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058 Countermeasures for Dealing with Spills of Viscous, Waxy Crude Oils

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COUNTERMEASURES FOR DEALING WITH SPILLS OF VISCOUS, WAXY CRUDE OILS

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SUMMARY

The high viscosity and atypical behaviour of waxy crude oil spills pose unique problems with respect to spill countermeasures. The objective of this study was to identify and investigate the most promising techniques to contend with spills of such oils in order to determine the focus for further development and testing.

Existing techniques and new concepts were systematically evaluated for their applicability to the oils of interest. For spills involving discrete particles of waxy oil, such as from an offshore blowout, hydrodynamic skimmers in conjunction with offshore booms were found to offer the greatest potential. In-situ burning, using fireproof booms, offers a possible alternative. For batch-type spills, such as from a tanker accident, nearshore cleanup with booms or netting systems and skimmers such as the B.P. toothed disc or Shark 5000 devices is recommended. In-situ burning of batch spills would likely be an effective alternative.

RESUMÉ

La viscosité élevée et l'évolution inhabituelle des nappes d'hydrocarbures paraffiniques présentent des difficultées particulières dans le choix des contremesures. Cette étude vise à identifier et examiner les techniques les plus prometteuses pour contrecarrer les déversements de ce type d'hydrocarbures afin de diriger leur mise au point et leur vérification expérimentale.

On a évalué systématiquement la portée des techniques existantes et des nouveaux concepts sur les hydrocarbures en question. Les récupérateurs hydrodynamiques combinés aux estacades seraient potentiellement les plus efficaces pour nettoyer les déversements formés de gouttelettes distinctes d'huile paraffinique provenant, par example, d'une éruption de puits extracôtier. Une autre méthode possible est la combustion in-situ à l'intérieur d'une estacade ignifuge. Pour le nettoyage des déversements en vrac près des côtes, provenant par exemple du naufrage d'un bateau-citerne, il est recommandé d'utiliser des estacades ou des barrières réticulaires en combinaison avec un récupérateur du type B.P. à disques déntes ou du type Shark 5000. La combustion in-situ serait probablement une autre méthode efficace.

INTRODUCTION

BACKGROUND

Interest in spills of highly viscous oil has increased with the recent oil discoveries off the Newfoundland coast. Oils in these finds have pour points near or above ambient temperatures, a particularly undesirable property with respect to oil spill countermeasures. This characteristic is probably due to a high wax content in the oil. Its effect is to cause the oil, once spilled in the environment, to become a non-spreading, semi-solid which could take the form of mats, globules and particles. Compounding the cleanup problem on the east coast is the harsh environment including low temperatures, high sea states and long periods of fog.

A combination of these factors has resulted in a pessimistic view of the capabilities of currently available cleanup equipment, as expressed in a recent study for Mobil Oil Canada Ltd. entitled "Hibernia Oil Spills and Their Control" (S.L. Ross 1984). In the investigation, cleanup capability was assessed over a range of spill and environmental conditions. The study was limited to currently available equipment and techniques that showed some promise for dealing with Hibernia spills. Although the study analysed the possible advantages and disadvantages of current technology, no attempt was made to investigate technological changes that might result in an improved capability to control spills of these oils.

The purpose of this study is to identify and investigate the most promising techniques and concepts to contend with spills of viscous, waxy crude oils. As a result the focus for further development and testing in this field is recommended.

APPROACH AND SCOPE

The approach used in this study involved:

- the screening of all existing technologies including those noted in the Hibernia report, and the selection of only those that appear to be the most promising;
- an analysis of the selected technologies to identify their shortcomings with respect to viscous waxy oils; and
- the proposal of improvements to increase their potential effectiveness and practicability.

The study concentrated on countermeasures devices and techniques for viscous oil spills that might occur in the area of the Grand Banks of Newfoundland. It is based on generalized predictions of the fate and behaviour of slicks of Hibernia crude oil, as described in the next section. Although the study results have primary application to spills offshore of Newfoundland, they should nevertheless have relevance to other locations or situations where waxy, viscous oil spills might occur.

EVALUATION METHODS

SPILL SCENARIOS

Two basic types of oil spills are of concern, a continuous well blowout and a large batch spill. For the well blowout it is predicted that the oil would be introduced onto the water surface in the form of droplets having diameters in the range of 1 to 5 mm. Because of the waxy nature of the oil it is postulated that these droplets would be highly viscous under most environmental conditions and would not spread or coalesce on the surface to form a conventional slick. Depending on the circumstances of the blowout these droplets would appear on the water surface downstream from a blowout as a 'slick' that would vary in width from several hundred metres to several kilometres. As it is expected that such a 'slick' of droplets would soon diffuse and cover an area too great for effective cleanup operations, the cleanup strategy would be to contain the oil with booms at a point near the blowout site and then remove the oil with the most efficient means available. Due to the non-fluid nature of the individual droplets it is postulated that the oil will not emulsify. Nonetheless, the droplets are expected to be highly viscous and non-coalescing, although they may agglomerate to form clumps. This type of oil, as may result from a subsea blowout, was named Type 1 oil for the purposes of this study.

The second type of oil (Type 2) is that which would result from a large batch spill. In this case, the spilled oil would be present as mats several metres in diameter and up to several centimetres in thickness, and globules of several millimetres or more in diameter. Considering likely spill scenarios, it is postulated that the oil would undergo a significant amount of weathering before countermeasures could be implemented. It is expected that the weathering would result in the formation of a surface skin or crust that would cause the mats or globules to be non-sticky, thus preventing their recoalesence. In fact, wave energy would probably cause the mats to eventually break into a number of discrete chunks of various sizes.

LABORATORY EXAMINATION OF OIL PROPERTIES

Because of the uncertainties regarding the exact nature of eastern Canadian crude oils, it was decided at the outset of this study to conduct a very brief, preliminary examination of sample oils in a small laboratory tank. Using fresh Hibernia and Terra Nova crudes as well as a 15% weathered Terra Nova crude, further data pertinent to countermeasures were obtained. For the fresh (Type 1) oil, it was found that droplets would agglomerate only when physical forces were applied to accomplish this confinement. A more natural recoalescence of droplets and globules did not occur either at 3°C or 12.5°C. The fresh oil adhered to PVC and aluminum surfaces to a moderate extent, particularly as the plates were immersed in the oil and water (yet not upon withdrawal). The fibrous surface of a polymeric sorbent pad displayed a more marked ability to absorb oil globules when placed on the water's surface.

For the weathered (Type 2) oil, mats and globules of oil were formed upon contact with the water. Both the globules and mats of waxy oil did not coalesce. Adhesion to PVC, metal, and the sorbent pad was negligible at 3°C and only very slight at 12.5°C.

SUMMARY OF OIL PROPERTIES

In general, based on oils from the Hibernia and Terra Nova wells, waxy crudes are oils of relatively low density (in the range 850 - 870 kg/m^3), high pour point (6 - 25°C), and high viscosity (1500 mPa.s or greater). Including the postulated spill conditions, two oils are considered for this study:

a) Type 1 oil is fresh crude that floats on the surface as individual, relatively small droplets (1-5 mm). These droplets will agglomerate only when confined by a boom, but "slicks" will probably comprise droplets and clumps. Adhesion to PVC, aluminum, and, particularly, fibrous surfaces will occur to a moderate extent.

b) Type 2 oil is the term given to weathered crude oil that forms globules and mats. These are not likely to adhere to one another even when concentrated by a containment barrier, nor will they cling to PVC, metal, or fibrous surfaces. Globules could be several millimetres to one or more centimetres in diameter, and mats could be up to several centimetres in thickness.

It was recognized that certain crude oils, when fresh, have pour points which are lower than ambient temperatures, but as these oils weather, the pour point increases above ambient temperature and the oil becomes a Type 1 or Type 2 oil as defined in this report. Conventional countermeasures would be applicable to these oils when fresh. Therefore, such oils, when fresh, are defined as not being waxy crude oils for the purposes of this study.

ENVIRONMENTAL CONDITIONS

In addition to the consideration of oil properties, environmental factors directly influence the selection of countermeasures systems for Grand Banks oil spills. In general, conventional offshore oil spill containment operations will be effective only during periods when wave heights are 2 m or less, the wind speeds are 10 m/s (20 knots) or less, and visibility is 1 km or greater.

Such moderate conditions persist in the Hibernia area for only brief periods. During the summer months, intervals of up to 60 h of favourable sea conditions occur intermittently, although for about 40% of such times visibility will be less than 1.5 km. During the other seasons, improved visibility can be expected but so can higher sea states. Booming, for example, is expected to be possible for less than one day at a time during winter months and for up to three-day periods during fall or spring.

In summary, including the loss of time from darkness at night (50%), poor visibility (fog), and high sea state, the estimated percentage of time during which conventional countermeasures would be applicable are 20% in summer, 15% in fall, 3% in winter, and 10% in spring (S.L. Ross 1984).

EVALUATION PROCESS

Using the spill scenarios as a basis, together with the postulated Type 1 oil (fresh crude droplets) and Type 2 oil (weathered globules/mats), control options were studied for their potential utility to clean up east coast spills of waxy crude. The options considered included:

- containment
- recovery
- in-situ burning
- chemical treatment
- sinking

The evaluation process was a sequential one. An initial screening step was conducted to reject systems that were obviously inappropriate. The use of an initial screen was especially appropriate for the numerous recovery techniques. Reasons for early rejection of a technique related mainly to limitations with respect to the specific oil properties. An extensive review of the literature was conducted during this phase of the study and several key experts were contacted in various countries for the provision of current, relevant research data (a list of those contacted is provided in Appendix A).

The second stage of the evaluation process comprised a further examination of the screened information in a brainstorming type of exercise attended by five study team members (Appendix A), all with extensive experience in oil spill technology. As an introduction to the problem, the study team was briefed on the preliminary findings on the oil properties including the division of properties as per Type 1 and Type 2 oil. As well, they were presented with the results of the screening process with particular note made of the specific limitations of each technique. Rather than delving into great detail on the possible spill scenarios, the team was asked to consider:

- a subsea blowout, flow rate in the range of 2000 to 5000 m^3/day, oil exhibiting Type 1 behaviour, namely, non-coalescing, somewhat sticky particles of diameter 1.0 to 5.0 mm; and
- a batch spill, volume in the range of 10,000 to 30,000 m^3, oil exhibiting Type 2 behaviour, namely, non-sticky mats, clumps and globules.

