ITOPF

PROMOTING EFFECTIVE SPILL RESPONSE

USE OF SKIMMERS IN OIL POLLUTION RESPONSE

TECHNICAL INFORMATION PAPER

5

Introduction

A number of options are available to respond to marine oil spills. The primary technique adopted by many government authorities is mechanical recovery of oil from the sea surface. This is usually achieved by use of booms to concentrate spilt oil, allowing a skimmer to selectively recover and pump the oil to storage. Many different types of skimmer exist with designs optimised to deal with different scales of operation, oil types and environmental conditions.

This paper describes the fundamental requirements for the successful use of skimmers in the situations most likely to be encountered during an oil spill and should be read in conjunction with other ITOPF papers in this series, in particular, on the use of booms, shoreline clean-up techniques and the disposal of oil.

Overview

The ultimate aim of any recovery operation is to collect as much oil as is reasonably and economically possible. A successful recovery system must overcome the interrelated problems of encountering significant quantities of oil and its subsequent containment, concentration, recovery, pumping and storage. The recovery and pumping elements of the overall operation are frequently combined in a skimmer. All skimmers are designed to recover oil in preference to water but designs vary considerably according to the intended use, for example, at sea, in sheltered waters or onshore. Skimmers for use on water include some form of flotation or support arrangement while more complicated designs may be self-propelled and may have several recovery elements, integral storage tanks and oil/water separation facilities (*Figure 1*).

A number of factors should be considered when selecting skimmers, the most important of which are the viscosity and adhesive properties of the spilt oil (including any change in these properties due to 'weathering' over time), together with the sea state and levels of debris. In relatively predictable situations, such as at fixed facilities, for example, marine terminals and refineries, the type of oil handled may be known and a specific skimmer can be selected. Conversely, a versatile skimmer, that may be required to address a variety of situations and oils, may be preferable, for example as part of a national stockpile. However, no single skimmer can cope with every situation that may be encountered as a result of an oil spill and a selection of skimmers may be required, particularly as the oil weathers (*Table 1*).

The intended use and expected operational conditions should then be identified, for example whether the skimmer is to form an integral part of a vessel-mounted, offshore recovery system or is to be deployed manually in a port or on a shoreline. Once these are established, other criteria such as size, robustness and ease of operation, handling and maintenance can be evaluated.

Cover image courtesy Ro-Clean Desmi/Danish Navy.

▲ *Figure 1: A self-propelled weir skimmer for use in ports and nearshore waters. The bow doors open to enhance the swath and allow entry of floating oil. Recovered oil is pumped to an internal storage tank.*

Oil recovery mechanisms and skimmer design

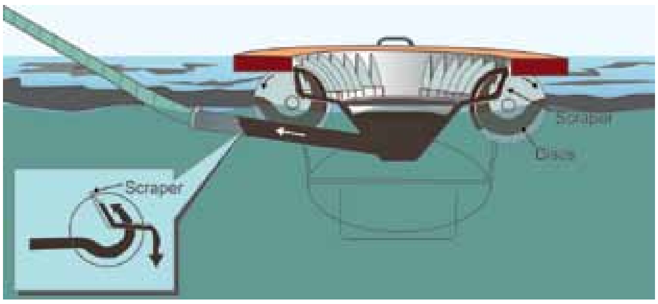
The recovery element of a skimmer diverts or skims the oil from the sea surface, where it flows to the inlet side of a pumping system for transfer to storage. The mechanisms through which oil is removed from the water surface include oleophilic systems relying on adhesion of oil to a moving surface, suction systems, weir systems relying on gravity, and systems that physically lift the oil with mechanical scoops, belts or grabs.

Oleophilic skimmers

Oleophilic skimmers employ materials that have an affinity for oil in preference to water. The oil adheres to the surface of the material, commonly taking the shape of a disc (*Figures 2 and 3*), drum (*Figure 4*), belt, brush (*Figure 5*) or rope-mop (*Figures 6 and 7*) which, as they rotate, lift the oil from the water surface. Once clear of the water the oil is scraped or squeezed off the oleophilic material and allowed to drop into a sump from where it is pumped to storage. Oleophilic skimmers usually achieve the highest ratio of recovered

Skimmer		Recovery rate	Oils	Sea state	Debris	Ancillaries
Oleophilic	**Disc**	Dependent on number and size of discs. Tests show grooved discs can be highly effective.	Most effective in medium viscosity oils.	In low waves and current can be highly selective with little entrained water. However, can be swamped in choppy waters.	Can be clogged by debris.	Separate power pack, hydraulic and discharge hoses, pump and suitable storage required.
	Rope mop	Dependent on number and velocity of ropes. Generally low throughput.	Most effective in medium oils although can be effective in heavy oil.	Very little or no entrained water. Can operate in choppy waters.	Able to tolerate significant debris, ice and other obstructions.	Small units have built in power supply and storage. Larger units require separate ancillaries.
	Drum	Dependent on number and size of drums. Tests show grooved drums are more effective.	Most effective in medium viscosity oils.	In low waves and current can be highly selective with little entrained water. However, can be swamped in choppy waters.	Can be clogged by debris.	Separate power pack, hydraulic and discharge hoses, pump and suitable storage required.
	Brush	Throughput dependent on number and velocity of brushes. Generally mid-range.	Different brush sizes for light, medium and heavy oils.	Relatively little free or entrained water collected. Some designs can operate in choppy waters, others would be swamped in waves.	Effective in small debris but can be clogged by large debris.	Separate power pack, hydraulic and discharge hoses, pump and suitable storage required.
	Belt	Low to mid-range.	Most effective in medium to heavy oils.	Can be highly selective with little entrained water. Can operate in choppy waters.	Effective in small debris but can be clogged by large debris.	Can deliver oil directly to storage at the top of the belt. Ancillaries required to discharge from a vessel to shore.
Non-Oleophilic	**Vacuum/ suction**	Dependent upon vacuum pump. Generally low to mid range	Most effective in light to medium oils.	Used in calm waters. Small waves will result in collection of excessive water. Addition of a weir more selective.	Can be clogged by debris.	Vacuum trucks and trailers are generally self-contained with necessary power supply, pump and storage.
	Weir	Dependent upon pump capacity, oil type etc. Can be significant.	Effective in light to heavy oils. Very heavy oils may not flow to the weir.	Can be highly selective in calm water with little entrained oil. Can be easily swamped with increase in entrained water.	Can be clogged by debris although some pumps can cope with small debris.	Separate power pack, hydraulic and discharge hoses, pump and storage. Some skimmers have built-in pumps.
	Belt	Low to medium.	Most effective in heavy oils.	Can be highly selective with little entrained water. Can operate in choppy waters.	Effective in small debris. Clogged by large debris.	As for oleophilic belt skimmer.
	Drum	Mid range.	Effective with heavy oils.	Can be highly selective in calm water with little entrained oil. However, can be swamped in waves.	As for weir skimmer.	As for weir skimmer.

