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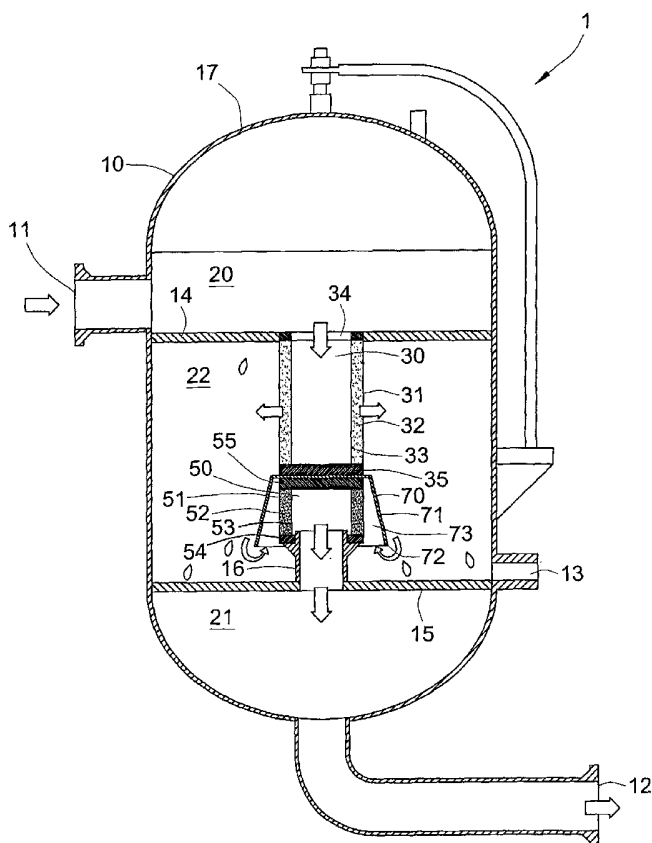
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(54) Title: COALESCING AND SEPARATING ARRANGEMENTS, SYSTEMS, AND METHODS FOR LIQUID MIXTURES



(57) Abstract: Coalescing and/or separating arrangements for separating a discontinuous phase liquid from a continuous phase liquid may comprise two or more of a coalescer (30), a separator (50) and a flow director (70).

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COALESCING AND SEPARATING ARRANGEMENTS, SYSTEMS, AND METHODS FOR LIQUID MIXTURES

5 TECHNICAL FIELD

The present invention relates to arrangements, systems, and methods for liquid/liquid separations. More particularly, the invention relates to arrangements, systems, and methods for coalescing and separating at least one immiscible liquid component, as the discontinuous phase, from another liquid component, as the
10 continuous phase.

BACKGROUND OF THE INVENTION

In many different types of fluid processing, it is often necessary to separate mixed immiscible liquid phases or components from one another. Common devices
15 used to separate mixtures into individual liquid components include coalescers and separators. When two or more immiscible components are very well mixed, coalescers may be used to aid separation by causing small particles of the discontinuous phase liquid to aggregate and form larger droplets within the continuous phase liquid. The discontinuous phase liquid may be heavier or lighter than the continuous phase liquid.
20 Separators may be used to aid separation by allowing one liquid component or phase (e.g., the continuous phase liquid) to pass through the separator while resisting or preventing passage of another liquid component or phase (e.g., the discontinuous phase liquid, such as the coalesced droplets of the discontinuous phase liquid). The continuous and discontinuous phases may thus be separated on opposite sides or surfaces of the
25 separator. In separating liquid components from one another, a typical liquid/liquid treatment system may thus include both a coalescer and a separator depending on the characteristics of the liquid mixture.

Liquid/liquid systems may include horizontal or vertical arrangements of coalescers and separators contained within a housing or vessel. An example of a
30 coalescing and separating arrangement is a vertically stacked arrangement wherein a coalescer is stacked, e.g., end-to-end, above or below a separator. Various exemplary coalescer and separator arrangements are disclosed, for example, in International Publication No. WO 97/38781 and United States Patent No. 5,443,724, herein

incorporated by reference. However, arrangements such as these and other separator and coalescer arrangements, while having many advantages, may produce less than ideal separation results in many applications and may be more expensive to manufacture than is economically feasible.

5 For example, poor separation may result when the continuous phase liquid has a high viscosity, e.g., is somewhat thick, and/or when the continuous and discontinuous phase liquids have similar specific gravities such that one liquid does not readily float on top of or sink to the bottom of the other liquid. Any discontinuous phase liquid which flows with the continuous phase liquid to the separator may remain in contact with the
10 surface of many conventional separators. Discontinuous phase liquid on the surface of the separator may block the flow of continuous phase liquid through the separator.

Regardless of the viscosity or specific gravity of the liquids, poor separation may also result whenever the discontinuous phase liquid is in constant contact with and/or builds up near or on the surface of the separator, especially for high-flow rate or high
15 velocity industrial and laboratory applications. As the flow velocity of the continuous phase liquid through the separator increases, the continuous phase liquid carries or forces more and more of the nearby discontinuous phase liquid through the separator. Thus, the quality of separation product (e.g., the continuous phase liquid) decreases because the discontinuous phase liquid is forced through the separator along with the
20 continuous phase liquid. One approach to this problem may include periodically shutting down the operation of the system and allowing the discontinuous phase liquid to drain away from the separator. However, this approach dramatically decreases throughput, i.e., the amount of separation product that can be produced by the system in a given period of time. Another approach may include using a larger vessel and/or a larger
25 separator. These approaches dramatically increase the cost of the system. Thus, along with issues of poor separation, industry has been confined to approaches that decrease throughput and increase equipment costs.

SUMMARY OF THE INVENTION

30 The inventions described or claimed in this application may address one or more of the problems set forth above and/or many other problems associated with separating an immiscible discontinuous phase liquid from a continuous phase liquid.

In accordance with one aspect of the present invention, a liquid/liquid separation arrangement for separating a discontinuous phase liquid from a continuous phase liquid may comprise a separator and a flow director. The separator may include an upstream surface. The separator resists the passage of the discontinuous phase liquid and allows
5 the passage of the continuous phase liquid. The flow director may be cooperatively arranged with the separator to direct the continuous phase liquid in a curvilinear flow path to the upstream surface of the separator.

In accordance with another aspect of the present invention, a liquid/liquid separation arrangement for separating a discontinuous phase liquid from a continuous
10 phase liquid may comprise a separator and a flow director. The separator may include a separator medium, and the flow director may be mounted to the separator.

