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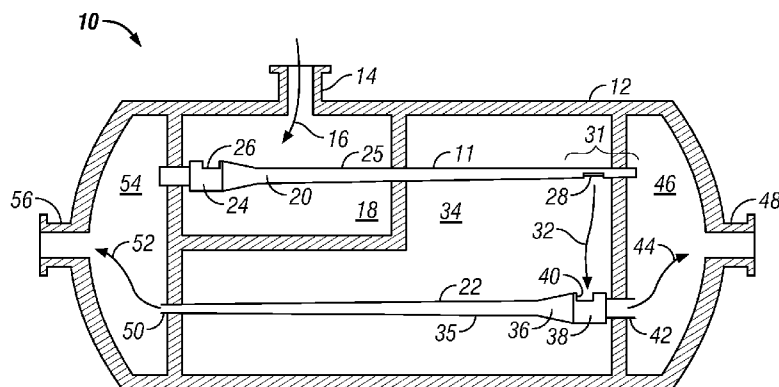


FIG. 1

(57) Abstract: Two hydrocyclones used in series enhances the removal of a dispersed liquid phase from a continuous liquid phase by cyclonic action. The first hydrocyclone has no overflow outlet and serves to coalesce the droplets or particles of the disperse phase together thereby increasing contaminant size distribution. The second hydrocyclone functions as a separator operating at higher removal efficiency. The method and apparatus are useful to clarify produced water from hydrocarbon recovery operations.

**METHOD AND APPARATUS TO ENHANCE SEPARATION
PERFORMANCE OF A LEAN AND LOW MEAN SIZE
DISPERSED PHASE FROM A CONTINUOUS PHASE**

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BACKGROUND OF THE INVENTION

[0001] The present invention relates to methods and apparatus for separating a liquid/liquid continuous mixture, and more particularly relates, in one embodiment, to methods and apparatus for separating or dividing a liquid dispersed phase from a liquid continuous phase of a fluid mixture.

[0002] The overall construction and manner of operation of hydrocyclones is well known. A typical hydrocyclone includes an elongated body surrounding a tapered separation chamber of circular cross-section, the separation chamber decreasing in cross-sectional size from a large overflow and input end to a narrow underflow end. An overflow or reject outlet for the lighter fraction is provided at the wider end of the conical chamber while the heavier underflow or accept fraction of the suspension exits through an axially arranged underflow outlet at the opposite end of the conical chamber. (It will be appreciated that the terms "reject" and "accept" are relative and depend upon the nature and value of the lighter and the heavier fractions.) Liquids and suspended particles are introduced into the chamber via one or more tangentially directed inlets, which inlets create a fluid vortex in the separation chamber. The centrifugal forces created by this vortex throw denser fluids and particles in suspension outwardly toward the wall of the conical separation chamber, thus giving a concentration of denser fluids and particles adjacent thereto, while the less dense fluids are brought toward the center of the chamber and are carried along by an inwardly-located helical stream created by differential forces. The lighter fractions are thus carried outwardly through the overflow outlet. The heavier particles and/or fluids continue to spiral along the interior wall of the hydrocyclone and exit the hydrocyclone via the underflow outlet.

[0003] The fluid velocities within a hydrocyclone are high enough that the dynamic forces produced therein are sufficiently high to overcome the effect of any gravitational forces on the performance of the device.

Hydrocyclones may, therefore, be arranged in various physical orientations without affecting performance. Hydrocyclones, especially those for petroleum fluid processing, are commonly arranged in large banks of several dozen or even several hundred hydrocyclones with suitable intake, overflow and underflow assemblies arranged for communication with the intake, overflow and underflow openings, respectively, of the hydrocyclones.

[0004] Hydrocyclones are used both for the separation of liquids from solids in a liquid/solid mixture ("liquid/solid hydrocyclones") as well as for the separation of liquids from other liquids ("liquid/liquid hydrocyclones"). Different constructions are used for each of these hydrocyclone devices. Generally, the liquid/liquid type of hydrocyclone is longer in the axial direction than a solid/liquid hydrocyclone and is thinner as well. As a result of these structural differences, it cannot be assumed that the design and structure of a liquid/liquid hydrocyclone usefully translates to a liquid/solid hydrocyclone and vice versa.

[0005] In the recovery of hydrocarbons from subterranean formations, it is common that the fluids produced are mixtures of aqueous fluids, typically water, and non-aqueous fluids, typically crude oil. These fluid mixtures are often in the form of tight emulsions that are difficult to separate. In general, oil-in-water emulsions (o/w) and water-in-oil emulsions (w/o) are separated by physical processes, chemical processes, such as through the use of demulsifiers and other additives, or combinations of the two. Hydrocyclones are known to be a useful physical method of separating oil phase fluids from aqueous phase fluids, along with other apparatus including, but not necessarily limited to, settling tanks, centrifuges, membranes, and the like. Additionally, electrostatic separators employ electrical fields and the differences in surface conductivity of the materials to be separated to aid in these separations.

[0006] "Produced water" is the term used to refer to streams generated by the recovery of hydrocarbons from subterranean formations that are primarily water, but may contain significant amounts of non-aqueous contaminants dispersed therein. Typically, produced water results from an initial separation of oil and water, and accounts for a majority of the waste

derived from the production of crude oil. After a primary process of separation from the oil, the produced water still contains drops or particles of oil in emulsion in concentrations as high as 2000 mg/l, and thus it must be further treated before it may be properly discharged to the environment. Every country has set limits for the concentration of oil dispersed in the water for offshore wells and for near-shore fields. Even if the produced water is returned to the field, it is advisable to remove as much of the oil and suspended solids (*e.g.*, sand, rock fragments, and the like) as possible in order to minimize the risk of clogging the field.

[0007] It would be desirable if methods and apparatus were devised that could simultaneously remove oil and other non-aqueous species from produced water and contaminated water with greater efficiency than at present.

