United States Patent

Cross, III

[15] **3,706,382**

[45] **Dec. 19, 1972**

[54] **OIL REMOVAL DEVICE**

[72] Inventor: **Ralph Herbert Cross, III,** Lexington, Mass.

[73] Assignees: **David Parks Hoult,** Wellesley; **Ralph H. Cross, III,** Lexington; **Jerome H. Milgram,** Cambridge, Mass.

[22] Filed: **March 12, 1971**

[21] Appl. No.: **123,567**

[52] **U.S. Cl.** **210/242,** 210/DIG. 21

[51] **Int. Cl.** **C02b 9/02**

[58] **Field of Search** ..... 210/83, 242, DIG. 21

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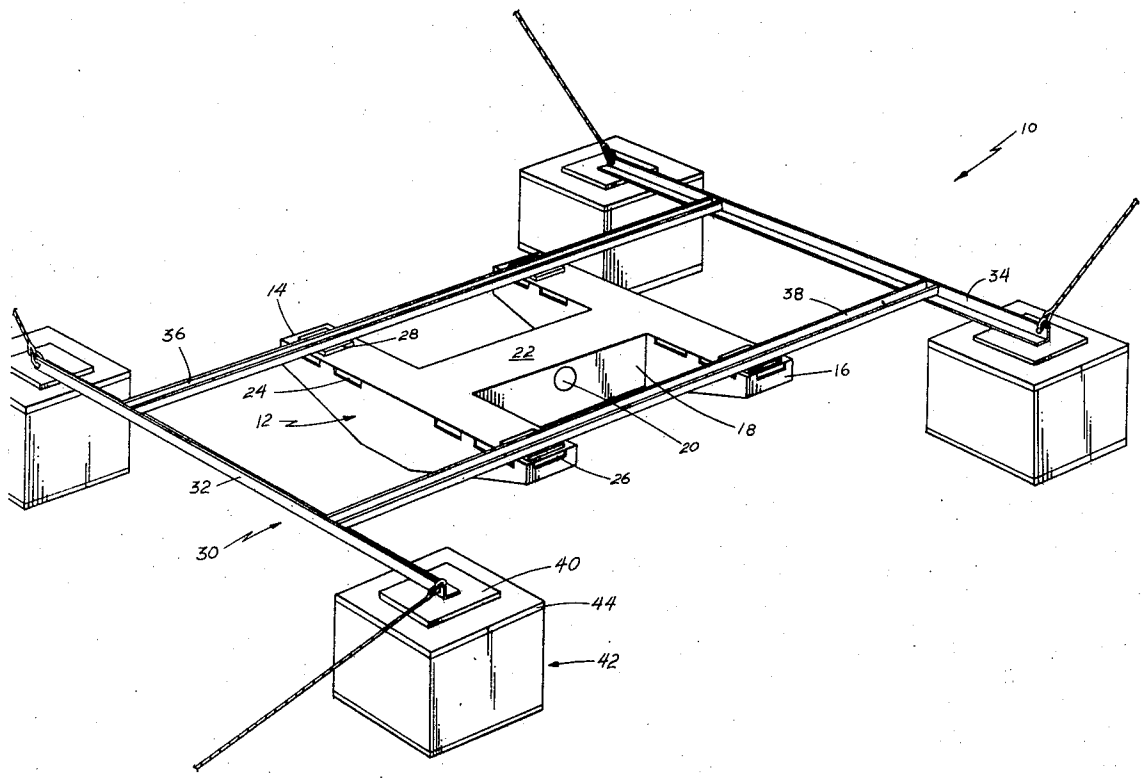
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Primary Examiner—Reuben Friedman
Assistant Examiner—T. A. Granger
Attorney—Martin Kirkpatrick

