Suction Head* (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
A	+47	+312	265	57	21		41.7	10	15
B	+47	+626	579	61	21		38.5	8	20
C	0	+79	79	57	21	Not Measurable	41.7	7	1.2
D	0	+265	265	55	21		32.7	7	15
E	-100	+261	361	56	21		34.1	8	14
F	-100	+261	361		(11.8 seconds to self-prime)				
G	-205	+374	579	56	21.5		34.1	8	14
Lube Test									
B	+50	+626	576	172	22		37.5	11	20
A	+50	+312	262	185	22		39.5	10	14
D	0	+262	262	192	22		39.5	10	15
C	0	+76	76	190	22		43.5	12	10
E	-100	+258	358	-	-		38.5	10	13
F	-100	+258	358		(10.3 seconds to self-prime)				
G	-170	+406	576	184	22		38.0	12	18

*Throttled for all runs

TABLE 9 TEST DATA - GORMAN RUPP DIAPHRAGM

Lube Test	Suction Head* (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
A	+46.57	+308.6	262	270	19	2253	27.3	1.5	25
B	+46.57	+622.6	576	257	20	2320	17.3	2	28
C	0	76	76	246	20	2531	16.9	3	20
D	0	+262	262	255	20	2301	28.6	5	25
E	-100	+258	358	250	2.5	2199	24.8	6	22
F	-100	+258	358		(17 seconds to prime)				
G	-239	+337	576	228	21	2273	17.2	8	18
Crude Test									
B	+47.6	+622.6	575	71	21	1901	48	1	27
A	+47.6	+308.6	261	58	21	1849	46.2	2	23
C	0	+71	71	53	21.5	1868	48.4	2	21
D	0	+261	261	53	22	1868	45.5	2	22
E	-100	+257	357	52	22	1914	42.9	3	23
F	-100	+257			(11.1 seconds to prime)				
G	-236	+339	575	53	22.5	1914	42.9	5	23.5

*Throttled for all runs

4.2.3 Sandpiper SA2-A - Warren Rupp Company, Mansfield, Ohio

The Sandpiper is a double-acting diaphragm pump which produced a smoother flow than the other diaphragm designs tested. Because it is driven by compressed air, this pump is limited to applications where it can be connected to a compressor. On a vessel more than one pump could be run from the same compressor, but this quickly gets out of hand in mobile oil skimming operations because a "spaghetti" of air and liquid lines ensues. The Sandpiper can also be utilized as a submersible pump which further increases its versatility.

The pump, without the compressor, weighed 38.6 kg (85 lbs) empty and measured 54 x 33 x 51 cm high. Its cold-water pumping capacity rates at 114-530 ℓ/min (30-140 USGPM) depending on the air supply. Fittings are 5.1 cm (2") female with a 1.27 cm (1/2") female air connection. It is claimed to pass solids to the full size of the inlet fitting, and the flap valves are hung so that debris will not likely create blockage.

As with other diaphragm pumps, the part most likely to require maintenance would be the diaphragm - an oil and cold-resistant spare should be stocked. Replacement is fairly straightforward and a variety of materials is offered.

The only control is a valve which throttles the air line; this valve can be operated with ease in the cold. Other problems, however, become evident in cold-weather operations; without drain plugs the pump would be difficult to drain completely unless disassembled, and the flap valves would tend to freeze shut.

Table 10 shows that like the other diaphragm pumps, the Sandpiper handled both fluids well and was insensitive to head requirements. Priming was prompt and the pump did not shear the fluid. The double-acting design reduced surging substantially; although the flow was not steady, the surging was acceptably calm for most cleanup applications.

The Sandpiper moves viscous fluids well through suction-lift; however, the air umbilical precludes a very mobile operation. Additionally, precautions against freezing are necessary and in most cases, a mechanical diaphragm design is more suitable.

4.3 Moving Cavity Pumps

4.3.1 Moyno 1L6 - Robbins & Myers, Brantford, Ontario

Figure 6 shows, in cut-away, the Moyno operating principle. As the rotor turns, the progressing cavity, with very little backflow or "slip", develops a positive displacement action. Table 11 presenting the test program data shows that this pump should always be fitted with some relief system to prevent overloads, otherwise it will develop unlimited pressures against a closed discharge. The 1L6 is rated at 178 ℓ/min (47 USGPM) on cold water.