BRIEF SUMMARY OF THE INVENTION

[0008] There is provided, in one non-restrictive form, an exemplary apparatus for separating a dispersed liquid phase from a continuous liquid phase within a fluid mixture. The apparatus has one or more coalescers that each includes a first separation chamber having a first inlet portion at one end of the separation chamber and a first outer wall portion throughout the first separation chamber. The coalescers also each incorporates one or more first inlets for introducing the fluid mixture into the first inlet portion of the first separation chamber to generate a swirling motion of the fluid mixture and to at least partially coalesce the dispersed liquid phase. The coalescers additionally each contains at least one outlet at the other end of the first separation chamber for discharging therefrom the fluid mixture that contains the at least partially coalesced dispersed liquid phase. The apparatus also includes one or more separator hydrocyclones each containing a second separation chamber having a second inlet portion at one end of the second separation chamber and a second outer wall portion throughout the first separation chamber. Each separator hydrocyclone also contains at least one second inlet for introducing the fluid mixture comprising the at least partially coalesced dispersed liquid phase into the second inlet portion of the second

separation chamber to generate a swirling motion of the fluid mixture and to substantially separate the at least partially coalesced dispersed liquid phase from the continuous liquid phase. Each separator hydrocyclone also includes at least one overflow outlet on the second separation chamber for discharging therefrom a relatively less dense, coalesced liquid phase of the fluid mixture, and at least one underflow outlet on the other end of the second separation chamber from the at least one overflow outlet for discharging a relatively more dense liquid phase of the fluid mixture. Further, an exemplary apparatus includes at least one fluid communication between the at least one outlet of the one or more coalescers and the at least one second inlet of the one or more separator hydrocyclones.

[0009] As another example and in another non-limiting embodiment, a method for separating a dispersed liquid phase from a continuous liquid phase within a fluid mixture that involves introducing the fluid mixture into at least one coalescer. The fluid mixture is swirled within the coalescer to at least partially coalesce the dispersed liquid phase. The fluid mixture comprising an at least partially coalesced dispersed liquid phase is discharged to at least one separator hydrocyclone. The fluid mixture is swirled within the separator hydrocyclone to substantially separate the at least partially coalesced dispersed liquid phase. A relatively less dense, coalesced liquid phase of the fluid mixture is discharged through an overflow outlet. A relatively more dense liquid phase of the fluid mixture is discharged through an underflow outlet.

[0010] In another non-restrictive example, an apparatus for separating a dispersed liquid phase from a continuous liquid phase within a fluid mixture includes a first elongate hollow member with a first inlet portion and a first outlet portion. The first inlet portion has a greater cross-section diameter, taken transverse to a longitudinal axis of the first elongate member, than the first outlet portion of the member. The first outlet portion is configured to effuse substantially all fluid flow egressing from the first elongate hollow member and received at the first inlet portion. The apparatus also includes a second elongate member with a second inlet portion and a second outlet portion. The second inlet portion has a greater

cross-section diameter, taken transverse to a longitudinal axis of the second elongate member, than the second outlet portion of the second elongate member. The second elongate member has a third outlet portion. The first outlet portion is in fluid communication with the second inlet portion; and the second inlet portion is upstream of the second and third outlet portions.

[0011] In still another non-limiting embodiment a method for separating a dispersed liquid phase from a continuous liquid phase within a fluid mixture, involves routing a flow of fluid into a first inlet portion of a first elongate hollow member and at least partially coalescing the flow by generating a vortex along an inner wall of the elongate hollow member. The flow of fluid egresses only from a first outlet portion located toward one end of the first elongate hollow member. The flow of fluid from the first outlet portion of the first elongate hollow member is routed to a second inlet portion of a second elongate hollow member. A relatively less dense, coalesced liquid phase of the flow of fluid is discharged through a second outlet of the second elongate hollow member and located toward one side of the inlet portion of the second elongate hollow member. A relatively more dense liquid phase of the flow of fluid is discharged through a third outlet portion of the second elongate hollow member and located on an opposite side from the second inlet portion of the second elongate hollow member and the second outlet portion of the second elongate hollow member.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0012] FIG. 1 is a schematic cross-sectional illustration of one non-limiting embodiment of the apparatus contained in a single vessel for separating a dispersed liquid phase mixed with a continuous phase as described herein;

[0013] FIG. 2 is a detailed, schematic, cross-sectional illustration of one embodiment of the outlet from the coalescer of FIG. 1;

[0014] FIG. 3 is an schematic, cross-sectional illustration of an alternate embodiment of the outlet from the coalescer of FIG. 1 as well as the circulation within the coalescer;

[0015] FIG. 4 is a schematic cross-sectional illustration of another non-restrictive embodiment of the apparatus contained in a single vessel for separating a dispersed liquid phase mixed with a continuous phase as described herein;

[0016] FIG. 5 is a schematic cross-sectional illustration of an alternate non-limiting embodiment of the system for separating a dispersed liquid phase mixed with a continuous phase as described herein, shown in two separate vessels;

[0017] FIG. 6 is a plot of a hypothetical series of curves of the separation probability as a function of droplet size; and

[0018] FIG. 7 is a plot of a hypothetical series of curves showing the distribution as a function of size at the outlet of the separator hydrocyclone.

[0019] It will be appreciated that the Figures are schematic illustrations that are not to scale or proportion, and, as such, some of the important parts of the apparatus may be exaggerated for illustration.

DETAILED DESCRIPTION OF THE INVENTION

[0020] Non-limiting exemplary methods and apparatus described herein enhance the removal of a dispersed phase from a continuous phase intermixed therewith by means of cyclonic action of two or more hydrocyclones in series. The first hydrocyclone or batch of first hydrocyclones (also called coalescers herein) increase the size distribution of the dispersed phase, while subsequently the second or separator hydrocyclone or batch of second or separator hydrocyclones separates the coalesced dispersed phase from the continuous phase at a higher removal efficiency. In one non-limiting embodiment, the dispersed phase may be a contaminant, such as oil in a continuous phase of produced water. A non-limiting application for the apparatus and methods herein is to separate the components of a wellbore fluid involved in hydrocarbon recovery, including, but not necessarily limited to produced water from a subterranean formation. In a non-restrictive instance, produced water on an offshore platform that has the contaminants sufficiently removed therefrom may be properly disposed of in the sea.