In accordance with another aspect of the present invention, a liquid/liquid coalescing arrangement for separating a discontinuous phase liquid from a continuous phase liquid may comprise a coalescer and a flow director. The coalescer may include a
15 downstream surface. The coalescer forms smaller particles or droplets of the discontinuous phase liquid into larger droplets. The flow director may be cooperatively arranged with the coalescer to direct continuous phase liquid in a curvilinear flow path away from the downstream surface of the coalescer.

In accordance with another aspect of the present invention, a liquid/liquid
20 coalescing arrangement for separating a discontinuous phase liquid from a continuous phase liquid may comprise a coalescer and a flow director. The coalescer may include a coalescer medium, and the flow director may be mounted to the coalescer.

In accordance with another aspect of the present invention, a liquid/liquid treatment arrangement for separating a discontinuous phase liquid from a continuous
25 phase liquid may comprise a coalescer, a separator, and a flow director. The coalescer may include a downstream surface. The separator may include an upstream surface. The flow director may be disposed between the downstream surface of the coalescer and the upstream surface of the separator.

In accordance with another aspect of the present invention, a liquid/liquid
30 treatment arrangement for separating a discontinuous phase liquid from a continuous phase liquid may comprise a hollow coalescer and a separator. The hollow coalescer may have an interior, an upstream side facing the interior and a downstream side facing away from the interior of the coalescer. The separator may be positioned at least

partially, and more preferably substantially or entirely, within the interior of the hollow coalescer. The separator is isolated from the upstream side of the coalescer.

In accordance with another aspect of the present invention, a liquid/liquid treatment arrangement for separating a discontinuous phase liquid from a continuous phase liquid may comprise a hollow coalescer and a separator. The hollow coalescer may have an interior, a first open end and a second open end opposite the first open end. The separator may be positioned at least partially, and more preferably substantially or entirely, within the interior of the hollow coalescer. The separator may be isolated from the first open end or the second open end of the coalescer.

10 In accordance with another aspect of the present invention, a liquid/liquid treatment arrangement for separating a discontinuous phase liquid from a continuous phase liquid may comprise a coalescer and a separator. The coalescer may have a coalescer medium. The separator may have a separator medium and a conical configuration, the conical separator pointing away from the coalescer.

15 In accordance with another aspect of the present invention, a method for separating a discontinuous phase liquid from a continuous phase liquid may comprise directing the continuous phase liquid from a coalescer in a curvilinear flow path to a separator.

In accordance with another aspect of the present invention, a method for separating a discontinuous phase liquid from a continuous phase liquid may comprise diverging the flow paths of the continuous phase liquid from the discontinuous phase liquid, including directing the continuous phase liquid along a curvilinear flow path.

In accordance with another aspect of the present invention, a method for separating a discontinuous phase liquid from a continuous phase liquid may comprise directing a mixture of the continuous phase liquid and the discontinuous phase liquid into the interior of a hollow coalescer and inside-out from the upstream side of the coalescer to the downstream side through a coalescer medium. The method may further comprise directing a continuous phase liquid into the interior of the hollow coalescer and through a separator which is isolated from the upstream side of the coalescer.

30 In accordance with another aspect of the present invention, a method for separating a discontinuous phase liquid from a continuous phase liquid may comprise directing a mixture of the continuous phase liquid and the discontinuous phase liquid through a first open end of a hollow coalescer and inside-out through a coalescer

medium. The method may further comprise directing the continuous phase liquid through an opposite open end of the hollow coalescer and through a separator which is isolated from the first open end of the coalescer.

Embodiments of the present invention may include one or more of these various aspects of the invention. Embodiments which include a flow director and/or which direct the continuous phase liquid in a curvilinear flow path provide many advantages. For example, the discontinuous phase liquid may diverge from the flow path of the continuous phase liquid as the continuous phase liquid flows around a flow director and/or in a curvilinear flow path, for example, to a separator. Consequently, the amount of discontinuous phase liquid which comes in the vicinity of, e.g., contacts, the separator may be significantly reduced. Therefore, the separator may be mostly contacted by the continuous phase liquid and less contacted by the discontinuous phase liquid. Blockage of the separator by the discontinuous phase liquid may be minimized and little, if any, discontinuous phase liquid may be forced through the separator by the continuous phase liquid, greatly enhancing the separation efficiency and allowing smaller separators and, therefore, smaller housings to be used.

Embodiments which include a conical separator may also provide several advantages, especially for liquids that have a high viscosity or similar specific gravities. A conical separator may have a larger surface area than, e.g., a planar, or flat, separator having a similar dimension. Further, a conical separator may provide a self-cleaning action that sweeps any droplets of the discontinuous phase liquid away from the sloped surface of the separator. Thus, blockage of the separator by the discontinuous phase liquid may be reduced, the separation efficiency may be enhanced and smaller housings may be used.

Embodiments which include a separator disposed in the interior of a coalescer are also very advantageous. For example, the arrangement of the coalescer and the separator may be much more compact, e.g., shorter. Consequently, the housing may be much more compact.

30

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial cross-section view of a fluid treatment system.

FIG. 2 is a partial cross-section view of another fluid treatment system.

FIG. 3 is a partial cross-section view of another fluid treatment system.

FIG. 4 is a partial cross-section view of another fluid treatment system.
FIG. 5 is a partial cross-section view of another fluid treatment system.
FIG. 6 is a partial cross-section view of another fluid treatment system.
FIG. 7 is a partial cross-section view of another fluid treatment system.
5 **FIG. 8** is a partial cross-section view of another fluid treatment system.
FIG. 9 is a partial cross-section view of another fluid treatment system.
FIG. 10 is a partial cross section view of another fluid treatment system.
FIG. 11 is a partial cross section view of another fluid treatment system.
FIG. 12 is a partial cross section view of another fluid treatment system.
10 **FIG. 13** is a partial cross section view of another fluid treatment system.

SPECIFIC DESCRIPTION OF THE INVENTION

The present inventions may enhance the separation of immiscible liquid components of a process fluid comprising a mixture of the components. For example,
15 the present inventions may enhance separation of one or more immiscible liquid components of the mixture, as the discontinuous phase, from one or more liquid components of the mixture, as the continuous phase.