Table 1: Generic characteristics of commonly encountered skimmer types. The choice of skimmer for effective operations will depend on the oil spilt. As the oil weathers, the effectiveness of a particular type may change, requiring an alternative design for continued recovery. The recovery rate assumes the skimmer would be in a homogenous slick of oil that has not spread or scattered widely.



Figures 2 and 3: Small oleophilic disc skimmer, suitable for oils of medium viscosity. Oil adheres to the rotating discs to be scraped off into a sump for pumping to storage. Requires a suitable pump and hydraulic power supply.

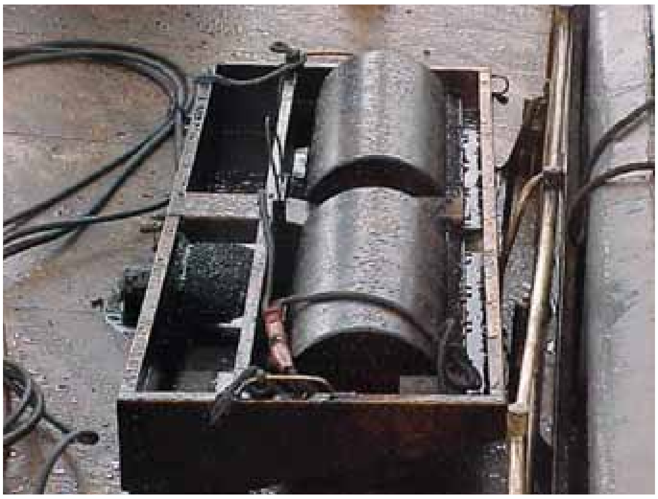


Figure 4: Oleophilic drum skimmer, suitable for oils of medium viscosity. Operates in a similar manner to a disc skimmer in that oil adheres to the rotating drums to be scraped off into a sump for pumping to storage.

Figure 5: Free floating brush skimmer. Oil adheres to the rotating brush sets and is lifted from the water surface. A comb removes the oil from the brushes to storage. A propeller behind the brush draws floating oil towards the skimmer to enhance the encounter rate and throughput (Image courtesy Lamor).

Figures 6 and 7: Horizontal and vertical oleophilic rope skimmers. Interwoven sorbent loops form a continuous mop which floats on the surface to which the oil adheres. The mop is pulled back to a roller and the oil squeezed to a storage tank. Rope mop skimmers are useful to recover oil from among debris, ice and other obstructions.

oil in relation to free or entrained water, also known as the recovery efficiency. They are most effective with medium viscosity oils between 100 and 2,000 centistokes. Low viscosity oil products, such as diesel or kerosene, generally do not accumulate on the oleophilic surfaces in sufficiently thick layers for high recovery rates to be attained. Higher viscosity oils, such as heavy bunker oil, are excessively sticky and can prove difficult to remove. In contrast, water-in-oil emulsions can be almost non-adhesive and can be difficult to recover with some designs of oleophilic skimmers, for example disc skimmers will cut through emulsion, instead of enabling its recovery. Oleophilic materials are usually made from some form of polymer, although metal surfaces have also been shown to be effective. Discs and drums with grooved surfaces have been shown to result in higher recovery rates than smooth surfaces*.

Suction skimmers

In terms of operational theory, the simplest design is a suction device, whereby oil is recovered by pumps or air suction systems directly from the water surface. In particular, vacuum trucks or trailers, that combine the elements of recovery, storage, transport and oil/water separation, are often readily available locally to a spill site, either commercially or from municipal or agricultural organisations and, as such, are ideally suited to recovery of oil on or near the shoreline (*Figure 8*). Smaller, more portable devices

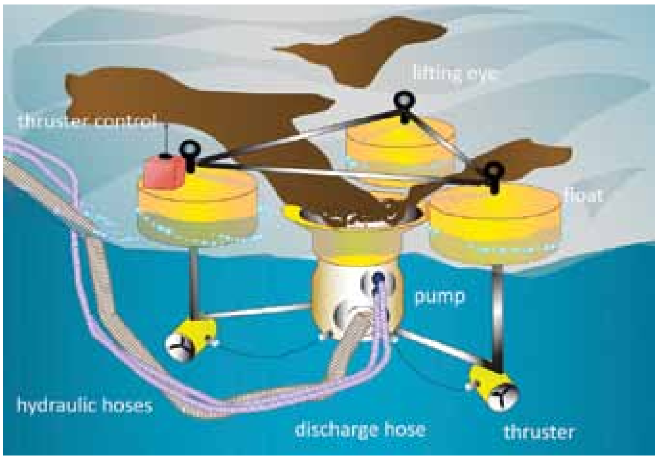
* *Source: Optimisation of Oleophilic Skimmer Recovery Surfaces: Field Testing at the Ohmsett Facility, V. Broje, A. Keller, Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, 36 pp., June 2006.*