[0021] In more detail, one non-restrictive example includes utilization of this method to enhance removal efficiency of hydrocyclones in a produced water treatment, where existing hydrocyclones or degassers or flotation units do not meet oil and grease discharge requirements due to small size distribution or lean concentration of the contaminants. Indeed, the apparatus and methods described herein are expected to find particular utility in removing lean and/or low concentrations of a dispersed phase from a continuous phase dispersed therewith, and/or separating a dispersed phase from a continuous phase where the dispersed phase has a relatively low mean size distribution therein.

[0022] Although conventional hydrocyclones generally have both an underflow outlet and an overflow outlet, it will be appreciated that the first hydrocyclone or coalescer in an exemplary apparatus described herein (or each of the first hydrocyclones or coalescers in the case of a batch thereof) does not have a conventional overflow outlet.

[0023] It should also be appreciated that the apparatus described herein are configured to separate a dispersed liquid phase from a continuous liquid phase within a fluid or liquid mixture and are not configured to separate solids from liquids in solid/liquid mixtures. Stated another way, the apparatus is configured to make these separations in an absence of solids.

[0024] Each hydrocyclone or batch of hydrocyclones may be contained within a single enclosure or vessel or may be housed within separate enclosures or vessels. For instance, in one non-limiting embodiment, the coalescers may be housed or contained in one vessel while the separators are contained or housed in a second vessel. In general, in another optional, alternative embodiment, the coalescers and the separators have a conical section or profile followed by a tubular tail section which may or may not be tapered, at least on the inside. The tapered shape may be convexly curved toward the interior so that the hydrocyclones have a flared profile or appearance.

[0025] Shown in more detail with respect to FIG. 1 is an exemplary system or apparatus **10** for separating a dispersed liquid phase combined with a continuous liquid phase in a fluid mixture, where the apparatus

includes a pressure vessel **12** or other container or enclosure, at least one first coalescer or first elongate hollow member **11** and at least one separator hydrocyclone or second elongate hollow member **22**. In one non-limiting embodiment herein, the first and second elongate hollow members **11** and **22** have generally tapered profiles as seen in FIGS. 1, 3, 4 and 5, and/or conical profiles. Vessel **12** has an inlet **14** for accepting the fluid mixture **16** into inlet chamber **18** of vessel **12**. This permits fluid mixture **16** to enter first separation chamber **20** of first coalescer **11** via first inlet portion **24** at one end (larger left end in FIG. 1) of the separation chamber **20**, where the separation chamber **20** is defined by a first outer wall portion **25** throughout the first separation chamber **20**.

[0026] In the known operation of hydrocyclones, the fluid velocity of fluid mixture **16** introduced into first inlet portion **24** through first inlet **26** generates a swirling motion or vortex in the first separation chamber **20** that at least partially coalesces the dispersed liquid phase (e.g., contaminant droplets, oil, etc.). In one non-restrictive embodiment of the method, the vortex is generated along the inner wall (opposite side of outer wall **25**) of the first elongate hollow member **11**. The vortex or swirling motion **30** is shown in more detail in the cross-section schematic illustration of FIG. 3.

[0027] As illustrated, coalescer **11** does not include an overflow outlet that might typically be found in a hydrocyclone at the larger end thereof, but does include at least one outlet or first outlet portion **28** at the other end thereof. In one non-limiting embodiment the first inlet portion **24** has a greater cross-section diameter, taken transverse to a longitudinal axis **29** of the first elongate member **11**, than the first outlet portion **28**. The vortex or swirling motion **30** discharges a fluid mixture **32** that contains an at least partially coalesced liquid phase into intermediate chamber **34** of vessel **12**. It will be appreciated that there is no particular threshold or level of coalescence that may or could be specified in advance for fluid mixture **32**, and that any degree or level of coalescence that improves the overall separation efficiency of the apparatus **10** is sufficient for the method and apparatus herein to be considered successful. That is, the method and apparatus herein should increase the separation efficiency as

compared with a method and apparatus using only one hydrocyclone. Understood another way, first outlet portion **28** is configured to effuse substantially all fluid flow egressing from the first elongate hollow member **11** and received at the first inlet portion **24**.

[0028] Partially coalesced fluid mixture **32** passes to separator hydrocyclone or second elongate hollow member **22** having a second separation chamber **36** having a second outer wall portion **35** throughout the second separation chamber **36** with a second inlet portion **38** at the larger (right) end of the second separation chamber **36**. Separator hydrocyclone **22** has at least one second inlet **40** in the larger (right) end of the second separation chamber **36** for introducing the partially coalesced fluid mixture **32** into the second inlet portion **38** of the second separation chamber **36** to generate a swirling motion of the fluid mixture and to substantially separate the at least partially coalesced liquid phase, *e.g.*, oily contaminants, from the continuous phase, *e.g.*, water. By “substantially separate” herein is meant that at least a majority (greater than 50 volume %) of the coalesced liquid phase, which is larger than certain size (cut size) is separated, alternatively at least 80 vol.% of the coalesced liquid phase is separated, and in another non-limiting embodiment, at least 90 vol.% of the coalesced liquid phase present is separated. The cut size refers to a specific contaminant size from the size distribution of dispersed phase, which is substantially separated in accordance with operational and geometrical parameters of the hydrocyclone.

