

FLUID TREATMENT APPARATUS

FIELD OF THE INVENTION

The present invention relates to a fluid treatment apparatus, and in particular, but not exclusively, to an apparatus for treating water produced from a subterranean hydrocarbon bearing formation. The present invention also relates to a method of treating a fluid.

BACKGROUND TO THE INVENTION

The fluids produced from subterranean reservoirs are typically a mixture of oil, water, gas, normally with a quantity of sand. In the early stages of production the fluids may be "dry", i.e., containing little or no water, but as production continues it is normal for greater quantities of water to be produced. In mature fields the proportion of water in the produced fluids can reach 90% and possibly around 95%. Reservoirs do not always produce large quantities of sand but when they do the sand production generally increases as the water production increases. The water produced from the reservoir is termed "produced water".

The produced water may be injected back into the formation or it may be discharged into the environment; for example, in off-shore production areas the water may be discharged into the sea. However, the produced water must be thoroughly treated in order to remove substantially all traces of oil and gas prior to being discharged into the environment in order to meet extremely strict environmental regulations.

In conventional production operations the produced fluid from the reservoir is initially treated to separate the saleable oil and gas from the un-saleable water and sand. However, the separated water will typically still contain unacceptable quantities of oil and gas and as such is normally subject to a secondary treatment to further reduce the concentration of hydrocarbons to acceptable levels for discharge to the environment or injection back into the formation.

A process known as "flotation" is commonly used to assist in the removal of oil and other contaminants from water. The principle of flotation is that bubbles of gas are introduced into (e.g., Induced Gas Flotation) or are established in (e.g., Dissolved Gas Flotation) a vessel containing a contaminated water, in which the bubbles will to a greater or lesser degree attach to the contaminants, such as oil droplets, and drag them to the surface of the water, leaving the bulk of the water depleted of contaminants, and the upper layers of the water enriched with contaminants. In subsequent discussions, each volume of water to which gas

bubbles are added or are created to separate contaminants may be referred to as a "cell" or "flotation cell".

Flotation is usually operated as a continuous process, where there is a continuous inflow of contaminated water into the cell and a continual outflow of contaminant enriched water drawn from the surface layers of the cell and a continual outflow of the contaminant depleted water from the cell at a rate so as to maintain an essentially constant level in the vessel.

It is usual for the contaminants floated to the surface of the water to be retained in a froth which is either formed naturally when the contaminants are present at the higher concentrations found at the water surface, or with the assistance of chemicals which are added to the inflowing liquid. Buoyant contaminants, for example droplets of oil, may not need to be frothed to keep them at the surface.

The contaminants on the water surface may be removed by a variety of means, the two most common being weirs set slightly below the water surface so that the contaminant enriched surface layer preferentially flows over them, or paddles which sweep the contaminant enriched surface layer over a weir which is normally set slightly above the water surface. A number of designs of floating skimming devices are also known which have the advantage that they can tolerate a wider variation in operating liquid level than either of the aforementioned fixed weir methods can accommodate.

In Induced Gas Flotation (IGF) methods, gas bubbles are typically added to the contaminated water by eductors or mechanical mixers. An IGF cell must be mixed to bring the gas bubbles into intimate contact with the contaminants, such as oil droplets, so that they can be separated by them, but this mixing has the side effects of making it more difficult for the bubbles to rise to the surface, and causing variation in the residence time of parcels of water within the cell. While the average residence time in the cell can be determined by the volume of the cell and the water flowrate, the mixing can mean that some parcels of water pass through the cell in a much shorter time than is required for good separation, and conversely some parcels of water may reside in the cell much longer than the average residence time.

The necessity to have mixing in the cell to contact the gas bubbles and contaminants reduces the efficiency of separation in the cell. For this reason IGF vessels are commonly horizontal vessels which contain a plurality of IGF cells in series, typically four, so that the overall efficiency of the separation is increased. Examples of known IGF systems of this type are shown in US 4,564,457, US 2006/0213840, US 3,972,815, US 3,647,069 and US 5,348,648.

Nevertheless, in some applications vertical single stage cell flotation units are known, which have a single IGF cell which typically has a cell volume, and hence residence time, somewhat larger than would be found in the four cells of a typical horizontal IGF unit. Examples of such IGF arrangements are shown in WO 2004/112936 and US 5,011,597.

It is understood that an IGF unit requires the fluid to reside within the vessel for a period sufficient to allow floatation of the oil and separation of the gas. However, increasing residence time will directly reduce the maximum fluid treatment rate which can be achieved. It may be possible to address this issue by increasing the size of the IGF unit but this is not desired due to the restricted available space in conventional production environments.

It is desirable to reduce the space occupied by, and weight of, equipment installed on offshore platforms, and for this reason compact floatation units have been proposed in the art for treating produced water with minimal plant footprint. For example, prior art reference WO 02/41965 discloses a vertically arranged vessel which receives fluid to be treated via a tangentially arranged fluid inlet. Arranging the fluid inlet in this manner establishes rotation of the fluid within the vessel which is alleged to assist coalescence of oil and gas bubbles and floatation to the surface. The vessel may incorporate a spiralling guide vane to enhance fluid rotation.

In WO 02/41965 the vessel is operated at a low pressure to permit dissolved gas to evolve from the water phase and create gas bubbles in the zone adjacent the fluid inlet to mimic the effect of IGF units. However, if an insufficient volume of gas is present in the fluid then additional gas may be added to the fluid.

EP 1 400 492 also discloses a compact floatation unit which comprises a vertically arranged vessel with one or more tangential fluid inlets to encourage fluid rotation. In EP 1 400 492 the vessel also includes tangentially arranged fluid/sparge gas inlets. These inlets communicate gassed water into the vessel.

