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(54) THE SEPARATION FROM A BODY OF LIQUID OF A CONTAMINATED LAYER SPREAD OVER THE LIQUID

(71) We, SEACLEAN SA, a body corporate organised under the laws of Luxembourg at Boulevard Royal 10A, Luxembourg/Luxembourg, do hereby declare the invention for which we pray that a patent may be granted to us and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a process and also apparatus for separating from a body of liquid at least a portion of a contaminated layer spread over the liquid, the contaminated layer comprising a contaminant which is immiscible with the liquid.

The problem of removing a contaminated layer, particularly a liquid spread in a thin layer on the surface of another liquid of a much greater thickness has acquired great importance since the serious danger constituted by the general increase of water contamination has been realized. Such contamination often leads to the formation of a thin layer of one or more contaminating liquids on the surface of the water, these contaminating liquids being immiscible with the water below and therefore being either in a pure state or in the state of an emulsion with the water. When rivers, lakes or the sea are contaminated by petroleum products the contaminant often forms, at least in the initial stage of contamination, a very thin and extensive contaminated layer consisting substantially only of "pure" contaminant which is not emulsified with the water below. But, mainly due to the effect of the swell and the wind, the contaminant quickly forms an emulsion with the water. This has happened in the case of catastrophes caused by shipwrecked tankers or by accidents in the operation of submarine petroleum extraction plants or in liquid hydrocarbon transfer and treatment plants.

The same problem occurs in the purification of waste water, particularly waste water coming from highly industrialized regions. In this case the contaminated layer is constituted by contaminant emulsified with the water below, but this layer can only cover a relatively

small area. In all these cases the contaminant, which may or may not be liquid, and the underlying liquid are immiscible and a thin contaminated layer is formed on the surface of the underlying liquid which has relatively great thickness. Therefore, it is difficult to separate the contaminated layer from the underlying thick layer of liquid to separate the contaminated layer from the liquid without taking particular measures for increasing the thickness of the contaminant layer.

According to one aspect of the invention, there is provided a process for separating from a body of liquid a contaminated layer spread over the liquid, the contaminated layer comprising a contaminant immiscible with the liquid, comprising the steps of:

encircling a portion of the liquid and contaminated layer to a depth exceeding the thickness of the contaminated layer;

moving the encircled portion to a recovery zone at which the contaminated layer is separated from the liquid progressively reducing, simultaneously with the movement, the surface area of the encircled portion so as to increase the thickness of the encircled contaminated layer;

The steps being repeated so that at least one further portion of the liquid and contaminated layer is being encircled as the first-mentioned portion is being moved to the recovery zone, the contaminated layer of the first-mentioned portion being separated from the liquid at the recovery zone as the or each further portion is moved to the recovery zone.

The process may be such that the free surface of the contaminated layer is maintained at an approximately constant level during the said movement and in the recovery zone.

According to another aspect of the invention, there is provided apparatus for carrying out the process of the said one aspect of the invention, the apparatus comprising: partitioning means for encircling a plurality of portions of the liquid and contaminated layer;

a recovery zone to which the encircled por-

tion of the contaminated layer can be moved by the partitioning means;

means for moving in succession each of the encircled portions to the recovery zone, and for progressively reducing, simultaneously with the movement the surface area of each encircled portion so as to increase the thickness of the encircled contaminated layer; and

means for separating the contaminated layer from the liquid at the recovery zone.

It is to be appreciated that the contaminant is immiscible with the liquid and may be, by way of example dust, such as soot, sawdust or other substances consisting of fine particles or grains, substances lacking cohesion or liquid substances. The contaminated layer may thus consist of, for example, substantially only contaminant or a mixture of the liquid and the contaminant. In the case of an immiscible liquid contaminant the contaminated layer may be an emulsion of the liquid contaminant and the liquid.

The present invention can be used for treating both large contaminated surfaces such as out at sea or in ports, and relatively small contaminated surfaces such as in purification plants.

For a better understanding of the invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:—

Figures 1 and 2 are diagrams illustrating in principle a first step of a process in accordance with the first aspect of the invention. Figure 1 being a plan view and Figure 2 a cross-sectional view;

Figures 3 and 4 are diagrams illustrating in principle a second step of the process, Figure 3 being a plan view and Figure 4 a cross-sectional view;

Figures 5 and 6 are cross-sectional views illustrating in principle a first form of carrying out the process between the first and second steps;

Figures 7 and 8 are cross-sectional views, illustrating in principle a second form of carrying out the process between the first and second steps;

Figures 9 and 10 are diagrammatic cross-sectional views illustrating in principle two different modifications of the process.