▲ *Figure 8: The widespread availability of vacuum systems make these devices ideally suited to recovery of oil on or near the shoreline.*

▲ *Figure 9: Portable vacuum systems can facilitate the recovery of oil on sand beaches and rocky shorelines. The compact system allows work in areas that are otherwise difficult to reach, although storage is limited.*

▲ *Figure 10: Workers placing a hose attached to a vacuum pump directly into the oil. In this instance, the small weir attachment has been removed to allow the viscous fuel oil to flow into the hose, with a consequent potential increase in entrained water.*

▲ *Figure 11: Fixed weir skimmer attached to a vacuum pump. A number of small inlets at the edge of the head allow oil to be selectively recovered. For use in calm water with minimal debris (Image courtesy Lamor).*



◄ ▲ *Figures 12 and 13: A weir skimmer selectively recovers oil over the top of the central weir sited just below the upper surface of the slick by the force of gravity into a central reservoir where it is pumped to storage.*

▲ *Figure 14: Improvised weir skimmer constructed from plastic bottles and metal offcuts, attached to a vacuum pump. This device allows rudimentary recovery and can be adjusted by removal or addition of bottles.*

▲ *Figure 15: A belt skimmer on a large recovery vessel. The belt, constructed from a mesh, allows water to drain through and encourages adhesion of the oil. The oil is lifted on-board and is scraped off to storage.*

▲ *Figure 16: A belt adaptor added to enhance the capability of the base weir skimmer in highly emulsified fuel oil. The high viscosity of the oil prevented its flow towards and over the lip of the weir. Instead, the toothed belt adaptor 'grabbed' the oil enhancing the efficiency, with the cohesive energy of the oil causing the remaining oil to 'flow' toward the skimmer (Image courtesy Ro-Clean Desmi/Danish Navy).*

are also available (*Figure 9*). Placing the suction hose directly into floating or stranded oil, with a mesh screen to inhibit the ingress of debris, provides the simplest method of recovery (*Figure 10*). However, the often indiscriminate nature of this operation may result in very high proportions of water also being collected. Where regulations allow, and the necessary equipment is available, this excess water should be decanted to maximise available storage.

Weir skimmers

Greater selection of oil may sometimes be achieved by the attachment of a device weir to the suction hose (*Figure 11*). Weir skimmers use gravity to selectively drain oil from the surface of the water. By positioning the lip of the weir at, or just slightly below, the interface between the floating oil and water, the oil flows over the weir to be selectively recovered with minimal amounts of water. Advanced types of weir skimmers have adjustable weirs and accurate vertical positioning of the weir is usually achieved by a self-levelling arrangement (*Figures 12 and 13*). Alternatively, weir skimmers can be very simple, rudimentary devices (*Figure 14*), although the level of entrained water may be higher. No weir skimmer is effective in steep waves, although swell alone does not generally interfere with skimmer operation. To overcome friction losses along transfer hoses, some weir skimmers have an on-board pump so that the recovered oil is pushed along the hose rather than relying on suction.

Other skimmer types

Other skimmer designs have been adapted to cope better with waves and rougher seas. Upward rotating belts, for instance, can be partially lowered beneath the oil/water interface to reduce the influence of surface waves. The oil is then scraped off the belt as it rises above the surface and drops into a storage tank or other containers. Belts may be constructed from an oleophilic material, as previously described, relying on the adhesion of the oil to individual elements of a rotating brush (*Figure 5*), chain link or mesh (*Figure 15*). Others use buckets or paddles on the belt to aid lifting of the oil from the water surface. Some belt designs may incorporate a combination of such features. Conversely, downward rotating belts push the oil down into the water and then capture it when it re-surfaces within a quiescent collection area behind the belt.

The localised water currents induced by rotating discs, belts and drums may be sufficient to allow oils of light to moderate viscosity to flow naturally towards a skimmer once recovery commences. Designs utilising toothed discs or belts to 'grab' the oil may enhance flow of more viscous oils and draw the oil into the skimmer. Some weir skimmer designs incorporate interchangeable adaptors to prolong their use as the oil weathers and its viscosity increases (*Figure 16*). One design intended for recovery of very heavy oils comprises a rotating drum or cylindrical mesh which allows the oil to be retained within the mesh while water drains through

Figure 17: Mechanical drum skimmer deployed in a port area. Teeth on the rotating drum draw the oil towards the device where it is recovered into the drum and pumped to storage. The drum is constructed from a mesh to minimise recovery of water.

(*Figure 17*). However, the very high viscosity of some oils or emulsions can eventually prevent flow towards the device and continued recovery will be possible only if some form of propulsion is provided to allow the skimmer to move to the oil or if the oil is pushed towards the skimmer.

Several skimmer systems have been designed for operation in fast-flowing waters or at higher towing speeds. The approach typically followed is to increase the area behind the collecting aperture, causing the velocity of the water and oil to slow upon entry to the skimmer and the oil to surface for collection. In order to be effective, such systems must be able to cope with large volumes of fast-flowing water and overcome the turbulence created.