Brainstorming was carried out with an initial consideration of existing (i.e., known) devices/concepts which were applicable as is or with possible modifications. This approach was felt to be justified since existing devices/concepts could be evaluated more accurately, and modifying an existing device would afford a greater probability of ultimate success than starting with a new concept. With this rationale in mind, the study group was first asked to consider promising existing devices, then to consider upgrading modifications if required, and finally, if these two methods failed to provide a satisfactory solution, to suggest new ideas.

Once concepts were optimized with respect to the concerns of both oil properties and sea state, conclusions and recommendations were made on the possible course to be taken in future research.

EVALUATION RESULTS

The evaluation of existing devices and the brainstorming of both improvements and new ideas were carried out in separate, succeeding phases. In the latter phase in particular, many ideas were analysed and subsequently rejected because of their impracticality. Rather than burden the reader with a representation of concepts which were dismissed, the following sections of text include only the most promising countermeasures. The complete brainstorming results are presented in Appendix B. This information may also be of future use as the spill-related properties of waxy crudes are further defined.

CONTAINMENT

The control and containment of offshore spills, regardless of type, is determined by environmental conditions. Generally, if waves are less than 2 m and winds are less than 20 knots, booming can be effective. Although such conditions are infrequent off the East coast of Canada, they do exist for short periods lasting a few days or less. Quick deployment and retrieval capabilities are, therefore, priority features to be incorporated in an offshore boom. Durability of construction and general robustness would be essential characteristics because the frequency of handling is relatively high. These same traits would allow the booms to survive brief periods of exposure to higher sea states if weather conditions deteriorated so rapidly that immediate retrieval were not possible. High reserve buoyancy and good wave response would be important to the adequate performance of an offshore boom. As Type 2 oil does not adhere to surfaces, there is less of a concern about the choice of material and incorporation of external bridle systems, although the fresh Type 1 Oil might cling to some booms.

The above criteria are met to some degree by the Vikoma Boom Deck Reel, Nordan Oil Boom, Roulunds Ro-Boom, and Kepner Sea-Curtain.

The Vikoma boom is air-inflatable in 500-m sections that can be deployed from a supply boat in a matter of minutes. The boom is rugged and has excellent wave-conforming characteristics. Although this product is ideal for fast response, it has two major drawbacks in that it requires continuous power to maintain inflation and its use of a single flotation chamber means that a major tear in the fabric would result in a complete loss of flotation. Nonethless, its successful use on previous spills and the familiarity of personnel with its operation give sufficient reason to expect that the boom could be successfully used for Grand Banks spills.

The Nordan boom and Ro-Boom are similar in that they offer a significant improvement over the Vikoma, particularly as concerns survival potential, with their use of sectionalized air chambers. A drawback of this improvement is a lengthier launching procedure (estimated at 2 h for a 500-m section) since each flotation chamber must be inflated individually. As each boom is extremely durable, a time-saving alternative may be to leave the boom in the water between periods of favourable conditions. Each boom has proven qualities of wave conformity and durability.

A fourth acceptable alternative is the Kepner Sea-Curtain which is sectionalized, stored on a reel, and is self-inflating. Like the others it displays good durability and conforms well to waves.

Another approach to containment that was reviewed was the Jackson/West Net system. It offers both fast deployment and retrieval using techniques similar to purse seining, and has been proposed for both the confinement and collection of oil. (Its use as a collection device is discussed later in the appropriate section.) Although the fine-mesh net might not yield significant oil losses, some oil might escape through the net as a sheen. Of greater concern is the structural integrity and vertical stability of the West Net if used as an offshore boom. Recent design changes have resulted in the use of vertical nylon stiffeners, prestretched rope tension members, expanded PVC floats, and an improved fabric weave, all of which are expected to improve the boom's durability although this is currently unproved.

In summary, four acceptable alternatives that are all currently available were identified for offshore containment. Although some time was devoted to containment techniques in the brainstorming phase, no modifications or new ideas were identified that would provide an improved capability.

RECOVERY DEVICES

Preliminary Screening

Because of the large number of existing oil spill recovery devices and techniques, an initial screening was carried out to eliminate obviously inappropriate techniques. Application to Type 1 and Type 2 oils was considered separately.

It was recognized from the outset that two independent problems had to be addressed: the 'oil property' problem and the 'harsh environment' problem. It was clear that spills of viscous, waxy crude oil would be very difficult to deal with even in a calm environment; and it was equally clear that few, if any, techniques would be fully effective in the harsh, east coast environment, regardless of the oil type spilled.

The 'oil property' problem was focused on so that techniques could be considered which would be applicable in the nearshore environment and at least some of the time in the offshore. The 'environmental problem' was deferred in the sense that it was unlikely that any techniques would be acceptable except in the brief periods of moderate sea conditions. Nonetheless, throughout the evaluation, comments were made on the applicability of each technique to the environmental conditions under which countermeasures operations would usually take place.

The recovery techniques were considered under the generic groups of:

- weirs
- oleophilic surface devices
- mechanical devices
- suction devices
- hydrodynamic devices

The screening was based mainly on the techniques' ability to process the oil of interest (i.e., Type 1 or Type 2). As well, recovery rates less than the range of 50 to 100 m^3/h were cause for rejection, although, if this was the sole drawback, the technique was considered for nearshore operations. A summary of the preliminary screening is presented in Table 1; detailed comments are presented in Appendix C.

Table 1

Preliminary screening of recovery devices

Device	Type 1 oil	Type 2 oil
Weirs	- potentially applicable - possible problems of adhesion/clogging at weir lip and in weir chamber	- not applicable because of clogging and poor flow characteristics of viscous mats/chunks
Oleophilic surface devices	- potentially applicable - better oil adhesion to fibrous rather than to smooth surfaces - effective oil stripping is paramount	- generally not applicable to oil of this type if weathered
Mechanical skimmers	- potentially applicable (non-oleophilic belt)	- potentially applicable for viscous mats (toothed disc, paddle wheel)
Suction devices	- generally not applicable because of adhesion/clogging of particles	- generally not applicable to viscous mats - weathered globules could be recovered albeit at low rates
Hydrodynamic devices	- potentially applicable - possible problems of adhesion/clogging on moving parts	- not applicable to viscous mats - applicable to weathered particles

To summarize further, the techniques worthy of further consideration are as follows:

Type 1 Oil
- weir devices;
- oleophilic surface devices, especially fibrous belts;
- mechanical devices, specifically non-oleophilic rotating belt; and
- hydrodynamic devices.

Type 2 Oil
- mechanical devices, specifically the Seawolf toothed disc and Shark 5000 skimmers; and
- hydrodynamic devices for weathered particles only.

For each type of oil, several important factors were noted that would apply to any collection device:

Type 1 Oil
- possible agglomeration of oil particles, causing clogging of recovery components and pump suctions; and
- oil is somewhat adhesive, a possible detriment to devices not using the oleophilic skimming principle.

Type 2 Oil
- extremely poor flow characteristics of the viscous mats requires that any skimmer must have some sort of feeding mechanism; and
- transfer mechanisms must be able to deal with viscous mats and chunks.

This preliminary evaluation was used as the basis for further consideration in the succeeding brainstorming phase, the results of which are discussed below in separate sections for Type 1 and Type 2 oil.

Type 1 Oil

As a result of the screening process, four generic recovery devices were identified as having promise: these are discussed below in roughly descending order of potential effectiveness (i.e., best to worst).

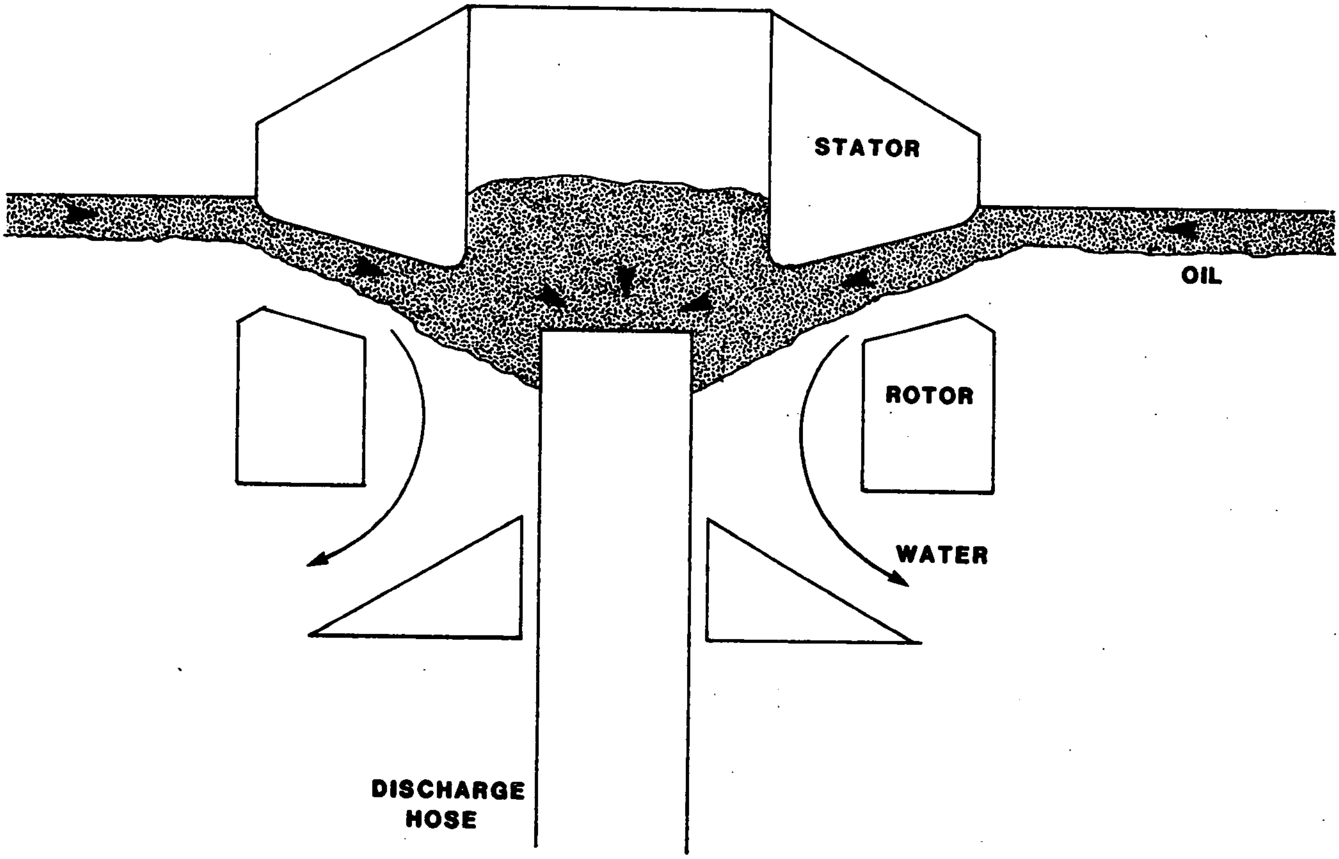
Hydrodynamic devices. One specific hydrodynamic device, the Mattson Walosep skimmer, was considered although the comments provided herein could be applied to other devices that use the same principle of operation. The Walosep was focused on because of encouraging test tank results (Smith and Lichte 1981) and its commercial availability.