TABLE 10 TEST DATA - SANDPIPER

Crude Test	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
B	+30.3	+609.3	579	53	19		12	2in-2psi	10
A	+30.3	+295.3	265	53	19		14.1	1.5in-1psi	6.8
C	0	+154	154	53	19	Not Measurable	17.8	1in-2psi	3
D	0	+265	265	-	-		14.5	1.5in-2psi	5
E	-100	+261	361	-	-		12.6	4in	7
F	-100						(38 seconds to prime)		
G	-209.3	+370	579	53	19.5		9.4	6in	7
Lube Test									
A	+39.3	+295.3	256	196	22.5		22.9	2in	8
B	+39.3	+609.3	570	205	22.5		16	3in	9.8
G	-200	+370	570	-	-		17	9in	8.5
E	-100	+252	352	-	-		16.2	5.5in	7.5
F	-100	+252	352	-	-		(26 seconds to prime)		
D	0	+256	256	-	-		24	3in	7.5
C	0	+80	80	205	22.5		20	2in	4

TABLE 11 TEST DATA - MOYNO

Lube Test	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
B	+30	+607	577	260	17.5	509	33.3	4	14
A	+30	+293	263	260	18	522	31.9	4	10
C	0	+77	77	251	19	515.1	31.6	4	7
D	0	+263	263	257	-	498	32.3	4	9
E	-100	+259	359	249	-	506.3	31.2	7	10
F	-100	+259	359		(9.6 seconds to self-prime)				
G	-193	+384	577	248	-	486.3	30.6	9	11.5
Crude Test									
B	+33	+607	574	63	18.5	489.4	31.6	1	11
A	+33	+293	260	59	19	483.3	32.6	1	7
D	0	+260	260	59	19.3	504.1	32.6	2	8
C	0	+71	71	61	19.5	508.4	33.7	2	5.5
E	-100	+256	356	59	20	496.6	32.6	3	8.5
F	-100	+256	356		(9.6 seconds to self-prime)				
G	-202	+372	574	59	20.5	515.1	31.2	6	10
Bunker Test					16	364	49 lb/min		