Limitations of oil recovery

As with many oil spill response techniques, successful mechanical recovery is limited by factors such as adverse weather conditions, oil viscosity and the effects of currents and waves. The spreading and fragmentation of a slick limit the amount of oil available to be recovered within a given timeframe, termed the encounter rate. Similarly, the ability of a system to recover oil selectively may be a significant concern if storage capacity is limited. A further limiting factor may be the pump capacity, affecting the distance over which the oil can to be moved to storage. An indication of the potential performance of a recovery system is given by test performance criteria such as throughput efficiency, recovery efficiency and oil recovery rate but each of these is fundamentally constrained by the encounter rate.

Encounter rate

The encounter rate has two components: the area of the water surface 'swept' by the skimming system, which is itself a combination of the swath, i.e. the width over which the oil is collected and the speed of advance of the recovery system; and the degree to which slicks have spread and fragmented. At sea, large slicks of freshly spilt oil may be recovered in suitable conditions without containment, provided the oil remains sufficiently thick, coherent and homogeneous (*Figure 18*). In such situations, the capability of a skimmer may be limited only by its recovery capacity and by suitable and sufficient storage. As a consequence, the prompt mobilisation of resources is an important factor in ensuring skimmers are able to work most effectively in freshly spilt oil.

The primary reason the recovery rates published by manufacturers of skimmers are often unobtainable is the inherent tendency for oil to spread, fragment and weather once spilt (*Figures 19 and 20*). Experience from numerous spills has consistently shown that oil cannot be expected to remain sufficiently concentrated to sustain recovery rates achieved under test conditions. Test results may therefore be misleading and should be used for comparative purposes only.

Once the oil has spread, the effectiveness of a recovery system becomes more dependent on the rate at which oil is encountered. The speed of the recovery vessel, its effective swath, as well as the thickness and extent of scattering of the oil, all determine this rate. These latter factors are determined by the spreading rate, the time elapsed, weather conditions, the oil type and the degree of emulsification, over which little control is possible. However, the swath and operating speed can be varied dependent on certain limitations. For example, the encounter rate is often enhanced with the aid of a boom, allowing a wider swath and concentrating and retaining the floating oil for subsequent recovery. Deployment strategies for booms will therefore largely determine the operating practices for many skimmers. In particular, where a recovery system is static in relation to water movement, the performance of most skimmers is impaired due to the tendency for floating oil to escape confinement by booms in currents exceeding 0.35-0.5 ms-1 (0.7–1 knot). This limitation is partly overcome in certain types of self-propelled skimmers where a belt or sorbent mop array is rotated, usually between catamaran hulls, so that its velocity relative to the floating oil is effectively reduced or is zero when the vessel is underway. This may have the added benefit of minimising turbulence in the oil and thereby reducing the potential for emulsification.

To some extent, the need for a large swath is offset by the tendency of the oil to form windrows at sea, whereby the oil becomes concentrated into narrow bands aligned with the wind direction. Any such oil may be collected using a recovery device with a relatively narrow swath and, ideally, direction from a spotter aircraft. The increased oil concentration and thickness within the windrows and the fact that the water between the windrows is relatively free of oil, means an encounter rate can be achieved that is comparable to a device with a larger swath.

In confined areas, such as ports, marinas, inland waterways or close to shore, the encounter rate may be more affected by the presence of obstacles, such as vessel hulls, pilings and other port infrastructure, rocks or debris and by the oil entering shallow water or stranding onshore. Oil trapped in sufficient thicknesses against natural barriers, such as

Figure 18: A recovery vessel in a large and homogeneous slick of thick oil, allowing highly effective use of resources.

Figure 19: As the oil spreads and starts to fragment, the encounter rate decreases, necessitating greater effort to recover.

Figure 20: After some weeks at sea, the oil has fragmented and weathered into small plates, a metre or less in diameter (ringed), and tarballs over a large area, causing the overall efficiency to drop significantly. At this point in the response, recovery vessels should have been demobilised as continued operations may not be considered effective.

seawalls and other features of the shoreline, may be readily recovered but if the oil moves around, the ability of skimmers to follow the oil may be restricted.

As the volume of oil remaining on the sea surface decreases, either as a result of evaporation, dispersion or other weathering processes, or because the majority has been collected, the encounter rate will similarly decrease and a point will arise when a decision to demobilise resources should be taken.

Performance criteria

A number of performance criteria can be established by testing skimmer systems within the confines of experimental tanks. An important determinant of a system's overall performance is the recovery efficiency, i.e. measuring the selectivity with which oil is recovered in preference to water. This is expressed as the ratio of the quantity of oil recovered to the total quantity of oil and water collected.

Throughput efficiency compares the quantity of oil collected with that encountered and hence highlights the losses that occur from the containment barrier and the recovery device itself. The throughput efficiency tends to decrease with increasing operating speeds and worsening sea states, notably increasing wave height and, more importantly, decreasing wavelength and choppy seas. In other words, at higher speeds, a trade-off exists between a reduced throughput efficiency and a greater encounter rate.

Waves lead to the loss of oil from a boom, either as a result of splash-over or due to poor wave-following characteristics so that bridging occurs between crests. Similarly, the failure of a skimming device, particularly weir skimmers, to remain at the optimum oil/water interface often results in the intake of large quantities of water. In addition, turbulence caused by the skimmer movement relative to any waves can lead to loss of oil under the skimmer. Ideally, a recovery device should be small with a low mass so as to faithfully follow wave movements. Devices that are rigidly attached or built into a vessel and so unable to move independently are less effective in higher sea states because they can move out of phase with the water surface. On the other hand, even a heavy swell is unlikely to be detrimental providing the wavelength is sufficiently long.

