At

INTERNATIONAL CONFERENCE OF TRANSPORT SCIENCE

The Full Paper

OIL SKIMMERS FOR COASTAL WATERS AND OPEN SEA CLEANING

Andrea Agrusta, Researcher
University of Trieste, Dep. DIA, via A. Valerio, 10, 34127 Trieste, ITALY, aagrusta@units.it
Filippo Bianco, Coordinator
Innovation Factory, Area Science Park, Padriciano (TS), ITALY, filippobianco@innovationfactory.it
Luigi Perrella, Coordinator
Jonathan Project, Trieste, ITALY, luigi.perrella@gmail.com
Giuseppe Perrella, Researcher
Jonathan Project, Trieste, ITALY, giuseppe.perrella@gmail.com
Igor Zotti, Professor
University of Trieste, Dep. DIA, via A. Valerio, 10, 34127 Trieste, ITALY, zotti@units.it

ABSTRACT

The transport of crude oil requires the adoption of safety measures in port terminals, especially during the operations of loading and unloading of crude oil. Accidents at sea are further serious cause of oil pouring and cause pollution. For these reasons the port terminals are equipped with oil skimmers and boats that intervene promptly to define and collect the spill at sea. The technology of oil skimmers is subject to continuous innovation, to ensure prompt actions when operating in restricted waters, as may be the area of the Gulf of Trieste, Northern Adriatic Sea or other restricted areas within the refineries and oil terminals.

In the paper the principles by which the oil skimmers recover and transfer oil and some of the more salient changes introduced recently in this technology will be explained. Then we will present a new oil skimmer design, called FL.O.C (Flexible Oil Collector), developed under the Jonathan Project, in collaboration with the University of Trieste and the Area Science Park of Trieste. This project is currently under construction and should allow the availability of such a system as a standard equipment in short time. The new skimmer will allow the recovery of a high percentage of hydrocarbon in comparison to the traditional oil skimmers, will be available in very short time and will require small maintenance.

Keywords
Sea Skimmers, Oil Pollution, Crude Oil Transport

1. INTRODUCTION

It is not easy to determine the amount of oil spilled into sea every year but, according to estimates, it is expected to be around 4 million tonnes in the whole planet and 600.000 tonnes for the only Mediterranean. No spill situation is similar to another, both because of the variety of existing hydrocarbons, both for the different locations and environmental conditions in which they occur. However, there are general and common characteristics that must be taken in planning activities. Generally, standard methods of decontamination are used, which consist mostly to contain the spill paid through special floating booms and then collect the spilled oil at sea. The amount that cannot be recovered is left in the sea, so that it degrades naturally. If, however, these substances are near the coast, it is possible to intervene with dispersants but, in long run, may prove harmful to the environment. The intervention depends greatly on the type of spill happened and the means used to recover the oil differ, depending on the operating steps of the intervention.

2. SPILLS

Spills at sea are injections of hydrocarbons, either intentional (e.g. washing tanks) or unintentional (e.g. explosion of an offshore platform), in the water mass. They are classified according to classes of crude oil paid. In industrial areas proximate to the sea or in port areas, small spills "inevitably" occur for the mere performing of routine activities in those areas. Oil spills and its derivatives draw together in thin extended surfaces and float, as a result of their lower specific weight than water. The extension of these surfaces increases over time, while their thickness decreases. Wind, atmosphere and water waves distort and shift the spills: they alter spills by oxidizing and beating them together, thus leading to their emulsification and/or sinking; they move spills by cracking them into thinner and wider extensions and pushing them onto the coasts, where the environmental damage is even worse.

Disasters result from exceptional circumstances, in scope and severity, and are caused by human activities, e.g. the explosion of the Deepwater Horizon in the Gulf of Mexico, or by natural events, such as an earthquake. Containment and remediation interventions last for a long time, they are imposing in extent and require supranational involvement. All possible means are put in place and in the course of the emergency new devices intended to help in the rescue will be designed, constructed and employed.

