

METHOD AND APPARATUS FOR SEPARATING MIXTURES OF OIL AND WATER

This invention relates to a separator apparatus and to a method for separating mixtures of oil and water.

Flotation cells are used in industry for the purpose of separating particles from a liquid. These operate generally by admixing gas bubbles to the mixture to be separated, whereby the gas bubbles are brought into contact with the particles so that the gas bubble-particle entities are effectively lightened and rise to the surface of the mixture where they can be drawn off. To facilitate this action, chemical reagents may be added to the mixture.

It has also been discovered that flotation cells may be used for separating liquid phases one from the other, if one of the liquid phases be present in the form of discreet droplets, such as in

an emulsion. However, it has been found that systems of this kind are only capable of satisfactory operation where the influent oil-in-water concentration does not exceed 500 ppm. One use, however, for oil-water separators lies in the cleaning up of residual water at oil wells, after removal of the principal oil concentration therefrom, such as in off-shore oil wells where the residual water must be decontaminated of residual oil to give a high water purity level before the water can, under environmental protection laws, be legally returned to the sea. In such instances, it is often impossible to maintain the influent oily water such that the concentration of oil therein is less than 500 ppm, with the result that unsatisfactory results are obtained, insofar as purity of the effluent water is concerned.

Similar considerations concerning the efficiency of operation of flotation cells of the types including means for introduction of gas bubbles and/or including agitation means apply in relation to efficiency of operation of "degassers" being a form of flotation cell not having provision for agitation of material being separated and not necessarily having provision of introduction of gas bubbles. In the latter, separation of gas and liquid and/or of liquid components is effected simply by gravitational settling. A so called "skimmer" is a form of degasser having provision for removal of free oil. The term "flotation device" is used in this specification to mean any device in which separation is effected by settling.

The invention generally envisages the use of a hydrocyclone to pre-condition a mixture of oil and water before admission to a flotation device.

According to the invention there is provided a separator apparatus for separating a liquid mixture comprising oil and water components wherein the oil component is comprised of droplets, to provide water which is substantially free of oil; comprising a hydrocyclone of the type designed, constructed and arranged to effect separation of a mixture of liquids and having a separating chamber with inlet means for inlet of the mixture to be separated, an overflow outlet for outlet of a less dense oil component of the mixture and an underflow outlet for outlet of a material comprised of the water component of said mixture having residual droplets of oil, and a flotation device coupled to receive the outlet material from said underflow outlet for further separation of the oil component from the water by flotation, and means on said flotation device for separate removal therefrom of each of the oil and water components separated therein.

According to a first aspect of the invention said overflow outlet arranged so that the oil component exiting therefrom is directed along a flow path that is outside the flotation device.

According to a second aspect of the invention the apparatus further includes means to effect a pressure reduction in the material emerging from said underflow outlet so that the outlet material entering said flotation device is at a pressure which is less than that of the outlet material after such outlet material has exited from the underflow outlet.

The invention also provides a method for separating oil and water components from a liquid mixture by use of a hydrocyclone of the type designed, constructed and arranged to effect separation of a mixture of liquids, and having inlet means through which the mixture is admitted, an underflow outlet, and an overflow outlet, wherein the material emerging from the underflow outlet of the hydrocyclone is in the form of a mixture comprising residual oil droplets dispersed in the water component of the mixture and wherein the material emerging from the underflow outlet is passed to a flotation device to effect further separation of the mixture to obtain a water component that is substantially free of oil, the material from the overflow outlet being directed along a flow path which is not in direct communication with the flotation device to which the underflow material is admitted and/or being passed through a pressure reducing device before entering said flotation device.

The invention is further described by way of example only with reference to the accompanying drawings in which;

Figure 1 is a flow diagram of an apparatus constructed in accordance with the invention;

Figure 2 is a diagram showing a hydrocyclone used in the apparatus of Figure 1;

Figure 3 is a diagram of a flotation cell used in the apparatus of Figure 1; and

Figure 4 is a diagram illustrating a modification of the invention; and

Figure 5 is a diagram illustrating a further modification of the invention.

Figure 6 is a diagram of another apparatus constructed in accordance with the invention.