A further parameter of interest is the oil recovery rate; the quantity of oil the skimmer recovers per unit time, for example m^3/h. The oil recovery rate is the product of the encounter rate and the throughput efficiency provided that all parts of the system (particularly pumps and storage) have the capacity to handle this flow rate. The maximum pump capacity, adjusted for typical oil viscosity and head loss, is often taken as the sole indicator of a skimmer's capacity and is also known as the 'nameplate rate'. While this is clearly important, other elements, such as how much oil the system has failed to collect and the amount of water collected with the oil, should also be considered. The overall performance of a system should be judged from a combination of pump capacity, oil recovery rate and recovery efficiency, which together define the rate at which oil can be recovered, and the amount of associated free water.

Oil viscosity

The viscosity of the oil is a primary limitation on the efficiency of most recovery devices. Oils with high pour points, including some heavy crudes and fuel oils, generally do not flow easily. If the ambient temperature is below the pour point, the oil will become semi-solid and, hence, will be difficult to recover, since it will not readily flow towards the skimmer.

Viscosity is also affected by the tendency of many oils to form water-in-oil emulsions, leading to an increase in the overall volume of pollutant by three to four times or more. As emulsions form, the viscosity also rises dramatically and viscosities of the order of 100,000 centistokes (cSt) and greater are common. In some situations, the injection and thorough mixing of demulsifying agents or chemical emulsion breakers can be used as a means of reducing this problem, thereby facilitating pumping while at the same time minimising the storage volume required.

The problems arising from increasing viscosity over time due to weathering of the oil necessitate continued re-evaluation of response strategies, including the use of the most applicable skimmer and pumping arrangement. For example, oleophilic skimmers may be able to operate efficiently in oil that has been freshly spilt and has not undergone significant weathering. However, with the increase in viscosity and possible inclusion of debris, recovery then becomes less effective, necessitating their replacement, possibly by weir skimmers using screw pumps with debris cutters (see front cover). However, any skimmer may ultimately become ineffective, necessitating the use of grabs (mechanical clam shell buckets) or excavators (*Figure 21*). Fishing or other vessels equipped with cranes, to handle nets and catch, can often be readily adapted to use grabs. However, while grabs and excavators are often readily available, their use is slow and, unless carefully operated, can incorporate large amounts of associated water. One of the simplest and most effective approaches to the recovery of these highly viscous and semi-solid oils is the use of manual scoops deployed from small fishing boats (*Figure 22*). Holes drilled in the scoops allow water to escape and the oil is transferred into drums or one tonne bags on board.

▲ *Figure 21: Use of an excavator to recover highly viscous fuel oil. The concentration of recovered oil was maximised by instructing the operator to hold the bucket above the water surface for a short period, to allow entrained water to run off. This reduced the subsequent disposal costs at the expense of recovery efficiency.*

▲ *Figure 22: A fisherman using a mesh scoop to recover small clumps of highly viscous fuel oil.*

Pumps, hoses and power supplies

The pumping phase often determines the overall performance of a skimmer because all pumps lose efficiency, albeit at different rates, as oil viscosity increases. In general, positive displacement pumps are more suitable for handling recovered oil. Centrifugal pumps are both limited in the viscosity of the oil they can handle and tend to promote the formation of water-in-oil emulsions. Some specialised pumps, including those designed to pump concrete or slurry and those based on an Archimedes screw principle, have a very high viscosity tolerance but the internal resistances of discharge hoses may then become a limiting factor.

Generally, the amount of water recovered with the oil should be kept to a minimum, in order to optimise storage and reduce subsequent processing costs. However, with high viscosity oils, recovery of free or entrained water may provide

▲ *Figure 23: Burst hose as a result of excessive internal pressure from pumping highly viscous oil (Image courtesy NOFO).*

an initial benefit in that the back pressure encountered from the resistance of the oil while pumping and the power required to pump over a specified distance can be reduced. This will reduce wear and tear on components (*Figure 23*). Skimmers that recover large amounts of water by virtue of their design may be advantageous in such situations, provided that sufficient storage is available or the water can be decanted subsequently. Steam heating to reduce blockages of pumps and hoses may also assist flow. Significant drops in pump inlet pressure have been demonstrated through the use of an annular water injection ring, where the injected water acts as a lubricating medium between the oil and hose wall (*Table 2*). Where available, the use of shorter and/or larger diameter discharge hoses may also serve to improve pumping efficiency.

Transfer hoses and hydraulic hoses should be fitted with flotation devices to prevent drag on the skimmer that may cause the skimmer to float at an incorrect attitude. Floats also ensure that the hoses are more readily visible to minimise fouling and the risk of entanglement with the vessel's propeller. All hoses, including hydraulic hoses, can prove troublesome to handle when oily and should be fitted with simple but effective couplings. A selection of adapters can prove useful for matching hoses of different diameters and joining different connectors.

Many skimmers are designed with a dedicated power pack for the pumping and, where necessary, for the recovery components of the system. Diesel power packs, for example, can be used directly or to drive electric, hydraulic or pneumatic systems. All but petrol engines can be built to comply with safety regulations imposed in refineries, tank farms and other restricted areas where there may be a risk of fire and explosion. In pumping high viscosity oils, power packs may need to operate at full capacity and so it is important that power supplies are chosen to match the full range of pump capabilities.

Storage

Storage of recovered oil and oily water is often a significant limiting factor of the overall operation. For many vessels, on-board storage will be limited, especially for many vessels of opportunity (*Figure 24*) and may be rapidly overwhelmed for any system where large volumes of oil are encountered. An oil/water separator can be used to concentrate recovered oil and maximise the use of limited space. Simple gravity separation in settling tanks is usually adequate. However, the ability to discharge separated water may be limited by local regulations. Vessels with large internal storage capabilities (*Figure 25*), or with suitable oil/water separation facilities, are able to spend more time at sea recovering oil but, by necessity, are larger and consequently may not be sufficiently manoeuvrable in many situations encountered, particularly close to shore.