The Walosep is shown schematically in Figure 1. Its principle of operation is the use of submerged rotating vanes which develop a flow of the surface layer into the device. In the collection chamber, water flows through openings in the bottom of the chamber, while the buoyant oil is concentrated in the centre. From this central concentrated area, the oil is pumped off by a remote diaphragm pump.

It is expected that the flow-through effect created by the rotating vanes would successfully entrain a stream of Type 1 oil particles. The capability of the skimmer has been proved in test tank trials with both light and heavy oils, and was found to be fairly insensitive to waves up to 0.5 m in height. Recovery rates in these trials were in the range of 50 to 100 m^3/h.

Several possible drawbacks were noted. The somewhat sticky and viscous nature of Type 1 oil particles could lead to problems with the oil adhering to the collection chamber and other surfaces. As well, the possible agglomeration of these particles could clog the inlet zone. It is expected that the flow-through effect would eliminate such clogging problems, but testing should be done to confirm this. The adhesion problem could be reduced

FIGURE 1 : WALOSEP SKIMMER PRINCIPLE OF OPERATION



through the use of surface coatings (such as teflon) or by heating the affected surfaces.

A more serious drawback is the lack of a positive suction feed at the point of oil removal (as indicated in Figure 1). With flowing oils, a positive head is developed within the stator; this head forces oil into the collection pipe allowing the oil to be removed by a remote diaphragm pump. It is not certain whether a slurry of Type 1 particles would flow into the collection pipe in the same manner, and whether a remotely located diaphragm pump could maintain the required suction head. It may be necessary to provide a suction feeding device within the stator. An example of such a modification proposed by the study team is the use of an auger to feed the collection pipe (Figure 2).

In summary, the Walosep skimmer should have great potential for the recovery of Type 1 oil in an offshore environment, and with a smaller sized unit, for nearshore operations as well. Possible problems with oil adhering to and clogging the surfaces of the collection chamber, and with feeding the collection pipe, appear to be solvable.

Mechanical devices. Although mechanical devices, in general, were not determined to be applicable to Type 1 oil, one device, the rotating non-oleophilic belt, was felt to offer some promise. One particular version of this concept is the JBF DIP (dynamic inclined plane) skimmer, shown schematically in Figure 3. Its principle of operation is essentially an advancing, submerging weir device. Its notable aspects are the enhanced flow-through created by the rotating belt, and the creation of a quiescent zone aft of the belt from which trapped oil is pumped.

FIGURE 2 : WALOSEP SKIMMER USE OF AUGER TO FEED DISCHARGE HOSE

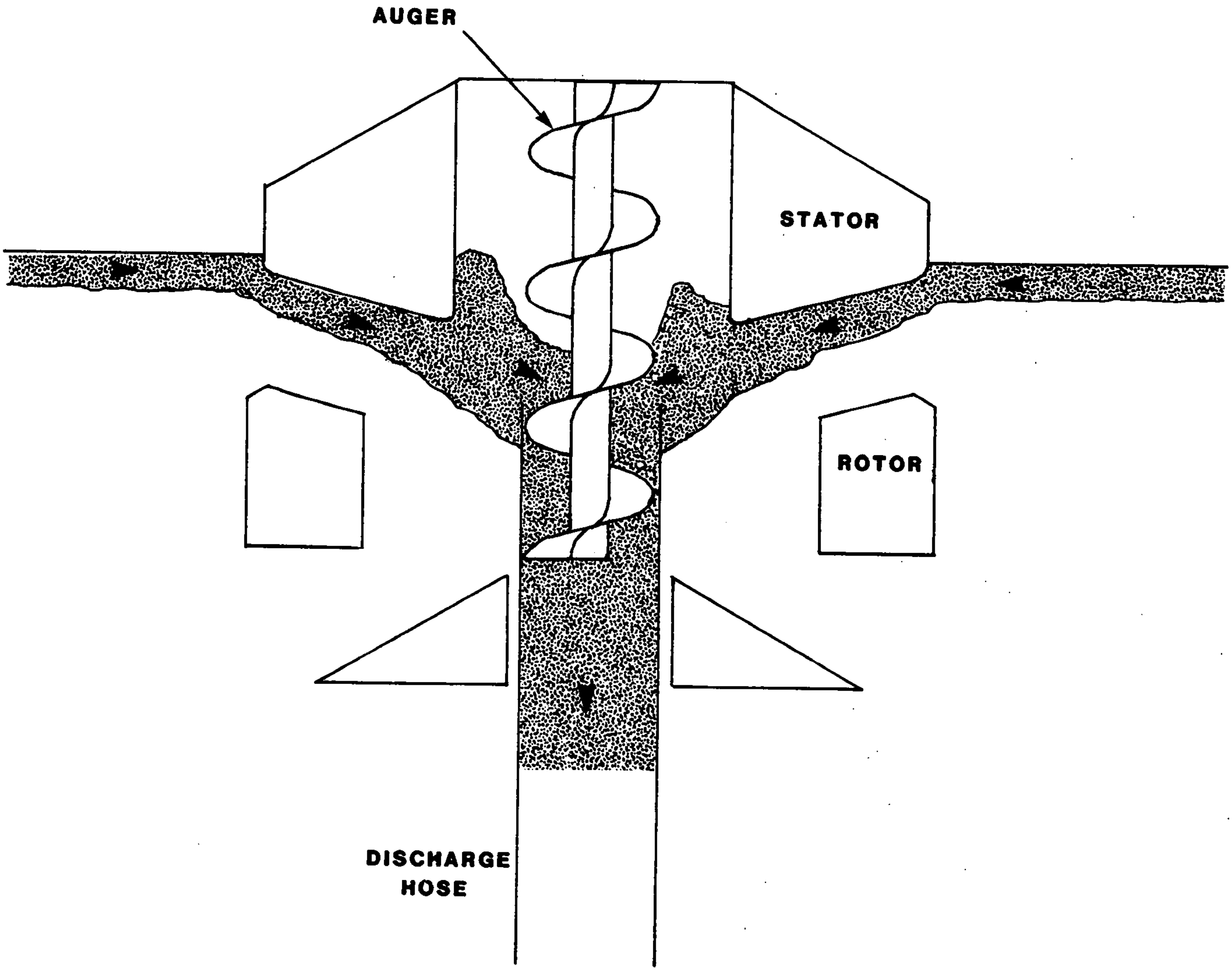
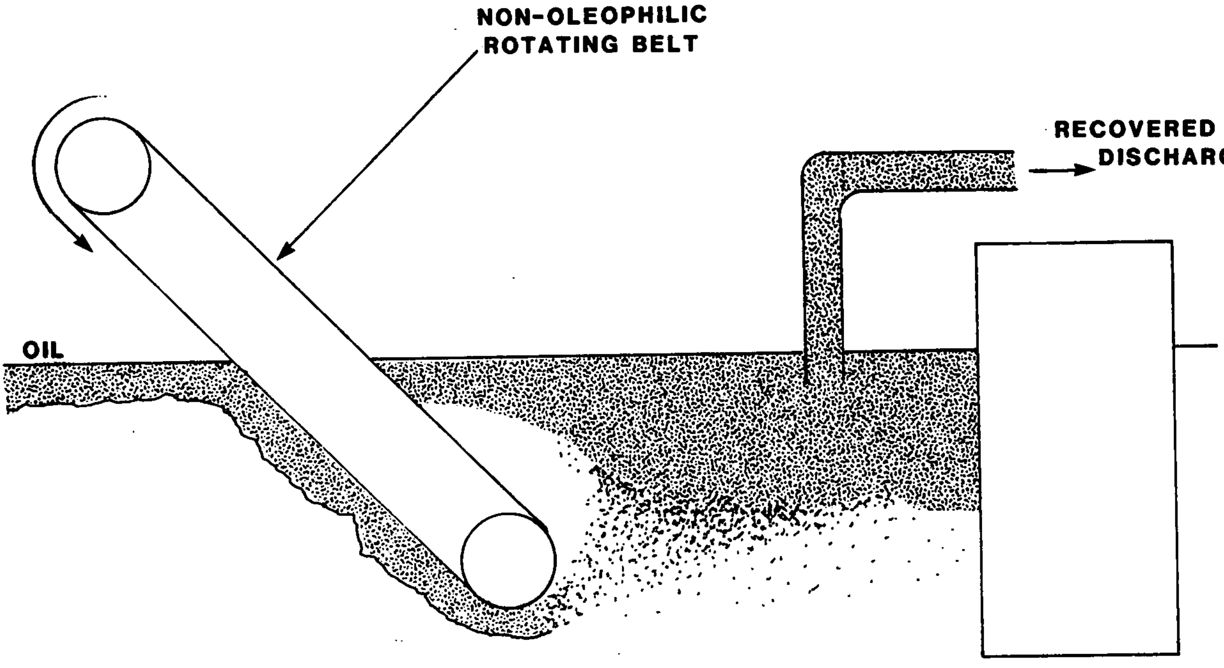


FIGURE 3 : JBF DIP SKIMMER
PRINCIPLE OF OPERATION



Its main advantages are its relative mechanical simplicity (less hardware than an oleophilic device) and its potential for oil/water separation. Small units (i.e., for nearshore recovery) could be easily deployed from a vessel of opportunity. Complexities associated with certain models such as oil-sensitive, automatic pump devices and spray systems could be eliminated.

The main drawback associated with this device is its sensitivity to waves, especially with a large unit suitable for the offshore. The sensitivity to waves is caused by the need for a stable, quiescent zone aft of the rotating belt; in high sea states, oil would pass this zone altogether. As well, the vertical motion of the belt as the device heaves could create a pumping action that would cause further oil losses.