Spills are classified as accidents resulting from mishandling, collision of ships or broken structures. The places most at risk of accidents are ports, refineries and industrial areas along the sea and pipeline terminals. The determination of the risk involves the on-site emergency response of specific organizations and materials to be used in case of need. The specific agencies are public (Coast Guard, Harbor Master, Fire Brigade) or private (industrial properties or companies formed for this purpose).

Spills can be classified as "routine" when they consist in small, but continuous discharges, resulting from leakage, loading / unloading, refueling, etc. Reclamation works are not consequent to states of alarm, but are maintenance works; they are daily operations carried out continuously by municipalities and private organizations, by means of limited-size instruments that scan and suck the water surface.

3. HUMAN INTERVENTION

Human intervention [1] is divided into the following phases:

3.1 Identification of pollution sources

In the event of an accident, the very ships involved call for help; in other cases (e.g. in illegal dumping of oil into sea), a very active surveillance of the coasts and sea with ships and aircraft by the competent authorities is required. In cases of a ship damage, the main task of the commander is to safeguard the lives of the people on board and then the integrity of the ship, trying to save the load; only later he should deal with the damage caused by the load poured at sea.

3.2 Limitation of the spill

In the event of an accident and whenever sea water reaches deposits, tanks, double bottoms or boxes containing pollutant liquids, their content must be transferred to other intact containers, when possible. To be effective and to limit the extent of damage, the intervention must be immediate, timely and performed by appropriate means.

3.3 Containment of oil

It is an operation that is carried out by using protective barriers with buoys and booms, both at an early stage and in the operational phase. In pipeline terminals, barriers are often present to prevent that the floating oil escaped into the sea could spread into the surrounding environment. In this case, the protections are anchored on the bottom and arranged in such a way as to be active at most, without being sucked or damaged by the currents. Currents with speed above 1.5 knots, typically found in rivers and estuaries, can cause the oil content to spill over the barrier. More recently air bubble chains, flowing from submerged pipes, generate an immersed barrier to the oil propagation near the oil pipeline terminals.

On the high seas, it is very difficult, if not impossible, to lay and secure the protective barriers. So they are free to float and must be able to contain, in limited size, the maximum amount of crude oil. There are several types of effective barriers in presence of wind, currents and waves. They have a sufficient free edge to prevent the oil from spilling over if driven by the waves and an adequate depth to avoid current carrying the oil from the bottom. In such fences, the oil reaches a thickness of a few centimeters (up to ten).

4. CLEANING THE SEA

Once defined the area affected by pollution, the sea must be swept by collecting or destroying the pollutant.

4.1 Use of fire

One of the first methods used, though only partially effective, is to ignite the oil. This operation must be done soon, before the lighter components volatize, and only under conditions of total safety. To activate the combustion, highly flammable substances can be shed on crude oil by planes or helicopters. There are also fire resistant barriers which restrict the wildfire burning through and cause the explosion of incendiary charges installed on the barriers. The results obtained with these operations are limited. The temperature of the water cools the pollutant and prevents the various components of crude oil from reaching the combustion temperature, especially if the state of the sea is rough.

4.2 Oil skimmers

The collection of spilled oil is performed by means of special vessels called oil skimmers. The ultimate aim of any recovery operation is to collect as much oil as is reasonably and economically possible. These vessels can be specially-built for the purpose or fitted with equipment to be used for intervention. The intervention can be very different depending on the theater of action; the open sea or ocean, rivers, harbors or confined areas; in the presence or absence of winds or currents, etc. Another factor which characterizes the operation is the quantity of oil that should be recovered. It can range from a few hundred kilograms (for example in port areas contaminated by routine operations) to the millions of tones (for example in the episode of the Gulf of Mexico). 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 recovery oil in preference to water, but designs vary considerably according to the intended use, for example in sea, in sheltered waters or onshore and for this reason the units used in these types of interventions are therefore deep sea, ocean, coastal, or port.

Furthermore, the unit responsible for the collection can be autonomous in operations, i.e. it can circumscribe, collect and transport the residue to the ground by itself; or it may require other units and vessels in order to perform, in which case it operates in groups of units.