[0029] Separator hydrocyclone **22** also includes at least one overflow outlet or second outlet portion **42** for discharging a relatively less dense coalesced liquid phase **44** into overflow outlet chamber **46** of vessel **12** and through overflow outlet **48**. Overflow outlet **42** may be coaxial with a vortex finder (not shown) in hydrocyclone **22** on the axis of separator hydrocyclone **22** typically found in a hydrocyclone, as is known in the art. In one non-limiting embodiment, the second inlet portion **38** has a greater cross-section diameter, taken transverse to a longitudinal axis (not shown) of the second elongate member **22**, than the second outlet portion **42**.

[0030] Separator hydrocyclone **22** additionally includes at least one underflow outlet or third outlet portion **50** on the other end of the second separation chamber **36** from the at least one overflow outlet **42** for discharging a relatively more dense liquid phase **52** (e.g., clarified water) of the fluid mixture. Relatively more dense liquid phase **52** enters underflow outlet chamber **54** of vessel **12**, and exits vessel **12** through underflow outlet **56**. In another non-restrictive version, second inlet portion **38** is upstream of the second and third outlet portions, **42** and **50**, respectively, and in another non-limiting embodiment the second inlet portion **38** is physically intermediate the second and third outlet portions, **42** and **50**, respectively. Further in another non-limiting embodiment, second outlet portion **42** of the second elongate hollow member **22** and located toward one side of the inlet portion **38** of the second elongate hollow member **22**. Third outlet portion **50** of the second elongate hollow member **22** may be located on an opposite side from the second inlet portion **38** of the second elongate hollow member **22** and the second outlet portion **42** of the second elongate hollow member **42**.

[0031] This apparatus or system has at least one fluid communication pathway between the at least one outlet **28** of the coalescer **11** and the at least one second inlet **40** of the at least one separator hydrocyclone **22**. In the non-limiting embodiment of FIG. 1, this fluid communication pathway is intermediate chamber **34**; however, as will be seen, other, alternate configurations may be usefully employed.

[0032] Shown in FIG. 2 is a detailed, schematic, cross-sectional illustration of one outlet **60** from the narrow end or tail section **31** of the coalescer **11** where the fluid mixture **32** that contains an at least partially coalesced liquid phase exits through the rectangular slot shape opening or openings **28** on the body and near the end of the tail section **31** of the coalescer **11**. As shown in FIGS. 1, 2 and 3, the opening **28** may be on a side of tail section **31**. The openings **28** may be of any shape and variation suitable for the application and adapted for better construction of the coalescer **11**. However, in one non-limiting embodiment, the openings **28** are rectangular and slot shape, meaning a narrow notch, slit or opening of

rectangular shape, narrow in one dimension and relatively more elongate in the other rectangular dimension.

[0033] Tail section may have an end **27** thereof, where an underflow outlet might normally be (see, for instance, underflow outlet **50** in separator hydrocyclone **22**). The total of all of the outlet(s) **28**, whether there is one or more than one, should have a cross-section area equal to or less than the cross-section of the end **27** of the tail section **31** or the cross section area of the third outlet portion **50**. In one non-limiting embodiment, end **27** has circular shape and a diameter of about 11 mm, to give a cross-section of about 95 mm² or about 100 mm². Thus, in one non-limiting embodiment, the cross-section of rectangular slot shape opening **28** should be equal to or less than 100 mm², alternatively about 95 mm², in another non-restrictive version 90 mm² or less, or even in a different embodiment, about 80 mm² or less.

[0034] It will be appreciated that first separation chamber **20** has a first interior diameter (not shown) and that second separation chamber **36** has a second interior diameter. While the two diameters may be identical, it will be appreciated that in most expected embodiments of the apparatus **10** the second interior diameter will be smaller than the first interior diameter. This design has the effect that the vortex or swirling motion **30** of coalescer **11** generates a first G-force and the swirling motion or vortex within the separator **22** generates a second G-force, where the second G-force is equal to or greater than the first G-force. However, it will be appreciated that in other alternate versions the second G-force may be less than the first G-force. In one non-limiting embodiment, the first G-force may be in the order of 100s, whereas the second G-force may be of the same magnitude or higher depending on the geometry of the second hydrocyclone or combination of geometry or number of batch of hydrocyclones. Alternatively, each hydrocyclone may be configured to separate a dispersed liquid phase from a continuous liquid phase within a fluid mixture at a G-force ranging from about 1000 to about 2000 for both hydrocyclones. This may be accomplished because the end **27** of the tail section **31** has a cross-section, and the rectangular, slot shape opening **28** on a side of tail section **31** has a cross-section that is equal to or less than

the cross-section of end **27** of the tail section **31**, or the cross section of third outlet portion **50**. The G is defined herein as a unit measuring the inertial stress on a body undergoing rapid acceleration, expressed in multiples of the acceleration of one earth gravity. The G-forces at which the hydrocyclones of the apparatus described operate are much higher than those separators of solids and liquids, which typically operate at a G-force of 10 or less.

[0035] Shown in FIG. 4 is another embodiment of the apparatus **70** where the coalescer **11** and the separator **22** are again within a single vessel **72**. Similar components or elements will be given similar reference numerals as those used in FIG. 1 for clarity. In the FIG. 4 embodiment fluid mixture **16** enters vessel **72** through inlet **14**, advances to inlet chamber **74** and, in turn, through openings **76** in wall **78**, and progresses into coalescer chamber **80** and through inlet **26** of coalescer **11** as described above.

[0036] As established above in the discussion of FIGS. 1 and 3, the fluid velocity of fluid mixture **16** introduced into first inlet portion **24** through first inlet **26** generates a swirling motion or vortex **30** in the first separation chamber **20** that at least partially coalesces the dispersed liquid phase (e.g., contaminant droplets, oil, etc.) to give at least partially coalesced fluid mixture **32** that exits into intermediate chamber **82** and passes into opening **84** of fluid communication **86** in the FIG. 4 embodiment a pipeline or conduit (shown in dashed lines) that connects with separator chamber **88** at aperture **90**.