Other techniques for treating fluids by the use of gas bubbles include cascade floatation techniques, in which fluid to be treated is passed through eductors into containers, in a cascading fashion. Examples of such techniques are disclosed in US 1,311,919, US 1,380,665 and US 4,406,782.

US 4,986,903 discloses a floatation apparatus for separating oil from water. The disclosed apparatus includes separate gasification and degasification chambers. Gasified water is introduced into the gasification chamber via a gas eductor. Recirculation of fluid to be gasified is possible between the degasification chamber and the gasification chamber through recirculation line 70 and the gas eductor 40.

It is among objects of the present invention to obviate or mitigate one or more problems in the prior art.

SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided a fluid treatment apparatus comprising:

- a fluid vessel;
- first and second fluid chambers defined within the fluid vessel;
- a fluid inlet for delivering a fluid to be treated into the first fluid chamber; and
- at least one nozzle assembly for providing fluid communication from the first fluid chamber to the second fluid chamber, wherein said nozzle assembly is adapted to facilitate mixing of a gas with said fluid.

The at least one nozzle assembly may facilitate entrainment of a gas into said fluid. Alternatively, or additionally, the at least one nozzle assembly may facilitate injection, commingling or delivery of a gas into said fluid. However, for brevity of the present summary of the invention, the general concept of mixing gas with or delivery of a gas into the fluid being treated shall generally be referred to as entrainment.

The apparatus may be adapted to treat a fluid containing multiple components, which components may comprise any one or a combination of liquids, gases and solids. For example, the fluid may comprise a water/oil mixture, water/oil/gas mixture or the like.

The first fluid chamber may be adapted to receive the fluid to be treated and distribute this fluid into the second fluid chamber, with entrained gas, to be treated therein. The first fluid chamber may therefore define a distribution chamber and the second chamber may define a treatment chamber.

The second fluid chamber may be adapted to accommodate a separation treatment of the fluid therein. The separation treatment may be adapted to effect separation of components of the fluid, such as components of different densities, chemistries, phases or the like. Advantageously, the gas entrained into the fluid entering the second chamber may enhance fluid separation. The separation treatment may comprise a floatation separation treatment.

In one embodiment the second fluid chamber may be adapted to accommodate a separation treatment to effect the separation of mineral oil and optionally gas from water, such as water produced from a subterranean hydrocarbon reservoir. In this arrangement the entrainment of gas into the fluid communicated from the first fluid chamber may assist floatation of the oil. The oil may be skimmed

or otherwise collected from the surface of the water within the second fluid chamber. Additionally, gas released from the water may be collected.

Advantageously, providing the at least one nozzle assembly to facilitate entrainment of gas into the fluid being treated may eliminate the requirement to provide external plant equipment, such as gassifiers, mixers, pumps, compressors and the like, associated with prior art arrangements. However, in embodiments of the present invention it may be desirable to utilise such external or additional equipment. Furthermore, the at least one nozzle assembly may be adapted to communicate fluid which has already been mixed with a gas into the second fluid chamber. Thus, the residence time of the fluid within the second chamber may be used substantially entirely for treatment of the fluid, such as separation of components of the fluid. This therefore differs from prior art arrangements in which the residence time must also accommodate sufficient gas/fluid mixing.

The fluid vessel may be arranged vertically. This arrangement may assist to minimise the footprint of the fluid treatment apparatus which is advantageous, particularly in offshore applications. Alternatively, the fluid vessel may be arranged horizontally. Alternatively further, the fluid vessel may be arranged to incline.

The first and second fluid chambers may be arranged to be adjacent each other within the vessel. Alternatively, the first and second chambers may be separately arranged within the vessel. The first and second fluid chambers may be vertically arranged within the vessel. That is, one chamber may be at least partially arranged above the other chamber. In one embodiment the first chamber may be at least partially arranged above a portion of the second chamber. This may facilitate a gravity feed of fluid between the chambers.

Alternatively, or additionally, the first and second chambers may be horizontally arranged within the vessel. That is, one chamber may be at least partially arranged beside the other chamber.

The apparatus may comprise a partition adapted to at least partially separate the first and second fluid chambers. The partition may divide the vessel into at least the first and second fluid chambers. The partition may comprise a plate or the like, and may be of any suitable shape, such as generally circular, annular, square, rectangular or the like. The partition may be secured to an inner surface of the vessel, for example by welding, a flanged connection, bolting, interference fitting or the like, or any suitable combination thereof. The partition may be formed as a single component, or may be formed of multiple components.

The partition may define a wall portion or boundary of one or both of the first and second chambers. The partition may define a base of one or both chambers.

The partition may define an upper region or ceiling of one or both chambers. In one embodiment of the present invention the partition may define a base of the first chamber and a ceiling of the second chamber.

The at least one nozzle assembly may be adapted to extend through the partition. The at least one nozzle assembly may be secured to the partition such that the partition provides support for the at least one nozzle assembly.

The at least one nozzle assembly may comprise a first fluid conduit defining a fluid port adapted to permit communication of fluid to be treated from the first fluid chamber into the first fluid conduit. The fluid port may be provided in the base region of the first fluid chamber. Alternatively, the fluid port may be provided at a raised location relative to a base region of the first fluid chamber. In this arrangement the raised location of the fluid port may permit the nozzle assembly to be operational only when a predefined head of fluid to be treated is present in the first fluid chamber. This arrangement may assist to permit a preferential flow velocity and flow range between the first and second chambers to be achieved. The first fluid conduit may be entirely contained within the vessel. Alternatively, at least a portion of the first fluid conduit may extend externally of the vessel.

The at least one nozzle assembly may comprise a second fluid conduit adapted to permit fluid communication of a gas from a gas source to a portion of the nozzle assembly. In this way, gas from the gas source may be entrained into the fluid being treated.