A number of factors should be considered when selecting a skimmer, the most important of which are viscosity and adhesive properties of the split oil (including any change in these properties due to "weathering" over time), together with the sea state and levels of debris. In relative 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. This can be the case of the upper Adriatic harbors, characterized by a pipeline terminal (Trieste) and fuel deposits for the ships (Koper, Rijeka, Trieste, Venice, etc.).

Conversely, a versatile skimmer, that may be required to address a variety of situations and oils, may be preferable 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). This classification, of the International Tanker Owners Pollution Federation Limited (ITOPF) [2], can be used to identify the best skimmer solution to be used in the different situations. In this table a primary identification is made between the oleophilic skimmers and the others.

The 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 disk, drum, belt, brush or rope-mop which, as they rotate, lift the oil from the water surface. Alternately to oleophilic skimmers there are the non-oleophilic skimmers, which can be classified as suction skimmers, weir skimmers or other skimmer type.

Non oleophilic skimmers can be the vacuum or suction skimmers in which the oil is recovered by pumps or air suction systems directly from the water surface. In particular these systems can operate in combination with vacuum trucks or trailers, that combine the elements of recovery, storage, transport and oil/water separation, which are often ready locally.

Table 1 : Generic characteristics of commonly encountered skimmers [2]

Skimmer		Recovery Rate	Oils	Sea State	Debris	Ancillaries
Oleophilic	Disc	Dependent on number and size of discs. Tests show grooved disc 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 requirements.
	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 of 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 require 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 dogged 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.
	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.

The 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 amount of water. Advanced types of weir skimmers have adjustable weirs and accurate vertical positioning of the weir is usually achieved by a self-leveling arrangement.

Other skimmer designs have been adopted to cope better with waves and rough 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 scrapped off the belt as it rises above the surface and drops into a storage tank or other container. Other skimmers use buckets or paddles on the belt, to aid lifting of the oil from water surface.

5. THE JONATHAN PROJECT (JP)

It is the result of a research carried out jointly at the Area Science Park (Padriciano, Trieste), with the support of Innovation Factory (Area Science Park branch) and the Department of Engineering and Architecture of the University of Trieste. This idea is related to a device for the interception and collection of oily substances pollutants, which float on the surface of the sea, rivers or lakes, to be used mainly in harbors and in coastal waters. The idea has been patented with patent Nr. 10884PTWO.

The idea of Jonathan Project [3] consists of a skimmer equipped with a funnel-shaped conveyor, supported by floats, drawn inside of the spill to be cleaned or self-propelled in it with its own drive and/or remote-controlled guide. This device has been named FL.O.C. (Flexible Oil Collector) and has the primary function to intercept and collect the share of surface water, on which float pollutants and debris to be removed. It can be classified as a weir skimmer (Table 1), which is very flexible and used with light and heavy oils. It can be equipped with different ancillaries, such as a separator and a collection tank, and used autonomously or have tugs or support ships to transfer the collected oil, to be treated on board. It is scalable in different sizes so to be used for land reclamation in areas with limited space up to catastrophic theaters. In reduced dimensions, it is equipped with inflatable floats, so that they can be stored in a tank of reduced overall dimensions, both for the boarding of vessel and for the transport (Figure 1).