[57] **ABSTRACT**

A buoyant oil-removal device for use with a floating oil-confining barrier on a water surface with oil slicks of substantial thickness floating thereon, the device having oil in-flow ports (of lesser vertical height than the oil slick thickness) with the ports normally floated at a level intermediate the thickness of the oil slick to provide inflow of the water-floated oil slick and to minimize either water or air inflow through said ports whether the water is calm or disturbed by waves, and designed to collect oil from the water surface at a rate which is maximized subject to the requirement that intake of water and air is minimized. The device has a longest overall dimension of not more than one-fourth of the wavelength of the shortest wave of significant amplitude, and includes a generally H-shaped skimmer structure; each arm portion of the structure is of generally rectangular or circular cross section, providing a plurality of inflow ports, each of vertical dimension of the order from 0.04 to 0.2 of the expected slick thickness. Inflow ports preferably are positioned immediately adjacent the top surface of the structure, and are horizontally elongated. The device is provided with a flexible, buoyant suctioning hose communicating with the inflow ports for the removal of oil.

5 Claims, 4 Drawing Figures



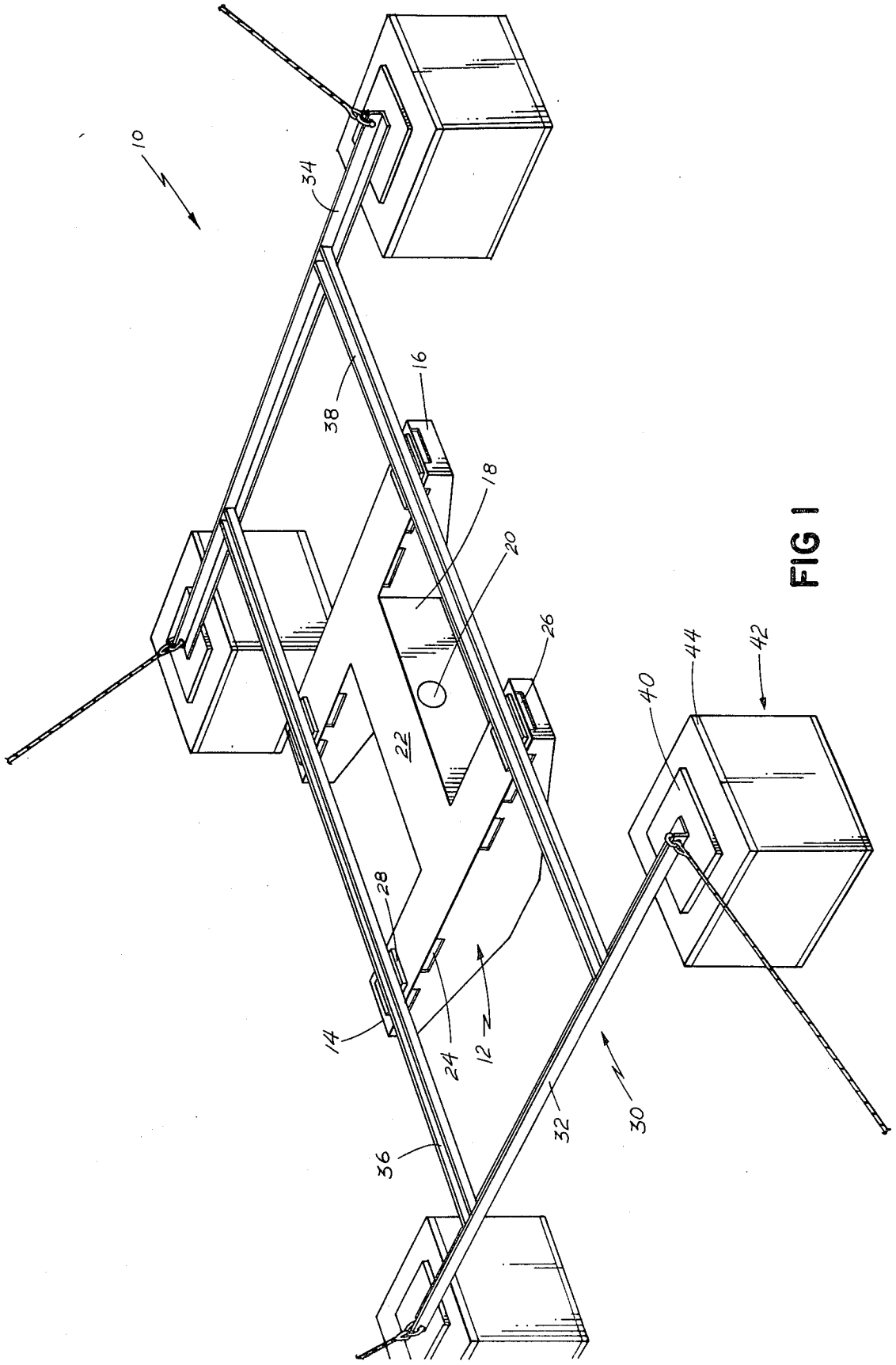


FIG 1

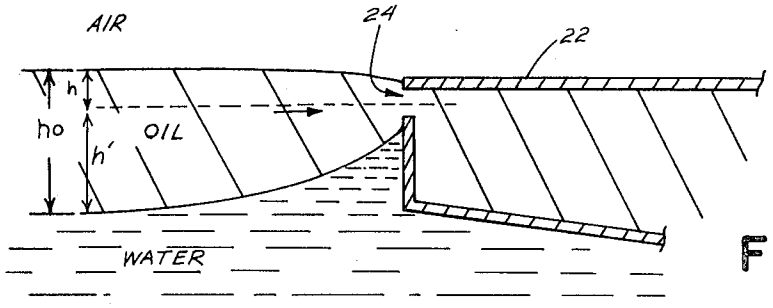


FIG 4

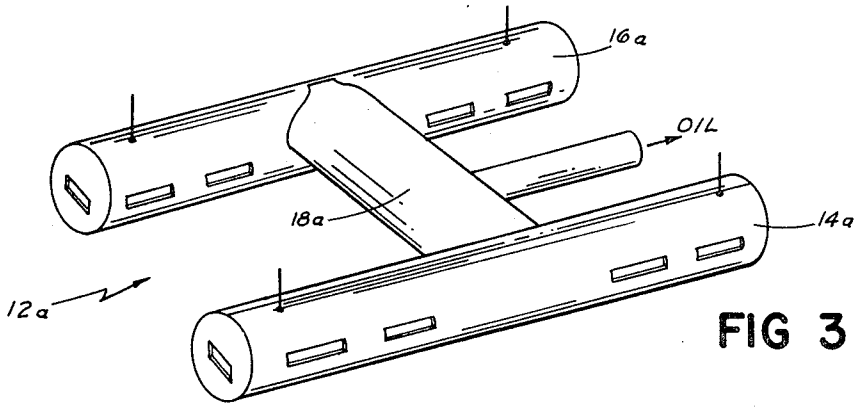


FIG 3

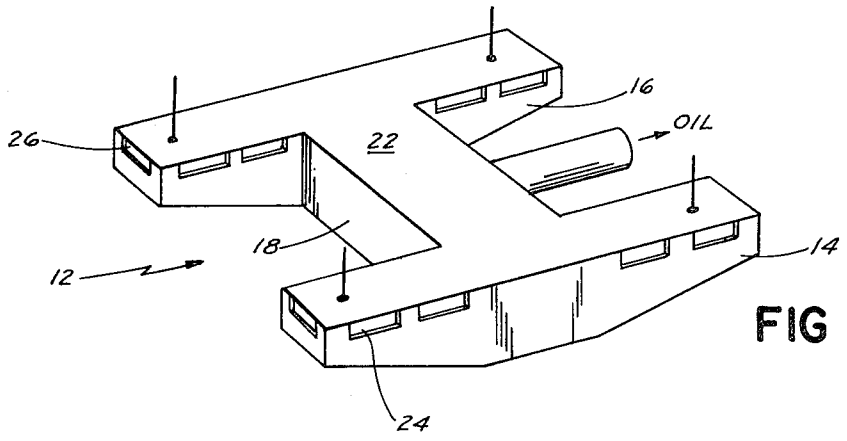


FIG 2

OIL REMOVAL DEVICE

This invention relates to the removal of oil from the surface of water.