[0037] At least partially coalesced fluid mixture **32** in separator chamber **88** enters separator **22** at inlet **40** and is separated therein as described with respect to FIG. 1, where the relatively less dense coalesced liquid phase **44** exits separator **22** at overflow outlet **42** into overflow outlet chamber **46** and is discharged at overflow outlet **48**. Correspondingly, relatively more dense liquid phase **52** leaves separator **22** at underflow outlet **50** into underflow outlet chamber **54** and is discharged through underflow outlet **56**.

[0038] In one optional embodiment, a chemical coalescing agent or demulsifier **92** may be introduced into the fluid mixture **16** (or at least

partially coalesced fluid mixture **32**) through an opening **94**. In one non-limiting embodiment, the chemical coalescing agent **92** is introduced upstream of first inlet **26**, but may be introduced at other locations in addition to or alternative to this one. The chemical coalescing agent **92** aids in coalescing the particles or droplets of the dispersed phase (*e.g.*, contaminant oil) together.

[0039] In another optional embodiment, a relatively clean side stream of the dispersed phase (*e.g.*, oil) can be introduced into the fluid mixture **16**. The overall effect is expected to be the promotion of collisions in the lean (low concentration) effluent. In one non-limiting embodiment, the side stream **92** is introduced upstream of first inlet **26**, but may be introduced at other locations in addition to or alternative to this one. This side stream **92** aids in coalescing the particles or droplets of the dispersed phase (*e.g.*, contaminant oil) together by increasing the population density of the dispersed phase.

[0040] Shown in FIG. 5 is schematic cross-sectional illustration of an alternate non-limiting embodiment of a system **100** for separating a dispersed liquid phase mixed with a continuous phase as described herein where coalescer **11** is in a first vessel **102** and separator **22** is in a separate, second vessel **104**. Again, like reference numerals will be used for like components or elements from the previously discussed Figures. Because the chambers **80** and **88** are in separate vessels **102** and **104**, respectively, the shape and design of fluid communication (pipeline or conduit) **86** for the FIG. 5 design is different from that of the FIG. 1 or FIG. 4 design, but its function of channeling at least partially coalesced fluid mixture **32** from outlet **28** through intermediate chamber **82** and opening **84** and aperture **90** into separator chamber **88** is the same.

[0041] In one non-limiting example of the system or apparatus herein, FIG. 6 shows a hypothetical droplet separation probability in the separator (*e.g.*, separator hydrocyclone **22**). The increased collision probability resulting from coalescence effect of the coalescer **11** ahead of the separator **22** will lead to additional separation, which will shift the curve A to the left to form curve B. Curve B indicates higher capture probability of a given size contaminant. The same trend can also be generated if the

geometry of the hydrocyclone is altered. In one non-limiting example of such alteration, curve C is indicative of a similar hydrocyclone with smaller diameter. This curve shows additional potential gain in capture probability realized by reducing the diameter of the hydrocyclone. Similar effects can be realized by alteration of one or multiple geometrical parameters.

[0042] FIG. 7 is a more practical demonstration of the effect shown in FIG. 6. Curve D is indicative of size distribution at the outlet of separator. The area under the curve E shows the decrease in concentration of the contaminant in the outlet compared to the area under curve D. The enhancement is attributed to the increase in droplet size distribution caused by the coalescer **11** ahead of the separator **22**. Curve F shows the potential effect of reducing the geometrical parameters of either the coalescer **11** to promote size distribution or separator **22** to promote capture probability of smaller species. The resulting effect is a reduction in mean and area under curve F.

[0043] In the foregoing specification, the invention has been described with reference to specific embodiments thereof, and is expected to be effective in providing methods and apparatus for separating mixed liquid phases more efficiently. However, it will be evident that various modifications and changes can be made thereto without departing from the broader scope of the invention as set forth in the appended claims. Accordingly, the specification is to be regarded in an illustrative rather than a restrictive sense. For example, the coalescers and separators may be changed or optimized from that illustrated and described, and even though they were not specifically identified or tried in a particular apparatus, would be anticipated to be within the scope of this invention. For instance, the use of more hydrocyclones in series would be expected to find utility and be encompassed by the appended claims. Different dispersed and continuous liquid phases, and different oily matter other than those described herein may nevertheless be treated and handled in other non-restrictive embodiments of the invention.

[0044] The terms “comprises” and “comprising” in the claims should be interpreted to mean including, but not limited to, the recited elements.

[0045] The present invention may suitably comprise, consist or consist essentially of the elements disclosed and may be practiced in the absence of an element not disclosed. For instance, an apparatus may consist of or consist essentially of a coalescer hydrocyclone and a separator hydrocyclone as described in the claims where these are the major functional units along with the indicated connections. Other ordinary equipment, such as pipes, conduits, valves, controllers, support structures, rivets and other fasteners, and the like, would also be included in a claim having "consisting of" or "consisting essentially of" language even though they would not be explicitly recited.

CLAIMS

What is claimed is:

1. An apparatus for separating a dispersed liquid phase from a continuous liquid phase within a fluid mixture, comprising:

a coalescer hydrocyclone having a first inlet portion and a first outlet portion near the end of a tail section thereof, the end of the tail section having a cross-section, the first inlet portion having a greater cross-sectional diameter, taken transverse to a longitudinal axis of the first elongate member, than the first outlet portion, where the coalescer hydrocyclone lacks an overflow outlet; wherein the first outlet portion is configured to effuse all fluid flow egressing from the coalescer hydrocyclone through at least one slot shape opening on a side of the tail section and received at the first inlet portion, the at least one slot shape opening having a total cross-section equal to or less than the cross-section of the end of the tail section;

a separator hydrocyclone having a second inlet portion and a second outlet portion, the second inlet portion having a greater cross-section diameter, taken transverse to a longitudinal axis of the separator hydrocyclone, than the second outlet portion, and further having a third outlet portion;

wherein the first outlet portion is in fluid communication with the second inlet portion; and

wherein the second inlet portion is upstream of the second and third outlet portions;

where each hydrocyclone is configured to separate a dispersed liquid phase from a continuous liquid phase within the fluid mixture at a G-force ranging from 1000 to 2000.