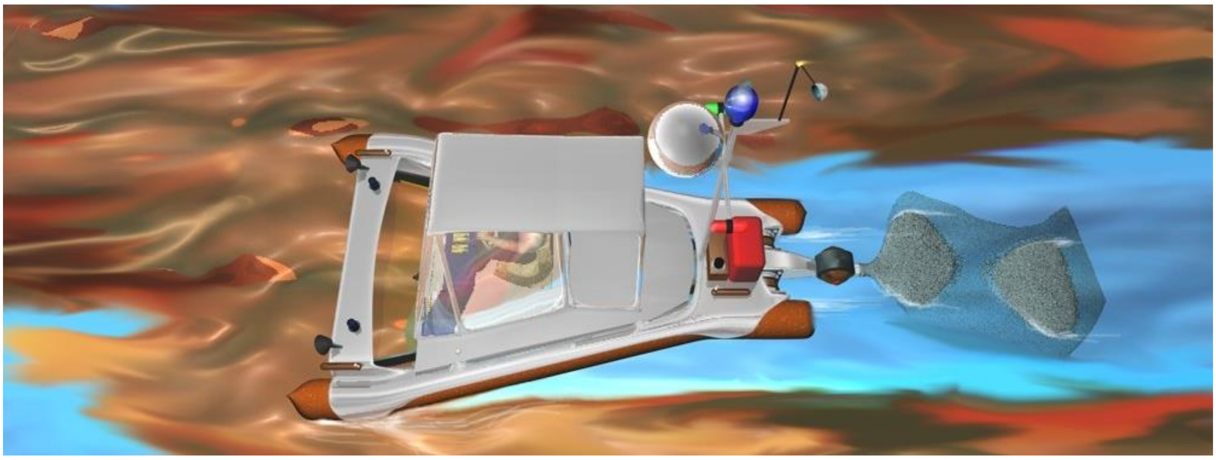
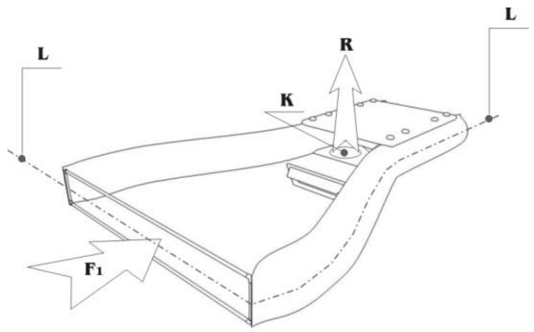
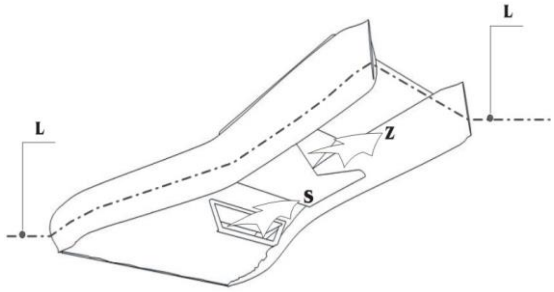


Figure 1 : Jonathn Project Oil Skimmer cleans the oil slick and collects the polluted oil.

5.1 System operation

The device, supported by suitable floats, is placed on the surface of the water to be reclaimed and moves in the direction of the pollutant to intercept and collect. The movement is obtained





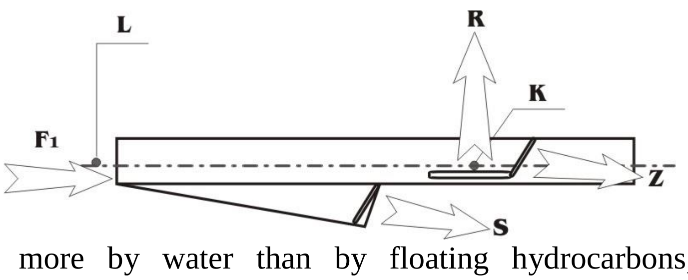
by towing or by using its own drive. The device is constituted by a funnel-shaped collector plate tapered from the larger cross-section, in the direction of motion, to the lower section, in the queue according to the motion. It is equipped with a front opening and with one or more rear openings.

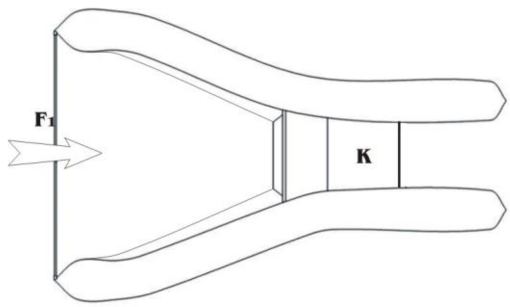
Figure 2 : View 3/4 front of the device **Figure 3 : View 3/4 rear the device**

The opening front generates an inlet flow (F1 in figure 2) function of the speed of advancement of the device and of the ratio of the immersed area of the opening itself. This inlet flow must be balanced by the sum of the flows at the output (R (recovered oil) in figure 2; S (water in excess) and Z (not collected oil) in figure 3).