One example of a fluid, or liquid/liquid, treatment system **1** is illustrated in **FIG. 1**. The fluid treatment system **1** may comprise a housing or a vessel **10**, one or more
20 coalescers **30**, and one or more separators **50**. The housing or vessel **10** may include at least one inlet and at least one outlet. Preferably, the housing **10** may include a process fluid inlet **11** and two or more outlets, e.g., a continuous phase outlet **12** and a discontinuous phase outlet **13**, and defines liquid flow paths from the process fluid inlet **11** to the continuous phase outlet **12** and to the discontinuous phase outlet **13**. The inlet
25 and the outlets may be arranged in any suitable place in the housing **10**. Preferably, the inlet and outlets are arranged within the housing in locations suitable to facilitate the coalescing and separation operation.

The housing **10** may be divided by one or more partitions, such as a tube sheet **14** and/or a support plate **15**, into chambers, such as a process fluid chamber **20**, a coalesced
30 liquid chamber **22**, and a continuous phase chamber **21**. The one or more partitions **14,15** may be fixed within the housing or removable from the housing. The housing **10** may also comprise other parts or components such as, but not limited to, one or more vents; valves, such as pressure relief valves; fittings, e.g., for pressure, temperature,

and/or flow meters; and backwashing or blowback mechanisms (not shown). The housing 10 may include a removable cover 17, such as a swing-around cover, or a non-removable cover.

The housing or vessel 10 may comprise any housing or vessel suitable for a particular fluid treatment operation. The housing 10 may comprise any of various shapes and sizes, and may be amenable to accommodate a single coalescer 30 and/or a single separator 50 or a plurality of coalescers 30 and/or a plurality of separators 50. Preferably, the housing 10 is substantially cylindrical in shape and has a longitudinal axis; however, any suitable shape that facilitates separation and houses the various fluid treatment arrangements may be employed. The housing may include a slant or slope, such as, a slanted or sloped partition or wall to assist, for example, in the removal of any settled or pooled liquid. Such a structure may comprise a wall of the housing or partition within the housing. The longitudinal axis of the housing may have any suitable orientation, for example, vertical, horizontal, or any suitable angle in between.

“Horizontal” may include any configuration of housings, coalescers, and separators where the average direction of the principal axis of the element is more horizontal than vertical. “Vertical” may include any configuration of housings, coalescers, and separators where the average direction of the principal axis of the element is more vertical than horizontal. **FIG. 1** shows an example of a vertical housing 10 and **FIG. 8** shows an example of a horizontal housing 710. Preferably, the housing may be dimensioned and/or oriented to gravitationally and/or fluid-dynamically assist the coalescing and/or separating operation.

The housing 10 may comprise any suitable material which is capable of providing sufficient structural integrity for the particular coalescing and separating operation and which will not adversely react with liquids being processed or hinder the separation operation. The housing 10 may be, for example, a plastic or a metal. Preferably, the housing comprises a metal, even more preferably a non-reactive metal. The housing may, for example, comprise a stainless steel and/or a carbon steel. The housing may be constructed such that it remains structurally stable in the presence of high pressures, temperatures, and/or flow rates. The housing 10 may further comprise any suitable design, material, or construction characteristics or any components or combinations, for example, as described in International Publication No. WO 97/38781.

Each coalescer **30** may be arranged in any suitable configuration within the housing. For example, the coalescer **30** may be arranged axially parallel to the axis of the housing, either along or offset from the axis of the housing. In the case of more than one coalescer **30**, any spacing between the coalescers **30** suitable for coalescence may be
5 used. For example, the coalescers **30** may be spaced closely to one another or spaced further apart. The coalescers **30** may be directly attached to the housing **10**, e.g., via a partition **15**, such as a tube sheet or support plate, or via stand-off tubes **16**.

Two or more coalescer cartridges may be joined together in open-end to open-end relation to increase the length of the coalescer **30**. For example, two coalescer
10 cartridges may be joined by joiner end caps or open end caps. Further, if more than one coalescer **30** is placed within a housing **10**, the coalescers **30** may have substantially equal lengths or may be unequal in length. For example, one coalescer **30** may include only one coalescer cartridge and another coalescer **30** may include more than one coalescer cartridge.

15 The coalescer **30** may comprise any type of coalescer suitable for a particular fluid treatment operation. For example, the coalescer **30** may comprise any suitable material, shape, or configuration to effectuate the coalescence of the discontinuous phase liquid. The coalescer **30** may comprise a substantially cylindrical, planar, polygonal, or conical configuration. While any suitable configuration or shape may be used, the
20 coalescer **30** preferably has a hollow, cylindrical configuration.

The coalescer **30** may comprise any of various components. For example, the coalescer **30** may comprise a coalescer medium **32**, one or more end caps **34**, **35**, an inner support structure **33**, and/or an outer support structure **31**. If more than one end cap is included, at least one of a first end cap **34** and a second end cap **35** may be open to
25 allow liquid to flow through the end cap to or from the interior of the coalescer **30** and at least one of the first end cap **34** and the second end cap **35** may be closed or blinded to prevent liquid from flowing through the end cap. In the illustrated embodiment of **FIG. 1**, the first end cap **34** may be open, fluidly communicating the upstream side, e.g., the interior, of the coalescer **30** through an opening in the tube sheet **14** with the process
30 fluid chamber **20** and the process fluid inlet **11**. The second end cap **35** may be closed. The inner support structure **33** may comprise a perforated core and the outer support structure **31** may comprise a cage. The inner and outer support structures may be perforated, permeable, foraminous, or any suitable configuration that directs and/or

allows liquid to flow therethrough. The coalescer **30** may also include, but is not limited to, one or more of an alignment element, a sealing collar, a fastener, a final classifier, and a perforated wrap. The coalescer **30** may further include a permanent or removable filter element (not shown). The coalescer **30** may be permanently fixed within the housing **10**, or preferably, the coalescer **30** may be removably associated within the housing **10**, e.g., removably mounted to the tube sheet **14**. The coalescer **30** may be disposable and/or cleanable.