The apparatus shown in Figure 1 comprises a hydrocyclone 10 to which a mixture of oil in water is admitted, such as on the line 42 shown, to provide at an outlet line 44 separated oil and at an outlet line 46 separated water which may, however, still contain some residual oil. The water component is passed on line 46 through a pressure reducing device 50 and thence on a line 52 to a flotation cell 54. Here, further separation occurs with the water component being taken on a line 58 from the flotation cell and

the oil component on a line 60 therefrom.

The hydrocyclone 10 may be constructed in known fashion, such as in accordance with the teachings of United States patent 4,237,006, Australian patent application 84713/79, or in my International applications PCT/AU83/00028 or PCT/AU85/00010. Figure 2 shows, diagrammatically, a separator of this general type. This is shown as having a tapered elongate separating chamber 25 which is of circular cross-section having, at its larger diameter end, a first cylindrical portion 12, a tangential inlet 26 having an inlet opening 30, and an axial overflow outlet 34 which communicates with an outlet opening 32. A tapered portion 12a of separating chamber 25 is provided adjacent portion 12, this leading to a second, also slightly tapered, portion 14 of the separating chamber 25, this in turn leading to an elongate cylindrical portion 16 of the separating chamber which opens to an axial underflow outlet 23 for the separator.

Oily water mixture to be separated is passed on the inlet 26 through the inlet opening 30 into the portion 12 of the separating chamber 25 so as to generate a vortex within the separating chamber. The oil component emerges from the outlet 34 via opening 32 and the water component emerges from the underflow outlet 23.

As shown, the first portion 12 has a length l_1 and a diameter d_1 , the second portion has a length l_2 and diameter d_2 at its larger diameter end, portion 16 has a length l_3 and a diameter d_3 , whilst the overflow outlet has a diameter

d_0 . As described in Australian patent application 84713/79, two strictly tangential inlets 26 may for example be provided or, as shown in International application PCT/AU85/00010, a single inlet 26 of involute form may be provided.

In accordance with the abovedescribed construction, the cyclone separator may be constructed in accordance with any one or more or all of the following dimensional constraints.

$$l_2/d_2 > 10, \text{ such as } 10 < l_2/d_2 < 25$$

$$3 \leq \frac{\pi d_1 d_2}{4A_i} \leq 30$$

$$\text{such as } 3 \leq \frac{\pi d_1 d_2}{4A_i} \leq 20$$

$$d_0/d_2 \leq 0.25, \text{ such as } d_0/d_2 < 0.1$$

$$d_1 > d_2$$

$$d_2 > d_3$$

where A_i is the total inlet area of all of the inlet openings combined or the inlet opening if there is only one. β , the half angle of the taper of the second portion, may be 20° to 2° , such as 1° . Portion 12a is optional. If provided, it may have a half angle, α , of 10° .

Other suitable constructions for hydrocyclone 10 are shown, for example, in the specification of Australian patent application 77610/87 and of International applications PCT/AU87/00402, PCT/AU86/00313, PCT/AU86/00173 and PCT/AU85/00181.

In the construction shown in Figure 2, the overflow outlet 23 communicates with a fourth portion 18 of the separator, which has the effect of providing a back pressure to facilitate the separating action. Such a fourth portion is described in International application PCT/AU83/00028 and may, as shown, comprise a first frustoconical portion 18a which leads from outlet 23 followed by a second cylindrical portion 18b. When used in the apparatus of Figure 1, this arrangement provides a pressure reducing action and permits omission of the pressure reducing device 50, line 46 in that case, communicating directly with line 52 to admit material from the separator 10 directly to the flotation cell.

The flotation cell 54 may also be constructed in accordance with conventional practice and may be of the dissolved gas type or of the induced air or gas types. Figure 3 shows, in diagrammatic form, one such form being of the induced air type. Here, a vessel 70 is provided into which the material to be separated is admitted. A rotor 72 is positioned within the vessel 70 and has impeller blades 74 in use rotated together with the impeller about a vertical axis. The design is such that air is drawn into the upper part of the rotor 72, as shown by arrow 80, and can then pass through

perforations in the rotor sidewardly outwardly therefrom and into the material to be separated. At the same time, the rotor draws material in the vessel upwardly into the rotor, also to pass outwardly through the aforementioned perforations. Material so admitted is shown diagrammatically, by arrow 82. In this arrangement, the air emerging from the rotor at the side openings thereof is in the form of bubbles which adhere to a desired one of the components to be separated so that that component is effectively lightened, whereby to float to the surface of the material within the vessel 70. This action may be facilitated by addition of suitable chemicals, such as surfactants. The means for admitting and removing the mixture to be separated, and the resultant separated components, is not shown, but the line 52 may communicate directly with the interior of the vessel 70, with the outlet for the downwardly settling component located towards the base of the cell to be taken off as desired. The component which rises to the surface may simply overflow the sides of the cell to be collected for take off in a suitable peripheral channel. In the present context, the cell 54 is arranged whereby the component which floats to the top of the vessel is oil, and that which settles is water.