To operate effectively, the skimmer requires movement of the oil slick to the skimmer which, conceivably, could be provided by vanes or paddles on the rotating belt. The recovery rate would be limited only by the presentation rate and the pumping rate.

In summary, a submerging, rotating plane that is non-oleophilic could have application to Type 1 oil, particularly in nearshore situations.

Oleophilic surface devices. The preliminary testing of oil properties indicated that Type 1 oil is somewhat sticky, that is, the oil would adhere to some oleophilic surfaces depending on the type of surface and the method of application. Specifically, it is expected that a fibrous belt could sorb oil even in the form of discrete droplets, but it is not certain that smoother PVC and metal surfaces could do the same. The fibrous belt would still be smooth enough to be easily scraped clean. (A rope mop, though it would provide the ultimate "roughness" would be difficult to strip of sorbed oil; it is expected that the squeezing action of rope mop rollers would simply smear any retained oil droplets.)

The use of an oleophilic belt is a proved and widely used cleanup concept which provides an efficient oil/water separation. Assuming a belt speed of 0.5 m/s and a maximum sorbed oil thickness of 10 mm, a theoretical maximum recovery rate of 18 m^3/h per metre of belt width could be achieved. This rate is lower than desirable for offshore recovery and may limit the concept to smaller scale, nearshore operations.

An additional disadvantage of oleophilic devices, in general, is their mechanical complexity in that several unit processes comprise such a device (i.e., drive mechanism, oil-stripping mechanism, recovered oil transfer mechanism). Also, a substantial working platform is required, the necessary size and weight of which may limit the effectiveness of a belt skimmer in heavy seas (because of poor wave response) and may limit its ability to be easily deployed and retrieved.

Therefore, for reasons of low recovery rates and limited applicability to offshore operations, further consideration of oleophilic devices is relegated to nearshore operations.

Weir devices. Weir devices were identified for further consideration because of their mechanical simplicity and their ability to be operated from a vessel of opportunity.

The main disadvantages of weir skimmers for offshore oil recovery are their high water intakes and their sensitivity to waves, even those only centimetres in height. Considering the high buoyancy of the known waxy crude oils, it is projected that the high water content in the recovered fluid could easily be reduced with simple tank separation on the support vessel.

Moreover, a major limiting factor was identified with regard to the specific properties of Type 1 oil. If, as suspected, this oil will agglomerate to form clumps of droplets, it is expected that a significant amount of oil might not traverse the weir lip and, therefore, might not reach the weir's transfer pump. To overcome this flow problem, some kind of positive feed mechanism would be required similar to that of both the hydrodynamic and mechanical devices discussed below. In short, skimming weirs do not appear to hold much promise for the recovery of Type 1 oil.

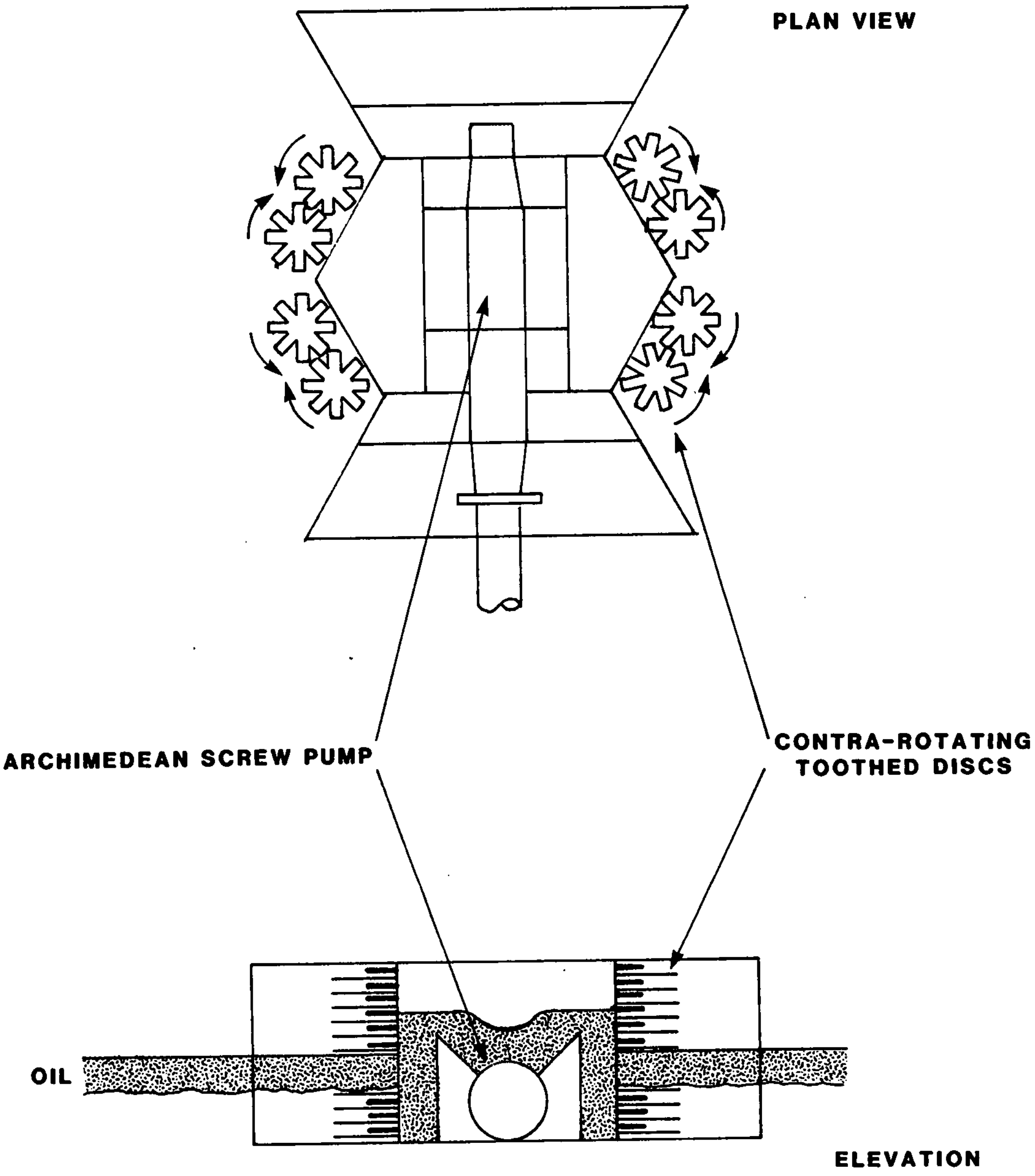
Type 2 Oil

As a result of the screening process, three recovery devices were identified as having promise for Type 2 oil. One new idea was developed during the brainstorming process. All four approaches are discussed below in descending order of potential effectiveness (i.e., best to worst).

Toothed disc. The Seawolf toothed disc skimmer, shown in Figure 4, was developed by the British Petroleum Company and is presently marketed by Vikoma International. Its principle of operation is the use of two vertical arrays of intermeshing toothed discs which draw in oil and push it into a collection chamber, from where it is pumped off by a screw pump. The pressure head created in the collection tube minimizes the amount of free water collected.

The vertical orientation of the disc arrays has the advantage of not requiring precise positioning at the oil/water interface, and enables the mechanism to work continuously, even when subjected to wave motion. The disc's teeth would pierce the mats and chunks of Type 2 oil, and would effectively draw in a cohesive oil mass.

FIGURE 4 : TOOTHED DISC SKIMMER PRINCIPLE OF OPERATION

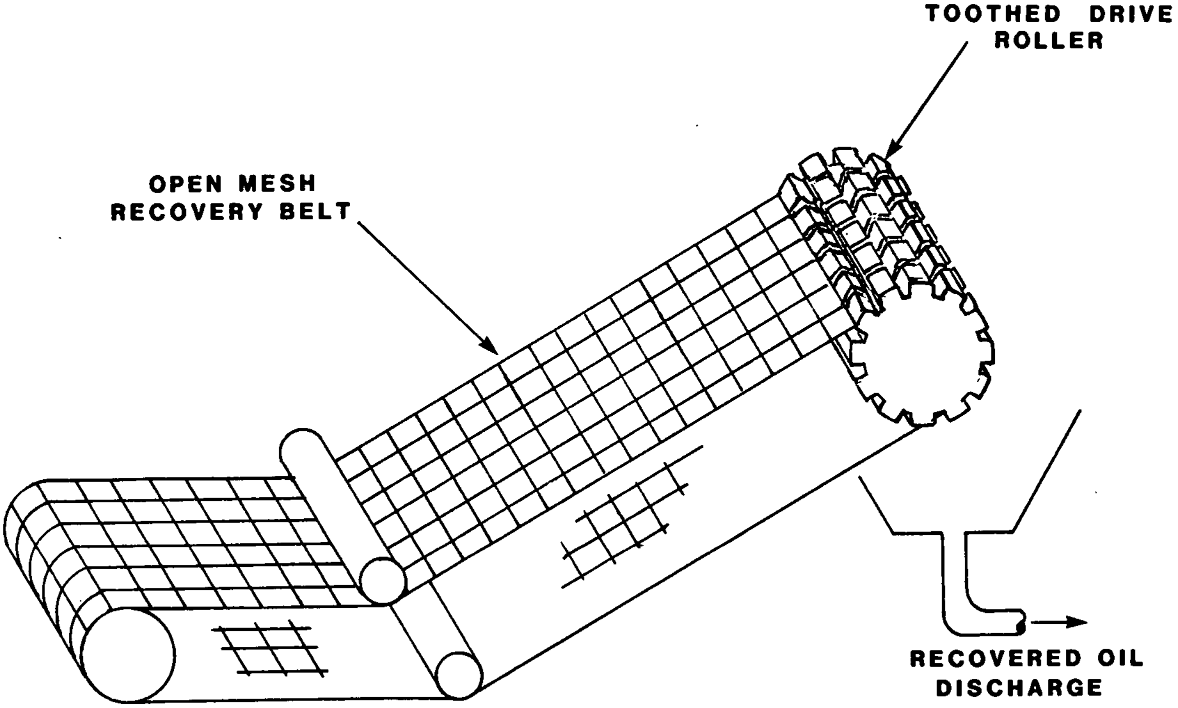


The main drawback associated with the toothed disc is its low recovery rate. Preliminary tests (Scott 1983) with the device indicated a maximum recovery rate of about 5 m^3/h per pair of disc banks. A conceptual design incorporating four pairs of disc banks has been developed, but even its rate of 20 m^3/h is insufficient for an effective offshore recovery operation. However, its proven capability of handling very viscous oils makes it ideally suited to smaller-scale, nearshore operations.