The coalescer medium **32** may comprise any material suitable for a coalescer in an application for which the coalescer is employed. For example, the coalescer medium **32** may comprise any porous structure which forms small immiscible discontinuous liquid particles or droplets into larger droplets. The coalescer medium **32** may comprise fibrous materials, such as a fibrous mass, fibrous mats, woven or non-woven fibrous sheets; may comprise porous membranes such as supported or non-supported microporous membranes; or may comprise a mesh or screen. The coalescer medium **32** may comprise inorganic or organic fibers or filaments. Exemplary organic fibers may include polymeric fibers or microfibers made from, for example, polyolefins (e.g., polyethylene), polyesters (e.g., polyethylene terephthalate), polyamides (e.g., nylon), fluoropolymers, and copolymers, mixtures, and blends thereof. Inorganic fibers may include fibers such as glass or metal fibers, such as metal titanates, e.g., potassium titanate. The coalescer medium **32** may include a surface treatment such as a coating or a surface modifying treatment. The coalescer medium **32** may have or may be modified to have any desired critical wetting surface tension (CWST). For example, the CWST may be intermediate the surface tensions of the continuous phase and discontinuous phase liquid components. In particular, the CWST may be between the surface tensions of the continuous phase liquid and the discontinuous phase liquid. CWST, in units of dynes/cm, may be defined as the mean value of the surface tension of a liquid which is absorbed and that of a liquid of neighboring surface tension which is not absorbed into the surface of the medium. CWST is defined, for example, in United States Patent No. 5,443,724 and United States Patent No. 5,480,547, both of which are herein incorporated by reference. The coalescer medium **32** may have a uniform or graded pore structure and any appropriate and/or effective pore size. Preferably the coalescer medium **32** includes a graded pore size that increases from the upstream side to the downstream side. For example, the pore size may be graded in a stepwise or continuous manner,

e.g., where the pore size increases from the upstream to the downstream side of the coalescer medium **32**. The coalescer **32** medium may be configured in a non-pleated or a pleated arrangement. When the coalescer medium **32** is pleated, the pleats may be straight, radially extending from the axis of the coalescer, or they may be arranged as set forth in United States Patent No. 5,543,047. The coalescer **30** may be any suitable size appropriate for the types of liquid components being separated and the particular processing conditions, such as, flow rates, temperatures, and pressures. The coalescer **30** may further comprise any suitable design, material, construction features, or any components as described in International Publication No. WO 97/38781, United States Patents No. 4,759,782 and No. 5,480,547, and International Publication No. WO 98/14257, all incorporated herein by reference.

Each separator **50** may be arranged in any suitable configuration within a housing **10**. For example, the separator **50** may be arranged axially parallel to the axis of the housing, either along or off-set from the axis of the housing. The separator **50** may be directly attached to the housing **10**, e.g., via a partition, such as a support plate or tube sheet, or via a stand-off tube **16**.

Two or more separator cartridges may be joined together in open-end to open-end relation to increase the length of the separator **50**. For example, two separator cartridges may be joined by joiner end caps or open end caps. Further, when there is more than one separator **50**, the separators **50** may have substantially equal lengths or may have unequal lengths. For example, one separator **50** may include only one separator cartridge and another separator **50** may include more than one separator cartridge.

The separator **50** may comprise a wide variety of suitable materials, shapes, or configurations to promote the separation of the discontinuous phase liquid from the continuous phase liquid. For example, the separator **50** may preferably be hollow. The separator **50** may comprise a substantially cylindrical configuration, a conical configuration, such as a truncated right circular conical or a frusto-conical configuration, or a planar configuration, such as a polygonal, annular, disc-shaped, quoit-shaped, or a toroid-shaped configuration. A disc-shaped configuration may comprise a right circular cylinder whose length is small compared with its diameter. A quoit-shaped configuration may comprise a flat, centrally bored, right circular cone shape. A toroid-shaped configuration may comprise a ring-like body. The separator **50** may also include

a planar, slanted, and/or sloped configuration. Further, the separator **50** may be any suitable size appropriate for the types of liquid components being separated and the particular processing conditions, such as, flow rates, temperatures, and pressures.

The separator **50** may comprise any of various components including, for example, one or more end caps **54**, **55**, an inner support structure **53**, an outer support structure **51**, and/or a separator medium **52**. In the case where the separator **50** comprises two end caps, at least one of a first end cap **55** and a second end cap **54** may be open to allow liquid to flow through the end cap and at least one of the first end cap **55** and the second end cap **54** may be closed to prevent liquid from flowing through the end cap. In the illustrated embodiment of **FIG. 1**, the first end cap **55** may be closed or blinded and the second end cap **54** may be open, fluidly communicating the downstream side of the separator **50** through an opening in the stand-off tube **16** with the continuous phase liquid chamber **21** and the continuous phase outlet **12**. The inner support structure **53** may comprise a perforated core and the outer support structure **51** may comprise a cage. The inner and outer support structures may be perforated, permeable, foraminous, or any suitable configuration that directs and/or allows fluid to flow therethrough. The separator **50** may be permanently fixed within the housing **10**, or preferably, the separator may be removably associated within the housing **10**. The separator **50** may be disposable and/or cleanable.

The separator medium **52** may comprise any type of medium suitable for allowing passage of the continuous phase liquid while resisting passage of a discontinuous phase liquid. For example, the separator medium **52** may be arranged such that the continuous phase liquid wets the separator medium **52** and the discontinuous phase liquid does not wet the separator medium **52**. The separator medium **52** may comprise any of various materials, for example, liquiphobic materials, such as hydrophobic or oleophobic materials, and/or may have a surface modification treatment, such as a coating. For many applications in which water is the discontinuous phase liquid, the separator preferably comprises a hydrophobic medium. The separator medium **52** may comprise, for example, a coated stainless steel screen or a pleated fibrous pack. Preferably, the separator medium **52** comprises a polyester woven or nonwoven screen, which may be treated with a surface treatment, such as one available under the trade designation REPEL available from Pall Corporation, or a Teflon® coated screen, a hydrophobic paper, or a woven fluoropolymer screen. The separator

medium **52** may have a uniform or graded pore structure and any appropriate effective pore size. The pore size may be any suitable size to effectuate separation and the pores may be regularly or irregularly spaced, shaped, or sized. Preferably, the nominal pore size of the separator medium **52** is smaller than the size of the coalesced discontinuous phase liquid droplets. For example, the pore rating of the separator medium **52** may be about 100 μ or less, or 40 μ or less or 20 μ or less or 10 μ or less, e.g., 8-10 μ . The separator **50** may further comprise any suitable design, material, or construction characteristics or any components or combinations, such as those described in International Publication No. WO 97/38781 or United States Patent No. 5,443,724.