The gas source may comprise gas contained within the vessel, and may comprise gas contained within one or both of the first and second fluid chambers. In this arrangement the second fluid conduit may define a fluid port open to a gas filled region of one or both of the first and second fluid chambers. The gas may comprise gas released from the fluid being treated. Alternatively, the gas may comprise gas provided from an external source.

The second fluid conduit may be directly coupled to an external gas source.

The second fluid conduit may be entirely contained within the vessel. Alternatively, at least a portion of the second fluid conduit may extend externally of the vessel.

The at least one nozzle assembly may comprise a discharge pipe in fluid communication with one or both of the first and second fluid conduits. At least a portion of the discharge pipe may facilitate mixing or commingling of fluid delivered via the first fluid conduit with gas delivered via the second fluid conduit. In this arrangement, turbulence and mixing in the discharge pipe may configure the gas into small bubbles and cause these bubbles to intimately mix with the fluid from the first

chamber. Accordingly, the nozzle assembly may deliver a fluid into the second chamber which contains a favourable distribution of gas bubbles for subsequent fluid treatment in the second chamber.

The discharge pipe may define a fluid outlet opening into the second fluid chamber to permit the gas and fluid mixture to be discharged into said second chamber. The fluid outlet of the discharge pipe may be adapted to be at least partially submerged within the fluid being treated within the second fluid chamber.

The discharge pipe may be arranged to discharge fluid into any region of the second chamber. In one embodiment, the discharge pipe may be arranged to discharge fluid into an outer region of the second chamber.

The discharge pipe may be oriented to permit the fluid and gas mixture to be discharged into the second chamber in a predetermined direction. This arrangement may assist to establish a preferred fluid motion within the second fluid chamber. In one embodiment the discharge pipe may be arranged to establish rotational flow within the second chamber. Rotational flow may be established relative to a central axis of the second chamber. Rotational flow within the second fluid chamber may assist fluid treatment therein. For example, the rotating flow may assist preferential movement of gas bubbles within the fluid being treated, preferential motion of components of the fluid to discharge regions of the second chamber and the like. The rotating flow may suppress forward mixing of the treated fluid towards an outlet (i.e., premature discharge of the fluid being treated), and may modify the residence time distribution.

The discharge pipe may be obliquely (i.e., non-parallel) arranged relative to a central axis of the second chamber. The discharge pipe may be obliquely arranged to discharge fluid into an outer region of the second chamber, advantageously to initiate rotational flow within said second chamber. The discharge pipe may be adapted to discharge fluid with a first velocity component which is parallel to a central axis of the second fluid chamber, and a second velocity component which is perpendicular to the central axis (i.e., tangential to a circle with an origin coinciding with the vessel central axis).

The apparatus may comprise a plurality of nozzle assemblies. At least one of the plurality of nozzle assemblies may be similar to the at least one nozzle assembly described above.

The nozzle assemblies may be arranged in an annular configuration relative to the first fluid chamber. However, other configurations may be utilised. For example, the nozzle assemblies may be arranged to generally conform to the outer peripheral shape of the vessel, which may be other than circular.

Each nozzle assembly may be adapted to be operational at substantially the same fluid head range within the first fluid chamber. For example, each nozzle assembly may comprise a fluid port adapted to permit communication with fluid contained within the first fluid chamber, wherein the fluid ports may be arranged at substantially the same height relative to a base region of the first fluid chamber. Accordingly, when the head, i.e., fluid level, within the first fluid chamber drops below the level of the fluid ports, all of the nozzle assemblies will be rendered ineffective, until a sufficient head is re-established.

Alternatively, at least one of the plurality of nozzle assemblies may be adapted to be operational at a different head of fluid within the first fluid chamber than at least one other of the plurality of nozzle assemblies. For example, at least two of the nozzle assemblies may comprise respective fluid ports adapted to permit communication with fluid contained within the first fluid chamber, wherein the fluid ports may be arranged at different respective heights relative to a base region of the first fluid chamber. Accordingly, in this arrangement, if the fluid head within the first fluid chamber begins to drop, for example as a result of a reduced flow rate through the inlet, the nozzle assemblies will sequentially be rendered ineffective in accordance with the heights of the respective fluid ports. This arrangement may therefore be utilised to maintain a preferred velocity range of the fluid entering the second fluid chamber through the nozzle assemblies. The preferred velocity range may be selected in accordance with the required flow within the second fluid chamber. In this arrangement, providing a degree of control over the velocity range may assist to maintain a preferential flow pattern (e.g., rotational) in the second chamber, reducing the effect of variations in the flow through the inlet to the first chamber.

The preferred velocity range may also be selected to maintain the proportion of gas entrained within the fluid and the mixing between them which occurs in the discharge pipe within predefined values.

The apparatus may optionally comprise a deflector arrangement located within the second chamber. The deflector arrangement may be configured to minimise forward mixing of fluid within the second chamber. The deflector arrangement may be positioned adjacent a wall surface of the second chamber. The deflector arrangement may be located in the region of the at least one nozzle assembly. The deflector arrangement may be configured to deflect fluid which is incident on a wall surface from the nozzle assembly.

The deflector arrangement may define a continuous barrier to fluid at the region of interest. Alternatively, the deflector arrangement may define a

discontinuous barrier. This may permit release of solid particles and the like which may collect on the deflector arrangement. The deflector arrangement may comprise apertures or the like. One or more apertures may be defined in a surface of the deflector arrangement. One or more apertures may be defined between an edge surface of the deflector arrangement and the wall surface of the second chamber.

The deflector arrangement may be aligned substantially perpendicular to the wall surface of the second chamber. The deflector arrangement may be obliquely aligned relative to the wall surface of the second chamber.