The logistics of a recovery operation may be enhanced by providing dedicated storage barges or tankers to receive recovered oil at sea. Alternatively, purpose-built floating temporary storage, for example, inflatable barges (*Figure 26*), may be employed. However, the potential for such craft to be overwhelmed in rough sea conditions when loaded should be considered. Dracones, bladders or other enclosed storage should be used with caution due to the potential difficulties with subsequent emptying and cleaning. Ultimately, recovered oil will require discharge to shore and suitable tank or other storage units close to available jetties with appropriate offloading equipment should be identified. Where vessels are not equipped with heated storage tanks, the use of portable heating coils may facilitate subsequent flow through pipe work and hoses to shore, thereby minimising the turnaround time for vessels to return to sea and resume recovery operations (*Figure 27*).

Similarly, the local storage of oil recovered on or near the shore may be a limiting factor and transfer directly to road tankers for onward transport is often preferable. As noted, industrial or farm vacuum tankers are useful in combining many of the individual elements of the oil recovery operation. Alternatively, portable storage tanks, skips or lined pits, placed above the high water mark, can provide intermediate solutions (*Figure 28*). For the latter, local permits may be required prior to construction. The ability to decant separated water should be included in the site plan.

Equipment	Discharge pressure (psi)	Flow rate (m^3m/hr)
Pump alone	181	4.5 – 5.9
Pump with water injection	7 – 9	46.7 – 58.2

Table 2: Improvements in pumping ability through use of water injection at the pump inlet and outlet, showing a 95% reduction in the discharge pressure and a 10-fold increase in flow rate. Oil with a viscosity of 210,000 cSt was pumped along a 92 metre hose, using a variety of screw pumps. (Source: Floating Heavy Oil Recovery – Current State Analysis, US Coast Guard, Research and Development Centre/David Cooper, SAIC Canada, 27 July 2006.)

Figure 24: A workboat with limited recovered oil storage on deck.

Figure 25: Highly viscous recovered oil in a storage tank on board a recovery vessel (Image courtesy NOFO).

Figure 26: A drum skimmer recovering oil to an inflatable storage barge.

Figure 27: Portable heating coil used to assist with discharge of viscous oil from recovery vessels to shore.

Figure 28: Emulsified fuel oil recovered from the shoreline by skimmers and pumps into temporary storage tanks placed at the top of a cliff.

Deployment of skimmers

Recovery at sea

When planning a response, consideration should be given to the entire suite of logistic requirements necessary to support a recovery operation at sea. Surveillance aircraft are required to locate areas of thickest oil and direct recovery vessels for optimum effectiveness. Suitable vessels from which to deploy booms and skimmers need to be made available as rapidly as possible, before the oil has spread and slicks become too fragmented for recovery to be feasible. Coordination from the air calls for aircraft equipped with air-to-sea communications for direct contact with recovery vessels, allowing a rapid response to shifting conditions. Sufficient storage capacity at sea is necessary to match the anticipated rate of recovery and, as discussed above, arrangements need to be in place ashore to receive recovered oil. The difficulties of ensuring that all these components are in place quickly enough means that only very rarely is more than ten percent of spilt oil recovered at sea and much lower percentages are the norm, despite the involvement of significant numbers of response vessels in many incidents.

To concentrate floating oil at sea, booms can be towed in U, V or J configurations typically using two vessels. The recovery device is either deployed from one vessel (*Figure 29*), or towed as part of the boom array (*Figure 30*). The skimmer should be kept in the maximum thickness of oil but contact between the skimmer and the boom should be avoided to protect the boom from abrasion and other mechanical damage. Wave reflection against large skimmers can interfere with the oil flow to the recovery element. Skilful handling of the equipment is called for, along with continuous adjustments as conditions change. The expertise necessary to tow booms at the slow speeds required is gained through spill experience and regular exercises. In practice, maintaining the required configuration of multi-vessel recovery systems

Figure 29: Boom towed in a U configuration with a skimmer deployed from the main recovery vessel.

Figure 30: A belt skimming vessel deployed with boom and towing vessels in a V configuration.

Figure 31: A single ship recovery system comprising inflatable boom attached to an outrigger and a high capacity free-floating weir skimmer mounted on a Coastguard vessel. The high freeboard allows deployment on the leeside in calmer waters (Image courtesy USCG).

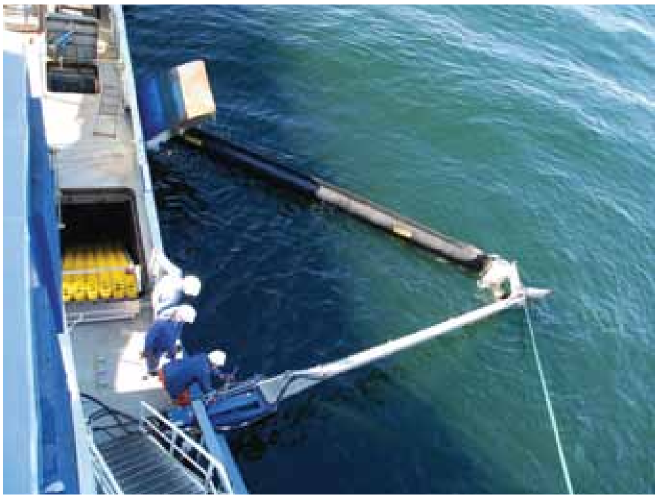


Figure 32: An in-built single ship recovery system. Boom stored in a compartment at the side of the vessel is deployed through an opening by an on-board crane. The opening also allows entrained oil to be recovered by the in-board skimmer, here comprising six sets of brushes in a conveyor arrangement (Image courtesy Lamor).

can be problematic, primarily due to difficulties in coordination between the vessels involved. An alternative solution is to combine oil concentration, recovery and storage functions in a single-ship system using a flexible or rigid sweeping arrangement.