There are various ways in which the coalescer **30** and the separator **50** may be arranged. For example, the coalescer **30** and the separator **50** may be positioned in a vertically stacked arrangement, for example, wherein the coalescer **30** and the separator **50** are positioned end-to-end along their axes as shown, for example, in **FIG. 1**. Another suitable arrangement may comprise a horizontally orientated coalescer and a horizontally oriented separator within a housing, for example, where a horizontal coalescer is positioned above or below a horizontal separator as shown, for example, in **FIG. 8**. In an arrangement where the coalescer and separator are stacked vertically and where the continuous phase liquid is less dense than the discontinuous phase liquid, the coalescer **30** is preferably positioned above the separator **50**. In an embodiment where the discontinuous phase liquid is less dense than the continuous phase liquid, the coalescer **30** is preferably positioned below the separator **50**. On the other hand, in an arrangement where the coalescer and the separator are stacked horizontally and where the continuous phase liquid is less dense than the discontinuous phase liquid, the separator is preferably positioned above the coalescer.

The coalescer **30** and separator **50** may be arranged along the same axis or along different or off-set axes from themselves and/or one another. In an embodiment where coalescers **30** and separators **50** are arranged along the same axis, a coalescer **30** may be joined together in end-to-end relation with a separator **50**. For example, a blind end cap of a coalescer **30** may be associated with, e.g., about, a blind end cap of a separator **50**, such that the coalescer **30** and separator **50** are joined in a closed-end to closed-end relation.

The ratio of coalescers **30** to separators **50** within the housing may be 1:1, or there may be more coalescers **30** than separators **50** or more separators **50** than

coalescers 30. Further, one or more coalescers 30 may be vertically arranged above or below a plurality of separators 50, or one or more separators 50 may be arranged below or above a plurality of coalescers 30. Where more than one coalescer 30 is used, the coalescers 30 may have the same diameter, width, and length as each other, or may have
5 different diameters, widths, and lengths from one another. Where more than one separator 50 is used, the separators 50 may have the same diameter, width, and/or length as each other, or may have different diameters, widths, and/or lengths from one another. For example, the diameter, width, and/or length of the coalescers 30 and separators 50 may be the same as or different from one another. Further some coalescers 30 and some
10 separators 50 may have the same diameter, width, and/or length as one another, while others may have different diameters, widths, or lengths from one another.

Flow through the coalescer 30 and the separator 50 may be outside-in flow through the coalescer 30 and inside-out flow through the separator 50. Preferably, flow through the coalescer 30 is inside-out, and flow through the separator 50 is outside-in.
15 However, any suitable operational flow-through arrangement may be employed. For example, flow may be inside-out for all of the coalescers and separators, or flow may be outside-in for all of the coalescers and separators, depending on the configuration and arrangement of the coalescers and the separators in the housing.

In the discussion of the illustrated embodiments, arrangements suitable for a
20 discontinuous phase liquid which is denser than continuous phase liquid are shown, and many of these embodiments, especially the vertical embodiments, preferably have the coalescer positioned above the separator. However, the inventions are not limited to these embodiments or arrangements. The inventions may also be applicable to other arrangements, including the inverse of the described and illustrated arrangements, e.g.,
25 wherein the discontinuous phase liquid is less dense than the continuous phase liquid and the coalescer is positioned below the separator. Some alternative embodiments are described in detail and these embodiments illustrate many alternative features. The inventions may cover any combination of these and additional features.

The exemplary fluid treatment system 1 shown in **FIG. 1** illustrates a preferred
30 configuration where the process fluid comprises an immiscible mixture including a discontinuous phase liquid and a continuous phase liquid which is less dense than the discontinuous phase liquid. In this embodiment, one or more coalescers 30 and one or more separators 50 are disposed within a housing or vessel 10 with the coalescers 30

above the separators **50**. Process fluid entering the system **1** may enter the housing or vessel **10** through the process fluid inlet **11** and pass to the interior of the housing in the process fluid chamber **20**. The tube sheet **14** may contain one or more openings directly associated with one or more open coalescer end caps **34**, allowing fluid to flow from the
5 process fluid chamber **20** into the interior of each hollow coalescer **30**.

The process fluid may then flow through the coalescer **30** from the upstream side, e.g., the interior, to the downstream side, e.g., the exterior, of the coalescer **30**, where the small particles or droplets of the discontinuous phase liquid in the process fluid are coalesced to form larger droplets. The coalesced discontinuous phase liquid and the
10 continuous phase liquid passing through the coalescer **30** may enter the coalesced liquid chamber **22**. The discontinuous phase liquid, the denser component, may pass to a lower portion of the coalesced liquid chamber **22**, which may be formed by a wall of the housing **10** or a partition **15**, such as a support plate. The discontinuous phase liquid may then exit the housing **10** through the discontinuous phase outlet **13** which may be
15 located in a wall of the coalesced liquid chamber **22**.

The continuous phase liquid passes from the coalesced liquid chamber **22** through the separator medium **52** of the separator **50** from the upstream side, e.g., the exterior, to the downstream side, e.g., the interior, of the separator **50**, while the separator medium **52** resists passage of any discontinuous phase liquid. From the
20 separator **50**, the continuous phase liquid passes through the stand-off tube **16** and through the one or more openings in the partition **15**, such as a support plate, and into the continuous phase chamber **21**. The continuous phase liquid may then exit the housing **10** through the continuous phase outlet **12** in fluid communication with the continuous phase chamber **21**.

25 To reduce the amount of discontinuous phase liquid which passes in the vicinity of the separator **50** or contacts the separator **50**, the separator **50** may be positioned on the stand off tube **16** above the lower portion of the coalesced liquid chamber **22**, and/or the separator **50** may have a CWST which resists passage of the discontinuous phase liquid. However, in accordance with a first aspect of the invention, a flow director **70**
30 may be arranged with the housing **10**, the coalescer **30** and/or the separator **50** to even more effectively enhance the separation of the continuous and discontinuous phase liquids, for example, to further reduce the amount of discontinuous phase liquid which passes in the vicinity of, e.g., contacts, the separator **50**.

The flow director **70** is preferably cooperatively arranged to direct at least a portion or, preferably, all of the continuous phase liquid in a curvilinear flow path. A curvilinear flow path includes any flow path that is not straight. Preferably, a curvilinear flow path includes a bend, e.g., a bend toward the separator. The continuous phase liquid may be directed along one or more than one curvilinear flow path. For example, all of the continuous phase liquid may flow along the same curvilinear flow path, or a portion of the continuous phase liquid may flow along one curvilinear flow path while a different portion may flow along a second curvilinear flow path. Further, there may be a variety of curvilinear flow paths through which portions of continuous phase liquid may flow.