A fluid passage may be provided between the first and second chambers to permit fluid communication therebetween, preferably in both directions. The fluid passage may be contained within the vessel. Alternatively, or additionally, a portion of the fluid passage may extend externally of the vessel. The fluid passage may be adapted to permit fluid communication of a gas between the first and second chambers. In one embodiment the fluid passage may be adapted to permit fluid communication of a gas from the second fluid chamber into the first fluid chamber. The gas may comprise gas released from a fluid being treated within the second chamber. Alternatively, or additionally, the gas may comprise a gas supplied from an external source. The fluid passage may alternatively, or additionally, be adapted to communicate a liquid or solids or the like between the first and second fluid chambers.

The fluid passage may be provided centrally or eccentrically of the vessel. A single fluid passage may be provided, or a plurality of fluid passages may be provided. The fluid passage may extend through a partition separating the first and second chambers. The fluid passage may be defined by a wall extending from a surface of the partition. In this arrangement the wall may define an annular region with the inner wall surface of the first fluid chamber, wherein said annular region is adapted to receive fluid to be treated from the vessel fluid inlet. The at least one nozzle assembly may be positioned within the annular region.

The first fluid chamber may comprise a distributor assembly adapted to receive fluid entering the first chamber via the fluid inlet. The distributor assembly may be adapted to dissipate the momentum of the incoming fluid. The distributor assembly may be adapted to distribute the fluid towards the at least one nozzle assembly while minimising turbulence. The distributor assembly may comprise a box-shaped structure adapted to receive fluid from the fluid inlet. The box-shaped structure may comprise a perforated region permitting communication of fluid from said structure.

The apparatus may comprise one or more fluid outlets to permit discharge of treated fluid or components thereof from the vessel. The fluid outlets may be provided within one or both of the first and second fluid chambers. In one embodiment the apparatus may comprise a first fluid outlet adapted to permit discharge predominantly of a first fluid component, such as a liquid, for example water. The first fluid outlet may be positioned within the second chamber, and may be positioned within a lower region of the second chamber.

The apparatus may further comprise a second fluid outlet adapted to permit discharge predominantly of a second fluid component, such as a liquid, for example oil. The second fluid outlet may be positioned within the second fluid chamber, and the second fluid outlet may be positioned within an upper region of the second chamber, or alternatively, or additionally, within a lower region of the fluid chamber, and/or at any location therebetween.

The apparatus may further comprise a third fluid outlet adapted to permit discharge predominately of a third fluid component, such as a gas, for example hydrocarbon gas. The third fluid outlet may be positioned within the first fluid chamber, and may be positioned within an upper region of the first chamber.

At least one fluid outlet may comprise an arrangement adapted to substantially eliminate or at least minimise vortex flow therethrough.

The apparatus may further comprise a skimming apparatus adapted to skim a component of the fluid being treated from a surface thereof. The skimmed component may comprise oil. A conventional skimming apparatus may be utilised.

The second fluid chamber may be adapted to receive fluid only from the first fluid chamber. Accordingly, in this arrangement the entire volume of fluid to be treated flows through the first fluid chamber. Alternatively, the second fluid chamber may be adapted to receive fluid from another source.

Communication of fluid being treated between the first and second fluid chambers may be achieved exclusively through the at least one nozzle assembly. Alternatively, fluid communication may be additionally achieved by other means.

The at least one nozzle assembly may permit the addition of a fluid treatment agent into the fluid being treated. For example, the fluid treatment agent may comprise a pH neutraliser, flocculant or the like.

The at least one nozzle assembly may comprise an eductor.

This vessel may comprise a single vessel containing both the first and second fluid chambers. The vessel may comprise a closed vessel. Alternatively, the vessel may comprise an opened vessel, for example open top, such that at least a portion of the vessel may be exposed to ambient atmosphere.

The apparatus may comprise a third fluid chamber adapted to receive fluid from the second fluid chamber for further treatment. Fluid communicated from the second fluid chamber into the third fluid chamber may be provided via at least one nozzle assembly.

According to a second aspect of the present invention there is provided a method of treating a fluid, said method comprising the steps of:

- defining first and second fluid chambers;
- delivering a fluid to be treated into the first fluid chamber;
- flowing the fluid from the first fluid chamber through at least one nozzle assembly adapted to mix gas with said fluid; and
- discharging the fluid from the at least one nozzle assembly into the second fluid chamber to be further treated therein.

The fluid may be treated within the second chamber and subsequently discharged, wherein the mixing of the gas with the fluid in the at least one nozzle facilitates or assists the subsequent treatment within the second fluid chamber. A floatation treatment may be provided in the second fluid chamber.

The apparatus utilised to perform the method may be provided in accordance with that apparatus of the first aspect, and the method of operating said apparatus should be understood to apply to the method according to the present aspect of the invention.

According to a third aspect of the present invention there is provided a fluid treatment apparatus comprising:

- a first fluid chamber;
- a second fluid chamber;
- a fluid inlet for delivering a fluid to be treated into the first fluid chamber; and
- at least one nozzle assembly extending between the first and second fluid chambers for providing fluid communication therebetween, wherein said nozzle assembly is adapted to facilitate mixing of a gas with said fluid.

The first and second fluid chambers may be provided in a single vessel. The vessel may be closed or alternatively may be open to atmosphere. Alternatively, the first and second fluid chambers may be defined in separate vessels. At least one of the vessels may be closed. At least one of the vessels may be open to atmosphere.

According to a fourth aspect of the present invention there is provided a fluid treatment apparatus comprising:

- a fluid treatment vessel adapted to receive a fluid to be treated from a fluid source; and

at least one nozzle assembly provided between the fluid treatment vessel and the fluid source, wherein the fluid from the fluid source is adapted to flow through the at least one nozzle assembly prior to entering the fluid treatment vessel, and wherein the at least one nozzle assembly is adapted to mix a gas with the fluid.

Accordingly, the entire volume of fluid is mixed with gas prior to entering the fluid treatment vessel. Thus, the residence time of the fluid within the fluid treatment vessel may be entirely used for treating of the fluid. This differs from prior art arrangements in which gas mixing is performed within the fluid treatment vessel.