As shown in Figure 4, the liquid mixture to be separated may also be passed on a line 92, in the first instance, to a mixing and/or residence vessel 90, before admission to the hydrocyclone. The remainder of the arrangement of Figure 4 is the same as that in Figure 1 and like reference numerals in Figures 1 and 4 denote like components.

The mixing and/or residence vessel may comprise a precoalescer or coalescer, for example a cross-plate interceptor skimmer. It is also possible in some instances to facilitate operation by positioning a low shear pressure increasing device, such as a suitable pump, either in line 92, to act on the inlet mixture prior to entering the vessel 90, or on line 42 to act on mixture having left vessel 90 prior to entry with hydrocyclone 10.

Where the vessel 90 is provided provision may be made for inlet thereto, separately or in admixture with liquid on line 92, of heated water or other fluid, such as from a heater treater device. Such device may effect injection of heated water periodically. Provision may also be made for introduction of chemicals to aid coalescence of the mixture.

The hydrocyclone 10 acts, as described, to effect removal of an oil component from an oily-water mixture when admitted thereto. Generally, the separator 10 is designed for use where there is a substantially smaller amount of oil than water in the incoming mixture. However, the concentration of oil may be of the order of several percent for example.

The hydrocyclone 10 is able to reduce the oil concentration to a quite low level in the water component which emerges from the outlet thereof, such as below 500 ppm. Then, after passage through the pressure reducing device 50 or through the portion 18 of the described hydrocyclone, the oily water as then passed to the flotation cell is further separated to reduce the oil component to an even lower level.

Thus, the emergent water from line 58 may be relatively very pure indeed, such as having an oil concentration of only a few parts per million.

The provision of the hydrocyclone 10, in addition to providing a separating action, also assists in that a substantial pressure drop will normally exist as between the inlet line 42 and the outlet 23 from the separator. This reduction in pressure, which may be example be 50%, has the effect that oil in solution in the water will tend to come out of solution and form droplets which, even if they are not separated totally in the cyclone 10 to emerge from the outlet line 44, and can be more readily be agglomerated together or are otherwise more readily capable of adherence by the bubbles in the flotation cell to effect final separation.

The described flotation cell is exemplary and may be replaced by other types such as types not having the described impeller blades 74 or rotor 72. Furthermore, as mentioned, the flotation cell may be replaced by other flotation devices such as degassers or skimmers.

Figure 5 shows an arrangement in which outlet from the described hydrocyclone 10 is taken on line 46, optionally, via the pressure reducing device 50, to a degasser 65 such as a skimmer (degasser with a provision for removal of free oil). The liquid from the underflow outlet of the hydrocyclone is passed on line 52 to the inlet of the degasser. The degasser is in the form of a closed vessel 68, for example, pressurised and acts to separate gas from

water in the incoming liquid and, furthermore to separate oil from the water, the separations being effected at least in part by gravitational settling. The water component may be removed from the bottom of the vessel 68 on the line 69 shown and the gas from the top of the vessel by a line 71. The oil may be removed from the top of the water in the vessel on a line 73, optionally aided by a suitable mechanical "skimmer".

The pressure reducing device 50, although preferable, may be omitted in some instances, as indicated. It is also possible to use, as the pressure reducing device, a suitable valve, or if desired, another hydrocyclone, particularly one designed to remove solids from admitted liquid.

In the apparatus of Figure 6, the flotation cell 70 has a cylindrical outer wall 100, arranged with its axis vertical. The wall 100 is closed at the lower end by a base 102 and, at its upper end, by a transverse wall 104 to define a substantially closed chamber 105. In this instance, the hydrocyclone 10 is disposed with its axis vertical and arranged to extend downwardly into the interior of the cell 70. The larger diameter end of the hydrocyclone, including the inlet 26, is positioned above wall 104, the portions 14 and 16, however, extending into the interior of the cell 70, coaxially with the axis of the wall 100. At the lower end, the

underflow outlet of the hydrocyclone 10 is fitted with a suitable pressure reducing device 50. In this case, the device is in the form of a venturi having a central passageway 50a therethrough. The exit from passageway 50a is disposed a short distance above the upper surface of the base 102 of the cell 70.