Often, the problem of removing spilled oil occurs on the open sea, as a result of damage to an oil tanker or the like. The escaping oil may be prevented from spreading by confining it within any of various types of barriers, such as the one described in copending applications Ser. No. 54,530 and Ser. No. 79,051. However, the oil must then be removed from the water.

Many devices have been developed to remove such oil but usually admixed with a substantial amount of water, including selectively wettable endless belts, skimmer boats, sorbents, and similar devices. In general, these devices provide only limited flow rates of oil, and usually they must be moved by, mounted on, or constructed as an integral part of, a vessel. These characteristics render most such devices unsatisfactory. Also, the problem is in general complicated by the presence of constant surface waves, which cause the collection device to move vertically through the oil slick, in and out of the water and air. This makes it difficult to maintain a continuous flow of oil into the device and also results in the entrainment of a good deal of water. Additionally, if waves are generally reflected from the device, oil will be carried away from it and cannot be removed.

It is therefore an object of this invention to provide an oil-removal device that permits a satisfactory rate of oil intake, and that need not be moved by, mounted on, or constructed as part of a vessel. It is a further object to provide such a device that is able to follow most wave disturbances of significant magnitude and thereby is able to maintain a generally uninterrupted flow of oil, even on the open ocean, and that causes minimum reflection of incident waves. The "significant wave height" is commonly defined as the average height of the highest one-third of all the waves in a record. A wave which will significantly affect the performance of the oil removing device has a height generally in excess of the oil slick thickness, and a length generally exceeding ten times that height.

A buoyant oil-removal device that draws the oil by suction through in-flow ports can provide a satisfactory rate of flow. However, when fluid is drawn through such ports, as a result of flow conditions at the ports, as the rate of flow increases, the quantities of air and water entrained and drawn into the device tend to increase also. Such air and water must then be separated from the oil, and the efficiency of such devices is much impaired. Moreover, this problem occurs even in the absence of large-scale wave disturbances.

It is therefore another object of this invention to provide an efficient oil-removal device capable of maximizing the rate and amount of oil flow while minimizing the relative quantities of air and water entrained with the oil.

Further, it is an object to provide such an oil-removal device that is simple and inexpensive to construct and reliable in operation.

The invention in its preferred form features a buoyant oil-removal device, normally for use with a floating oil-confining barrier on a water surface with oil slicks of substantial thickness floating thereon, the device having in-flow ports of lesser vertical height

than the oil slick thickness, normally continuously floated at a level within the thickness of the oil slick. In preferred embodiments, the device includes an H-shaped skimmer structure, consisting of a cross member and two arm portions; each arm portion of the structure is of generally rectangular or circular cross section and provides a plurality of inflow ports each of vertical dimension of the order of 0.04 to 0.2 of the expected slick thickness, positioned immediately adjacent the top surface of the oil and horizontally elongated. A flexible buoyant suction hose communicates through the structure with the inflow ports for the removal of oil. Buoyancy means are provided in the form of a float frame, from which the skimmer may be suspended, and float elements suspended from the frame outboard of the skimmer. The longest dimension of the entire device is preferably not more than one-fourth the wavelength of the shortest waves whose amplitude is significant in disturbing the device, and preferably less, permitting the device to move substantially with the water surface under the action of such waves, thereby normally continuously maintaining the inflow ports generally within the oil slick thickness.

Other objects, features and advantages will appear from the following description of a preferred embodiment of the invention, taken together with the attached drawings thereof, in which:

FIG. 1 is a perspective view of a preferred embodiment of the oil-removal device of the invention;

FIG. 2 is a view of the skimmer portion of the device of FIG. 1;

FIG. 3 is a view of an alternative form of the skimmer portion; and

FIG. 4 is a schematic view of flow conditions near an inflow port.