$$F1 = R + S + Z \qquad (1)$$

Outgoing flows are generated by the flow of a suction pump (R in figure 2), which sucks to water's surface as much as possible, and by one or more openings controlled by heads and placed in the lower face of the funnel (S and Z in figure 3). The balancing of the flows generates the benefit of facilitating the entry of the inlet flow, without opposing pressure waves. The inlet flow is necessarily constituted





more by water than by floating hydrocarbons, because the film of the hydrocarbons can be very thin and for the effect of water motion. The openings controlled on the face of the funnel immersed allow the escape of the excess water, in order to convey the maximum possible rate of hydrocarbons into the suction area of the pump (K in figure 2).

Figure 4 : Side view

Figure 5 : Plan view

The concentration of hydrocarbons in a thicker mass floating on water is generated by the dual-dimensional gradient of the funnel. The face is immersed inclined downwards from the front opening and narrows in the plan view towards the rear opening; in this way the section of the inlet flow varies from a flat rectangular shape, very wide and very low, to a narrower and higher rectangular shape. The area of the free surface of the funnel is reduced and then generates a greater thickness for hydrocarbon. The excess water is discharged downwards, directly before the suction area.

A more general representation of the functioning of the collector is shown in figure 6.

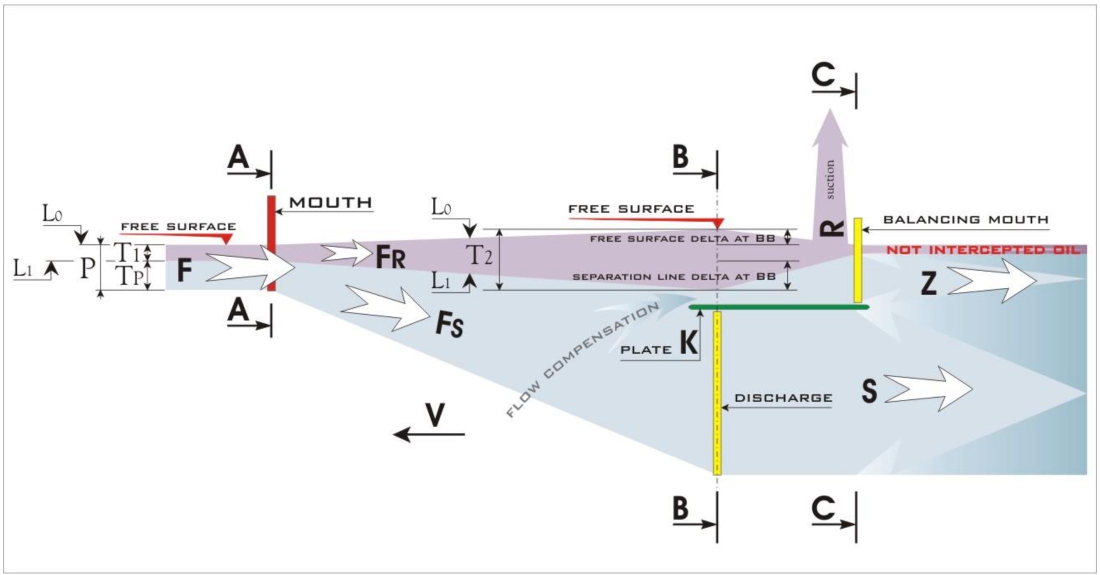
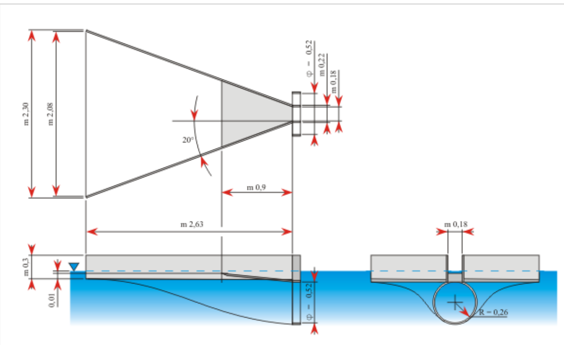


Figure 6 : General representation of the collector.