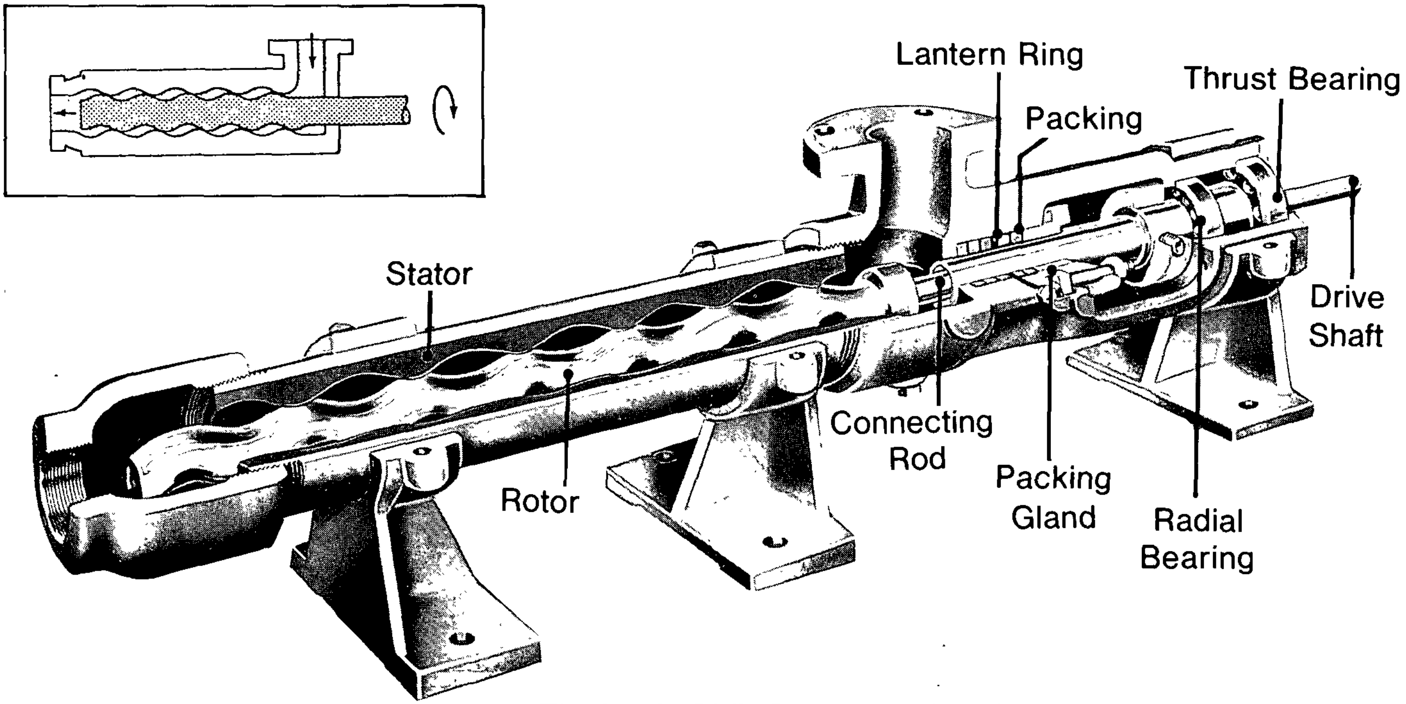


Fig.6 - MOYNO—Principle of Operation

This pump is available in a wide variety of materials and configurations and is designed to handle extremely viscous materials gently. Some models will pass solids up to 2.5 cm (1") in diameter, although the unit tested is rated for only 1 cm (0.4") particles. The flow is steady and without surge.

The pump measures 25 x 102 x 30 cm high and the model tested weighed 82 kg (180 lbs). When mounted with a 2237 watt (3 hp) motor and belt drive, the unit measured 100 x 102 x 35 cm high and weighed 164 kg (360 lbs). The suction is a 7.6 cm (3") flange fitting with a 6.4 cm (2.5") female discharge. The pump is therefore substantially built and not designed with portability in mind. Although it has no lifting eyes, the pump could be slung easily by the body.

In operation, the pump itself has no control points and ease of operation will depend on the prime mover with which is fitted. A gasoline-driven unit is offered, although electric power seems more common. In all cases, repair involves rather elaborate dismantling of the system and an entire replacement pump might have to be kept on hand.

The pump can be completely purged by running it without feed and a drain plug is provided in case of freezing. However, the opening of the drain plug will not drain the entire pump this fact should be borne in mind for cold-weather operations.

Table 12 shows that the pump's delivery rate is unaffected by head or viscosity and that the pump primes easily. The pump did not heat or shear the oil appreciably as the viscosities remained relatively constant.

TABLE 12 TEST DATA - BLACKMER

Crude Test (Low Speed	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
A	+45.4	+303	257.6	14	23.5	107	2.82	2	4
B	+45.4	+617	571.6	25	23.5	88	8.18	0-4	7-12
B	+45.4	+617	571.6	9	22	104	10.91 11.04 10.91	2	5
C	0	+110.5	110.5	21 20	22.5 22.5	114 114	14	1-5	3-7
D	0	+258	258	20	22.4	114	12.5	0-9	3-7
E	-104	+249.5	353.3	20	22.1	105	12	2-8	3-8
F	-104	+249.5	353.3			(Primes in 21 seconds)			
G	-184.15	+387.5	571.6			(Would not prime)			
G	-184.15	+387.5	571.6	20	23.5	96	6.92	2-10	4-8
Lube Test (High Speed)									
A	+56.8	+303	246.2	159	26	166	20.5	2-6	2-7
B	+56.8	+617	560.2	160	26	159	18.9	2-5	4-12
C	0	+147.3	147.3	157	26.2	159	22.0	0-6	0-4
D	0	+246.2	246.2	157	26.2	159	21.2	0-7	1-7
E	-99.1	+243.1	442.2	153	26.5	156	22.0	2-9	2-7
F	-99.1	+243.1	442.2			(Primes in 22 seconds)			
G	-167.66	+392.5	560.2	148	28	156	20	6-8	4-11

TABLE 12 (Cont'd) TEST DATA - BLACKMER

Lube Test (Low Speed	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
G	-167.66	+392.5	560.2	147	27.5	114	12.4	2-7	5-8
B	+56.8	+617	560.2	145	27.8	111	10.5	0-4	4-13
A	+56.8	+303	246.2	145	27.8	114	13.3	0-3	4-7
D	0	+246.2	246.2	145	27.8	114	13.3	2-4	4-7
C	0	+193.0	193.0	-	-	117	11.5	3-6	3 1/2
E	-99	+243.1	342.1	137	28	114	12.6	2-6	4-7
F	-99	+243.1	342.1	(26.5 seconds to prime)				(Failed first time)	
Crude Test (High Speed)									
G	-184.11	+387.5	571.6	20	-	130	12.9	0-10	2-10
B	+45.39	+617	571.6	25	24	129	14.8	0-5	7-11
A	+45.39	+617	257.6	22	24.2	133	24	0-6	4-9
C	0	+35.6	35.6	28	24.4	133	24	0-6	1-6
D	0	+353.6	353.6	22	24.7	133	20.7	0-8	2-7
E	-104.1	+353.6	457.7	23	25	137	16.1	0-9	3-7
F	-104.1	+353.6	457.7	20	25	137	16.1	(18 seconds to prime)	
Bunker Test	+39	+123	+48		16	85	31.4 lb/min		

The Moyno fulfills the primary requirements of effectively moving viscous oil through head and suction-lift, as well as possessing limited trash tolerance. It is not, however, designed for mobile field use, nor is it easily stripped down and repaired under field conditions. Its use would be more effective with a fixed, barge-mounted installation where a proper strainer system could be assured.