According to a fifth aspect of the present invention there is provided a nozzle arrangement for distributing a fluid to be treated between a first fluid chamber and a second fluid chamber, said nozzle arrangement comprising:

a first nozzle assembly comprising a first fluid conduit extending between the first and second fluid chambers, wherein the first fluid conduit comprises a first fluid port providing communication with the first fluid chamber; and

a second nozzle assembly comprising a second fluid conduit extending between the first and second fluid chambers, wherein the second fluid conduit comprises a second fluid port providing communication with the first fluid chamber;

wherein the first and second fluid ports are provided a different heights relative to a base of the first fluid chamber to facilitate operation of the first and second nozzle assemblies with different head ranges of fluid within said first fluid chamber.

This arrangement may therefore permit a preferred velocity range of fluid distributed into the second fluid chamber, irrespective of the flow rate of liquid into the first fluid chamber.

The first and second nozzle assemblies may be adapted to facilitate mixing of a gas with said fluid. The first and second nozzle assemblies may facilitate delivery of a gas into said fluid.

Each of the first and second nozzle assemblies may comprise a further fluid conduit adapted to permit fluid communication of a gas from a gas source to a portion of the respective nozzle assembly.

Each of the first and second nozzle assemblies may comprise a discharge pipe defining a fluid outlet opening into the second fluid chamber. The discharge pipe of the first and second nozzle assemblies may be arranged to establish rotational flow within the second chamber.

It should be understood that although different aspects of the invention have been presented, features presented in relation to one aspect may be applied to one or more other aspects.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a longitudinal cross-sectional view of a fluid treatment apparatus in accordance with an embodiment of the present invention;

Figure 2 is a lateral cross sectional view of the apparatus in the region of an upper chamber;

Figure 3 is an enlarged view of an inlet region of the apparatus first shown in Figure 1;

Figure 4 is a diagrammatic representation of anticipated flow patterns within the apparatus of Figure 1;

Figure 5 is a cross-sectional view of a nozzle assembly according to one embodiment of the present invention, which is suitable for use in the apparatus of Figure 1;

Figure 6 is a cross-sectional view of a nozzle assembly according to an alternative embodiment of the present invention, which is suitable for use in the apparatus of Figure 1; and

Figure 7 is a diagrammatic representation of a fluid treatment apparatus in accordance with an alternative embodiment of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Reference is first made to Figures 1 and 2 of the drawings in which there is shown cross-sectional views of a fluid treatment apparatus, generally identified by reference numeral 10, in accordance with an embodiment of the present invention. The apparatus 10 is shown in Figure 1 in longitudinal cross-section, and in Figure 2 in lateral cross-section. The fluid treatment apparatus 10 may be used in many applications. However, in the present embodiment the apparatus 10 is utilised to treat water produced from a subterranean reservoir which comprises quantities of oil and gas. As will be described in further detail below, the apparatus 10 is adapted to separate the oil and gas from the produced water by floatation separation. The apparatus 10 may therefore be described as a Compact Floatation Unit (CFU).

The apparatus 10 comprises a vertically arranged generally cylindrical vessel 12 which defines therein a first or upper fluid chamber 14 and a second or lower fluid chamber 16. The upper and lower fluid chambers are separated by a partition 18 secured to an inner wall surface of the vessel 12. The partition defines a base of the upper chamber 14 and a ceiling of the lower chamber 16.

A fluid passage 20 extends between the upper and lower chambers 14, 16 and is defined by a wall portion 22 upstanding from the partition 18. The wall portion 22 in combination with the inner wall surface of the vessel 12 defines a generally annular region or channel 24 within the upper chamber 14. As will be described in further detail below, the fluid passage 20 permits communication of gas between the upper and lower chambers 14, 16.

A fluid inlet 26 is formed in a side wall of the vessel 12 and in use communicates produced water to be treated into the upper fluid chamber 14, and specifically into the annular region 24. A distributor assembly 28 is provided within the upper chamber 14 and is arranged to initially receive the produced water entering via the inlet 26. The distributor assembly 28, which is most clearly shown in Figure 2 and in the enlarged view in Figure 3, is in the form of a box defined by the partition 18, the wall portion 22, an inner wall portion of the vessel 12, perforated side plates 30 and a solid lid 32 (shown only in Figure 3). Thus, produced water entering the upper chamber 14 via the inlet 26 will be first received into the distributor assembly 28 and then distributed into the annular region 24 through the perforated side plates 30. The distributor assembly 28 functions to dissipate the momentum of the incoming produced water and to distribute this into the annular region 24 with minimum turbulence, preventing or minimising the risk of inadvertent splashing or leakage of the water into the lower chamber 16 through the passage 20.

The apparatus 10 further comprises a plurality of nozzle assemblies or eductors 34 which provide fluid communication of the produced water from the annular region 24 of the upper chamber 14 into the lower chamber 16. Thus, the upper chamber 14 receives produced water via the fluid inlet 26, and subsequently distributes this into the lower chamber 16 through the nozzle assemblies 34. The produced water is then subject to a flotation treatment within the lower chamber 16. Accordingly, the upper fluid chamber 14 may define a distribution chamber and the lower fluid chamber 16 may define a treatment chamber.

Each nozzle assembly 34 facilitates entrainment of a gas into the produced water flowing therethrough. The gas is entrained from a header region 36 of the upper chamber 14 and turbulence and mixing within each nozzle assembly 34 configures the entrained gas into small bubbles and causes these to intimately mix with the produced water before being discharged into the lower chamber 16. Thus, the nozzle assemblies 34 deliver the produced water into the lower chamber 16 with a favourable distribution of gas bubbles for subsequent fluid treatment therein. This is particularly advantageous in that the subsequent residence time of the water within the lower chamber 16 may be utilised exclusively for the floatation treatment and

separation of the oil and gas from the water. This significantly differs from prior art arrangements in which the mixing of gas takes place within a floatation chamber and thus the residence time must accommodate both gas mixing and floatation separation.