Figure 11 is a schematic sectional view of a first embodiment of apparatus in accordance with the invention;

Figure 12 is a schematic sectional view of a second embodiment of apparatus in accordance with the invention;

Figure 12b is a cross section taken on the line XII—XII of Figure 12;

Figure 13 is a sectional view showing the second embodiment of the apparatus as adapted for a particular application;

Figure 13b is a detail view showing part of Figure 13 on a larger scale;

Fig. 14 is a plan view on a larger scale, showing part of Figure 13;

Fig. 15 is a schematic representation of various modifications of the apparatus shown in Fig. 13;

Fig. 16 is a longitudinal section showing a modification to the second embodiment of the plant, and

Fig. 16b is a cross section taken on the line XVIIb—XVIIb of Fig. 16.

The process is based on the consideration that, as is schematically shown in Figs. 1 and 2, if a portion of a liquid, for example, water 1 covered by a thin contaminant layer of oil 2 is encircled, with the aid partitioning means comprising two movable walls 3 and 4, two fixed walls 5 and 6 and a bottom wall 7 and the movable walls are moved toward each other relative to the fixed walls and the bottom wall into the positions 3' and 4', respectively (shown in Figs. 3 and 4) the thickness of the oil layer 8 thus enclosed is increased from an initial value Z_H to a final value Z'_H . The height of the enclosed mass of water 9 as measured from the bottom 7 is likewise increased from the initial value Z_B to the value Z'_B .

In the case illustrated in Fig. 4 it is assumed that there are no leaks between the movable walls 3', 4' and the fixed walls 5 and 6 or the movable walls and the bottom wall 7. Therefore, the free surface 10' of the enclosed contaminated liquid has risen above the free surface 10 of the contaminated liquid outside and the separating surface 11' between the water and oil has likewise risen above the level 11 at which this separating surface is located outside. If, as shown in Figs. 5 and 6, there is free communication between the portion of isolated water 9'' and the water outside 1, the free surface 10'' of the enclosed contaminated liquid is nevertheless located at a higher level than the free surface 10 of the contaminated liquid outside whereas the separating surface 11'' is located below the level 11 at which it is located outside. This is due to the difference between the density of the oil and that of the water.

By providing a hole 12 in the bottom wall 7, as shown in Figs. 7 and 8, through which the enclosed water 9''' can escape to the water outside 1, the height h of the free surface 10''' of the enclosed contaminated liquid above the free surface 10 of the contaminated liquid outside can be varied as desired as a function of time as this height only depends on the speed at which the movable walls 3 and 4 are moved toward each other, and on the diameter of the hole 12.

By drawing off the enclosed water 9', 9'', 9''' all the situations may arise between those schematically illustrated in Figs. 9 and 10. Fig. 9 showing schematically the case in which

there is simply free communication between the water outside 1 and the enclosed water 9" and in which the free surface 10" of the enclosed liquid is located above the free surface outside 10, and Fig. 10 showing the case in which the liquid is drawn off through the hole 12, as indicated by the arrow 13, and consequently the free surface 10"" of the enclosed liquid is brought down to the level of the free surface outside 10. As is evident from the Figs., in both cases the thickness of the layer of liquid contaminant is increased from the value Z_{π} outside to the value Z'_{π} inside the "cell" formed by the partitioning means 3, 4, 5 and 6.

Thus, the invention consists in continuously and successively isolating portions of the contaminated liquid between the movable walls moving at variable speed between two fixed walls so as to form a succession of "cells" which, as they move along, become narrower and narrower. These cells may be moved along a "bottom" which permits the uncontaminated liquid contained in each cell to escape or this liquid may be drawn off as the cells move along.

A plant for carrying out this process is schematically shown in Fig. 11. This plant comprises a basin 15 provided with a plurality of fixed walls 16 located with their tops 17 at a level 17 at a certain depth p below the free surface 18 of the contaminated liquid outside formed by "pure" liquid 19, for example water, covered by a layer 20 of a liquid contaminant, for example oil. The fixed walls 16 are secured to the side walls of the basin 15, only one of these side walls, the side wall 21, being shown in Fig. 11. The bases of the fixed walls 16 are located at a distance a above the bottom 23 of the basin 15. The fixed walls 16 together define a plurality of shafts 24 opening into a discharge space 25 formed by the free space between the bases of the fixed walls 16 and the bottom 23 of the basin 15 and communicating with a discharge channel 26 at the downstream end of the basin 15. Arranged in the upper portion of the basin 15 is a plurality of movable walls 27 which are continuously moved by drive means, not shown, at a variable speed in a closed loop path schematically indicated by the dash line 28 in Fig. 11.