4.3.2 Blackmer NPZ - Dover Corporation, Blackmer Pump Division, Grand Rapids, Michigan

Blackmer describes this unit as a "sliding vane" pump when in fact it is a rotary positive displacement device as described in Figure 7 (from the Blackmer catalogue). It has an intergral pressure relief valve and its output is controlled by adjusting the speed of rotation. It is rated at 276 ℓ/min (73 USGPM) on cold water.

The unit tested was assembled by the Societé Technique d'Etudes et Fournitures Industrielles of France and was driven by a Hatz L79 diesel engine. Although the pump itself measured 25 x 25 x 29 cm high, the complete unit was 29 x 107 x 68 cm high. Fittings were 5.1 cm (2") female threaded flanges (non-standard flange configuration). The power train was connected through a clutched transmission and a continuously-variable-speed belt drive. This drive train added substantially to the size and weight of the unit, but the clutch was an excellent feature as it allowed start-stop operation without touching the engine or making valve adjustments. Engine speed could also be controlled. The unit tested tended to jump out of gear, but this problem required only minor adjustment for correction.

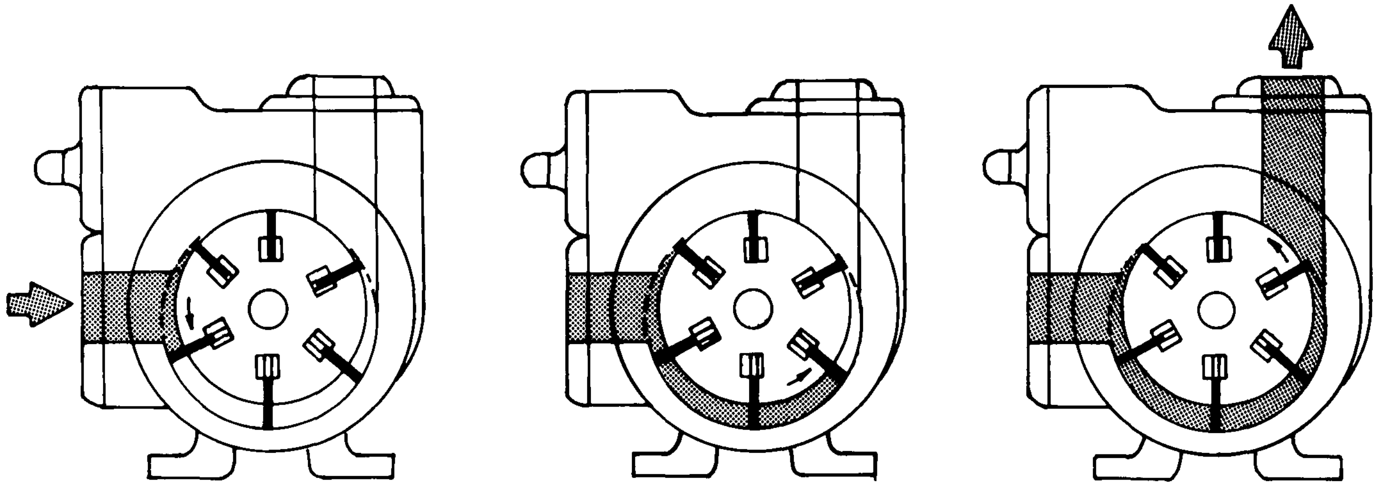
The Hatz diesel was heavy, noisy and difficult to start. The unit vibrated severely and would "walk" on a smooth surface. The decompression switch was difficult to work and its position next to the muffler made it necessary to employ two persons for engine start-up when the muffler was hot. Similarly, the engine exhaust was about 10 cm from the pump discharge - a fire hazard in most spill cleanup situations. Obviously then, the engine arrangement would not be recommended for use in spill cleanups.