Shark 5000. The Shark 5000 Heavy Oil Recovery Unit, shown in Figure 5, is produced and marketed by Oil Recovery International(ORI). The concept is similar to that of other rotating, oleophilic belt skimmers, but it has two key improvements which allow it to cope with very viscous oils. The first is the use of an open-mesh, chain-link recovery belt to collect oil from the water surface, and the second is a toothed drive roller to eject the collected oil from the belt by force.

The Shark 5000 was designed specifically for use in harbours, lagoons, and other calm-water environments; the oil-recovery mechanism must be accurately located at the water surface, and would be adversely affected by wave motion of 100 mm or greater. As such it is a poor candidate for offshore recovery operations. During field tests (Thomas 1982) of the device in a calm environment, its recovery capability was proved with a variety of viscous oils, including a fuel oil emulsion and Beatrice crude oil, a waxy North Sea crude with properties similar to the specified Type 2 oil. A maximum recovery rate of about 20 m^3/h was obtained during these trials.

FIGURE 5 : SHARK 5000 SKIMMER PRINCIPLE OF OPERATION



Netting systems. The use of porous nets has been proposed for the containment and possible recovery of highly viscous oils. Several systems have been tested (Thomas and Morris 1983; Suzuki 1985; and Gill 1985) using nets with a pore size of about 1 mm. Such nets are able to contain viscous, non-flowing oils under non-extreme sea conditions.

If one were dealing with smaller slicks such as in a nearshore protection situation, the limited recovery rate is not as serious a concern. Nets could be used to recover nearshore slicks in a batch-type operation.

The reasons for considering the use of nets are threefold.

a) Compared with conventional boom materials, the porous material provides less resistance to sea forces; hence greater boom lengths can be used.

b) The boom is easily deployed and retrieved, and is compact when stored, allowing small fishing boats to carry and use it.

c) As with the purse-seining of fish, the net surrounding an oil slick can be drawn in, thus thickening the oil for the subsequent use of oil recovery devices.

The main disadvantage of a netting system is that it is essentially a batch system. (Its use as a substitute for conventional booms, in which case the net is merely used in a V-shaped configuration to divert oil, is discussed in the subsection on Containment.) Considering its use in a large-scale recovery operation, the following brief scenario highlights the possible limitations:

- maximum length of net that can be deployed and manoeuvred is 1,000 m;
- if deployed in a circle, maximum surrounded area is 80,000 m^2;
- assuming, as a maximum, an average oil thickness of 1 mm, the maximum ensnared oil volume is 80 m^3;
- minimum time required to deploy the boom, encircle the oil, and increase the oil thickness would be about 2 h;
- as such, the maximum average 'recovery' rate is 40 m^3/h (this figure is stated as a maximum because it is dependent on an oil thickness of 1 mm, a maximum expected value, and on a total operation time of 2 h, a minimum value); and
- note that this operation simply concentrates the oil; additional equipment (e.g. skimmers and pumps) are required to remove the contained oil.

For nearshore response, a possible mode of operation using nets is to capture oil slicks, then recover the nets with a trawler-type vessel. Although it has been found that lifting the net and its contained oil out of the water results in excessive oil losses by extrusion through the mesh, it may be possible to drag the net and its oil up the ramp of a stern trawler.

Three other possible methods were proposed for the use of nets. The first is to tow the contained oil to shore at high tide; when the tide falls and the 'package' is on dry land, the net and oil can be removed with loaders and dumptrucks. This method was used successfully during the Patmos spill in Italy, in March 1985. It may not prove to be practical in the Canadian area of interest because of lack of access, and abrasion and tearing of the net on rocky beaches. A second proposed idea was to provide a strip (say 30 cm wide) of conventional boom material along the bottom of the net boom; as the net is drawn in this strip would provide an impervious barrier to prevent or limit extrusion losses as the net is lifted out of the water.

A third idea for the use of nets relates specifically to subsea blowouts; it was suggested that a piece of netting suspended over the blowout plume (Figure 6) could divert oil from the plume to a collection point. Major unknowns with this idea are the ability of the net to selectively divert oil particles in the presence of gas, and the location of the net vis-a-vis oil particle cooling and accompanying viscosity increase.

Paddle-wheel. A paddle-wheel device, shown schematically in Figure 7, was envisioned by the study team as a feeding device to overcome the flow problems of Type 2 mats. Its principle of operation is essentially an improved weir, the improvement being the feeding action provided by the paddles and the separation of water from oil as it is pushed up the ramp. An auger/screw type pump could be used to remove oil from the contained area aft of the weir crest. The device is similar in concept to the Clowsor Paddle-Wheel Skimmer sold commercially by Anti-Pollution Inc. of Louisiana.

The expected recovery rate is fairly low, a trait common to devices using a mechanical skimming principle. A further drawback is the requirement of accurately positioning the paddle/weir lip just below the water surface, a requirement that limits the device's applicability to calm water (i.e., nearshore) operations. Various configurations of mechanical paddle-wheels were reviewed, including devices rotating in both the vertical and horizontal planes. As well, paddle-wheels that could be incorporated into containment booms (as feeding devices for other skimmers) were discussed.

In summary the paddle-wheel approach appears to be severely limited, whether it is considered for offshore or nearshore spill situations.

FIGURE 6 : USE OF POROUS NETS
TO DIVERT OIL DROPLETS
FROM A SUBSEA BLOWOUT

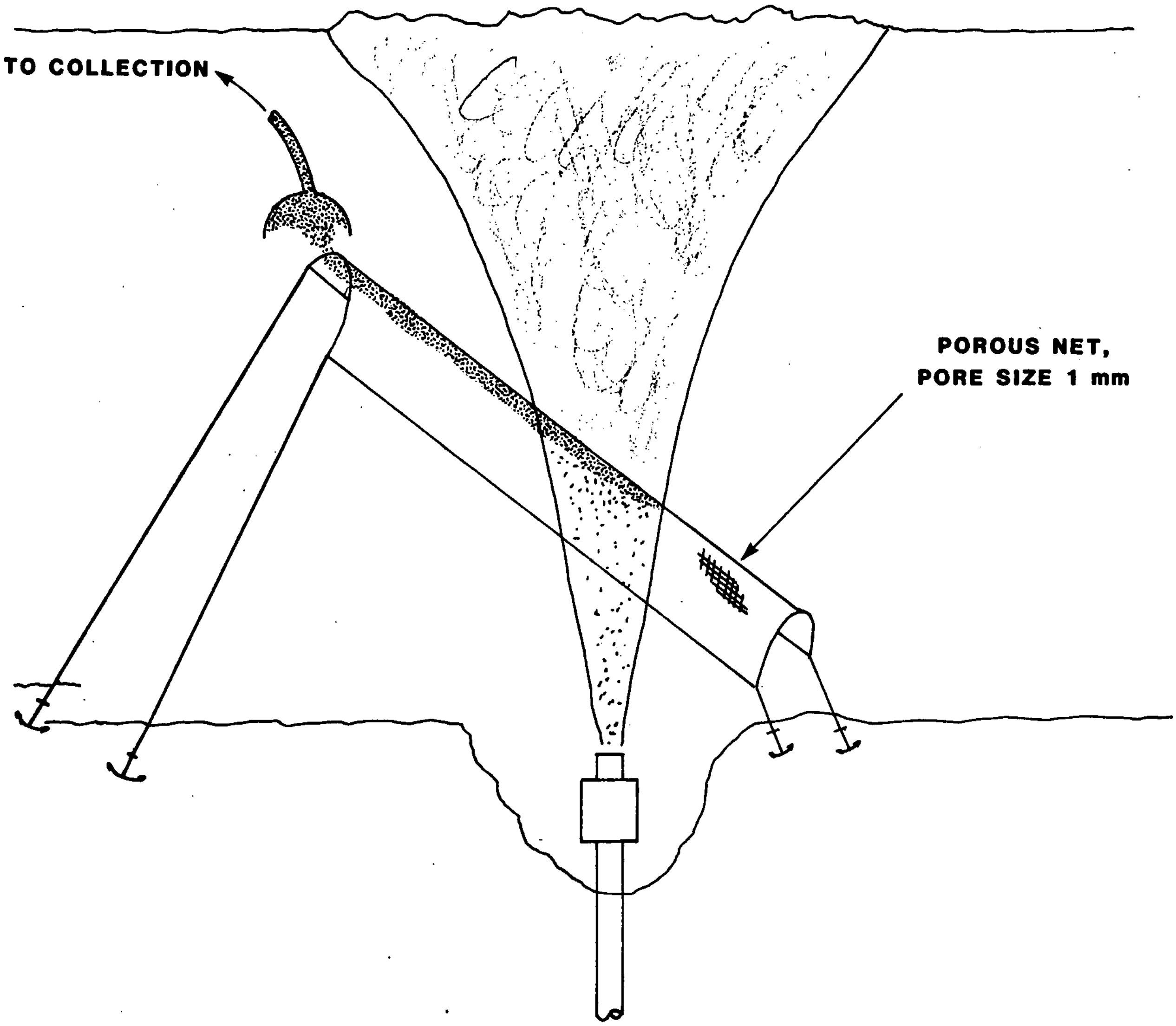
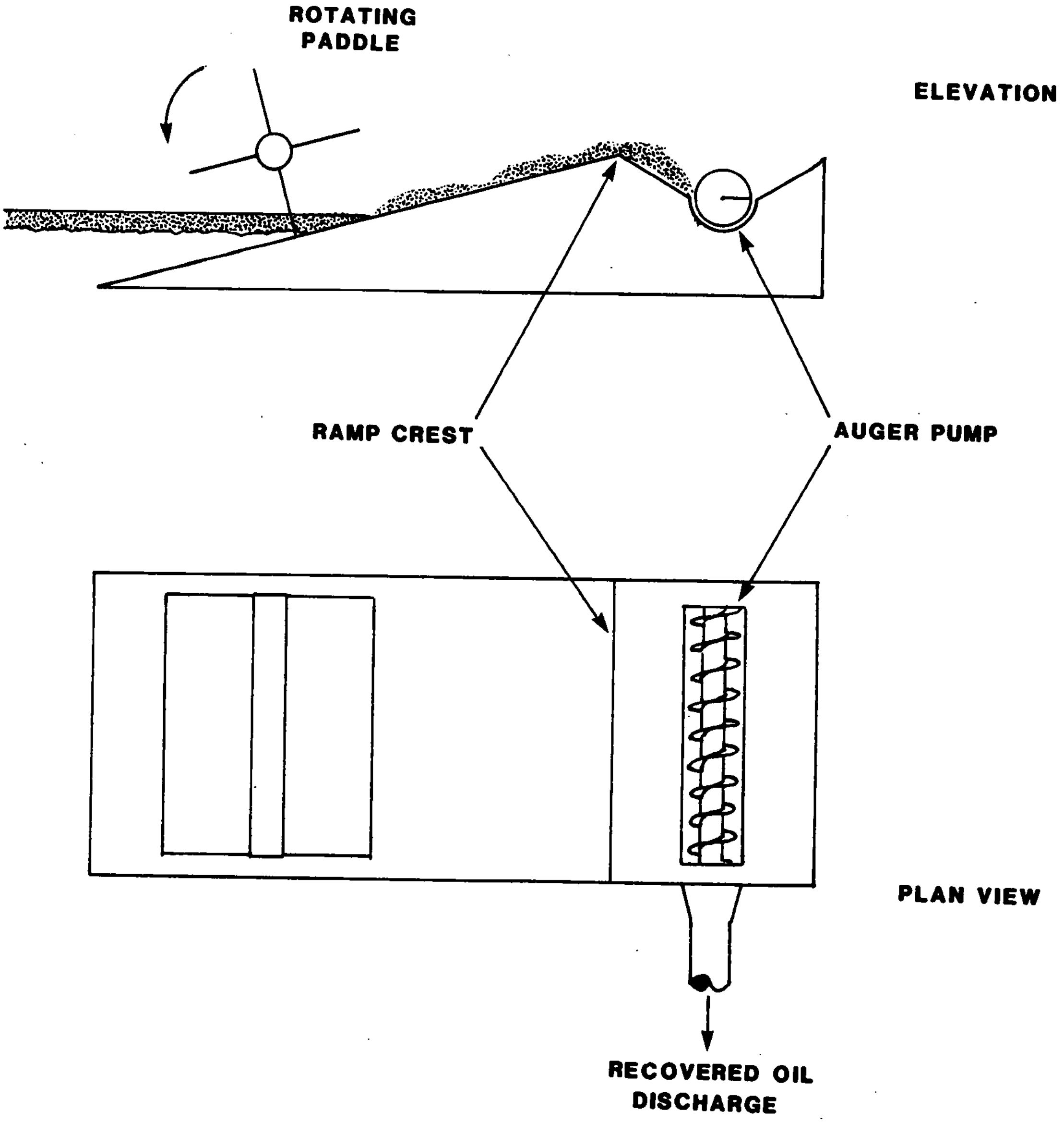