The flow director **70** may thus enhance separation of a discontinuous phase liquid from a continuous phase liquid by diverging the flow paths of the continuous phase liquid from the discontinuous phase liquid, e.g., by directing the continuous phase liquid along a curvilinear flow path toward the separator **50** and by diverging the discontinuous phase liquid from the curvilinear flow path away from the separator **50**. The flow director **70** may be cooperatively arranged with a separator **50** to direct continuous phase liquid in a curvilinear flow path to the upstream surface of the separator **50** and/or the flow director **70** may be cooperatively arranged with a coalescer **30** to direct continuous phase liquid in a curvilinear flow path away from the downstream surface of the coalescer. Preferably, the flow director **70** is positioned between a coalescer **30** and a separator **50**, e.g., between the downstream side of the coalescer **30** and the upstream side of the separator **50**, to direct continuous phase liquid in a curvilinear flow path from a downstream surface of the coalescer **30** to an upstream surface of the separator **50**, the discontinuous phase liquid diverging from the curvilinear flow path, for example, to the lower portion of the coalesced liquid chamber **22**. The discontinuous phase liquid may diverge from the continuous phase liquid for a variety of reasons, e.g., due to projectile motion, gravitational forces, inertial forces, and/or other fluid dynamics.

The flow director **70** may be cooperatively arranged, for example, with one or more of the separator **50**, the coalescer **30**, and the housing **10**. Depending on the direction of flow through the coalescer **30** and separator **50**, the flow director **70** may be positioned at the exterior of the separator **50**, near the interior the separator **50**, near the exterior of the coalescer **30**, near the interior of the coalescer **30**, and/or between the downstream side of the coalescer **30** and the upstream side of the separator **50**. The flow

director **70** may be removably or permanently fixed in any arrangement suitable to facilitate separation. For example, the flow director **70** may be directly associated with a coalescer end cap **35**, a separator end cap **55**, or between a coalescer end cap **35** and a separator end cap **55**. The flow director may be directly associated with a coalescer **30** and/or a separator **50** by being permanently or removably attached, fixed, bonded, welded, adhered, or any suitable means of associating. Further, the flow director may be directly associated via an intermediary piece or connection, such as via a gasket or a flange. Preferably, flow director **70** and at least one of and, even more preferably, both of the coalescer **30** and the separator **50** are permanently or removably attached to one another to form an integral unit that can be easily mounted to and removed from the housing **10**. Further, the flow director **70** may be indirectly associated with the coalescer **30** and/or the separator **50** by being mounted to or, part of, the housing **10** and/or any structural member within the housing **10**, such as a flow diverting partition, barrier, or wall.

The flow director **70** may comprise a wide variety of materials, shapes, positions, and orientations. For example, the flow director **70** may be oriented in any suitable way to direct the continuous phase fluid in a curvilinear flow path. The flow director **70** may be arranged to extend in a planar configuration. For example, the flow director **70** may be substantially perpendicular to the axis of the coalescer **30** and/or the separator **50**. Alternatively, the flow director **70** may have a hollow configuration, e.g., a hollow conical or cylindrical configuration. The flow director **70** may be arranged to surround the exterior of the coalescer **30** and/or the separator **50**, e.g., as a skirt or shroud, or align along the interior of the coalescer **30** and/or the separator **50**. Further, the flow director **70** may extend along part of, all of, or more than the axial length of the coalescer **30** and/or separator **50**. Thus, the length of the flow director **70** may be shorter than, equal to, or longer than, the length of the separator **50** and/or coalescer **30**. For example, the flow director **70** may extend longitudinally along the upstream surface of the separator **50** about 25% or more of the length of the separator **50**, e.g., about 50% or more, about 80% or more, about 90% or more, about 95% or more, or about 100% or more of the length of the separator **50**.

The flow director **70** may be spaced from the upstream surface of the separator **50** or the downstream surface of the coalescer **30** to form a gap between itself and the separator **50** and/or coalescer **30**. The flow director **70** may extend along the separator

50 or coalescer **30** at any suitable angle from the axis of the separator **50** or coalescer **30**. For example, the flow director **70** may extend at an angle from about 0 degrees or greater to about 180 degrees or less from the central axis of the separator **50** and/or the central axis of the coalescer **30**. The gap may thus be uniform or tapered along the
5 length of the separator **50** or coalescer **30**.

The flow director **70** may comprise any suitable shape to direct the continuous phase liquid in a curvilinear flow path. For example, the flow director **70** may comprise a substantially cylindrical, hollow configuration. The flow director **70** may comprise a substantially conical, hollow configuration, such as a truncated right circular conical or a
10 frusto-conical configuration. The flow director **70** may have a closed end and an open end which may be spaced farther from the coalescer **30** than the closed end and may open away from the coalescer **30**. The flow director **70** may comprise a polygonal, including circular, configuration, such as an annular, disc-shaped, quoit-shaped, or a toroid-shaped configuration. The flow director **70** may also include a planar, slanted,
15 and/or sloped configuration, such as a barrier or partition. Further, the flow director **70** may be any regular or irregular shape. An irregular shape may comprise, for example, a helmet-shape or any variations of the above-described shapes, such as corrugated or including furrows.

The flow director **70** may include one or more portions suitable to direct the
20 continuous phase liquid in a curvilinear flow path. For example, the flow director **70** may comprise a surface **71** and an edge **72**. The flow director **70** is preferably suitable to allow the continuous phase liquid and the discontinuous phase liquid to flow along or to move past the surface **71**. Further, the flow director **70** is preferably constructed to direct the continuous phase liquid in a curvilinear flow path, such that the curvilinear
25 flow path may bend around the edge **72**. The flow director **70** may bend the flow of all or at least a portion of the continuous phase liquid from the coalescer **30** back to the separator **50** through one or more bends. Each bend may be in the range from greater than about 0 degree to about 360 degrees or more. Preferably, the bend may comprise about 90 degrees or greater, about 180 degrees or greater, about 220 degrees or greater,
30 or about 360 degrees or more. The flow director **70** may direct discontinuous phase flow away from the separator **50**, e.g., by diverging the discontinuous phase flow from the continuous phase flow at or near the edge **72** of the flow director **70**.