The drive means is so arranged that the bases of the movable walls 27 will pass substantially at the level 17 of the tops of the fixed walls 16 in the useful portion 28a of their path of movement in the direction of the arrow 32a and so that in the portion 28b of their path of movement, in which they are moved back to the front of the basin 15 in the direction of the arrow 32b, they are out of the liquid. Further, the drive means moves the walls 27 at a speed which is considerably higher in the upstream portion of the basin 15 than in the downstream portion there-

of so that the spacing between the walls 27 is progressively reduced toward the outlet end of the basin 15. This reduction of the spacing between the walls 27 causes the cells defined between each pair of adjacent walls 27, for example, the cell formed by the space 29 between the walls 27a and 27b and the side walls 21 and 22, to behave in the manner described above with reference to Figs. 7 and 8, i.e. the thickness of the enclosed layer of oil 30 is progressively increased and its free surface 31 is progressively raised. The last one of the fixed walls 16 is connected to the rear wall 33 of the basin 15 by a bottom plate 34 provided with an aperture 35 so as to form a recovery chamber 36 in which the thickness of the accumulated oil 37 is sufficiently great to permit it to be recovered by conventional means, for example, by pumping. The remaining water 38 collecting on the bottom plate 34 is evacuated through the aperture 35 into the discharge channel 26. The water below the layer of oil, which is moved on by the cells 29, is discharged into the various shafts 24 from which it escapes into the discharge space 25 and further through the discharge channel 26. If desired, the discharge channel 26 may be provided with propulsion means such as a propeller 39 to keep the water circulating. If the uncontaminated water contained in the cells is drawn off, the free surface 31 of the liquid may then be kept at a substantially constant level by appropriately adjusting the flow rate of the water and by producing a carefully calculated pressure drop in each shaft 24. As the propeller 39 constitutes an optional feature it is drawn in dash lines.

The path of the closed loop 28 comprises an inclined upstream portion 28c at the inlet 14 to the basin 15 and an inclined downstream portion 28d adjacent the recovery chamber 36. In these loop portions 28c and 28d the walls 27 remain equidistant so that during their immersion in the loop portion 28c, where they are equally spaced widely apart, and during their emergence in the loop portion 28d, where they are equally spaced close together, the contaminant layer is not disturbed as would be the case if the spacing between the walls 27 was varied during the immersion or emerging of the walls 27.

In the described plant the movable walls 27 must move at a variable speed. Although many ways are known to produce such a movement, the means for producing such movement are all relatively complex, particularly because the walls have to be recycled, i.e. moved back to the inlet of the basin and simultaneously spaced apart to regain their initial spacing.

Therefore, another plant is proposed according to the present invention, which plant is schematically shown in Figs. 12 and 12b. In this plant the movable walls are formed by

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the immersed portions 45 of the helical blade 46 of an Archimedean screw 47 with varying pitch. The axle 48 of the Archimedean screw 47 is arranged in a substantially horizontal position. The Archimedean screw 47 is rotatively driven by any known means, not shown, in the direction of the arrow 44 in the case of the plant shown by way of example in Fig. 12. The pitch of the helical blade 46 decreases from its upstream end toward its downstream end. The fixed walls are in the form of inclined walls 49 which guide the flow of the water in the shafts 50 formed by the spaces between the walls 49. The walls 49 in a certain sense serve as guide blades for the flowing water. The screw 47 is rotatably mounted in a trough 51 which together with the immersed portions 45 of the helical blades 46 of the screw forms the cells 52 in which the contaminated liquid is enclosed. The walls 49 are secured to the trough 51. The bottom 53 of the plant likewise has a hydrodynamic shape to facilitate the flow of the water in the discharge space 54 formed by the free space between the guide walls 49 and the bottom 53. The discharge space 54 communicates with a discharge channel 55 which may be provided with a propeller 56. At the downstream end of the plant there is a recovery chamber 57 having in its bottom wall a discharge aperture 58 through which the water 59, which has accumulated below the oil layer 60, is evacuated into the discharge channel 55.

Removal means, for example, a pump not shown in Figs. 11 and 12 but shown in Figs. 13 and 16, is provided for recovering the oil of the thickened layer which accumulates in the recovery chamber 57.

If required, the water may be pumped off. In this case a servo-mechanism is installed which ensures the pumping rate is adjusted as a function of the position of the interface between water and contaminant layer so that the pump does not suck in contaminant.