Referring now to the drawings, and particularly to FIG. 1, the oil-removal device **10** includes a generally H-shaped skimmer portion **12**, of generally rectangular cross-section. The choice of an H-shape for the skimmer manifold is not critical, but provides a compact structure with relatively short arms, thereby ensuring a relatively small pressure drop over the length of the arm. The cross-sectional area of the arms **14** and **16** generally increases from the free ends toward cross-piece **18**. A hose fitting **20** is provided in cross-piece **18**, positioned immediately adjacent top surface **22** of skimmer **12**. In-flow ports **24** in the form of slots are provided along the inner and outer sides of arms **14** and **16**. Further slots **26** are provided in the ends of arms **14** and **16**, but none are provided on cross-piece **18**, for reasons that will appear more fully in what follows. Skimmer **12** is preferably constructed of ⅛ inch thick aluminum alloy 5086, intended for marine use; seams may be welded or riveted, and the top or bottom plates may be bolted to the rest of the skimmer **12** to simplify cleaning after use.

The purpose of the top plate on the device is to control the pressure gradient in the flow of oil within the skimmer. This pressure gradient is caused by accelerating the oil from rest to the exit velocity from the skimmer body into the flexible hose. If the top plate were absent, free surface waves would form on the air-oil interface inside the skimmer, and the pressure gradient (and hence flow-rate) through a given orifice would be uncontrolled. Moreover, additional air would

be entrained at the entrance to the hose. The bottom plate performs a similar function with respect to the oil-water interface.

Four frame-mounting plates **28** are provided for attaching the float frame. Float frame **30** is constructed of aluminum alloy structural sections. Two angle sections **32** and **34** are welded to two channel sections **36** and **38**. Skimmer **12** is bolted to channel sections **36** and **38** through frame-mounting plates **28**, using long studs to allow adjustment of the vertical position of the skimmer **12**. Float mounting plates **40** are fastened to the free ends of angle sections **32** and **34**.

The floats **42** may be closed cell foam blocks, with plywood sections **44** bonded to the top and bottom of the foam for strength. Floats **42** are bolted to float mounting plates **40** with stainless steel bolts or threaded rod. The choice of spaced float elements, rather than a single buoyant skimmer, results in a device that presents a small reflecting area to incident waves. Thus waves tend to move past the skimmer, carrying the oil slick with them past the inflow ports. This choice also provides superior wave-following ability, as described below.

In order to keep the oil fraction of the oil-water mixture removed by the skimmer relatively high enough for the device to be practical, the skimmer inflow ports must follow the motion of the free surface. This requires that the skimmer heave and roll in unison with the free surface. Therefore, the natural frequencies of the heave and roll motions must be at least twice as high as the frequencies of most of the waves and the physical dimensions of the entire device must be much smaller than the lengths of most of the waves.

As a practical matter, if the oil slick is, e.g., ¼ foot to 1 foot thick, as it may be if concentrated by a barrier, waves shorter than about 30 feet, crest to crest, do not interfere significantly with the operation of the device. Waves of this length have a height of about 2 feet or so and a period of about 2.7 seconds.

Therefore, the physical length and width dimensions of the device should not exceed 10 feet and the natural periods in heave and roll should be less than 1.4 seconds. If such devices do not have enough collection capacity, a number of them must be used instead of increasing the size of a single device so much that it does not follow the waves well.

In the preferred embodiment described here, the over-all length of the device, from the outer edge of one float **42** to the outer edge of the next, is 66 inch or 5.5 feet. This length is suitable for use in conditions in which the significant wave height considered is about 5 feet, corresponding to a wavelength of about 40 to 70 feet. Thus the length of the device is about one-eigth of the shortest wavelength considered, permitting the device to respond well to most surface motions. The entire unit weighs about 100 pounds.