The flow director **70** may comprise any suitable material compatible with a particular fluid treatment operation. For example, the flow director **70** preferably comprises an impervious material, such as an impervious metal or plastic material. However, the flow director **70** may comprise a porous, permeable, semi-permeable, or perforated material that allows the passage of some liquid through it, while directing a substantial portion of the continuous phase liquid along a curvilinear flow path to the separator **50** and a substantial portion or all of the discontinuous phase liquid away from the separator **50**.

Liquid passing from the downstream side of the coalescer **30** may pass by and/or contact the flow director **70** and flow or drain along the flow director surface **71**. The continuous phase liquid preferably flows along the curvilinear flow path and bends around the flow director **70** to and through the separator medium **52** of the separator **50**. The discontinuous phase liquid may continue flowing past the edge **72** of the flow director **70** and away from the vicinity of the separator **50**, e.g., to the lower portion of the coalesced liquid chamber **22** if the discontinuous phase liquid is denser than the continuous phase (or to the upper portion of the coalesced liquid chamber **22** if the discontinuous phase liquid is less dense).

There are many advantages associated with using a flow director in a liquid/liquid treatment system. In particular, a flow director may minimize the amount of discontinuous phase liquid that comes in the vicinity of, e.g., into contact with, the separator. Therefore, the separator may be mostly contacted by the continuous phase liquid and less contacted by the discontinuous phase liquid, greatly enhancing the separation efficiency. Further, the chance that the separator may become blinded by the discontinuous phase liquid is significantly reduced. Production times may be lengthened, without any shut-down periods being necessary for draining the discontinuous phase liquid from the separator. Further, a smaller separator may be used, which, in turn, may allow a smaller housing, thus reducing the overall equipment and manufacturing costs.

In **FIG. 1**, a flow director **70** is illustrated as comprising a conical configuration while the separator **50**, including the separator medium **52**, has a hollow cylindrical configuration. The flow director **70** is spaced from and extends axially along the exterior of a separator **50**, which may be along the upstream surface of the separator **50**, forming a gap **73** between the flow director **70** and the separator **50**. The gap **73** may be

tapered, the open end of the gap **73** being larger than the closed end. For example, the diameter of the flow director **70** at the edge **72** may be up to about 25% greater or more than the diameter of the separator **50**, while the diameter at the closed end of the flow director **70** may be about equal to the diameter of the separator **50**. Further, in this
5 embodiment, the flow director **70** may be directly associated with the coalescer **30** or the separator **50**. For example, the flow director may be mounted to or part of the blind coalescer end cap **35** or the blind separator end cap **55**, or may be mounted within the housing between the coalescer **30** and the separator **50**. The flow director **70** may extend below a lower end of the separator **50** such that the edge **72** of the flow director is
10 shown to extend beyond the length of the separator **50**.

From the downstream surface of the coalescer **30**, the coalesced discontinuous phase liquid and the continuous phase liquid flow past the flow director **70**. Near the edge **72** of the flow director **70**, the continuous phase liquid flows along a curvilinear flow path to the separator **50** and through the separator medium **52**. The continuous
15 phase liquid flow bends under the edge **72** of the flow director **70** and enters the tapered gap **73** between the flow director **70** and the separator **50**, as indicated by the arrows in **FIG. 1**. The heavier discontinuous phase liquid generally diverges from the continuous phase liquid flow path. Rather than following the curvilinear flow path of the continuous phase liquid, the discontinuous phase liquid may generally pass to the lower
20 portion of the coalesced liquid chamber **22** and hence through the discontinuous phase outlet **13**. Consequently, the amount of discontinuous phase liquid in the vicinity of the separator **50**, e.g., in the gap **73**, is significantly reduced. With less discontinuous phase liquid in the vicinity of the separator **50**, the continuous phase liquid passes easily through the separator **50** without carrying or forcing significant amounts, if any, of the
25 discontinuous phase liquid along with it. From the interior, e.g., the downstream side, of the separator **50**, the continuous phase liquid passes through the stand-off tube **16** into the continuous phase chamber **22** and hence through the continuous phase outlet **12**.

Another fluid, or liquid/liquid, treatment system **100** is shown in **FIG. 2**. This system preferably includes many elements, such as a housing (not shown), coalescer
30 **130**, flow director **170** and separator **150**, which may have one or more of any of the features described with respect to the other embodiments, especially the embodiment shown in **FIG. 1**. For example, the housing may include a tube sheet **114**, a support plate **115** and a process fluid chamber **120**; the coalescer **130** may include a coalescer

medium **132**, an open end cap **134** and a blind end cap **135**; the separator **150** may include an open end cap **154** and a closed end cap **155**; and the flow director **170** may include a surface **171**. (Elements of one illustrated system which generally correspond to elements of another illustrated system may be identified by reference numerals having the same last two digits.) In the embodiment shown in **FIG. 1**, the flow director **70** is generally conical and extends axially beyond the separator. However, a flow director is not limited to these features. For example, as shown in **FIG. 2**, the flow director **170** may comprise a cylindrical configuration and may be spaced from and extend along the exterior of a cylindrical separator **150** only a part of the length of the separator **150**, the flow director **170** being shorter than the separator **150**. For example, the flow director **70** may extend from less than about 25% to less than 100% of the length of the separator **50**. A uniform gap **173** may be formed between the separator **150** and the flow director **170** instead of a tapered gap. Again, the flow director **170** may be directly associated with any of the coalescer **130**, the separator **150**, or the housing.

Flow of the continuous phase liquid and the discontinuous phase liquid may be similar to that described with respect to the other embodiments, especially the embodiment shown in **FIG. 1**. The continuous phase liquid may flow from the downstream surface of the coalescer **130** in a curvilinear flow path around the edge **172** of the flow director **170** to contact the separator **150**. The continuous phase liquid may then flow through the separator medium **152** of the separator **150** beyond, e.g., below, the edge **172** of the flow director **170** or it may flow into the gap **173** and then through the separator medium **152** of the separator **150**. The continuous phase liquid may then pass through the stand-off tube **116** into the continuous phase chamber **121** and hence to the continuous phase outlet (not shown). The flow of discontinuous phase liquid may diverge from the curvilinear flow path of the continuous phase liquid, e.g., at the edge **172** of the flow director **170**, flowing away from the separator **150** to the lower portion of the coalesced liquid chamber **122**.