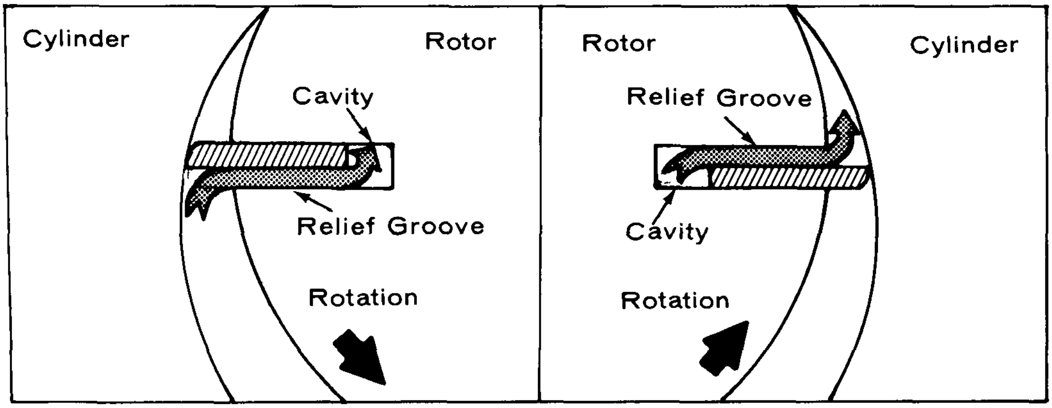
The adjustable belt drive worked well in the tests, but belt drive systems are subject to slip if they get oily. This can be avoided with a timing-style toothed belt, which unfortunately is not available in a spring-loaded variable-speed design. The belt guard enclosed the drive so completely that it was not possible to adjust the speed with gloves on; once the adjusting wheel becomes oily, it is difficult to turn at all without the fabrication of a special wrench to engage the adjusting wheel.

The NP series Blackmer pumps have self-lubricating bearings and should not be run dry; other bearings, however, are offered.

The pump body has no drain plug and would be subject to freeze-up in cold weather. Because of drainage difficulties, even if the pump were filled with hydrocarbon overnight, any water droplets trapped behind the sliding vanes could cause serious damage in the event of freezing. The vanes are not designed to grind the smallest ice chips, and literature on the pump specifies absolutely clean feed.

Blackmer's operating principle is shown below. As the pump rotor turns counterclockwise, the liquid (shaded) is carried from left to right by the vanes, which slide in and out of the rotor slots.





Three forces are constantly at work to move the vanes outward against the cylinder wall: centrifugal force; hydraulic pressure (explained above); and metal "push rods" inside the rotor which slide between opposing pairs of vanes. These are called "positive-displacement" pumps because each revolution of the rotor discharges a positive, pre-determined volume. And because of its even motion, this self-priming pump provides smooth, non-pulsating flow.

Fig.7 - BLACKMER—Principle of Operation

The Blackmer NPZ was the first pump tested, so extra tests were run to break in the system. The results, which are presented in Table 12, indicate that the pump moved all three viscosities effectively, but that trouble was experienced with high suction-lifts. Runs in the "E" configuration show lower delivery rates, and the first "G" run was aborted as the pump could not establish a flow. The pump self-primed through 1 m suction-lift (the "F" runs) with difficulty, and failed to prime with lubricating oil (145 cp) at low rpm (114). The delivery had a slight 2 cycle/sec surge despite the claims reproduced in Figure 8, but this was not comparable with that observed for the diaphragm designs, and would not normally be a problem.

In contrast with the other similar tables, Table 12 is not in strict chronological sequence of testing. As a result, it is not possible to unambiguously identify shearing of the fluids in the viscosity or temperature data. However, two detailed studies of the Blackmer's emulsification behaviour are available in the literature (Refs. 5, 6); they confirm less emulsification with the Blackmer than with centrifugal designs, but more than that which occurred with a diaphragm pump.

The Blackmer possesses no outstanding feature that particularly advocates its use in oil spill cleanup; furthermore, its debris and cold-weather intolerance pose serious drawbacks.