2. The apparatus as recited in claim 1, wherein the second inlet portion is physically intermediate the second and third outlet portions.

3. The apparatus of claim 1 or 2, wherein the first and second elongate hollow members have generally tapered profiles.
4. The apparatus of claim 3 where the cross-section of the end of the tail section is 100 mm^2 or less.
5. The apparatus of claim 3 where the coalescer hydrocyclone further comprises a body, and where the slot shape opening is rectangular.
6. The apparatus of claim 1 or 2 further comprising an opening adapted to introduce a chemical coalescing agent into the fluid mixture.

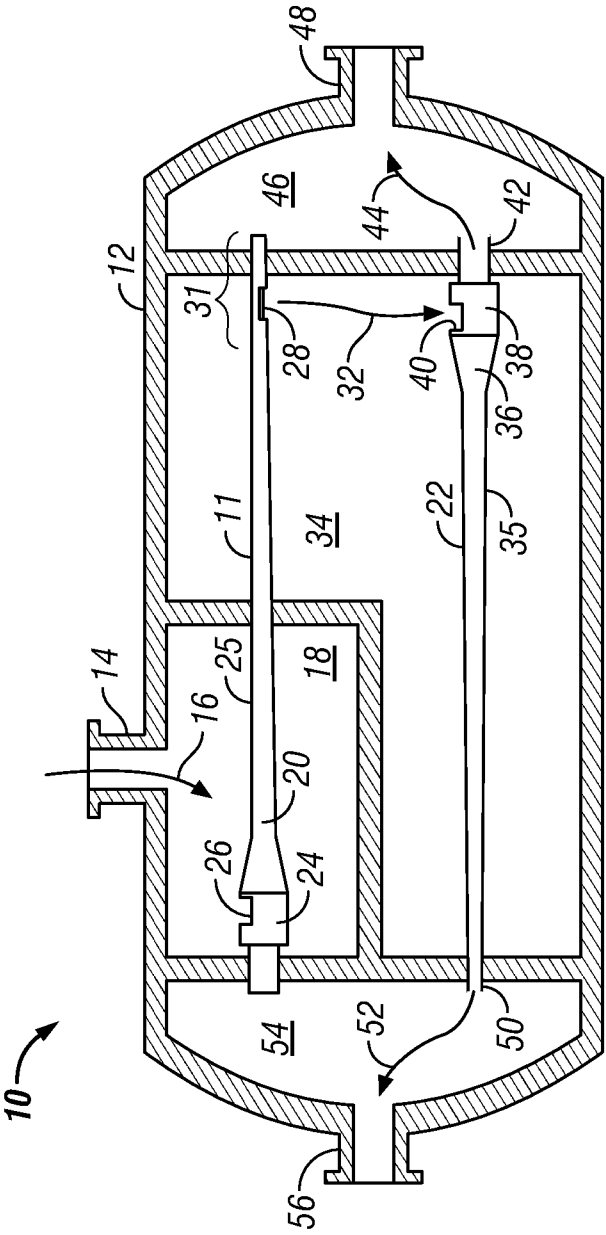


FIG. 1

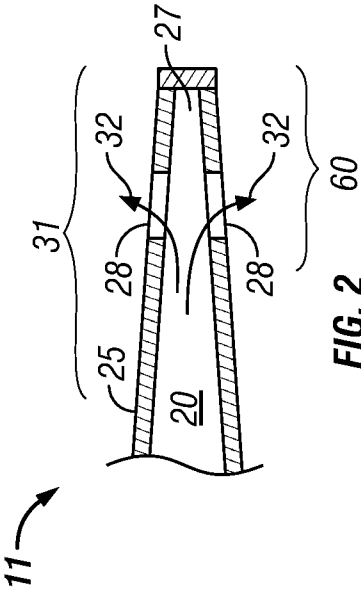


FIG. 2

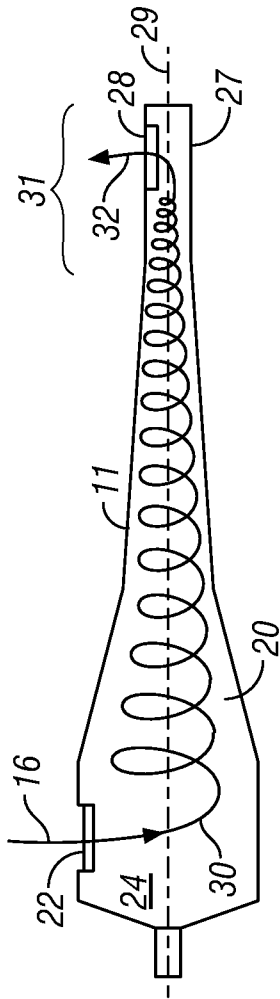


FIG. 3

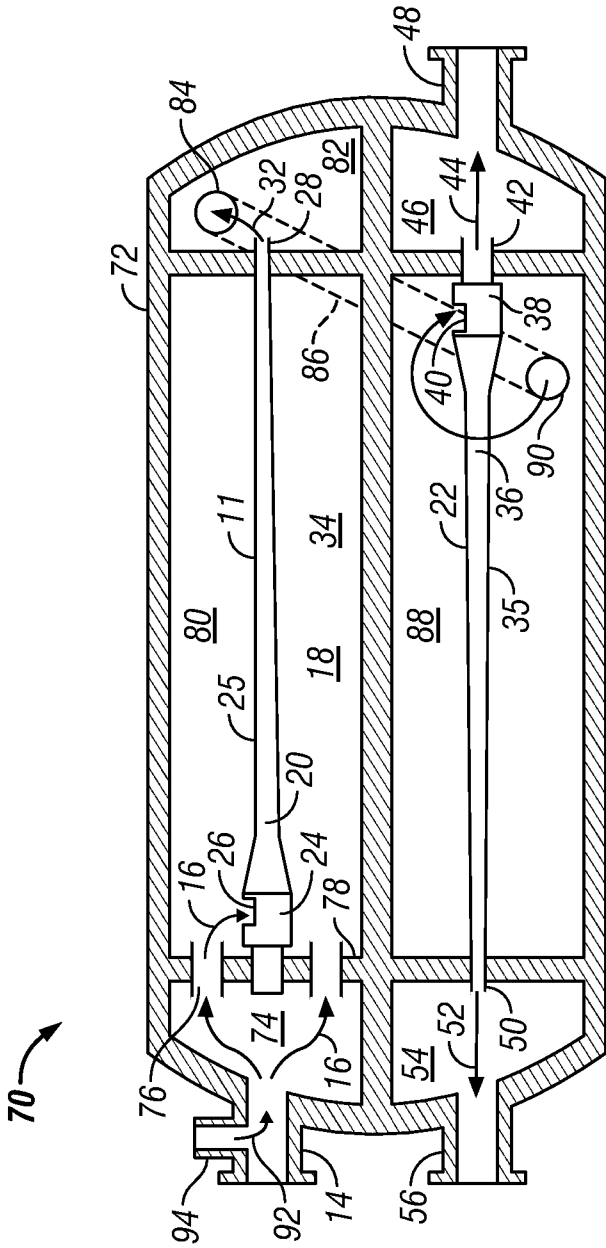


FIG. 4

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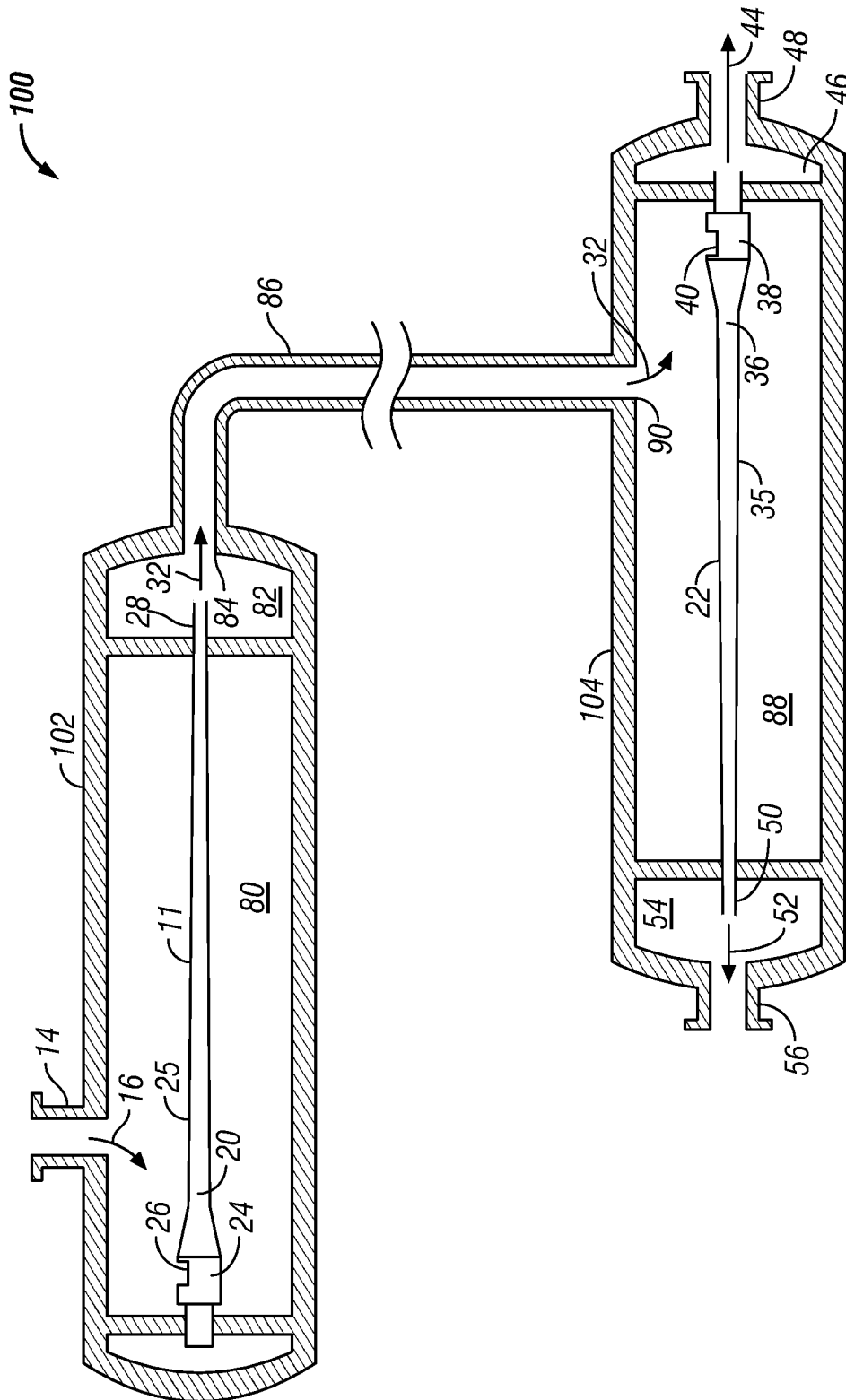