It will be seen that this type of plant operates in a similar manner as that shown in Fig. 11. In effect, the rotation of the screw 47 causes the mass of liquid contaminant enclosed in the cells 52 formed by the spaces between the turns of the screw 47 to move downstream and, as the pitch of the screw 47 decreases toward the downstream end thereof, the cells 52 narrow and the same effect as in the embodiment shown in Fig. 11 is obtained, i.e. the layer of liquid contaminant, in the present case oil, floating on the surface of the contaminated liquid, in the present case water, is progressively thickened.

The delivery of the pump for removing the oil layer 60 from the recovery chamber 57 is regulated by servo control means in such a manner that the suction rose of the pump will remain constantly immersed in the layer of oil so that the interface between

oil and water is prevented from rising above a given level and the free surface of the oil is prevented from dropping below another given level. Thus, this servo control means controls the delivery of the pump in dependence on the level of the interface between oil and water and/or the level of the free surface of the oil.

The screw 47 is also mounted for axial movement in the direction of the arrow 62 to obtain the greatest efficiency of the plant by adapting it to the thickness of the initial layer of oil 20 and to the flow of liquid contaminant at the inlet 61.

The axle 48 of the screw 47 can further be inclined relative to the horizontal plane and this inclination can be varied according to requirements, as indicated by the arrow 63.

The described embodiment has a screw provided with only one helical blade. However, the screw 47 may also be provided with several helical blades the pitches of which decrease from the upstream end toward the downstream end of the screw. The effect obtained thereby is the same in principle, but in this case the speed of rotation of the screw 47 may be reduced and thereby the risk of forming an emulsion of the two liquids is avoided.

The two embodiments of the plant shown in Figs. 11 and 12, respectively, are designed for fixed installation for the treatment of a contaminant liquid which flows freely toward the inlet thereof. This is the case in the treatment of contaminated water coming from industrial plants and large cities. This is also the case in certain industrial processes in which a light fluid floating in the form of a thin layer on the surface of a heavier liquid is to be removed.

But these plants, especially that with the Archimedean screw, can also be mounted on board a ship to permit the treatment of contaminated waters of rivers, lakes and the sea.

Fig. 13 shows such contaminant removing vessel. Located in the front portion of the hull 65 is an Archimedean screw system 66 with varying pitch and, in the illustrated embodiment, only one blade, this screw being similar to that described with reference to Fig. 12. This screw is driven by a motor 68 with reduction gear for rotation in a cylindrical trough 69 in front of a plurality of vertical partitions 70 similar to the partitions 16 of the plant shown in Fig. 11. The partitions 70 are secured to the trough 69 at heights decreasing progressively from the upstream end to the downstream end of the screw along a line 71 (see Fig. 13b) which approximately follows the variation of the interface between the water and the contaminant, for example, water and oil, in the cells 72 formed by the spaces between the spiral blades of the screw 66. The axle 86 of the screw 66 is located slightly above the upper

surface 87 of the contaminated water. The screw 66 is longitudinally movable by control means 88 in the reduction gear of the motor 68 so that the longitudinal position of the screw can be varied as shown by the arrow 89 to adapt it to the thickness of the contaminant and/or the speed of the vessel. A recovery chamber 73 is located rearwardly of the screw 66 to collect the contaminant. A pump 74 is provided to pump off the contaminant from the chamber 73 and feed it into a storing basin 75. The water flowing into the shafts 76 formed by the spaces between the partitions 70 is collected in a discharge space 77. The discharge space 77 (contrary to the discharge space 25 shown in Fig. 11 and the discharge space 54 shown in Fig. 12) is so arranged that the water is forced to flow in the direction indicated by the arrow 78, i.e. contrary to the direction of flow of contaminated liquid indicated by the arrow 79. The reason for this arrangement will be explained hereinafter. From the discharge space 77 the water flows into a discharge channel 80 under the action of a pump 81 which forces it out of the vessel through a discharge pipe 82 provided on the bottom of the hull below the storing basin 75. A Venturi tube is inserted between the discharge channel 80 and the pump 81 to draw off through a pipe 84 the water 85 which may collect on the bottom of the recovery chamber 73.

The following hydrodynamic considerations constitute the reason why the liquid in the discharge space 77 is forced to flow in a direction opposite to the direction of flow at the inlet of the plant. In fact, if the flow of the liquid through the first shaft 90 is not restrained in some way or another, there is a risk of the entire amount of incoming liquid including the contaminant dropping into the shaft 90. Due to the counter flow below the first shaft 90, the pressure drop therein is increased so as to force the surface layer of contaminated liquid to pass on over the second shaft 91. The same applies to the second and the following shafts. Therefore, the passage cross section of the discharge space 77 must be adapted to the flow in the various shafts, which must gradually decrease as the amount of water contained in the masses of liquid in the cells 72 diminishes toward the downstream end of the screw 66.