The cross-sectional area of the arms increases from 5 inches × 2.5 inches at the outer ends to 5 inches × 5 inches at the cross-piece, which causes the flow velocity at the center to be about one-half the inlet velocity. This tapered structure assists in the control of entrained air, and enhances the wave response.

The over-all dimensions of the device have been determined to ensure that ports **24** and **26** are maintained within the oil slick thickness a substantial portion of the time. Further theoretical considerations determine the dimensions of the ports themselves.

The maximum velocity at which oil floating on water can be drawn through an orifice or slot is limited by two phenomena: the entrainment of air from the surface, and the entrainment of water from below. Referring to FIG. **4**, the Venturi effect at the slot draws the air-oil interface downward and the water-oil interface upward, and thus vertically thins down the slick locally. Because this effect occurs at the ports on the inner sides of arms **14** and **16**, if ports were placed on the cross-piece **18** of the skimmer, the slick would be so thinned locally that more water and air than oil would be drawn into the skimmer. Moreover, the pressure inside cross-piece **18** is lower than in arms **14** and **16**, and thus inflow through ports in the cross-piece would be more likely to entrain air or water. Therefore, no ports are placed on the cross-piece.

The thinning down of the slick near the ports depends on the velocity of flow through the ports. Treating the inlet as having no vertical extent, and letting h be the depth of the inlet below the undisturbed air/oil interface, the inlet oil velocity at which air begins to be entrained with the oil may be calculated by applying the steady-state energy (Bernoulli's) equation for irrotational flow, giving

$$V_{air} = \sqrt{2\Delta g h}\,.$$

Similarly, letting h' be the depth of the undisturbed oil/water interface below the inlet, the same equation gives for the inlet oil velocity at which water begins to be entrained

$$V_{water} = \sqrt{2\,g\Delta h'}$$

where Δ = (water density − oil density)/(water density). The total oil slick thickness is $h_o = h + h'$.

Combining the two equations, and expressing h and h' as

$$h = \frac{\Delta}{1+\Delta}\,h_o,\; h' = \frac{1}{1+\Delta}\,h_o$$

the maximum inlet velocity without air or water entrainment when the inlet is located at a depth h below the air/oil interface and h' above the water/oil interface is given by

$$V_{max} = \left(2g\,\frac{\Delta}{1+\Delta}\,h_o\right)^{1/2}$$

Thus, the maximum velocity at which oil can be drawn into an inlet port without entrainment of air or water depends on the specific gravity of the oil (through Δ) and the local (undisturbed) oil slick depth h_0.

In practice, the inlet port is not of zero height, but has a vertical height S which must be subtracted from the local thickness, as entrainment of air begins at its top edge and entrainment of water at its lower edge. Since the maximum inlet velocity is fixed, the total rate of flow of oil will depend on the total inlet area, which is a product of the number of inlet ports, and the width and height of each. Two practical considerations affect the choice of slot height S. First, as oil is removed from the confined pool, the thickness of the pool decreases. Thus, if the value of S is chosen to be an appreciable

fraction of the initial thickness of the slick h_o, while the initial flow rate will be large, the entrainment of air and water will become a serious problem before the oil pool is entirely removed. Also, if S is an appreciable fraction of h_o, small deviations in the position of the slot, caused for example by buoyancy changes as the pool is exhausted, or by small waves, will cause entrainment of air or water. These considerations lead to the choice of a value of S that is much smaller than the expected slack thickness. In practice, it has been found that for a slick 1 foot thick, a slot height S of ½ inch to 1¼ is appropriate.

In practice, the flow rate of oil through the device can be such that the velocity through each and every orifice is less than V max. In such operation, less than the maximum rate of oil collection is achieved, but my theory and experiments have shown that very little water or air is entrained in the oil.

