DEVICE AND METHODS FOR THE RECOVERY OF SUBSTANCES AND/OR LIQUID FLOATING IN OPEN SEA

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ABSTRACT

The request for ships and devices able to collect oil and polluting spills from the sea has been more and more increasing in recent years. These systems may remain unused for years and, at the same time, need frequent and very expensive maintenance. Their availability requires transferring them to the site of the incident, which may be reached many hours or days after the oil spill has occurred. The new idea is to design a light and flexible system that can be docked directly on the ships or in small boats capable of laying down and containing the oil slick. By so doing, the pollution control could be more effective and the environmental damage could be better controlled in very short time.

The FLOC (FLexible Oil Collector), protected by the international patent application) has been studied and developed by Jonathan Project, in partnership with Innovation Factory of Area Science Park and the Hydrodynamic Laboratories of the University of Trieste. It consists in a floating funnel-shaped collector with an I/O balanced flow that conveys the free surface of the mixture of water and hydrocarbons for their separation and their collection into pollution tanks. By so doing, the percentage of hydrocarbon recovery is higher in comparison with traditional oil skimmers. The availability of a such system could be used as standard equipment, thus allowing fast and timely rescue. A small layout of the device can be used for cleaning maintenance of stretches of water in ports and docks.

1. INTRODUCTION

The paper is aimed to present a new and innovative device for fighting pollution at sea. The conception and subsequent development of the device will stand out for its qualities of originality, simplicity, effectiveness and economy of construction and use. Before examining the topic, to better understand the reasons determining the choice of solutions, we will explain, in the first part of the work, the problems that arise and that have to be tackled in a marine pollution event. The second part of this research presents the description of this device and prospects for its future development and use.

The recent ecological disasters in the Gulf of Mexico and the many incidents that cause significant damages leading to the pollution of vast areas demonstrate the devastating effects of these events. They threaten and affect wide regions of the globe and, in order to avoid their consequences, devices and systems that limit damage extension have been and are being developed. On the other hand, the continuously increasing demand for oil and its derivatives requires a corresponding increase in research of new deposits, mining, processing and transportation. These activities generate, for historical reasons, risks of accidents resulting in oil spills in the environment (see ENI World & Gas Rewiew, 2011).

2. THE 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 (see Biliardo et all, 2005). 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.

2.1 Disasters

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.

2.2 Accidents

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).

2.3 Routine Spills

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.

2.4 Physical transformations of spills.

Oil is an extremely complex mixture of hydrocarbons dissolved in one another, whose specific chemical composition varies with its origin. Crude oil spilled into the sea tends to expand and slide on the surrounding surface and reduces its thickness to an extremely small value; the expansion stops when the magnitude of oil viscous forces equals that of the gravitational components, which are indeed responsible for the flow on the sea. The extension of the oil spot depends on the amount poured and on the environmental conditions. At the same time as the expansion stage, the evaporation phase also starts; it is detected that 25% - 30% of the crude oil spilled evaporates in the first two days. The rate of evaporation depends on the percentage of volatile components present in the oil; greater is the evaporation and thus heavier becomes the residue present in the sea. The extension of the oil surface activates the following phenomena (see Apollonio F. et al, 1983):

- prevents air oxygen from penetrating into the water;
- prevents light from penetrating into the water;
- discharges toxic and poisonous substances into the environment.

The residual oil floating in the sea, exposed to weather and solar radiation, is subject to photochemical oxidation. This process can lead to the formation of compounds which may be either lighter or heavier than the original ones; the lighter components tend to dissolve in water, while the heavier ones tend to agglomerate and accumulate. In addition, the effect of the surface movements caused by waves, wind and currents, activates the particular phenomenon of emulsion water in oil or oil in water. In the first case of water in oil emulsion, clots of oil are generated, containing approximately 80% (by weight) of infiltrated water, and result in products known as "chocolate mousse", a kind of floating gelatinous mass which can remain long in the sea and easily reach the coast, giving rise to land tarry lumps. The second case of oil in water emulsion, is due to the presence of natural emulsifiers occurring in the oil or water or by the action of detergents specially scattered at sea. Also this phenomenon is favored by the action of waves and allows the dispersion of oil in a huge mass of tiny droplets in the sea.
Besides physical phenomena, other biological, sea bacteria-induced phenomena are also triggered. Organic substances discharged into the sea are attacked by several species of microorganisms that gradually transform them into simpler substances, and produce energy. The set of these two processes takes the name of metabolism and implies a continuous consumption of oxygen. Once oxygen is exhausted, anaerobic bacteria combine the excess of carbon with hydrogen, methane or similar products. The damage caused by pollution affects the marine flora and fauna, which are destroyed and altered. The coast is defaced and poisoned. To limit the damage, it is therefore necessary that man intervenes directly and later leaves natural processes, by their nature very long, to complete the cleaning action.