The symbols of figure 6 correspond to those of figures 2 - 4 as follows : F is F_1, R is F_R,, S is F_S; other symbols have not been changed.

The collector functioning and its response to the different speeds of the skimmer have been simulated with specific programs and in creating physical models, which have been tested in the towing tank of the University of Trieste. The presence of oil has been simulated with different density foams, product easily removable from the basin. With the experiences carried out it has been verified, at different speeds of the collector, the ability to collect and convey the floating material into the collection bags; in fact it is not uncommon that the collector, with little ability to suck, rejects the crude oil that must collect.



5.2 Application of FL.O.C. to JP skimmers

The collector FL.O:C. is part of all the JP skimmers that, in the first series, are sized according to the maximum measures transportable by trucks and are devoted to the maintenance of pools of water and emergency measures for occasional spills up to 7 tons.

It is shown in figure 7 a general outline of

FL.O.C..
A further accessory plant is called Drac - Oil, which is a container - filter (Figure 8) in which the collected oil is conveyed. This is also a filter, as it keeps the oil polluting, pulling it away from water/oil, while releasing the water clean. Drac - Oil is a "core - product" that JP uses in setting its skimmers and can it supply as
third part to manufacturers who wish to use this device downstream of their skimmer systems.

Figure 7 : FL.O.C. general outline.

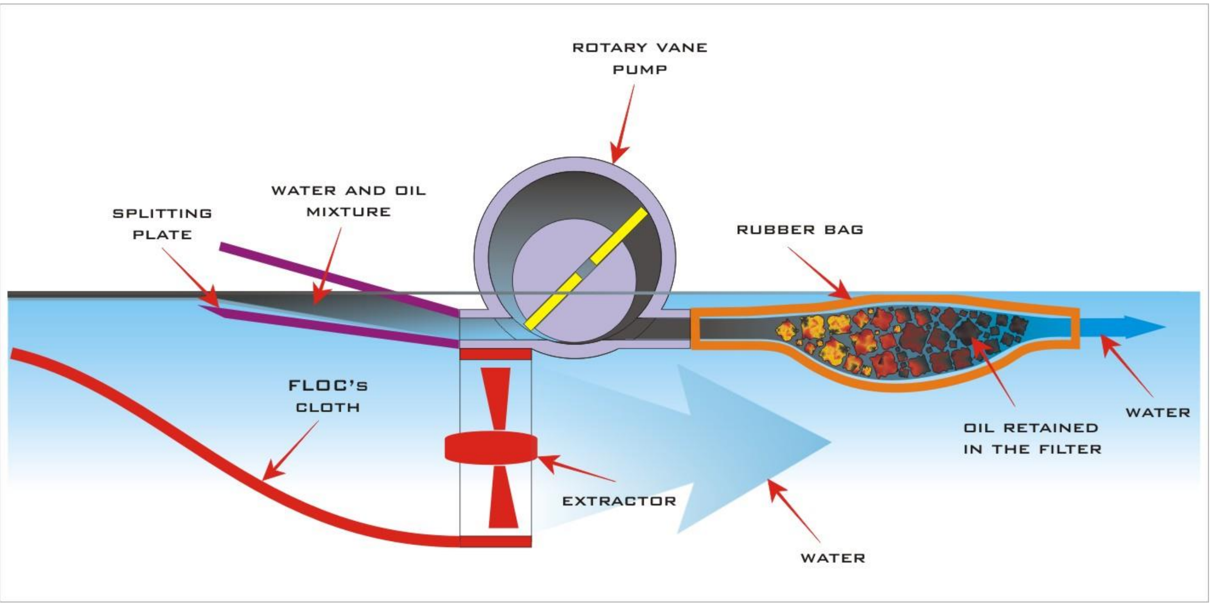
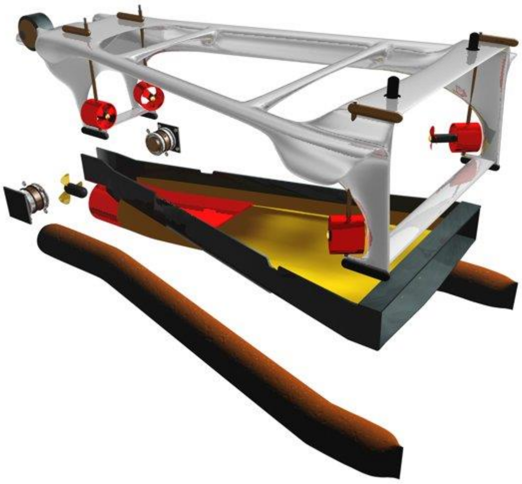