However, since the horizontal spacing between ports along the skimmer does not influence entrainment, elongated holes, or slots, can be used, with essentially minimum spacing between adjacent slots, to obtain the desired flow rate. Such an arrangement of slots is shown in FIG. **1**. The slots are placed adjacent top surface **22** of skimmer **12** to assist in the control of entrained air.

An oil-removal device constructed as shown in FIG. **1** is conservatively designed to collect 5 tons of oil per hour, from an oil pool initially about 1 foot deep when the value of Δ is 0.10. For a slick 1 foot thick, with waves and a current, a ratio of oil to total fluid collected of 0.9 can be expected in 3 foot waves, and 0.80 or better in **5** foot waves, using properly selected pumps and hoses, and with proper operation of the entire system. A suitable suctioning means for use with the device of FIG. **1** may comprise a non-emulsifying, self-priming pump or pumps (such as a double Edson diaphragm pump) with variable speed control; using such equipment, the velocity in each inlet port is less than V_{max}, and no valves are required to control this velocity.

The oil-removal device of the present invention is operable when there is a current in the water of as much as, say, 2 knots, and the efficiency of the device may even be increased, as the device may be oriented so that the current carries oil to the skimmer and concentrates it in a deep pool for collection. The device may be readily oriented, as desired, to take account of current, wave and wind conditions by tethering or anchor lines, adjusted to suit.

While a skimmer with rectangular cross-section has been described, one having a circular cross-section, as shown in FIG. **3**, may also be employed. Alternatively, inlet ports may be located in the horizontal top surface of the skimmer, rather than in the side walls; the flow through the ports is not significantly altered by such an arrangement so long as the hole is located a distance h down from the top of the oil surface.

The vertical position of the inlet ports, as well as the vertical dimension, may be made adjustable if desired for use in varying conditions. In the embodiment described here, this adjustment may be provided by double nuts on the long-threaded studs connecting plates **28** on the skimmer **12** to the channels **36,38** on the flotation structure **30**. Alternatively, interchangeable side walls for skimmer **12** could provide inlet ports of various slot heights or vertical position.

What is claimed is:

1. In a buoyant oil-removal device for use on a water surface with an oil slick of substantial thickness floating thereon, a generally H-shaped skimmer structure adapted and arranged to be water-floated having a plurality of oil-inflow ports disposed around arms of said H-shaped structure with said ports normally floated at a level within said oil slick,

separate buoyancy means attached to said skimmer structure for floating the same,

and conduit means attached to the cross-piece of said H-shaped structure communicating with said ports for withdrawing oil collected from said water surface,

whereby said device floats generally parallel to said water surface both when said surface is calm and when it is disturbed by waves, normally maintaining said ports substantially at a level within said oil slick, thus providing a maximum ratio of withdrawn oil to entrained withdrawn air and water.

2. The device of claim **1** wherein the cross-section of each arm of said H-shaped skimmer structure is generally rectangular, the area of said cross-section generally increasing from each end of said arms toward said cross-piece.

3. In a buoyant oil-removal device for use on a water surface with an oil slick of substantial thickness floating thereon, a generally H-shaped skimmer structure adapted and arranged to be water-floated having a plurality of oil-inflow ports with said ports normally floated at a level within said oil slick,

separate buoyancy means including float elements and a float frame attached to said skimmer structure for floating the same, said H-shaped skimmer structure being suspended from said float frame, and said frame providing float-suspending portions spaced from said H-shaped structure, said float elements being suspended therefrom,

the longest dimension of said device being the distance from one said float element to an adjacent said float element, including the length of said float elements,

and conduit means communicating with said ports for withdrawing oil collected from said water surface,

whereby said device floats generally parallel to said water surface both when said surface is calm and when it is disturbed by waves, normally maintaining said ports substantially at a level within said oil slick, thus providing a maximum ratio of withdrawn oil to entrained withdrawn air and water.

4. The device of claim **3** wherein the vertical dimension of said inflow ports is adjustably fixed.

5. The device of claim **3**, wherein the vertical distance between said float elements and said inflow ports is adjustably fixed.

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