3. HUMAN INTERVENTION

Human intervention is divided into the following phases (see Apollonio F. et al, 1983):

- identification of pollution sources;
- limitation of the spill;
- containment of oil;
- cleanliness of the sea.

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.

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 (see Apollonio F. et al, 1983).

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 (oil skimmers). These can be vessels 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). 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.

4.3 Classification of Oil Skimmers

The classification follows from the skimmer’s operating procedures for the recovery and for the separation of spilled material. It is useful to highlight the two phases: first, a shut-off and collection (recovery) phase, and later a separation and storage phase. Sometimes the same device provides for both phases, while in other cases the two phases are the prerogative of two different devices, one recovers and the other separates. It is also useful to highlight the fact that the recovery can be done from "fixed point" or by probing the surface water with a device in motion. The collection and separation systems can therefore operate mechanically or by gravity or by difference in specific gravity, or by adhesion of viscose tapes, discs or drums or by systems of mixed type:

- mechanical filters (networks) which are towed through the liquid mass to be cleaned, with the disadvantage that the networks are not able to hold the liquid nor smaller-sized solid particles in their meshes. Furthermore, the networks become clogged due to their movement and thus always generate greater resistance to forward, with the formation of pressure waves in front of the mouth of the basket and consequent loss of overall efficiency of the device;
- containment barriers around the point of release of pollutants in water. The pollutants are then collected with the help of a plurality of pumping stations; the main drawback to this solution is the difficulty of its use, since the device requires a long phase of transport and positioning before it can be operative;
- vessels designed to operate using the different specific weight between the two fluids in order to achieve the separation with static or dynamic systems. The separation is obtained in static-settling tanks in which the heterogeneous mixture of water and oil is fed and allowed to decant. The dynamic separation exploits instead the phenomenon of centrifugation in special centrifugal separators in which the rotation imparted to the mixture accumulates the water away from the axis of rotation, while the oil is concentrated around it; the two fluids are intercepted and discharged from the respective positions to be transferred into the coffers or deposits;
- weir fitted with floats supporting the pumps that suck the mixture and separate it by centrifugation;
- machines that exploit the differences in viscosity between oil and water and uses so-called hydrophobic or oleophinic materials. These machines typically have discs that "extract" oil from the sea surface, with a cyclical movement; these systems obtain the best results and are the most currently used. They are transported and lowered into the sea, by use of a crane, from a support ship fitted with a pump that sucks the collected oil. The main drawbacks reside in the cost of the devices and their management, the limitation of oily materials to attract only dense oils, but not light oils or gelatinous lumps and the need for continuous movement of the device which, by its nature, works in the fixed point; also their effectiveness depends on the thickness of the film of the oil floating and therefore they require floating barriers which concentrate quantity and thickness inside the device.

There are other systems, derived from the previous ones, which operate with mixed methods, such as the D.I.P. (Dynamic Inclined Panel) system, in which the oil is forced by a conveyor belt to go below the surface of the sea to be then collected by gravity by a settling tank. The collection takes place by exploiting the differences in specific gravity and conveyance by adhesion.

5. OPERATING MODES

In cleaning operations in small areas along coasts or ports, in calm or smooth water, spillage collecting means are mostly autonomous, and have holding tanks on board. The same applies