An upper manifold 120 is positioned to provide an outlet opening for light phase separated material from the chamber 105 of the cell 70 and a further manifold 122 is positioned adjacent the lower end of the cell 70 for outlet of heavy phase separated material. As shown, baffles 126, 128 may be provided in the interior of the cell 70 adjacent the manifolds 120, 122.

Provision is made for injecting air or gas into the apparatus as shown. In this case, an inlet pipe 140 extends through the side wall 100 and opens to an outlet opening 140a in the passageway 50a through the device 50. This outlet opening 140a is positioned at the point of smallest diameter of the passageway 50a.

As shown, the hydrocyclone 10 may extend through an opening in wall 104 whereby the hydrocyclone is supported by the wall 104 at the junction between portions 12a and 14. The overflow outlet 34 may be provided, as before, in an axially arranged position relatively to the hydrocyclone 10, at the larger diameter end thereof.

In use of the apparatus of Figure 6, the liquid mixture to be separated is fed to the hydrocyclone 10, inwardly through the inlet 26 so that at least the heavier of the phases to be separated the mixture is passed axially downwardly

along the interior of the hydrocyclone, thence passes through the pressure reducing device 50 and enters the chamber 105. The material so passing through the hydrocyclone and pressure reducing device 50 has air or gas injected therein via the pipe 140 and opening 140a. Within chamber 105, the liquid emerging from the outlet 50a fills until it overflows the baffle 126. The lighter of the separated phases moves to the surface and is thus taken off via the manifold 120, whilst the heavier material settles to the bottom and is taken off past the baffle 128 through manifold 122.

The pressure reducing device 50 may be of any suitable form and may not necessarily be in the form of a venturi. A suitable valve or nozzle, may, for example, be employed. The air or gas may be induced or inducted into the liquid to be separated in ways other than described. For example, the air or gas may be injected upstream of the device 50 if desired. It is preferred that the device 50, however, be adjustable so as to permit a variation of flow therethrough.

CLAIMS

1. Separator apparatus for separating a liquid mixture comprising oil and water components wherein the oil components is comprised of droplets, to provide water which is substantially free of oil; comprising a hydrocyclone of the type designed, constructed and arranged to effect separation of a mixture of liquids and having a separating chamber with inlet means for inlet of the mixture to be separated, an overflow outlet for outlet of a less dense oil component of the mixture and an underflow outlet for outlet of a material comprised of the water component of said mixture having residual droplets of oil, and a flotation device coupled to receive the outlet material from said underflow outlet for further separation of the oil component from the water by flotation, said overflow outlet being arranged so that the oil component exiting therefrom does not enter the flotation device and means on said flotation device for separate removal therefrom of each of the oil and water components separated therein.

2. Separator apparatus according to claim 1, further including means to effect a pressure reduction in the material emerging from said underflow outlet so that the outlet material entering said flotation device is at a pressure which is less than that of the outlet material after such outlet material has exited the underflow outlet.

3. Separator apparatus for separating a liquid mixture comprising oil and water components wherein the oil component is comprised of droplets, to provide water which is substantially free of oil; comprising a hydrocyclone of the type designed, constructed and arranged to effect separation of a mixture of liquids and having a separating chamber with



inlet means for inlet of the mixture to be separated, an overflow outlet for outlet of a less dense oil component of the mixture and an underflow outlet for outlet of a material comprised of the water component of said mixture having residual droplets of oil, and a flotation device coupled to receive the outlet material from said underflow outlet for further separation of the oil component from the water by flotation, and means on said flotation device for separate removal therefrom of each of the oil and water components separated therein, the apparatus further including means to effect a pressure reduction in the material emerging from said underflow outlet so that the outlet material entering said flotation device is at a pressure which is less than that of the outlet material after such outlet material has exited from the underflow outlet.

4. Separator apparatus according to any one of claims 1 to 3, wherein pressure reducing means outside the hydrocyclone is provided to reduce pressure of the material passed from the hydrocyclone to the flotation device.