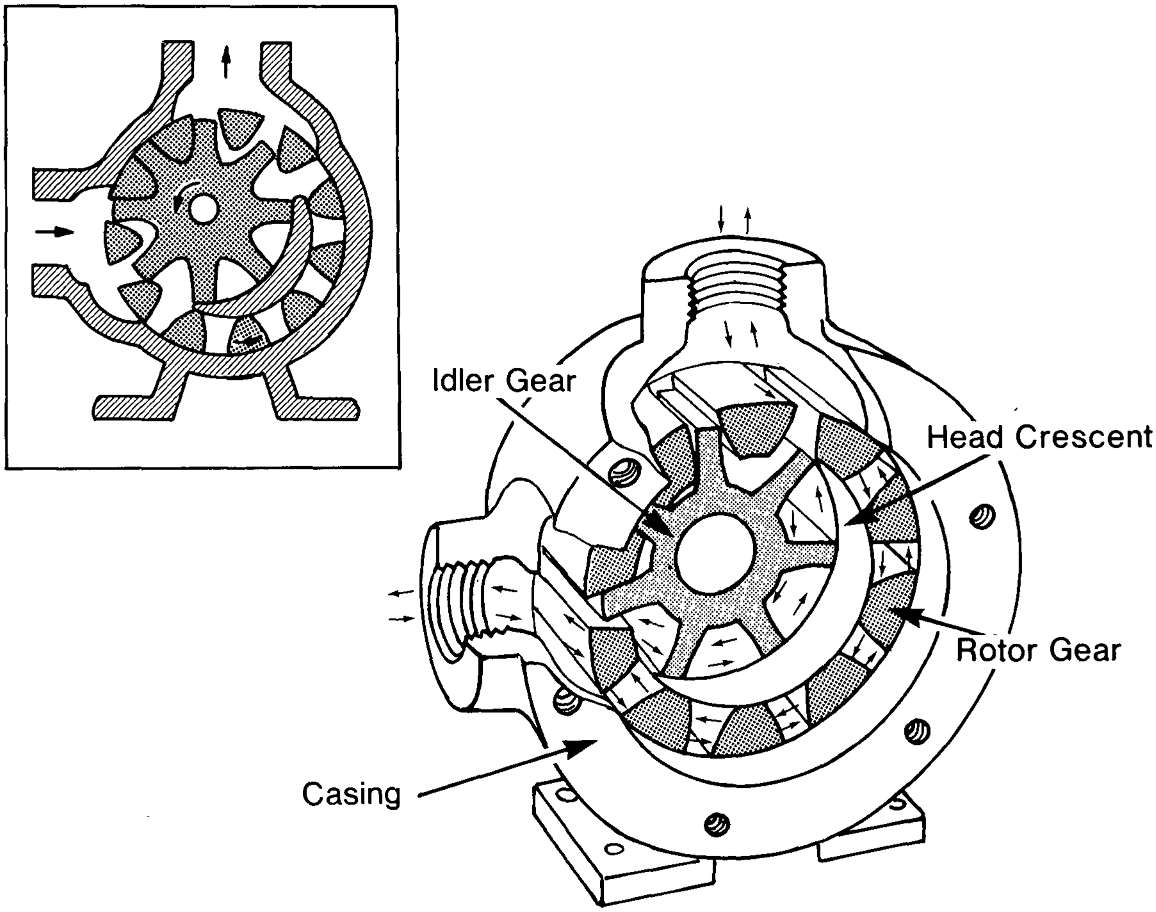
4.3.3 Rotoking K124 - Rotoking Pump Division, Houdaille Industries, Cedar Falls, Iowa

The Rotoking is a rotary gear pump which operates according to the principle described in Figure 8 (from Rotoking catalogue). This design is often referred to as a "Viking" pump as it is sold in the U.S. under that name. In Canada, however, "Viking" is the trade name of another manufacturer.

As a positive-displacement device, the pump has a built-in relief valve. When properly driven, the pump will transfer in either direction, but the relief valve works in one direction only.

The unit tested was mounted on a 39 x 9 cm channel beam with a 2237 watt Canron electric motor and Viking 3-551-007-765 offset reducing gears. The unit measured 144 x 38 x 34 cm high and weighed 213 kg, although the pump itself measured 24 x 50 x 27 cm and is listed as weighing 47.7 kg. It is rated at 227 ℓ/min (60 USPGM). Difficulties were encountered in moving this rather heavy unit around because tipping resulted in oil loss from the transmission. Although lifting eyes were not provided, the long, narrow unit could be readily slung.

The unit was well designed for safety and maintenance. The motor was explosion-proof and all couplings were guarded. The pump can be dismantled without removal from the system. Being electrically driven, the unit is without controls and therefore pumps at a fixed speed. The pump tested had no drain plug (although one is exhibited in catalogue drawings) but drainage should be complete if the pump is allowed to run dry at shutdown.



This cut-away view of the Rotoking pumping principle shows flow of liquid through the pump. Power is on the rotor gear. As the gears unmesh, liquid is drawn into the pump, filing the spaces between the gear teeth. Liquid moves smoothly around the crescent and is forced out at the discharge port by the meshing of the gear teeth, as indicated by direction arrows in diagram above. Rotoking pumps operate equally well in either direction.

Fig.8 - ROTOKING –Principle of Operation

The Rotoking is designed to pump high viscosity materials, but specifically for clean fluid service. It is built ruggedly enough to crush small ice chips, but good strainers would be required in spill cleanup service. The pump runs quietly and delivers a steady flow.