to average-sized units that, with the use of inflatable balloons or rigid barriers bound to their sides, convey and collect automatically the oil residue floating at sea.
Larger ships usually carry boats of support that are needed to stretch the protective barrier or to transport floating pumps to be placed over the residue to be collected at sea. The support of other units is sometimes necessary only for ground transportation of the recovered residue; so either decanting must be performed at sea between the recovery units and those of transport or waste can be loaded in containers that are subsequently loaded on rafts for forwarding to land.
Particular problems are encountered in ocean recoveries, where it is preferred to destroy the residue directly on board. Specially-designed incinerator vessels recover the residue and destroy it: these vessels are provided with a large furnace for burning both solid and liquid residues recovered in the sea.
Instead of the physical recovery of the pollutant as treated so far, it can sometimes be convenient to use different techniques that leave the polluting substances in the sea and make them harmless and easy to be attacked by micro-organisms of the marine environment. Techniques so employed are basically two, namely the sinking and the dispersion of pollutants.
The sinking technique consists in spreading over the surface of the oil spilled in the sea a large amount of granular material or powder, usually sand, having a high density, so that, mixed with the crude, brings about its sinking. This technique entails the availability of large quantities of properly treated sand and of ships fit for its transport.
This system causes damage to the flora and fauna of the sea bottom and cannot be used in areas with low-oxygen-containing water (ports, channels, etc…) or in areas densely populated by fish or in the vicinity of fish farms or cultures. As the oil may re-emerge in time, this technique demands a uniform distribution of large quantities of sand over the surface (ratio sand/oil = 1.0).
The dispersion technique consists in spreading chemicals such as detergents, solvents, emulsifiers, etc. in the sea. The principle underlying their application is to create, through their natural sprinkling and subsequent moving of the water, an endless amount of oil droplets that are dispersed in the water and are thus more easily attacked by marine life. In this way, the pollutant is prevented from reaching the coast in a large quantity and sunlight is allowed to penetrate into the water, thus enabling photochemical oxidation and oxygenation to take place.
The solvents are toxic and cause considerable damage, even if the current degree of toxicity of these products has reduced. The sprinkling is performed with suitable guns installed on the vessel or by dispersion by planes. This technique is among the most expensive, but it is also among the most used, although with the drawback that these chemicals do not eliminate or diminish pollution, but rather they worsen it as they added on to it (see Apollonio F. et al, 1983).

6. JONATHAN PROJECT FLEXIBLE OIL COLLECTOR

6.1 Why

The observation of intervention tools used in episodes such as spills in the Gulf of Mexico or in the river Lambro have highlighted the difficulty of interception and collection (recovery) of the spill and the difficulty of reaching the place with expensive equipment, which normally is resident in a few ports and countries, not necessarily in the place where it will be needed. Thus it has become evident that new tools, combining efficiency and low operating costs, should be developed and made widely available.

6.2 How

The innovative idea of Jonathan Project consists of device 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 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 must be removed. It can be equipped with a separator and a collection *tank and can be used to pump the mixture on a support ship to be treated on board*. It is scalable in different sizes so as 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.

6.3 Objectives

The reduction of the device into its strictly necessary elements capable of performing their intercepting and collecting functions, and the innovative feature of the design have allowed the designers to reach two basic objectives:

- efficiency that comes from specializing in one function (it is not a ship that, among other things, can also operate in areas of reclamation);
- a highly advantageous cost/benefit ratio, owing to its simple construction, low cost of material and components used, its cost-effectiveness in management and flexibility in use.

7. THE PATENT

The device is protected by international demand for extending priority PCT/IB2012/050687 Italy - No PD2011A000045.

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.

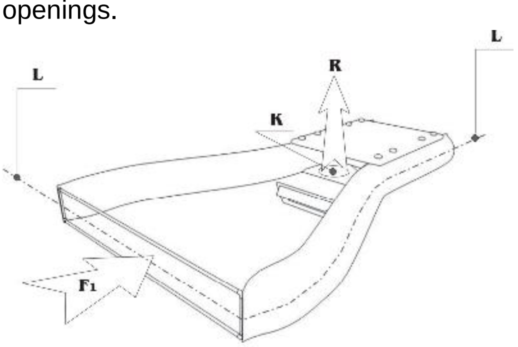

Figure 1 : View 3/4 front of the device

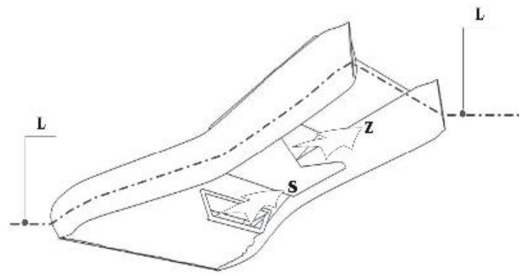

Figure 2 : View 3/4 rear the device

The opening front generates an inlet flow (F1 in figure 1) 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 in figure 1; S and Z in figure 2).

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

Outgoing flows are generated by the flow of a suction pump (R in figure 1), 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 2). 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 1).
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.