5. Separator apparatus according to claims 4, further comprising a residence vessel having an inlet for the fluid mixture to be separated, and an outlet, the outlet being coupled to the inlet of the hydrocyclone, said residence vessel being designed to promote coalescence of a least one component of the mixture.

6. Separator apparatus according to claim 5, wherein means are provided in said residence vessel for introducing heated fluid into the fluid mixture therein.

7. Separator apparatus according to any one of claims 1 to 6, including means for introducing into the mixture, materials to



enhance coalescence and/or facilitate flotation.

8. Separator apparatus according to any one of claims 1 to 7, wherein said flotation device comprises a vessel and said hydrocyclone extends into said vessel whereby said outlet material is passed from said underflow outlet directly into the vessel for separation.

9. Separator apparatus according to any one of claims 1 to 8, wherein means is provided for entraining gas in the material emerging from said underflow outlet.

10. Separator apparatus according to claim 9, wherein said gas entraining means includes a port in a passageway between said underflow outlet and the flotation device and means for causing said gas to emerge from said port into the passageway for admixture with said outlet material as it passes through the passageway.

11. Separator apparatus according to claim 10, further including a pressure reducing device in said passageway for reducing the pressure of said outlet material prior to entering said flotation device.

12. Separator apparatus according to any one of claims 1 to 11, wherein said flotation device is a device of the type having means for introduction of gas bubbles and/or agitation means.

13. Separation apparatus according to any one of claims 1 to 11, wherein the flotation device is a skimmer.

14. Separator apparatus according to claim 13, wherein said flotation device is a cross-plate interceptor.



15. Separator apparatus substantially as described herein with reference to Figs. 1 to 3 or Figs. 2 to 4 or Figs. 2, 3, and 5 or Fig. 6 of the drawings.

16. A method for separating oil and water components from a liquid mixture by use of a hydrocyclone of the type designed, constructed and arranged to effect separation of a mixture of liquids, and having inlet means through which the mixture is admitted, an underflow outlet and an overflow outlet, wherein the material emerging from the underflow outlet of the hydrocyclone is in the form of a mixture comprising residual oil droplets dispersed in the water component of the mixture, and wherein the material emerging from the underflow outlet is passed to a flotation device to effect further separation of the mixture to obtain a water component that is substantially free of oil, and the material from the overflow outlet is directed along a path which does not communicate with the flotation device to which the underflow material is admitted.

17. A method according to claim 16 wherein the material emerging from the underflow outlet is passed through a pressure reducing device before entering said flotation device.

18. A method for separating oil and water components from a liquid mixture by use of a hydrocyclone of the type designed, constructed and arranged to effect separation of a mixture of liquids, and having inlet means through which the mixture is admitted, an underflow outlet and an overflow outlet, wherein the material emerging from the underflow outlet of the hydrocyclone is in the form of a mixture comprising residual oil droplets dispersed in the water component of the mixture wherein the material emerging from the underflow outlet is passed to a flotation device to effect further separation of



the mixture to obtain a water component that is substantially free of oil, the material emerging from the underflow outlet being passed through a pressure reducing device before entering said flotation device.

19. A method according to any one of claims 16 to 18 wherein prior to introduction into the hydrocyclone the mixture is passed to a residence vessel for coalescing, in part, at least one component of the mixture.

20. A method according to claim 19 wherein heated fluid is passed into the residence vessel to mix with the material therein.

21. A method according to any one of claims 16 to 20 wherein separation in the flotation device is enhanced by adherence of gas bubbles to the oil droplets.

22. A method according to claim 21 wherein gas is introduced into said material prior to its entering said flotation device.

23. A method according to claim 22 wherein gas is introduced into the mixture within the flotation device.

24. A method according to any one of claims 16 to 23 wherein the flotation device comprises a vessel having upper and lower outlets and the separated less dense component is removed from the upper outlet and substantially pure water is removed from the lower outlet.

25. A method according to any one of claims 16 to 24 wherein coalescing and/or flotation aids are introduced into the mixture.



26. A method according to any one of claims 16 to 25 wherein the material leaving the underflow outlet of the hydrocyclone and admitted to the floation device has an oil content which is less than 500 ppm.

29. A method for separating oil and water components from a mixture thereof substantially as described herein with reference to Figs. 1 to 3 or Figs 2 to 4 or Figs 2, 3, and 5 or Fig. 6 of the drawings.