The form of the nozzle assemblies 34 will be described in further detail below.

Once the produced water enters the lower chamber 16, the water and oil will naturally begin to separate with the oil tending to float to the surface of the water. The presence of well distributed gas bubbles within the produced water augments this separation effect in that the bubbles adhere to oil droplets within the water and assist coalescence and floatation of the oil. Upon reaching the surface of the water the gas bubbles will be released into an upper region 90 of the lower chamber 16, and will subsequently flow into the header region 36 of the upper chamber 14 through the passage 20. Accordingly, gas released from the produced water may replenish the header region 36 to maintain a sufficient volume of gas for entrainment into incoming produced water by the nozzle assemblies 34.

The apparatus 10 further comprises a first outlet 38 formed in a lower region of the lower chamber 16 and adapted to facilitate discharge of treated water. A baffle 40 and vortex breaker 42 are also present within the lower region of the lower chamber 16 and are adapted to prevent gas bubbles from being discharged through the first outlet 38 with the treated water. As shown in Figure 1, the baffle 40 is positioned concentrically of the vessel 12 and has a diameter which may be approximately 80 to 95% of the inner diameter of the vessel 12.

A skimming apparatus 44 is provided in an upper region of the lower chamber 16 and is adapted to skim oil from the surface of the water. The skimmed oil is discharged through a pipe 46 and ultimately through a second outlet 48 formed in a side of the vessel 12 above the location of the partition 18. The vessel 12 is advantageously maintained at a pressure slightly above atmospheric to drive the skimmed oil upwardly through the pipe 46 towards the second outlet 48. The oil may then be collected and processed as required. In an alternative arrangement, the pipe 46 may extend downwardly from the skimming apparatus 44 and discharge through an outlet in a lower region of the vessel 12, for example from a bottom region, below the baffle 40.

The skimming apparatus 44 is self levelling such that an upper skimming region 50 is maintained at a predefined position relative to the surface of the water/oil within the lower chamber 16 to preserve efficient skimming of the oil.

A third outlet 52 is provided in the upper region of the upper chamber 14 and permits gas within the header region 36 to be discharged from the vessel 12. The

gas may be collected, flared, recycled or the like. The outlet 52 may also function as an inlet to permit gas to be supplied into the vessel 12.

In the present embodiment the nozzle assemblies 34 comprise discharge pipes 54 which are partially immersed within the produced water in the lower chamber 16 and are arranged in a common direction to discharge the produced water downwardly and circumferentially relative to the vessel 12. This arrangement effects rotation of the water within the lower chamber 16 which advantageously assists fluid treatment therein and provides preferential movement of gas bubbles within the fluid and floating oil towards the skimming assembly 44. Also, the rotation of the produced water assists to suppress water from passing through the lower chamber 16 without allowing sufficient time for the gas bubbles and oil droplets to separate from the water.

A deflector arrangement in the form of an annular baffle 55 may optionally be secured or integrally formed with the wall of the lower chamber 16 in a region below the discharge pipes 54 of the nozzle assemblies 34. In use, the baffle 55 minimises a downward velocity component of the fluid to assist to minimise forward mixing of fluid.

Although not illustrated, the baffle 55 includes a number of apertures arranged to permit release of any solid matter which may collect on an upper surface thereof.

Reference is now made to Figure 4 of the drawings in which there is shown a diagrammatic representation of an anticipated flow pattern within the vessel 12. The left hand side of the vessel 12 shown in Figure 2 illustrates an anticipated water secondary flow pattern, and the right hand side shows the anticipated bubble trajectories within the lower chamber 16. It should be understood that the primary rotational motion of the fluid about the central longitudinal axis of the vessel 12 is not represented in Figure 4 for clarity. Furthermore, the optional annular baffle 55, shown in Figure 1, is not shown in Figure 4.

A lateral circulation loop 60 (loop 1) is driven by the gas lift of the large bubbles 62 discharged from the nozzle assemblies 34 rapidly rising to the surface. Circulation loop 60 makes sure the flow on the liquid surface is towards the skimming assembly 44, so that separated oil 64 may be carried in this direction. A longitudinal circulation loop 66 (loop 2) is driven by radially inward flow in the liquid boundary layer 68 on the baffle 40. Circulation loop 66 captures the small gas bubbles 70 which have downward trajectories out of the main water flow and carries these towards the centre and then upwardly towards the surface, to be captured by

circulation loop 60. The small gas bubbles 70 must therefore cross into circulation loop 60 to finally reach the surface, and/or coalesce into larger bubbles.

A detailed description of the form of a nozzle assembly 34 will now be described with reference to Figure 5, in which the nozzle assembly 34 is shown in sectional view. The assembly 34 comprises a first fluid conduit 72 which extends upwardly and defines a fluid inlet port 74. A lower end of the first conduit is secured to the angled discharge pipe 54. The first fluid port 74 permits produced water in the annular region 24 (see Figure 1) to flow into the first conduit 72 and thus into the discharge pipe 54. A flange 78 is secured to the first fluid conduit 72 and permits the nozzle assembly 34 to be secured to the partition 18 (see Figure 1) separating the upper and lower chambers 14, 16.

The assembly 34 also comprises a second fluid conduit 80 which extends through the first fluid conduit 72. The second conduit 80 defines an upper fluid port 82 which opens into the header region 36 (see Figure 1). A lower end of the second conduit 80 is open in the region of the discharge pipe 54.

Thus, in use, water flowing through the first fluid conduit 72 will cause gas to be entrained from the second fluid conduit 80 from the header region 36 and subsequently mixed within the discharge pipe 54, thus established a good distribution of gas bubbles within the water prior to being discharged through an outlet 84 into the lower chamber 16.