The flow rate in the various shafts can be adjusted by means of a pair of movable panels 92 and 93 arranged at the bottom of the shafts. This arrangement is shown in detail in Fig. 14 which shows the lower ends of the partitions 70 below which the panels 92 and 93 are arranged. The panels 92 and 93 are positioned between the lower ends of the partitions 70 and the discharge space 77 which opens into the discharge channel 80. The panels 92 and 93 are pivotally mounted at one of their ends on pivots 94 and 95

which permit them to move apart under the action of screws 96 and 97 which are secured to their other ends and threadedly engage a shaft 98 having two halves provided with opposed screw threads 101 and 102 respectively. In the embodiment illustrated in Fig. 14, the panels 92 and 93 have rectilinear side faces 99 and 100, but these side faces may also be curved.

The shaft 98 is arranged in the forecastle of the vessel 98 and can be rotated with the aid of a control means (not shown) to permit the distance between the panels 92 and 93 to be varied as desired, as indicated by the arrows 103 and 104.

Obviously, two or more plants of the type described above may be combined and installed on the same vessel. A few possibilities for such combinations are schematically illustrated in Fig. 15. Thus, the diagram A in Fig. 15 represents in a simplified manner the arrangement described with reference to Fig. 13. In this case the vessel 110 is equipped with a single plant schematically indicated by the block 111, which receives the contaminated water through an inlet 109 and collects the contaminant in a storing basin 112. This vessel is designed for operation in only one direction as indicated by the arrow 114, which is the direction of movement of the vessel when it is driven by its propeller 113.

The diagram B shows a reversible vessel 115 which is capable of travelling in either one of two opposed directions as indicated by the arrows 116 and 117. This vessel is equipped with two similar plants 120 and 121 mounted back to back so that the contaminated water entering the inlet 122 is treated when the vessel travels in the direction of the arrow 116 and the contaminated water entering the inlet 123 is treated when the vessel travels in the direction of the arrow 117. In both cases the plants 120 and 121 discharge the contaminants into a common storing basin 124.

The diagram C in Fig. 15 is a schematic cross section through a pair of plants 125 and 126 mounted side by side in a hull 127 of the catamaran type. With this arrangement the amount of treated liquid can be doubled. Obviously, such a catamaran type hull may contain a pair of double plants such as the pair 125 and 126, one of such pairs being arranged to operate when the vessel is travelling in one direction and the other pair being arranged to operate when the vessel is travelling in the opposite direction.

The invention is not limited in application only to the applications of the process and plants described above. Apart from the described applications in the field of treatment of waste water from industrial plants and large cities and in the field of treatment of contaminated water in rivers, lakes and the sea, the process of the present invention may

also be used for any industrial or even domestic treatment, in which it is necessary to remove a contaminated layer of liquid from the surface of a heavier liquid.

- 5 Moreover, the described process and plant, which have been designed for recovering a liquid spread on the surface of another liquid with which the first liquid is immiscible, can also be used for recovering "contaminants" 10 which are not really liquid in the exact sense of this term, but are similar to liquids. Such contaminants may be, for example, emulsions, particularly detergent emulsions, or dusts such as soot or fine grains such as sawdust. In other 15 words, in this manner substances floating in a thin layer on the surface of a liquid with which they are immiscible can be recovered.

- With reference to Fig. 11 it has been pointed out that the relative movement of the walls 27 delimiting the cells 29 should not begin before the walls 27 are completely immersed in the liquid and should have stopped before the walls 27 leave the liquid as a variation of the spacing between the walls 27 during their movement into or out of the liquid would produce disadvantageous disturbances of the contaminant layer. The same applies to the plant comprising a screw of varying pitch of the type illustrated in and 30 described with reference to Fig. 12.

- For this purpose the plant is modified as shown in Figs. 16 and 16b which represent a multiple plant mounted on board of a contaminant removing vessel 150 of the catamaran type. In this modified embodiment the screw is made longer and comprises two longitudinal portions in which the pitch is constant. Thus, as shown in Fig. 16, the screw 151 comprises an upstream portion 152, in 40 which the pitch is constant, a centre portion 153 over which the pitch varies, and a downstream portion in which the pitch is constant. Both portions 152 and 154 with constant pitch extend over lengths which are equal to at least one and a half times the ratio of the pitch P to the number of spiral blades N in the respective screw portions 152 and 154. Thus, the upstream screw portion 152 with constant pitch, in which there are two spiral 50 blades 155 and 156 and in which the pitch P_m is greatest, extends over a length greater than or equal to $1.5 \times (P_m/2)$. The downstream screw portion 154 with constant pitch, in which the screw has only one spiral blade, as the spiral blade 155 ends at the point 157, and the pitch P_m is smallest, extends over a length greater than or equal to $1.5 \times P_m$.