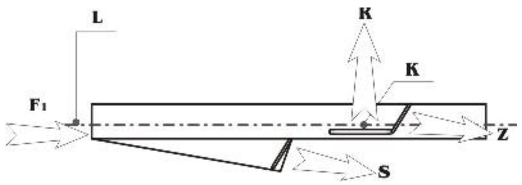

Figure 3 : Side view.

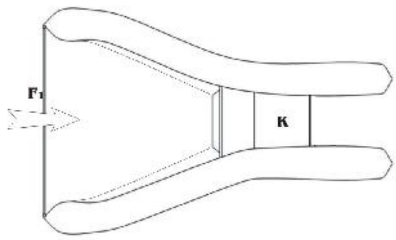

Figure 4 : Plan view.

8. THE RUNNING

The design of FL.O.C. is aimed to achieve two objectives :

- conveying the free surface of the water mass and the hydrocarbons floating on it towards the recovery zone K in the tail section; in the area K is placed the device adopted for the removal of pollutants. This objective is attained by the funnel-shape in plan.
- promoting the thickening of the pollutant film, so as to make their removal more effective. This is achieved with the adoption of a shape which forces (due to the movement) water and pollutants within a controlled environment (with appropriate geometric shape in plan and side) in which there is provided a balanced flow.

8.1 The flow diagram

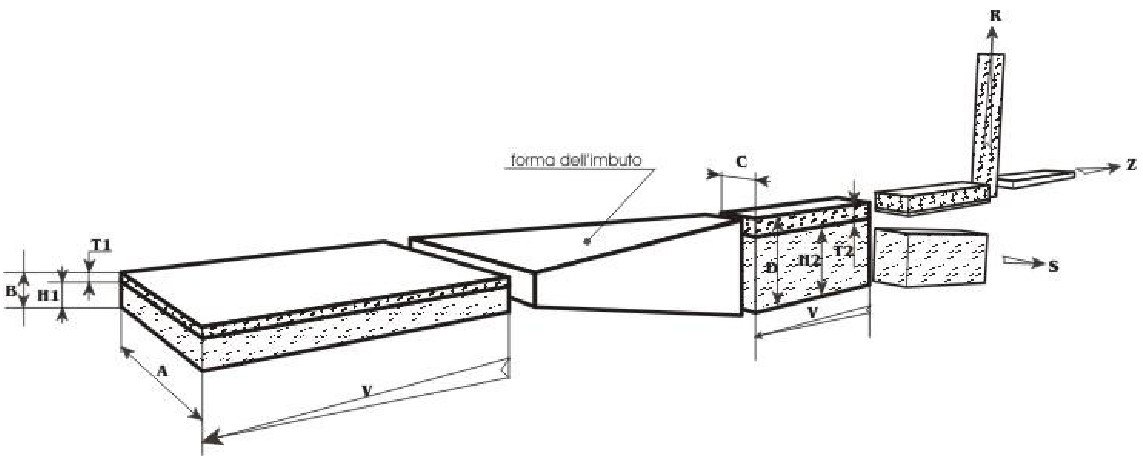

Figure 5 : The flow diagram
Symbols :

A : width of the front opening;
B : depth of the front opening;
C : width of the zone of detection;
D : depth of the area of detection;
L : level of the free surface of water and pollutants;
V : direction of advance of FL.O.C.;

S : depth of the discharge of the excess water; Z : safety relief in the queue.
A physical model of FL.O.C. has been tested at the towing tank of Trieste University.

8.2 The flow

The shape of the flow of input volume (water and pollutants), intercepted by FL.O.C., changes in unit time. Then changes :
the depth intercepted passes from B to D; the thickness of the pollutants pass from T_1 to T_2; the width of the flow passes from A to C. The flow F_1 at the entrance of the tapered shape of the funnel is given by : $F_1 = A*B*V$ (2)
Where B is the sum of T_1 and H_1, T_1 being the thickness of the oil and H_1 that of the water. The flow F_2 at the end of the tapered shape of the funnel is given by : $F_2 = C*D*V$ (3)
Where D is the sum of $T_2 + H_2$, T_2 being the thickness of the oil and H_2 that of the water.
In order that the flow through the funnel is balanced, the flow rates F_1 and F_2 must be equal. The condition is obtained with the constancy of V and the sectional areas of the initial and final flow. So $A * B = C * D$ (4)
Said ξ the A/C ratio of taper of the tunnel, will be :

$$C = A / \xi \qquad D = B * \xi \qquad T_2 = T_1 * \xi \qquad H_2 = H_1 * \xi \qquad (5)$$