FIGURE 7 : PADDLE WHEEL CONCEPT

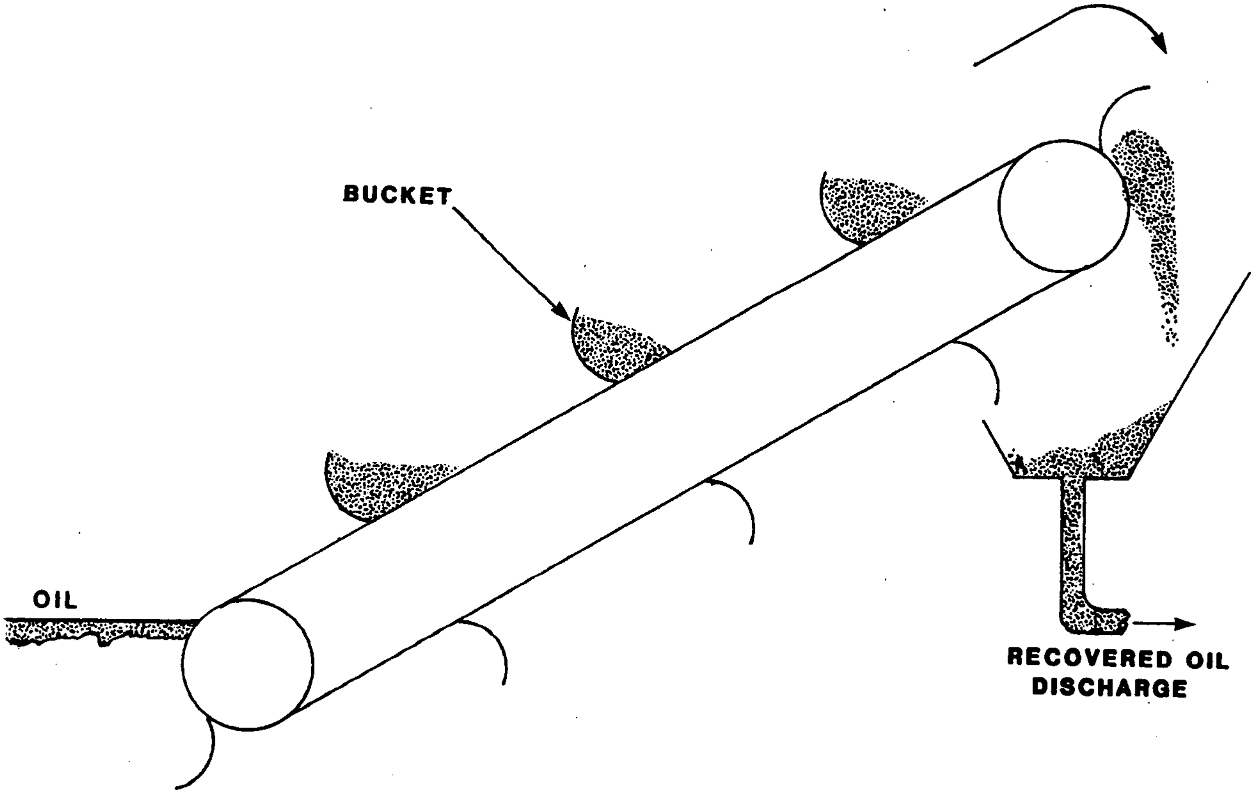


Bucket conveyor. This concept is shown schematically in Figure 8. The basis for its suggestion is the fact that Type 2 oil mats and chunks can be mechanically lifted because of their non-flowing nature. As conceived, the device would be inherently self-feeding, thus solving the problem of a non-continuous flow of oil on the water surface.

One serious and limiting drawback with this concept is its mechanical complexity. Another drawback is its size, which would dictate the use of a large vessel to deploy and to support it. Its size and weight would also make the device fairly unresponsive to waves, a serious problem as the draft must be accurately maintained if the paddles are to draw oil in rather than to push oil away. This situation was determined to be the case even though various types of buckets (e.g., perforated and rounded), configurations of bucket support, and immersion structures were considered.

In summary, such a device may be feasible for nearshore recovery operations but would be limited in its application to offshore, Type 2 oil recovery.

FIGURE 8 : BUCKET CONVEYOR CONCEPT



IN-SITU BURNING

In-situ burning of Type 1 and Type 2 oils was discussed at length during the brainstorming session. As no burning experiments have been done with viscous, waxy crudes, the following comments are based upon previous experience on the in-situ burning of conventional crudes and on the oil property assumptions stated previously.

For Type 1 and Type 2 oils, it is expected that the oil could be contained for burning, although the environmental limitations are similar to those for conventional booming operations. Specifically, favourable sea and weather conditions exist for only 3% of the time in winter and for 20% of the time in summer. Further complicating the use of in-situ burning is the fact that currently available fireproof booms are heavy and cumbersome, and thus are not easily deployed and retrieved. This is a serious drawback considering the short duration of favourable conditions, following which the boom would have to be retrieved. New, lightweight fireproof booms that are now becoming available could overcome this limitation although these may suffer from lower durability.

With respect to the burning properties of waxy crudes, it is expected that both Type 1 and Type 2 oils will burn once ignited.

For Type 1 oil it is expected that the heat from the fire would continually melt surrounding droplets, allowing them to flow into the fire zone, thus sustaining the burn. It might be necessary to promote initial ignition with diesel fuel to ensure an adequate initial heat source. Further testing is required to determine the limiting parameters.

For Type 2 oil, mats and chunks, it is expected that ignition and subsequent combustion would be comparable to that of conventional crudes. In fact, the non-spreading nature of these oils may allow removal efficiencies equal to or greater than that of conventional oils.

CHEMICAL TREATMENT

It is known that chemical dispersants are not effective on viscous oil spills. Oil viscosities of about 2000 mPa.s are believed to be the upper limit (ITOPF 1982). It is likely , then, that the conventional use of dispersants will not work on Type 1 or Type 2 oils. That is, dispersants will not be effective on surface concentrations of waxy crude oil when the pour point of the oil is significantly greater then ambient temperatures, say, 10°C higher (Martinelli and Lynch 1980).

It is conceivable that dispersants could be effective on waxy crude oils when their temperature is higher than their pour point, that is, when they are still relatively non-viscous. This circumstance exists in oil-well blowouts when the hot oil has yet to enter the relatively cold environment or when the hot oil enters the water environment (for subsea blowouts) but has not yet cooled to a temperature below its pour point. These situations are different and are discussed separately.

Injecting Dispersant into the BOP Stack

Oil flowing through the blowout preventer (BOP) stack in an oil-well blowout is hot and thus non-viscous. If dispersants could be injected into this oil prior to its entering the water, it is possible that the dispersant would mix with the oil. Quick dispersion of the oil once it enters the water phase would be inevitable if good dispersant and oil mixing occurred in the pipe. A recent, brief study of the concept (Westergaard 1985) concluded that the technique presents no engineering problems in terms of using either existing choke and kill lines on a BOP or a purpose-built access port and line. Research would be required to determine if the oil would indeed mix well with the injected dispersant considering the two-phase nature of the flow (oil and gas) and the short mixing time available.

One serious drawback with the approach is that it might be seen as interference by those attempting to work on the same BOP stack to bring the blowout under control, an activity which obviously would take precedence over spill cleanup. If both operations could not be accomplished simultaneously or cooperatively, then the spill countermeasures approach could become a two-phased one: one could first attempt to inject and mix dispersant into the oil plume immediately above the discharge point and away from the BOP stack; if attempts at blowout control at the well-head failed, then the use of the BOP lines to inject dispersant could proceed.

Injecting Dispersant into the Oil Plume in Water

Hot oil discharging from a subsea blowout into the water would cool quickly but if dispersants could somehow be added to the discharging oil prior to its reaching environmental temperatures, dispersion could be effected. The main concern related to this idea is that major losses of dispersant to the water phase could occur. Thus, to be feasible the approach would require the use of highly oleophilic dispersants or so-called emulsion inhibitors (Ross et al. 1985), and the use of a mixing system to ensure good oil and dispersant contact. One such mixing device could be a short chimney positioned over the well in which baffles or other mixing aids operated.