- Fig. 16 also shows that it is not indispensable to provide guide blades, such as the guide blades 49 in Fig. 12 in the discharge channel 158 through which the underlying water is discharged. By giving an appropriate shape to the bottom 159 of the discharge channel 158 a perfectly regular flow of the 65 underlying water can be obtained.

Finally, Fig. 16 shows how the screw 151, its trough 159, discharge channel 158, drive motor 161 and the transmission gear 162 connecting the screw 151 to the drive motor 161 can be moved in an axial direction by means of a screw 163 driven by a motor 164, and in an angular direction by means of a screw jack 165 supported by a transverse beam 166. To permit these movements the upstream end 168 of the axle of the screw 151 is shiftably mounted in a bearing 169 capable of pivotal movement about a transverse axle 170.

As in the embodiment shown in Fig. 12, the contaminant 171 accumulates in a recovery chamber 172 in a layer which is much thicker than the initial layer 173. A suction rose 174 connected to a pump, not shown, permits the contaminant to be removed from the recovery chamber 172.

A plant of this type has been mounted in a fixed dam in a laboratory and subjected to tests with fresh water with calm surface and a contaminant formed by Libyan crude oil. The results of the tests were as follows:

Libyan crude oil

Density	$\rho=0.82 \text{ (kg/m}^3\text{)}$
Viscosity	$\nu=8.4 \text{ (cS)}$
Temperature	$t=8.0 \text{ (}^\circ\text{C)}$

Variable pitch rotating screw

Speed of entry	$V_E=0.4 \text{ (m/s)}$
Speed of rotation	$n_r=43.0 \text{ (r.p.m.)}$

Flows

Oil at entry	$q_{HE}=3.60 \text{ (l/mn)}$
Oil at exit	$q_{HS}=3.58 \text{ (l/mn)}$
Water at exit	$q_{ES}=0 \text{ (l/mn)}$

Thickness of oil slick at screw intake
 $h_{HE}=0.5 \text{ mm}$

Thickness of oil at screw exit
 $h_{HS}=60 \text{ mm}$

Efficiency

$$\eta_1 = \frac{q_{HS}}{q_{HE}} \cdot 100 = 99.4\%$$

$$\eta_2 = \frac{q_{HS}}{q_{HS} + q_{ES}} \cdot 100\%$$

WHAT WE CLAIM IS:—

1. A process for separating from a body of liquid a contaminated layer spread over the



also be used for any industrial or even domestic treatment, in which it is necessary to remove a contaminated layer of liquid from the surface of a heavier liquid.

5 Moreover, the described process and plant, which have been designed for recovering a liquid spread on the surface of another liquid with which the first liquid is immiscible, can also be used for recovering "contaminants" 10 which are not really liquid in the exact sense of this term, but are similar to liquids. Such contaminants may be, for example, emulsions, particularly detergent emulsions, or dusts such as soot or fine grains such as sawdust. In other 15 words, in this manner substances floating in a thin layer on the surface of a liquid with which they are immiscible can be recovered.

With reference to Fig. 11 it has been pointed out that the relative movement of the walls 27 delimiting the cells 29 should not begin before the walls 27 are completely immersed in the liquid and should have stopped before the walls 27 leave the liquid as a variation of the spacing between the walls 25 27 during their movement into or out of the liquid would produce disadvantageous disturbances of the contaminant layer. The same applies to the plant comprising a screw of varying pitch of the type illustrated in and 30 described with reference to Fig. 12.

For this purpose the plant is modified as shown in Figs. 16 and 16b which represent a multiple plant mounted on board of a contaminant removing vessel 150 of the catamaran type. In this modified embodiment the screw is made longer and comprises two longitudinal portions in which the pitch is constant. Thus, as shown in Fig. 16, the screw 151 comprises an upstream portion 152, in 40 which the pitch is constant, a centre portion 153 over which the pitch varies, and a downstream portion in which the pitch is constant. Both portions 152 and 154 with constant pitch extend over lengths which are equal to at least one and a half times the ratio of the pitch P to the number of spiral blades N in the respective screw portions 152 and 154. Thus, the upstream screw portion 152 with constant pitch, in which there are two spiral blades 155 and 156 and in which the pitch P_m is greatest, extends over a length greater than or equal to $1.5 \times (P_m/2)$. The downstream screw portion 154 with constant pitch, in which the screw has only one spiral blade, 50 as the spiral blade 155 ends at the point 157, and the pitch P_m is smallest, extends over a length greater than or equal to $1.5 \times P_m$.