Flexible systems employ a boom attached to an outrigger (*Figure 31*). However, if the swath is too wide, the set-up can become prone to damage in rough weather or large swell and manoeuvrability can be restricted, severely affecting vessel handling. In such systems, the skimmer is positioned at the apex of the boom where oil is highly concentrated and may be free floating or built into the side of a vessel with a suitable opening to allow the ingress of oil (*Figure 32*). Rigid systems comprise a solid floating barrier or sweeping arm deployed from a vessel by crane or hydraulic arms (*Figure 33*). The skimmer, usually a weir or brush depending on the oil to be recovered, is built into the arm, close to the vessel to facilitate recovery. The comparative ease of deployment and straightforward design are strong factors contributing to the success of rigid sweeping systems.

Flexible or rigid systems can be used from specially designed vessels or from vessels of opportunity with suitable fittings. Ideally, the vessel used as a working platform should have suitable handling gear and sufficient manoeuvrability to quickly assume and maintain a selected position against winds and currents. The large open decks of Anchor Handling Tug Supply (AHTS) vessels or Platform Supply Vessels (PSV) are convenient for the storage, handling, deployment, maintenance and cleaning of equipment. However, experience has shown that the exposed decks of such vessels are hazardous for crew in heavy seas. Other vessel types with low freeboard can experience similar problems with large amounts of water and oil washing on-board in heavy swell conditions (*Figure 33*).

Certain types of vessels have been shown to be particularly effective for the recovery of large volumes of floating oil. In particular, the large storage capacities of dredgers, coastal

▲ *Figure 33: Rigid sweeping arm attached via hydraulic crane to the recovery vessel. The low freeboard and large swell encountered made conditions on deck hazardous for the vessel crew (Image courtesy WSA Cuxhaven).*

▲ *Figure 34: Self-propelled weir skimmer recovering oil at a sheltered rocky inlet. The shallow draft of the vessel allows work close to shore. Operators assist by moving oil towards the mouth of the weir.*

▲ *Figure 35: Self-propelled vessel, normally used to recover debris in a port. Here, the low temperature and relatively high pour point of the oil caused the oil to become semi-solid, necessitating recovery by scoops and grabs into a floating skip.*

tankers and bunker barges allow for longer periods at sea before discharge is required. The relatively high freeboard of these and other types of vessels can assist in allowing recovery on the lee side (*Figure 31*), although deploying equipment from a height can introduce problems of windage. Handling of recovered oil will be assisted by the high-capacity pumps with which such vessels are typically equipped and the fact that storage tanks are often fitted with heating coils. For dredgers, the use of dredge pipes or buckets directly in the oil may be feasible in limited circumstances and the non-selective nature and large pipe diameters of these systems reduce the potential for debris and highly emulsified oil to cause blockages.

Recovery nearshore and onshore

Self-propelled skimmers can be used to good effect in the calmer waters of ports, harbours and sheltered areas (*Figures 34 and 35*), where they may also serve some secondary function, for example as debris collectors. These vessels are often an integral part of response arrangements for oil terminals and refineries where the pollution risk and oil type may be appreciated and understood and planning a response may be relatively straightforward. Purpose-built, self-propelled skimmers are comparatively expensive but are effective in confined areas, particularly where access from the shore is impractical.

For portable skimmers, the use of shallow-draught vessels may provide optimal work platforms close to shore (*Figure 6*). In such cases portable storage tanks or Intermediate Bulk Containers (IBCs) may be placed on-board to receive the oil. However, care should be taken to ensure that the volumes of oil stored, together with the presence of power packs and other equipment, do not affect vessel stability.

In common with other floating materials, oil accumulates in certain places along the shore under the influence of wind and water movement. Such natural collection points can assist recovery operations (*Figure 10*), provided the skimmers are capable of dealing with the debris that is usually present, often in large amounts, in these areas. Oleophilic rope-mop skimmers, which are less constrained by debris than other types of skimmer, may be most effective (*Figure 6*). Recovery can be enhanced with the aid of booms to further concentrate the oil and to reduce the possibility of remobilisation on changing wind or currents. Rope-mop skimmers can also be deployed effectively inside a boom to collect small quantities of oil along its length.

Where possible, it is usually easier to operate skimmers from the shore, particularly if road access, hard standing or a flat working area is available close to the point where the oil is to be recovered. Skimmers can be operated from cranes on dock walls and jetties (*Figure 7*) or, if the oil is sufficiently thick, some types of pump can even be placed directly into the oil.

Once the working site has been identified, a simple site plan can streamline the handling of recovered oil and reduce working hazards. Careful thought must be given to providing operators with the necessary logistical support, including fuel, provisions, shelter and communication with the incident command centre.

Where oil has stranded on mud or sand shores, conditions may allow the oil to be concentrated in trenches for recovery, most commonly by vacuum devices (*Figure 8*). Oil pooled between rocks or in crevices may be similarly recovered. On hard-packed sand beaches, recovery may be accelerated by tractor-mounted oleophilic drums or other devices to collect tarballs (*Figure 36*). Other specialised skimmers may be effective in specific situations onshore. However, in the majority of instances, other techniques, including manual recovery, will be more appropriate.