Other problems that must be addressed include the identification of appropriate storage and injection systems for underwater use and the logistics of supplying the required dosage of chemical.

SINKING AGENTS

Given the constraints on conventional recovery operations imposed by the harsh environment, consideration was given to the application of sinking agents. Such agents, when applied to a floating oil slick, could sink the slick and could limit the areal extent of environmental damage. This technique has several advantages: it does not require sophisticated and wave-sensitive application equipment and it offers the possibility for a high-rate, single-step disposal process. Environmentally, the main disadvantages are that the oil is sunk to the bottom in its most toxic (unweathered) form and once there, biodegrades at a low rate.

To be effective the application of sinking agents must satisfy three criteria:

- the oil must stick to or be incorporated into the agent;
- the agent must be hydrophobic in the presence of excess water; and
- the application must result in the majority of the oil or oil particles being hit by the agent.

Little information is available in the literature on the use of sinking agents. One study carried out for Environment Canada (Dick and Feldman 1975) examined the efficiency and retentivity testing of several sinking agents. Although the investigators observed an increase in efficiency with viscosity, for an extremely viscous oil (Bunker C at 2°C) the sinking of the agent/oil mass was found to be a rather ineffective and slow process. In addition, the retentivity of oil was found to be quite variable; after 150 h, none of the agents retained more than 80% of the oil originally sunk and in some cases, retentivity was as low as 30%.

Moreover, there are several negative aspects that relate specifically to the properties of viscous, waxy crude oils. The first is the possibility that, after even slight weathering, the surface of the oil chunks or particles will be non-sticky and, therefore, not amenable to sinking agent application. Secondly, the oils of interest are of relatively low density and, therefore, are generally more difficult to sink.

For these reasons, the use of sinking agents was not seen to be a viable alternative. Should an agent be found to be effective (i.e., a 'sticky' agent) with viscous, waxy crudes, other factors which will require consideration (and which might limit their attractiveness) include sinking agent delivery and application operations, i.e., logistical requirements.

CONCLUSIONS AND RECOMMENDATIONS

An evaluation of existing and proposed countermeasures devices, and a brainstorming of possible improvements have led to the following conclusions and recommendations.

CONCLUSIONS

1. For the purposes of this study, two categories for the properties of viscous, waxy crude oils were defined:

   - Type 1: fresh oil that floats as individual, relatively small (1-5 mm) droplets. These droplets may agglomerate but will not recoalesce, and 'slicks' will comprise droplets and clumps; and
   - Type 2: weathered oil that forms globules and mats. These oil masses are not likely to coalesce or agglomerate, nor will they cling to or adhere to oleophilic surfaces. Globules could be millimetres to centimetres in diameter, and mats could be up to several centimetres in thickness.

2. The effective skimming of viscous, waxy oil spills (or other types of oil spills) is dependent on the ability to contain and to concentrate the oil. The main criterion for the selection of containment devices is the shortness of the periods of acceptable working conditions that are characteristic of the east coast where waxy crudes have been discovered. As such, desirable booms are those that are robust and easily deployed and retrieved, booms such as the Nordan oil boom and Kepner Sea Curtain, both of which are stored on reel-packs. The Roulunds Ro-Boom and Vikoma Boom Deck Reel are other acceptable alternatives.

3. For inshore containment, netting systems such as the Jackson/West Net may be useful. Small vessels, each handling up to 1 km of boom, could be used to encircle and to concentrate oil in a batch-type process.

4. Of the recovery devices considered for Type 1 oil, hydrodynamic devices - specifically the Mattsson Walosep skimmer - were felt to offer the best prospects for the recovery of offshore oil. Several specific problems were noted with the device, namely, possible adhesion of oil to the vanes and collection chamber and lack of a positive suction feed at the collection pipe inlet. It was felt that these problems could be overcome with further research and equipment modifications.

   Other devices considered for offshore Type 1 oil spills were deemed unacceptable because of their inapplicability vis-a-vis the specific oil properties, or limitations with regards to oil recovery rate or environmental conditions or both.

   The nearshore recovery of Type 1 oil could be effected with a down-sized hydrodynamic device, or with a mechanical device such as a rotating non-oleophilic belt (i.e., a device similar to the JBF DIP). Although the latter is not recommended for offshore use because of its low recovery rate and sensitivity to waves, these factors are less critical in a nearshore operation.

5. For the recovery of Type 2 oil, no techniques were judged to be applicable to recovery offshore. Although several techniques were determined to be applicable to the specific oil properties, each had severe limitations with respect to achievable recovery rates and sensitivity to waves.

   Three techniques were noted for nearshore recovery operations: the toothed disc and Shark 5000 skimmers, and the use of porous nets for containing and concentrating nearshore slicks.

6. Conventional chemical dispersion is not applicable because of the high viscosity of the subject oil. The only possibility for using dispersants is to apply them when the oil is fresh and not yet cooled to

ambient temperatures. This might be accomplished by injecting the dispersants into or near the well-head of a blowing well, a concept which is currently unattractive, but which may be refined through further research.

7. In-situ burning is an attractive countermeasures option; however, it requires containment of the oil slick and, therefore, its applicability would be subject to the environmental limitations of booming operations.

8. The use of sinking agents is not applicable because of the poor adhesive properties of the subject oil, and the known problems of sinking a high viscosity, low density oil.

RECOMMENDATIONS

1. Further study is required to elucidate the spill-related properties of waxy crude oils, especially concerning droplet formation, droplet agglomeration, droplet recoalescence, adherence properties, skin or crust formation, and emulsion tendencies.*

2. Field tests of the Walosep skimmer with Type 1 oil would be useful to confirm the assumptions made in the evaluation process. Upgrading modifications are recommended in the form of surface coatings or the use of heat to prevent oil adhering to the vanes and collection chamber, and in the use of a vertically oriented screw-auger to provide a positive suction feed at the collection pipe inlet.

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* These questions are being addressed in a current ESRF study entitled, "The behaviour and fate of waxy crude oil spills".

3. Field tests of the Seawolf toothed disc and Shark 5000 skimmers with Type 2 oil would be useful to confirm their applicability to the specific oils of interest.

4. The concept of injecting dispersants into or near the well-head of subsea blowouts warrants further research to determine its logistical limitations, possible effectiveness, and technical feasibility.

5. Further research is required on the burning of Type 1 droplets, and to determine the limiting parameters of burning both Type 1 and Type 2 oil.

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APPENDICES

APPENDIX A

LIST OF CONTACTS
AND
BRAINSTORMING TEAM

Letters to and/or personal communication with:

1. B. Breiland, PFO, Norway
2. M. Foulds, Vikoma International Limited, England
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4. K. Hebron, EPS, W. Vancouver
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6. H.W. Lichte, OHMSETT
7. T. Mackey, Hyde Products Inc.
8. D. McKechnie, Hurum Engineering Ltd.
9. K. Meikle, EPS, Ottawa
10. D.E. Morris, Morris Industries Ltd.
11. P.R. Morris, Warren Springs Laboratory, England
12. R.J. Percy, British Petroleum Company
13. W. Ryan, CCG, St. John's
14. E. Tedeschi, Versatech Products Inc.
15. R.E. Williams, Exxon, Houston

Brainstorming Team

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APPENDIX B

RESULTS OF BRAINSTORMING SESSION

SUMMARY OF BRAINSTORMING IDEAS

A. Containment

Type 1 Oil

- use of nets to contain the surface plume of a subsea blowout: utilizes main advantage of nets which is the ability to use great lengths of boom
- could be shaped to funnel droplets to a downstream pocket for further treatment (i.e., recovery or dispersion)

Sea State

- Containment of oil in east coast waters should be possible during intervals of moderate sea conditions using nets. Flow through characteristics of net boom should enhance survival potential.

Deployment/Retrieval/Operation

- Compactible nature and overall construction and design of net booms allow storage of long lengths and uncomplicated deployment and retrieval.

Factors re This Study

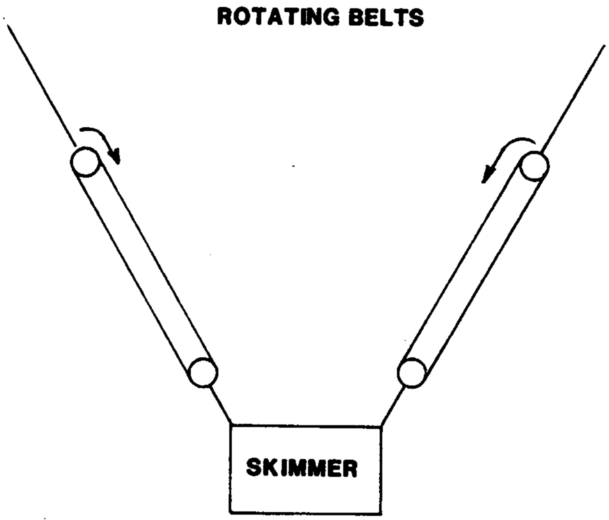
- Testing of most recent net configuration is required to confirm capability as a containment device, specifically in nearshore situations. More limited use is envisaged for offshore spills.

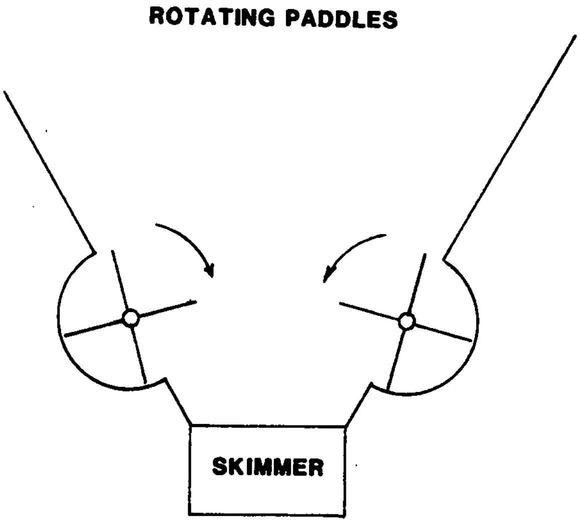
Type 2 Oil

- main problem is the poor flow characteristics of mats
- could overcome this using feeding mechanisms along the boom lengths
- possible feeding mechanisms:
  - rope mops
  - belts (on vertical axes)
  - paddles (on vertical axes)

Sea State

- Mechanical feeding systems are likely to be sea state sensitive: since they are simply entraining a surface flow they would work best in calm conditions.