The height of the fluid port 74 of the first fluid conduit will dictate the head of fluid within the annular region 24 which is required for the nozzle assembly 34 to operate. This operational head may be varied and pre-selected by the provision of an extension pipe 86 of a required length secured or integrally formed with the first fluid conduit 72. The operational head of the nozzle assemblies 34 may be in the region of 400-500mm, for example.

In one embodiment of aspects of the present invention, the operational head may be equivalent for all nozzle assemblies 34 provided within the apparatus. However, in alternative embodiments two or more nozzle assemblies 34 may be provided with different operational heads by arranging the respective fluid ports 74 at different heights. Accordingly, in this arrangement, if the fluid head or level within the annular region 24 of the upper chamber 14 begins to drop, for example as a result of a reduced flow rate through the inlet 26, the nozzle assemblies 34 will sequentially be rendered ineffective in accordance with the heights of the respective fluid ports 74 until the flow passing through the reduced number of operating nozzle assemblies 34 into the second chamber 16 matches the flow entering the annular region 24 from the inlet 26. This arrangement may therefore be utilised to maintain a preferred velocity

range of the fluid being discharged through the outlets 84 of the discharge pipes 54 into the second fluid chamber 16. The preferred velocity range may be selected in accordance with the required flow within the second fluid chamber 16. For example, a range of fluid discharge velocities may be required to establish and maintain rotational flow within the lower chamber. The preferred velocity range may also be selected to maintain the proportion of gas entrained within the fluid and the mixing between them which occurs in the discharge pipe within preferred values.

An alternative embodiment of a nozzle assembly 34a which may be utilised in the apparatus 10 first shown in Figure 1, is shown in Figure 6, reference to which is now made. The assembly 34a of Figure 6 is similar to the assembly 34 in Figure 5 and as such like components share like reference numerals, followed by letter "a". As noted, nozzle assembly 34a is similar to assembly 34 and as such comprises a first fluid conduit 72a defining a fluid port 74a, and a second fluid conduit 80a defining a fluid port 82a. However, in this embodiment the fluid port 82a of the second fluid conduit 80a opens into a header region 90 (see Figure 1) of the lower chamber 16. Thus, gas from the header region 90 may be entrained and mixed with produced water within a discharge pipe 54a prior to being discharged via an outlet 84a into the lower chamber 16. Although not illustrated, the nozzle assembly 34a may include an extension pipe, similar to pipe 86 of the example shown in Figure 5.

A fluid treatment apparatus according to an alternative embodiment of the present invention will now be described with reference to Figure 7. The fluid treatment apparatus, generally identified by reference numeral 110, is similar to the apparatus 10 first shown in Figure 1 and as such like features share like reference numerals, incremented by 100.

The apparatus 110 therefore comprises a vessel 112, which in this case is horizontally arranged. First and second fluid chambers 114, 116 separated by a partition 118 are defined within the vessel 112. A fluid passage 120 is provided between the first and second chambers 114, 116 to permit passage of gas therebetween. A fluid inlet 126 communicates produced water into the first chamber 114, and a plurality of nozzle assemblies 134 are provided to permit communication of the produced water from the first chamber 114 and into the second chamber 116. The nozzle assemblies 134 facilitate entrainment of a gas within a header region 136 of the first chamber 114, or a header region 190 of the second chamber 116, into the produced water. This arrangement therefore provides a good mix and distribution of gas bubbles within the produced fluid prior to being discharged into the second chamber 116.

The produced fluid may then reside for a period of time within the second chamber 116 such that the gas and oil within the water may float to the surface thereof, while the water moves in a generally left-to-right direction. Perforated baffles 92, preferably at least two, are provided within the second chamber 116 to suppress backmixing of the water.

The treated water with significantly reduced gas and oil content may be discharged via a first outlet 138. The floating oil may be skimmed from the surface of the water by a skimming assembly 144 and subsequently discharged via a second outlet 148. The gas released from the water may be discharged via a third outlet 152.

It should be understood that the embodiments described herein are exemplary and that various modifications may be made thereto without departing from the scope of the present invention. For example, features of the present invention described above may be utilised in circumstances where the first and second chambers are provided in separate vessels. In this arrangement, the benefits of the present invention may still be achieved by virtue of passing the produced water to be treated through the nozzle assemblies such that a good mix and distribution of bubbles within the water is achieved before being discharged into the second fluid chamber for treatment. In other embodiments the first chamber may be dispensed with and fluid from a source may be directly supplied to at least one nozzle assembly to be discharged into a fluid treatment chamber.

Furthermore, in the embodiments described various conduits and passages are provided and located internally of the vessel. However, such conduits and passages may extend entirely or at least partially externally of the vessel.

Additionally, the apparatus may comprise a third fluid chamber adapted to receive fluid from the second fluid chamber for further treatment. Fluid communicated from the second fluid chamber into the third fluid chamber may be provided via at least one nozzle assembly.

Further, the gas to be entrained into the fluid being treated may be supplied from an external source.

The vessel may be opened to atmosphere.

Although the nozzle assemblies are arranged to entrain gas into the fluid being treated, in alternative arrangements at least one of the nozzle assemblies may be adapted to permit gas to be injected or otherwise delivered into the fluid being treated.

CLAIMS:

1. A fluid treatment apparatus comprising:

a fluid vessel;

5 first and second fluid chambers defined within the fluid vessel, wherein the second fluid chamber is adapted to accommodate a floatation separation treatment of a fluid therein;

a fluid inlet for delivering a fluid to be treated into the first fluid chamber; and

10 at least one eductor nozzle assembly for providing fluid communication from the first fluid chamber to the second fluid chamber, wherein said eductor nozzle assembly is adapted to facilitate mixing of a gas with said fluid to communicate a mixture of said fluid and said gas into the second fluid chamber.