Fig. 16 also shows that it is not indispensable to provide guide blades, such as the guide blades 49 in Fig. 12 in the discharge channel 158 through which the underlying water is discharged. By giving an appropriate shape to the bottom 159 of the discharge channel 158 a perfectly regular flow of the 65 underlying water can be obtained.

Finally, Fig. 16 shows how the screw 151, its trough 159, discharge channel 158, drive motor 161 and the transmission gear 162 connecting the screw 151 to the drive motor 161 can be moved in an axial direction by means of a screw 163 driven by a motor 164, and in an angular direction by means of a screw jack 165 supported by a transverse beam 166. To permit these movements the upstream end 168 of the axle of the screw 151 is shiftably mounted in a bearing 169 capable of pivotal movement about a transverse axle 170.

As in the embodiment shown in Fig. 12, the contaminant 171 accumulates in a recovery chamber 172 in a layer which is much thicker than the initial layer 173. A suction rose 174 connected to a pump, not shown, permits the contaminant to be removed from the recovery chamber 172.

A plant of this type has been mounted in a fixed dam in a laboratory and subjected to tests with fresh water with calm surface and a contaminant formed by Libyan crude oil. The results of the tests were as follows:

Libyan crude oil

Density	$\rho = 0.82 \text{ (kg/m}^3\text{)}$
Viscosity	$\nu = 8.4 \text{ (cS)}$
Temperature	$t = 8.0 \text{ (}^\circ\text{C)}$

Variable pitch rotating screw

Speed of entry	$V_E = 0.4 \text{ (m/s)}$
Speed of rotation	$n_r = 43.0 \text{ (r.p.m.)}$

Flows

Oil at entry	$q_{HE} = 3.60 \text{ (l/mn)}$
Oil at exit	$q_{HS} = 3.58 \text{ (l/mn)}$
Water at exit	$q_{ES} = 0 \text{ (l/mn)}$

Thickness of oil slick at screw intake
 $h_{HE} = 0.5 \text{ mm}$

Thickness of oil at screw exit
 $h_{HS} = 60 \text{ mm}$

Efficiency

$$\eta_1 = \frac{q_{HS}}{q_{HE}} \cdot 100 = 99.4\%$$

$$\eta_2 = \frac{q_{HS}}{q_{HS} + q_{ES}} \cdot 100\%$$

WHAT WE CLAIM IS:—

1. A process for separating from a body of liquid a contaminated layer spread over the



liquid, the contaminated layer comprising a contaminant immiscible with liquid, comprising the steps of:

5 encircling a portion of the liquid and contaminated layer to a depth exceeding the thickness of the contaminated layer;

10 moving the encircled portion to a recovery zone at which the contaminated layer is separated from the liquid progressively reducing, simultaneously with the movement, the surface area of the encircled portion so as to increase the thickness of the encircled contaminated layer;

15 the steps being repeated so that at least one further portion of the liquid and contaminated layer is being encircled as the first-mentioned portion is being moved to the recovery zone, the contaminated layer of the first-mentioned portion being separated from
20 the liquid at the recovery zone as the or each further portion is moved to the recovery zone.

25 2. A process according to claim 1, wherein the free surface of the contaminated layer is maintained at an approximately constant level during the said movement and in the recovery zone.

30 3. Apparatus for carrying out the method of claim 1 or 2, the apparatus comprising:

partitioning means for encircling a plurality of portions of the liquid and contaminated layer;

35 recovery zone to which the encircled portions of the contaminated layer can be moved by the partitioning means;

40 means for moving in succession each of the encircled portions to the recovery zone, and for progressively reducing simultaneously with movement, the surface area of each encircled portion so as to increase the thickness of the encircled contaminated layer; and

means for separating the contaminated layer from the liquid at the recovery zone.

45 4. Apparatus according to claim 3, comprising means for maintaining the free surface of the contaminated layer at an approximately constant level in the encircled portions and in the recovery zone.