The test data of Table 13 show that the Rotoking moved all three fluids effectively. With the higher viscosity lubricating oil, some reduction in rate is apparent at higher suction-lifts; this does not appear in the crude oil data. The pump also seemed to shear the lubricating oil which results in emulsification oil/water mixtures; this effect was observed to be small and was not noted in the crude oil tests. The pump self-primed effectively.

The debris intolerance of the Rotoking would present a serious problem in most spill cleanup situations.

4.3.4 Megator L150 - Megator Corporation, Pittsburg, Pennsylvania

The Megator is described in the literature as a "sliding shoe" pump, but in reality is essentially a triplex reciprocating pump with rubber pistons. Figure 9, retrieved from a Megator brochure, describes its operating principle. The pump was originally designed for seepage control in coal mines. Due to the fact that this application is similar to oil spill cleanup in its requirements for suction-lift, self-priming and debris tolerance, a marketing effort has been directed toward the spill cleanup field in recent years.

The pump is available on wheels, but the unit tested was a "sedan chair" design equipped with four lift handles arranged for stretcher-like carrying. Despite these features, the unit (weighing 139 kg with a prime but no fuel) was a difficult lift. The handles did, however, provide a good means by which the unit could be slung. Overall pump dimensions were 60 x 173 x 60 cm high.

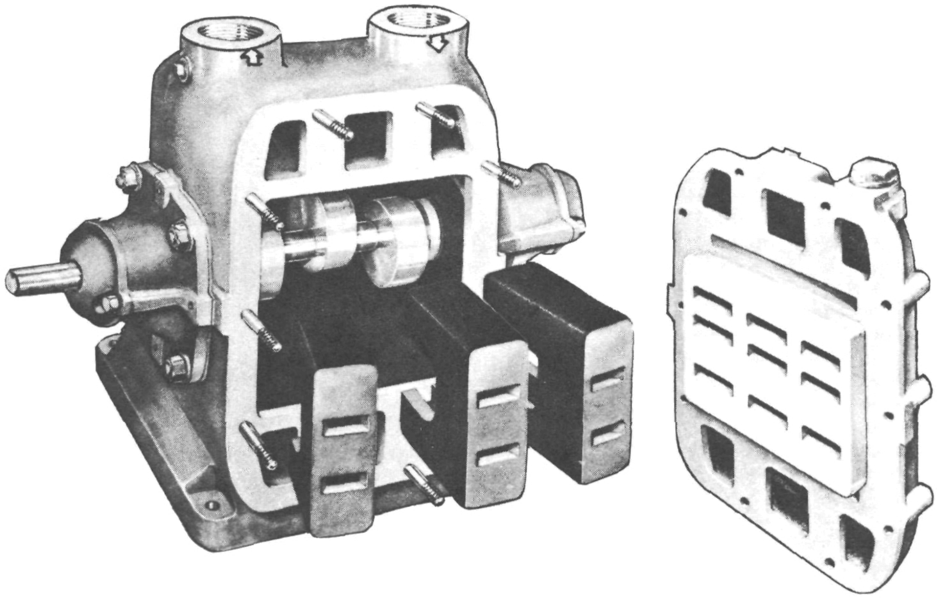
The pump's standard fittings are 3.8 cm (1 1/2") female. Of a positive displacement design, this pump must be installed with a relief valve, though none is built in. Its literature claims "instant" priming based on a priming chamber like that of a centrifugal pump. The chamber is large and its contents account for much of the pump's weight.

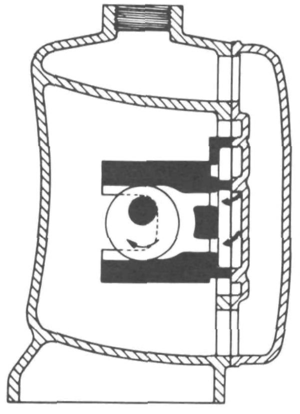
The pistons fit loosely in their cavities resulting in their inability to pump air like a normal piston pump. The Megator can pass solids up to 3/16" and as a coal slurry pump, should perform well with small ice chips as well as have some ability to crush larger pieces.

The unit tested was powered by a 3729 watt Briggs & Stratton gasoline engine through a belt drive. It is rated at 136.3 ℓ/min (36 USPGM) against 30 m (100 ft.) total head. The gasoline engine presents an obvious hazard in many spill situations and the belt drive tends to slip when splashed with oil. Diesel and explosion-proof electric drives are offered as well as a timing belt transmission.