FIG. 5

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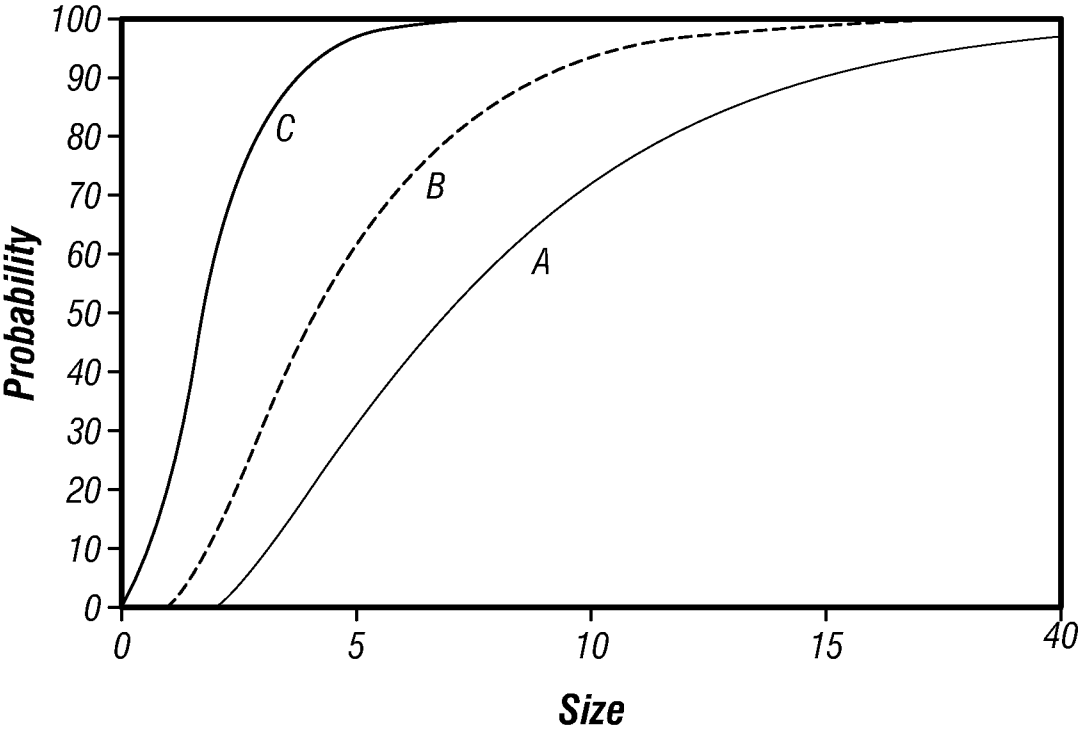


FIG. 6

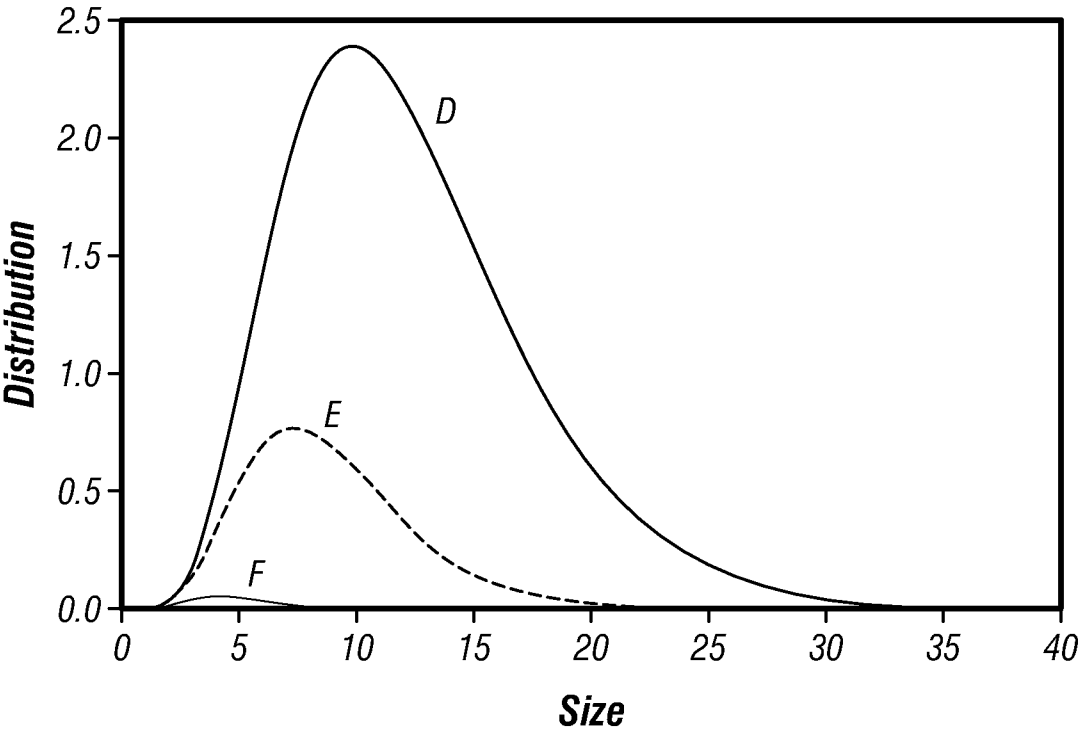


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 11/47552

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B01D 17/02 (2011.01)

USPC - 210/512.2

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - B01D 17/02 (2011.01)

USPC - 210/512.2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC: 210/512.2

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PubWEST(USPT,PGPB,EPAB,JPAB); Google; Google Patents

Search Terms: Coalescing, hydrocyclone, cross section, g-force, dispersed liquid, diameter

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2007/0262033 A1 (Movafaghian et al.) 15 November 2007 (15.11.2007) figs. 1, 3, 5; para [0008]; [0022]; [0032]; [0036]	1-3, 5-6
Y		4
Y	US 5,071,556 A (Kalnins et al.) 10 December 1991(10.12.1991) col 6, ln 63 to col 7, ln 5	4
A	US 2008/0035586 A1(Chen et al.) 14 February 2008 (14.02.2008) entire document	1-6
A	US 2009/0223118 A1 (Everton et al.) 10 September 2009 (10.09.2009) entire document	1-6

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 December 2011 (10.21.2011)

Date of mailing of the international search report

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