15 2. The fluid treatment apparatus according to claim 1, further comprising a partition adapted to at least partially separate the first and second fluid chambers.

3. The fluid treatment apparatus according to claim 2, wherein the at least one eductor nozzle assembly is adapted to extend through the partition.

20 4. The fluid treatment apparatus according to any preceding claim, wherein the at least one eductor nozzle assembly comprises a first fluid conduit defining a fluid port adapted to permit communication of fluid to be treated from the first fluid chamber into the first fluid conduit.

25 5. The fluid treatment apparatus according to claim 4, wherein the fluid port of the first fluid conduit is provided at a raised location relative to a base region of the first fluid chamber.

30 6. The fluid treatment apparatus according to claim 4 or 5, wherein the at least one eductor nozzle assembly comprises a second fluid conduit adapted to permit fluid communication of a gas from a gas source to a portion of the eductor nozzle assembly.

35 7. The fluid treatment apparatus according to claim 6, wherein the gas source comprises gas contained within the vessel.

8. The fluid treatment apparatus according to claim 6 or 7, wherein the gas source comprises gas released from the fluid being treated.

5 9. The fluid treatment apparatus according to claim 6, 7 or 8, wherein the gas source comprises gas provided externally of the vessel.

10 10. The fluid treatment apparatus according to any preceding claim, wherein the at least one eductor nozzle assembly comprises a discharge pipe defining a fluid outlet opening into the second fluid chamber.

11 11. The fluid treatment apparatus according to claim 10, when dependent on any of claims 6 to 9, wherein at least a portion of the discharge pipe is configured to facilitate mixing of fluid delivered via the first fluid conduit and gas delivered via the second fluid conduit.

15 12. The fluid treatment apparatus according to claim 10 or 11, wherein the discharge pipe is arranged to establish rotational flow within the second chamber.

20 13. The fluid treatment apparatus according to any preceding claim, comprising a plurality of eductor nozzle assemblies.

25 14. The fluid treatment apparatus according to claim 13, wherein at least one of the plurality of eductor nozzle assemblies is adapted to be operational at a different head of fluid within the first fluid chamber than at least one other of the plurality of eductor nozzle assemblies.

30 15. The fluid treatment apparatus according to any preceding claim, further comprising a fluid passage between the first and second chambers to permit fluid communication therebetween.

35 16. The fluid treatment apparatus according to claim 15, wherein the fluid passage is adapted to permit fluid communication of a gas from the second fluid chamber into the first fluid chamber.

17. The fluid treatment apparatus according to claim 15 or 16, wherein the fluid passage extends through a partition separating the first and second chambers.

18. The fluid treatment apparatus according to claim 17, wherein the fluid passage is defined by a wall extending from a surface of the partition.

5 19. The fluid treatment apparatus according to claim 19, wherein the wall defines a wall portion of the first chamber.

10 20. The fluid treatment apparatus according to any preceding claim, further comprising a distributor assembly adapted to receive fluid entering the first chamber via the fluid inlet.

21. The fluid treatment apparatus according to any preceding claim, further comprising one or more fluid outlets to permit discharge of treated fluid or components thereof from the vessel.

15 22. The fluid treatment apparatus according to any preceding claim, wherein the second fluid chamber is adapted to receive fluid only from the first fluid chamber.

20 23. The fluid treatment apparatus according to any preceding claim, wherein communication of fluid being treated between the first and second fluid chambers is achieved exclusively through the at least one eductor nozzle assembly.

25 24. The fluid treatment apparatus according to any preceding claim, further comprising a deflector arrangement positioned within the second chamber to assist to minimise forward mixing of a fluid being treated.

30 25. A method of treating a fluid, said method comprising the steps of:
defining first and second fluid chambers;
delivering a fluid to be treated into the first fluid chamber;
flowing the fluid from the first fluid chamber through at least one eductor
nozzle assembly, wherein the eductor nozzle assembly facilitates mixing of a gas
with said fluid; and
discharging a mixture of said fluid and said gas from the at least one eductor
nozzle assembly into the second fluid chamber; and
treating the fluid within the second chamber by floatation separation.

35 26. A nozzle arrangement for distributing a fluid to be treated between a first fluid chamber and a second fluid chamber, said eductor nozzle arrangement comprising:

a first eductor nozzle assembly comprising a first fluid conduit extending between the first and second fluid chambers, wherein the first fluid conduit comprises a first fluid port providing communication with the first fluid chamber; and

5 a second eductor nozzle assembly comprising a second fluid conduit extending between the first and second fluid chambers, wherein the second fluid conduit comprises a second fluid port providing communication with the first fluid chamber;

10 wherein the first and second fluid ports are provided at different heights relative to a base of the first fluid chamber to facilitate operation of the first and second eductor nozzle assemblies with different head ranges of fluid within said first fluid chamber, and wherein the first and second eductor nozzle assemblies are adapted to facilitate mixing of a gas with said fluid.

15 27. The nozzle arrangement according to claim 26, wherein each of the first and second eductor nozzle assemblies comprises a further fluid conduit adapted to permit fluid communication of a gas from a gas source to a portion of the respective nozzle assembly.

20 28. The nozzle arrangement according to claim 26 or 27, wherein each of the first and second eductor nozzle assemblies comprises a discharge pipe defining a fluid outlet opening into the second fluid chamber.

25 29. The nozzle arrangement according to claim 28, wherein the discharge pipes of the first and second eductor nozzle assemblies are arranged to establish rotational flow within the second chamber.

30 30. The nozzle arrangement according to claim 28 or 29, wherein at least a portion of the discharge pipes of the first and second eductor nozzle assemblies are configured to facilitate mixing of fluid delivered via the first fluid conduit and gas delivered via the second fluid conduit.