Recovery of oil in rivers and lakes will be subject to similar limitations, particularly of access and currents. However, the recovery of oil in ice presents a number of specific problems, not least that oil may be trapped within the ice itself. Devices to crush the ice allowing recovery are the subject of on-going research. A fundamental problem with this approach, however, is that typically the concentration of oil in the recovered oily ice is very low and, in such instances, better recovery rates may be achieved following a period of thaw. The use of rope-mop skimmers may allow free floating oil to be recovered between drift ice, although the machinery runs the risk of seizing-up in the cold.

Management of recovery operations

Experience from past spills suggests that the most successful recovery operations have generally involved a well-prepared organisation with all logistics in place, well trained crews and the ability to mobilise rapidly. In all cases, the effectiveness of the overall response organisation is as important as the performance of the equipment. The successful deployment of a system requires that all the components of containment, recovery and storage are monitored continuously and that the system remains sufficiently manoeuvrable to follow changes in the distribution of the oil.

All recovery operations require supervision to ensure that oil is reaching the skimmer and debris is not accumulating or entering the device to reduce efficiency or cause damage. Many skimmers are fitted with debris screens which can frequently become blocked by oil or debris. To maintain a high performance, the skimming speed should be adjusted to suit conditions and to match the rate at which oil is arriving at the collection site. If only small amounts of oil are present, skimming should be carried out at intervals to avoid excessive collection of water and, where possible, the oil concentrated using booms.

Generally, skimmers and related equipment such as power packs are robust but, inevitably, breakdowns occur through damage, clogging with debris, incorrect use or wear and tear. Repair will usually require specialised knowledge, access to replacement parts and appropriate tools. The use of suitably trained operational personnel, with an understanding of equipment limitations and the ability to strip down machines and to rebuild them as required will reduce delays. If equipment is subject to a routine maintenance programme, it is more likely to be immediately serviceable when drawn from a stockpile and the risk of breakdowns in the field reduced. Such a programme might comprise a fixed schedule to include replacement of wearing surfaces after a given period in service, topping up or replacing lubricants and starting-up equipment to check for faults.

The application of dispersants in tandem with skimming operations is to be strongly discouraged since the underlying principles of the two methods are mutually exclusive and oil dispersed into the water column cannot be recovered using surface skimmers. Furthermore, dispersants change the surface properties of the oil and, when applied in proximity to oleophilic skimmers in particular, can render such devices ineffective. Similarly, broadcasting sorbent materials, particularly in a loose form or as pads, onto the sea surface in conjunction with skimming operations is likely to lead to blockages of recovery systems.

Recovery operations at night may be feasible in specific locations such as ports, where oil has been previously identified and contained and where adequate lighting is available. However, attempts to locate oil and recover oil at sea at night are unlikely to be effective and may be unsafe for personnel involved.

A record of daily activity, detailing the use of recovery resources, the amounts of oil recovered and any damage or repairs made, will allow progress to be monitored within the command centre and will assist with the formulation of subsequent claims for compensation. For larger recovery vessels, this information may be routinely incorporated into ships' logs that are usually required by maritime authorities.

Demobilisation of skimmers and associated resources should be undertaken as the effectiveness of the operation

▲ *Figure 36: Tractor-mounted oleophilic drum skimmer, used to collect fresh tarballs on a hard-packed sand beach (Image courtesy Le Floch Dépollution).*

diminishes, i.e. as the encounter or oil recovery rates reduce and become negligible. After use, skimmers and ancillary equipment should be cleaned and over-hauled to identify and rectify any wear and damage (*Figure 37*). Steam lances or solvents can be used to remove oil, but cleaning chemicals should not be used on oleophilic discs or sorbent mops as the oleophilic properties of these skimming devices may be adversely affected. When equipment is returned to storage it should be protected from damage and damp, salty atmospheres causing corrosion. Sorbent mops, rubber belts and plastic materials incorporated in skimmers will perish if exposed to direct sunlight for long periods. Storage of equipment should allow ready access to encourage regular inspections, maintenance and testing, particularly as its use is likely to be infrequent.

Figure 37: A weir skimmer brought ashore after recovery of heavy oil. Following demobilisation, equipment should be cleaned and overhauled in readiness for future use.

Key points

- The merits of recovery options at sea and nearshore should be assessed against prevailing conditions such as sea state, wind, currents and the location of sensitive areas.
- The type of oil to be recovered, its viscosity at ambient temperatures and any change with time will dictate the type of skimmer that will be most effective.
- The criteria of capacity, reliability, robustness, field performance, weight, handling, versatility, power source, maintenance and cost should be considered when selecting the most appropriate skimmer.
- Vacuum trucks and other suction systems are often readily available for recovery of thick layers of oil on or near the shore.
- Effective coordination of oil recovery operations at sea is enhanced by use of aircraft to monitor the oil and the progress of the clean-up and to direct recovery vessels to the thickest patches of oil for optimum effectiveness.
- Skimmer performance should be continuously monitored to ensure optimum efficiency.
- The logistics of pumping, storing and disposing of recovered oil must be addressed to ensure delays in recovery are kept to a minimum.
- Regular inspections and testing of equipment should be arranged to maintain personnel training standards and rectify any equipment faults.

TECHNICAL INFORMATION PAPERS

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff. Information in this paper may be reproduced with the prior express permission of ITOPF. For further information please contact:

ITOPF Ltd

1 Oliver's Yard, 55 City Road, London EC1Y 1HQ, United Kingdom

Tel: +44 (0)20 7566 6999
Fax: +44 (0)20 7566 6950
24hr: +44 (0)20 7566 6998

E-mail: central@itopf.org
Web: www.itopf.org