Figure 8 : Drac-Oil container - filter

The mixture water-oil is selected from the splitting plate; the extractor flows the deep water clean, while the rotary vane pump pushes the water-oil mixture into the rubber bag, without increasing significantly the emulsion. The filtering particles absorb the oil, by holding it, while the clean water comes out from the bottom. Drac-Oil can be used to filter any mixture of oil and water collected by skimmers; its use makes unnecessary the use of separators for the storage of the pollutant mixture; for this reason is not necessary the use of settling tanks on board the support ship or moving the collected pollutant. The saturated Drac-Oil containers are placed directly into a container box and can be sent to landfills for disposal. All basic operations, within the cycle, are extremely clean.

The range of oil skimmers JP consists of three subsystems : a) The system FL.O.C., b) the collected system and c) the vessel. We already discussed in detail on the FL.O.C. system.

The sampling system has the function to remove the pollutant from the bulk water by filtration in a filter bag (Drac - Oil system) or adduction of the mixture on board of a support boat. The vessel has the function of assembling and connection between FL.O.C., the collection system and the auxiliary machines (engines, generators, batteries, piloting, etc..) necessary for the correct functioning of the whole skimmer system and ensures the operation and navigation.



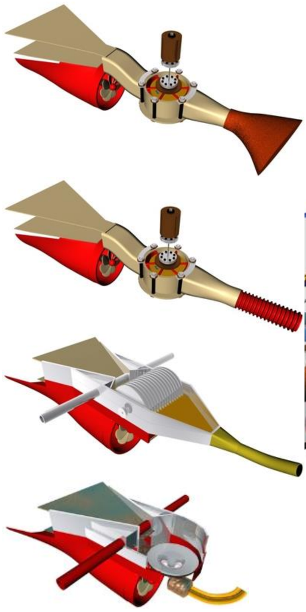


Figure 9 : JP systems to collect and transfer the pollutant mixture.

The systems used to collect and transfer the mixture can be (see figure 9, in progression): a) FL.O.C. and Drac-Oil systems; b) FL.O.C. and a connecting pipe; c) FL.O.C. and oleophilic drum; d) FL.O.C. and a weir system.

The boat is the rigid structure which groups together and allows working all the systems placed

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Figure 10 : JP skimmer components **Figure 11 : Self propelled JP skimmer**

on board. It is composed of a rigid frame to which are attached the floats, the azimuth pod engines for propulsion, the control systems for the pods, FL.O.C., its frame and its planting, the deep flow extractor and the suction rotary pump. Il figure 10 a view of the different component parts of the skimmer is shown.

A more complete visualization of a possible self-propelled skimmer is shown in figure 11.

We can notice that the solutions provided for JP skimmers are various and include the wire-guided solution, the remote distance controlled and unmanned solution and the piloted one. One of the basic principles that have inspired the choice of these solutions is that they must be readily available, as soon as the operational need arises. It will then be the user to define in detail the type of solution that best suits to the local port requirements.

6. CONCLUSIONS

The solution presented for the oil skimmer to be used in coastal waters and ports is the result of studies, research and experiments on models carried out at the University and Research Area of Trieste. The solutions presented take into consideration the needs required to have a unit that is available quickly, easily manageable and easy to use, adaptable to complementary activities, such as cleaning of beaches and small harbors. The obtained product, still in the experimental phase, should respond to the requirements and be available in short time.

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