The data relating to an intervention of use of FL.O.C. will be :
a) the geometrical dimensions of the funnel and its relationship of taper; b) the flow rate R of the extraction device of the pollutant (e.g. pump); c) the thickness T_1 of the pollutant floating; d) the ratio B/T_1 between the pollutant and the water entering the front opening depends on the conditions of the wave motion of the water surface and tends to 1.
The balance of the capacity of flows across FL.O.C. is given by : $F_1 = F_2 = R + S + Z$ (6)
R being the capacity of the extraction device, S the flow of excess water discharged into the depth and Z the excess flow not downloaded in S and not intercepted in R.
In a condition of calm sea, with a thickness T_1 of floating oil on it, assuming ξFL.O.C. = 10, $B = 4 * T_1$ and Z = 10% of F_2, the operating speed V can be calculated as :

$$V = [R + S + (A * B * 10/100)] / ((T_1 + H_1) * A) \qquad (7)$$

R, A, B, T_1 and H_1 are known values; $A * B * 10/100$ is the value of Z; $T_1 * \xi = T_2$ is the depth of the extraction device. Special doors regulate the output streams S and Z.

8.3 Sizing sample : small skimmer for maintenance works

Symbols according to figure 5.
A : Flow rate of extraction pump : 100 l/min. V : speed of operation : 0.5 knots
T_1: Thickness of oil film : 5 mm; ξ : FL.O.C. ratio restriction : 10
The depth of the mouth of the skimmer (B) will depend on the sea conditions; assume a ratio $T_1/B = 1/10$, and then B = 50 mm, 5 mm of polluting oil and 45 mm of water.
At the exit from the collector the immersion is D and $D = B*\xi$ and $T_2 = T_1 * \xi$ and the thickness of the floating oil changes from 5 mm to 50 mm, which is the theoretical depth of the suction pump.
Then it is : $T_2 = R*C*V$; $C=A/\xi$ and can be obtained: R = 0.0016667 m^3/s, V = 0.257 m/s; T_1 = 0.005 m; T_2 = 0.05 m
$A = (R * \xi)/(T_2 * V) = 1.29$ m and then $F_1 = A * B * V = 0.016667$ m^3/s = 1000 l/min, inflow into the manifold.
Of these 100 l/min are sucked by the pump R and 900 l/min are disposed at the discharge S, the flow of which is $S = C * H_2 * V$, which yields H_2 = 0.452 m.
Thus the mouth of the discharge has dimensions equal to : 0.129 m * 0.452 m.
Any excess flow not sucked into the discharge flow rate is Z (see figure 5)

9. USING FL.O.C.

The realization of FL.O.C. is scalable in several sizes and configurations for the obtainment of devices suitable for different uses, with the aim of always using what is specifically required for the purpose, without any waste and over-sizing.

9.1 Maintenance of ponds

It is a device (2 to 4 meters of opening of the mouth), equipped with an extraction pump and a float tank for the storage of collected residue. The pump is driven by a small internal combustion engine. The motion is given by engines on board. The construction is essential (includes only what is necessary to perform the function; it is not a ship, does not have cabins, bridges, cranes, kitchens or perform other functions).
The inflatable tubes are flexible and allow to slide against piers and docks without damage and facilitates easier cleaning. The device has no operator on board, is driven by ground or from an inflatable support. The inflatable device is deflated, can be stored in a box; it is not necessary a dock for mooring. The device is transportable by truck; it has a low cost of ownership and management and it is easy to be maintained.

9.2 Incidents

The device can be quickly transported to the place of use, with a helicopter or a truck, with easy loading and unloading. The installation for the containment of the damage takes a short time (of order of hours). The device is controlled from the bridge of a ship support; it is powered (energy) from the deck by a cable. The replacement of the dracone (float tank for the storage of the pollutant) is quick and simple.

9.3 Equipment on board

The device is placed in a housing/container of small size (about 2 – 4 m^3) which can be mounted in all types of ships. The widespread distribution of the device on many boats allows interventions to be more rapid in any geographical location.

9.4 Disasters

FL.O.C. larger (up to 20 m mouth opening) can be connected to a system of pumps and separators on board of support ships, too ensure significant efficiencies and capacities.

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