50 5. Apparatus according to claim 3 or 4, wherein the moving means and the partitioning means comprise an Archimedian screw arrangement, the Archimedian screw arrangement comprising:

55 a helical blade the pitch of which reduces from one end to the other at which the recovery zone is located, the blade being operable when immersed in the liquid and contaminant to a depth less than the radial extent of the blade;

60 side walls at respective sides of the screw arrangement and in substantially sealing contact with a portion of the blade to define with the blade the partitioning means; and

65 drive means for rotating the screw arrangement so that a portion of the contaminated

layer can be displaced in the direction from the end of the screw arrangement of greatest pitch to the other end.

6. Apparatus according to claim 3 or 4, wherein the moving means and partitioning
70 means comprise:

75 side walls and moveable walls arranged to move relative to the side walls in substantially sealing engagement therewith to define the partitioning means; and drive means for moving the moveable walls relative to the side walls with a varying velocity so that the portions encircled between the side walls and moveable walls are moved in succession to the recovery zone, the surface of each encircled
80 portion being progressively reduced simultaneously with the movement.

85 7. Apparatus according to claim 5 or 6, wherein the said side walls extend downwardly (in an operative orientation of the apparatus) so as to define between the extended side walls and the partitioning means a discharge path for discharging from the partitioning means liquid encircled by the partitioning means.

90 8. Apparatus according to claim 7, when appended to claim 4, wherein the maintaining means comprises the discharge path and a flow path from the recovery zone to the discharge path for discharge of liquid from the recovery zone.

95 9. Apparatus according to claim 7 or 8, comprising guide means arranged in the discharge path for directing the flow of liquid so as to prevent liquid being urged towards the encircled portions from the discharge path and for preventing encircled portions of the contaminated layer being sucked into the discharge path.

100 10. Apparatus according to claim 9, wherein the guide means comprises at least one fixed guide blade.

11. Apparatus according to any one of claims 3 to 10, wherein the separating means comprises a pump arranged to remove the portions of the contaminated layer from the
110 recovery zone.

12. Apparatus according to any one of claims 3 to 11, wherein the separating means incorporates a control servo-mechanism acting in dependence upon the level of the free surface of the contaminated layer or in dependence upon the level of the interface between the contaminated layer and the liquid for controlling the separating means so that a mixture of contaminated layer and liquid is
120 not removed from the recovery zone.

13. Apparatus according to claim 5 or any one of claims 7 to 12 when appended to claim 5, wherein the Archimedian screw arrangement comprises a plurality of parallel helical blades
125 the pitch of each of which reduces from one end to the other of the blade.

14. Apparatus according to Claim 13, wherein the blades are equally angularly spaced about the shaft.
130

15. Apparatus according to claim 13 or 14, wherein there is a greater number of blades at one end of the shaft than at the other end, the blades at the said one end of the shaft having a greater pitch than the or each blade at the said other end.

16. Apparatus according to claim 5 or any one of claims 7 to 15 when appended to claim 5, wherein the or each helical blade comprises at least one additional helical blade portion of constant pitch.

17. Apparatus according to claim 16, wherein the or each additional helical blade portion extends over a portion of the shaft for a distance greater than or equal to one and a half times the ratio of the pitch of the blade portion to the number of blades on the shaft at that portion of the shaft.

18. Apparatus according to claim 5, or any one of claims 7 to 17 when appended to claim 5, comprising positioning means for adjusting the axial position of the shaft.

19. Apparatus according to claim 5 or any one of claims 7 to 18 when appended to claim 5, comprising adjusting means for adjusting the inclination of the axis of the screw arrangement relative to the horizontal.

20. Apparatus according to claim 5, or any one of claims 7 to 19 when appended to claim 5, mounted on board a ship, the Archimedian screw arrangement being arranged with its axis parallel to the longitudinal axis of the ship, the end of the shaft associated with the largest pitch or the or each helical blade facing the prow of the ship.

21. Apparatus according to claim 20, wherein the drive means of the screw arrangement is arranged to rotate the shaft at a speed such that, in use of the apparatus with the ship moving, no relative movement with respect to the plane or water on which the ship moves is imparted to the contaminated layer and liquid entering the screw arrangement until the contaminated layer and liquid has been encircled.

22. Apparatus substantially as hereinbefore described with reference to Figure 11 or Figures 1, 2 and 12b or to Figures 13 and 13b and 14, optionally as modified by any one of Figures 15a to c or to Figure 16 optionally as modified by Figure 16b of the accompanying drawings.

23. A process for separating from a body of liquid a contaminated layer spread over the liquid, substantially as hereinbefore described with reference to Figure 11 or Figures 12 and 12b, or to Figures 13, 13b and 14b optionally as modified by any one of Figures 15a to c, or to Figure 16 optionally as modified by Figure 16b of the accompanying drawings.

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