ROTATING BELTS


ROTATING PADDLES

B. Recovery

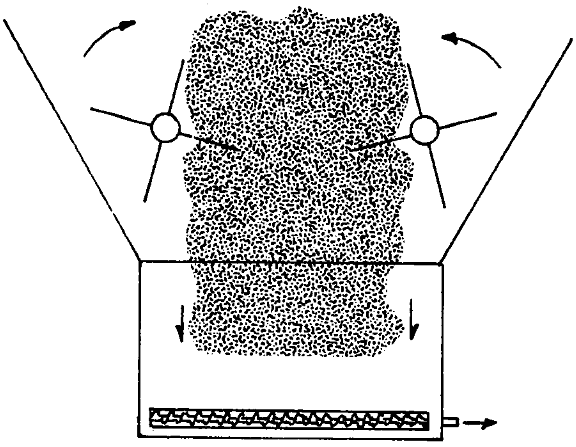
Type 1 Oil
- use a huge weir (or large pipe), submerged approx. 150 mm to suck up everything: take care of oil/water separation on board
- use 'filter press' for continuous flow oil/water separation
- use oleophilic 'brushes' to 'sorb' oil, stripping achieved with 'combs', or water spray
- in the plume of a subsea blowout, use nets to direct oil to subsea collection device
- nets may be able to separate oil droplets from gas/water flow
- non-oleophilic belt: good possibilities as it creates a quiescent zone from which collected droplets can be recovered

- Walosep skimmer: good prospects, requires modifications to overcome: sticking, clumping of droplets - use slippery surface coatings, or heat offending surfaces to reduce problem; and internal feeding problem - use auger type pump to feed collection pipe, thus maintaining a positive head in transfer hose.

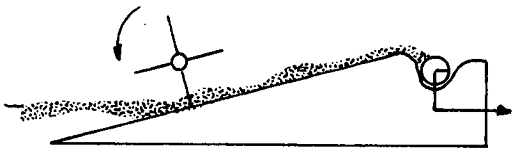
Type 2 Oil

- to obviate the feeding problem, use small portable skimmers within a boomed area; skimmers could be remotely controlled
- to ease the flow of oil within the boomed area, break up the mats into manageable chunks using mechanical means or high pressure water
- use mechanical devices (paddles, progressive auger) to push mats up a ramp, or over a weir

PADDLES ON VERTICAL AXES



PADDLES ON HORIZONTAL AXIS



- use two porous belts (on vertical axes) to draw in oil, squeeze out water
- use porous nets to recover oil in a batch process; to overcome problem of oil extruding through net as it is lifted out of the water, use a strip of impervious material along the bottom of the net boom, as the boom is drawn in to form a sac this material forms an impervious bottom of the sac
- another method using nets which has been employed elsewhere is to draw the boom in forming an oil containing sac, tow the sac to shore at high tide, and pick up the oil off the shore at low tide using earth-moving equipment
- alternatively the oil containing sacs could be dragged up the ramp of a stern trawler
- Shark 5000: oil stripping mechanism - toothed drive roller that forcibly ejects oil from the open link recovery belt - is very attractive and worth considering for use on other design hybrids

Sea State

- All recovery devices discussed are adversely affected by even moderate states. Weir devices and mechanical devices (paddles, oleophilic and non-oleophilic belts) are particularly susceptible to breaking waves.

Deployment/Retrieval/Operation

- With the exception of large belt devices and netting systems, most devices could be deployed using a hydraulic arm similar to the Framo skimmer. This would allow fast deployment and retrieval in changing sea conditions.

Factors re This Study

- Developing a modified Walosep skimmer and a comprehensive evaluation of the Shark 5000 and Seawolf toothed disc skimmers were concluded to afford the greatest potential for recovering viscous, waxy crude oils.

C. Chemical Treatment

Dispersants	- blowout plume or well-head injection - use static mixer above injection point to promote oil/dispersant mixing: limitations due to back pressure created - use oleophilic chemicals due to their greater affinity to oil in presence of water
Gelling Agents	- for Type 1 oil, not expected to be effective due to a questionable ability of the agent to cross-link droplets among water - for Type 2 oil, oil is already essentially 'gelled'
Pour Point Depressants	- wax crystal modifiers, used to increase pumpability of high pour point oils - could be useful as aid to other methods (recovery, dispersion, in-situ burning) - may increase fluidity of oil and allow mats and droplets to recoalesce - however, PPD's are known to leach quickly from oil slicks on water, within 2 to 4 hours

Sea State

- Dispersants, gelling agents and pour point depressants are not expected to be of use as surface-applied agents due to mixing requirements. If dispersants were successfully injected at well-head, high sea states would aid dispersion.

Deployment/Retrieval/Operation

- Subsea injection of chemicals is fraught with logistical problems: delivery and storage systems, chemical dosage regulation, quantities of chemical required.

Factors re This Study

- Chemical treatment does not appear to be promising for viscous, waxy crude oils. Well-head injection of dispersants may have some promise if technical and logistical problems can be solved.

D. In-Situ Burning

- use nets to contain blowout products at the surface, enhance burning of oil in the gas fireball

Sea State

- Burning should be possible during intervals of calm or moderate sea conditions when containment of slicks can be achieved.

Deployment/Retrieval/Operation

- Deployment and retrieval are positive aspects of netting systems when used for containment. Durability of nets is questionable in presence of a surface burn.

Factors re This Study

- Containment ability of nets in offshore environment must still be proved. Life expectancy of nets would be low in a burning situation; could be used for short periods as sea states allow.

APPENDIX C

PRELIMINARY SCREENING OF RECOVERY DEVICES: DETAILED COMMENTS

WEIRS

Oil Recovery

- Type 1 Oil

Potentially applicable.

Possible problems include adhesion of oil to weir lip, inner surface of weir chamber, and transfer hose with resultant clogging.

Very high uptake of water, generally, but some reduction if hydro-adjustable weir lip is utilized.

- Type 2 Oil

Inapplicable to viscous mats and chunks.

Sea State

Optimal application is in calm seas or quiescent zone that is mechanically created.

Deployment/Retrieval/Operation

Simple device that can incorporate robust components.

Readily deployable from vessel of opportunity.

Factors re This Study

Teflon coating of components might alleviate potential clogging problems for globules.

Concentration and build-up of globules into oil layer several centimetres in thickness could preclude usefulness of this approach.

Positive displacement pump at skimmer head must be considered.

OLEOPHILIC SURFACE DEVICES

(disc, rope mop, belt, drum)

Oil Recovery

- Type 1 Oil

Some adhesion of oil to smooth PVC and metal surfaces occurs; more pronounced adhesion to fibrous material.

Method of presentation of oleophilic surface may have a bearing on oil recovery potential.

Rotation downward into oil is essential to recovery by adhesion.

Recovery rate per machine (assuming oil adhesion occurs) is relatively low for commercial units.

- Type 2 Oil

Generally non-applicable to weathered globules and mats of oil due to non-sticky skin.

Sea State

Generally, not severely affected by sea state for envisaged sea conditions when used. Some units require substantial working platform to house recovery mechanism.

Deployment/Retrieval/Operation

Generally more mechanically complex device involved compared with weir skimmers.

Higher recovery rate demands larger machine which in turn complicates deployment and retrieval; operation from mothership still a possibiltiy.

Factors re This Study

Design of oil recovery component must consider its appropriate initial placement, stripping of oil, and subsequent transfer.

Recovery rate is expected to vary significantly depending upon physical/chemical properties of specific oil spilled.

MECHANICAL SKIMMERS

(toothed disc, paddle wheel, non-oleophilic belt)

Oil Recovery

- Type 1 Oil

Submerging, non-oleophilic belt has potential to process globules of oil; other mechanical devices are less or non-applicable, i.e., no advantage gained by using most other mechanical skimmers.

- Type 2 Oil

Potential utility to recover viscous mats.
Possible application of submerging belt only to globules.

Sea State

Generally, require specifically designed platform which can be larger for some skimmer types.

Location of oil removal mechanism (relative to water's surface) is critical to recovery, particularly in other than calm conditions. Toothed disc, however, is less sensitive to wave action.

Deployment/Retrieval/Operations

Operations from mother ship is possible; free-floating skimming vessel tethered to main ship is likely to be required.

Relatively mechanically complex compared with other skimming principles.

Factors re This Study

Specific concerns include:

Clogging of paddle wheel skimmer with viscous oil.
Rotating, submerging belt requires relative flow of oil to it.
Very high rate of water uptake by toothed disc skimmer is possible when operated in oil in globule form.

Further study of these devices including redesign of some components may be warranted.

SUCTION DEVICES

(air conveyor, vacuum truck)

Oil Recovery

- Type 1 Oil

Agglomeration of globules and clogging would preclude the use of such devices.

- Type 2 Oil

Mats would not be collected by suction devices.
Globules could be removed but recovery rate is relatively low.

Sea State

Limitations of open hose end; floating head could conceivably accommodate some wave action.

Deployment/Retrieval/Operations

Truck-size unit can be positioned on vessel of opportunity.

Proven mechanical reliability.

Minor design changes needed to incorporate skimming head.

Factors re This Study

Suctioning of oil in globule form that does not adhere is most likely substance that could be collected.

Commercial units are widely available as skid-mounted and truck-mounted systems.

Major limitation is the very low rates possible (in the 10 to 20 m^3/hr range).

HYDRODYNAMIC PRINCIPLES

(rotating vane, cyclonic chamber, vortex machines)

Oil Recovery

- Type 1 Oil

May be able to redirect globules into skimmer but their agglomeration and adhesion properties could clog the device.

- Type 2 Oil

Processing of viscous mats is not likely to be possbile

Theoretically, globules of oil could be redirected by induced flow; however, skimming principles vary in their ability to do so.

Sea State

Most devices would be adversely affected by increasing sea state. However, test results for one particular device (Walosep rotating vane skimmer) indicate that this is not the case.

Deployment/Retrieval/Operations

Deployment, retrieval and operation in a contained area is readily accomplished from a vessel of opportunity; an exception is larger, advancing units which depend upon a relative velocity between the oil and the device.

Factors re This Study

Consideration of design of transfer systems is necessary.

One skimming principle in this category, the rotating vane skimmer, has proven capabilities superior to others; oil adhesion, pumping may be problem areas.