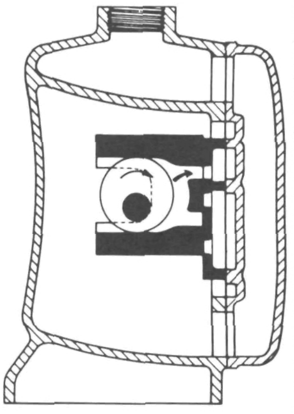
TABLE 13 TEST DATA - ROTOKING

Lube Test	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
A	+39	+295	256	185	23.5	232.5	52.2	1	2.5
B	+39	+609	570	179	24	233.8	44.4	1	9.75
C	0	+73	73	171	24.3	232.5	48	1.5	2
D	0	+256	256	170	24	232.5	42.9	1.25	5.5
E	-100	+252	352	187	21	230.1	31.6	3	7
F	-100	+252	352			(13 seconds to self-prime)			
G	-201	+369	570	185	22	229.4	31.6	4	8
Crude Test									
A	+34	+295	261	53	22	229.4	32.0	0.5	5
B	+34	+609	575	53	20.5	232.5	31.2	0.5	8
C	0	+42	42	53	20.5	229.5	31.2	0.5	2
D	0	+262	262	53	20.5	232.5	32.0	0.5	5
E	-100	+258	358	53	20.5	230.1	31.6	2	6
F	-100	+258	358	53	20.5	(14 seconds to prime)			
G	-210	+366	576	53	20.5	229.4	31.2	3	6
Bunker Test					17	228	46.7 lb/min		





Suction stroke



Discharge stroke

The pumping action is derived from the rotation of three or more eccentric discs, which fit closely into three plastic displacement chambers or shoes, lined with synthetic rubber. Each disc reciprocates horizontally in its shoe, like a piston in a cylinder, and at the same time makes the shoe reciprocate vertically, so that the ports in the base of the shoe register alternately with the suction and discharge ports in the hardened stainless steel port plate.

Although the delivery from each shoe is intermittent, the combination of three or more gives a continuous smooth discharge and an even turning moment. When the pump is working, the shoes are seated on the port plate and also, due to their calculated flexibility, on the rotor discs, by the hydraulic pressure developed, which not only ensures a tight seal but automatically compensates for wear. The performance of the pump does not depend on fine fits or clearances.

Fig.9 - MEGATOR—Principle of Operation

The unit seems well designed for field operation and repair. The rubber shoes are relatively easy and inexpensive to replace. A drain plug is provided for overnight drainage of the priming charge and an electric heater is also available for possible use in special situations. All controls can be operated with gloved hands.

To maximize efficiency, the pump should always be operated against total head of at least 3 m so that hydrostatic pressure will seat the shoes. In the spill cleanup situation, efficiency is not as important a consideration as "slip" or backflow through the shoes because the latter could become an emulsification mechanism for oily water.

Under test the Megator moved all three fluids at acceptable rates (see Table 14) and seemed unaffected by increasing suction-lifts. Self-priming was prompt if not "instant". The change of viscosities with lubricating oil indicates that the pump was shearing oil to some extent, but this was not observed with the crude oil. The triple-piston action produced a smooth flow.

In summary, the Megator is a positive displacement pump which displays a tolerance for solids up to 3/16" in diameter. As such, it should be considered for application in many cleanup operations.

TABLE 14 TEST DATA - MEGATOR

Lube Test	Suction Head (cm)	Pressure Head (cm)	Total Head (cm)	Viscosity (cp)	Oil Temp. (°C)	RPM	Rate (USGPM)	Suction Pressure (in Hg)	Discharge Pressure (psi)
B	+44	+604	560	149	27	820	36	6	9.2
G	-180	+380	560	144	27.5	784	36	10	7.2
A	+44	+290	246	137	28.5	820	34.8	5	5.8
D	0	+246	246	131	28.5	799	34.8	6	5.9
C	0	+134.5	134.5	130	28.5	820	35.8	5.5	4.4
E	-100	+242	342	129	29	820	35.6	8	6.3
F	-100	+242	342	(Priming time 13.6, 13.0 seconds)					
Crude Test									
A	+26	+290	264	25	25.5	820	42.1	3	4
B	+26	+604	578	28	28	804	43.6	3.5	7.4
G	-233	+345	578	27	25	820	38.7	8	6
C	0	+173	173	30	25	918	42.9	3.5	<4
D	0	+264	264	30	25.2	703	42.9	3.5	4
E	-100	+260	360	30	25	879	45	6	4.1
F	-100	+260	360	(Prime in 10, 10.6 seconds)					
Bunker Test	+125	+138	+13		17	799	24.2 lb/min		

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