Another fluid, or liquid/liquid, treatment system **200** is illustrated in **FIG. 3**. This system also preferably includes many elements, such as a housing (not shown), coalescer **230**, and separator **250**, which may have one or more of any of the features described with respect to the other embodiments. For example, the housing may include a tube sheet **214** and a process fluid chamber **220**, the coalescer **230** may include a coalescer medium **232**, and the flow director **270** may include a surface **271**. However,

the flow director **270** shown in **FIG. 3** has a substantially planar configuration, extending outward from the coalescer **230** and separator **250**, e.g., at about 90 degrees to the axis of the coalescer **230** and/or the separator **250**. The flow director **270** may comprise a circular configuration, such as an annular or disc-shaped configuration.

5 Alternatively, the flow director **270** may comprise any other polygonal configuration or a toroidal, quoit, sloped, slanted, and/or irregular configuration. The flow director **270** may have a diameter up to about 25% or more greater than the diameter of the coalescer and/or separator. The flow director **270** may be associated with the coalescer **230**, the separator **250**, or the housing.

10 Flow of the continuous phase liquid and discontinuous phase liquid may be similar to that described with respect to the other embodiments. The continuous phase liquid, represented by the arrows in **FIG. 3**, may flow from the downstream surface of the coalescer **230** in a curvilinear flow path to bend around the flow director edge **272** back to and through the separator medium **252** of the separator **250**. From the separator
15 **250**, the continuous phase liquid may flow through the stand-off tube **216** into the continuous phase chamber (not shown) and hence to the continuous phase outlet (not shown). The discontinuous phase liquid, represented by droplets in **FIG. 3**, may flow from the downstream surface of the coalescer **230**, diverge from the curvilinear path of the continuous phase liquid and pass to the lower portion of the coalesced liquid
20 chamber **222** and hence to the discontinuous phase outlet (not shown).

Another fluid, or liquid/liquid, treatment system **300** is illustrated in **FIG. 4**. This system also preferably includes many elements, such as a housing (not shown), coalescer **330**, flow director **370**, and separator **350**, which may have one or more of any of the features described with respect to the other embodiments, especially the
25 embodiments shown in **FIG. 1** and **FIG. 2**. For example, the housing may include a process fluid chamber **320**, the coalescer **330** may include a coalescer medium **332** extending between an open end cap **334** and a blind end cap **335**, and the flow director **370** may include a surface **371**. However, the separator **350**, including the separator medium **352**, preferably comprises a hollow, substantially conical configuration, as
30 shown in **FIG. 4**. The separator **350** is preferably tapered in a vertical direction. For example, the apex of the conical separator preferably points downward in a system designed for a discontinuous phase liquid which is denser or heavier than the continuous phase liquid (or upward for a system designed for a less dense or lighter discontinuous

phase liquid). Conical separators are mentioned in API/IP Specification No. 1582, "Specification for Similarity for API/IP 1581 Aviation Jet Fuel Filter/Separators," published jointly by The American Petroleum Institute and the Institute of Petroleum, London, UK, February, 2001.

5 A conically configured separator, especially a conically configured, nonpleated separator, may have many advantages. For example, the conical configuration may provide a larger surface area in the liquid flow path of the continuous phase liquid, e.g., a larger surface area within the envelope defined by a flow director. Further, a conical configuration may provide a self-cleaning action. This self cleaning action may be
10 highly advantageous for separating liquid mixtures wherein the continuous phase liquid has a high viscosity (e.g., a viscosity greater than or equal to about 10 centipoise, such as ≥ 20 , ≥ 30 , ≥ 35 , or ≥ 40 centipoise) or wherein the continuous phase liquid and the discontinuous phase liquid have similar specific gravities. Any droplet of the discontinuous phase liquid which reaches the sloped surface of a conical separator
15 medium may experience a net force which sweeps the droplet away from the surface of the separator. While the beneficial effect of a sloped surface may be observed at many angles, a more preferred angle for the surface is in the range from about 15° to about 75°, more preferably about 20° to about 70°, more preferably about 30° to about 60°, e.g., more preferably about 45°, to the axis of the separator.

20 The flow director 370 may have any suitable configuration. For example, the flow director 370 may have a cylindrical configuration, forming a tapered gap 373 between the flow director 370 and the conical separator 350, or a conical configuration, forming, for example, a uniform gap. The flow director 370 may extend axially less than, equal to or greater than the length of the separator 350 and may have a diameter
25 greater than the coalescer 330 and/or separator 350. Preferably, the diameter of the flow director 370 is less than or equal to the diameter of the coalescer 330, e.g., less than or equal to the diameter of the open end cap 334 of the coalescer 330, and the coalescer 330 and the flow director 370 are arranged generally coaxially. The coalescer 330, flow director 370, and separator 350 may then be attached to one another and mounted, for
30 example, as an integral unit to the housing, e.g., through an opening in the tube sheet 314.

Flow of the continuous phase liquid and the discontinuous phase liquid may be similar to that described with respect to the other embodiments, especially the

embodiments shown in **FIG. 1** and **FIG. 2**. The continuous phase liquid, represented by the arrows in **FIG. 4**, flows from the downstream surface of the coalescer **330** in a curvilinear flow path around the flow director edge **372** into the tapered gap **373** to the upstream surface of the separator **350** and through the separator medium **352**. From the downstream side of the separator **350**, the continuous phase liquid may flow through the stand-off tube **316** into the continuous phase chamber (not shown) and hence to the continuous phase outlet (not shown). The discontinuous phase liquid may flow past the flow director **370**, diverging from the curvilinear path of the continuous phase liquid and away from the separator **350** to the lower portion of the coalesced liquid chamber **322**, and then pass to the discontinuous phase outlet (not shown).

Another fluid, or liquid/liquid, treatment system **400** is illustrated in **FIG. 5**. This system also preferably includes many elements, such as a housing (not shown), coalescer **430**, flow director **470** and separator **450**, which may have one or more of any of the features described with respect to the other embodiments. For example, the housing may include a tube sheet **414** and a process fluid chamber **420**, the coalescer **430** may include a coalescer medium **432** extending between an open end cap **434** and a blind end cap **435**, and the flow director **470** may include a surface **471**. The separator may have a hollow cylindrical or a hollow conical configuration, e.g., with the apex of the conical separator pointing up or down. However, in **FIG. 5**, the separator **450** may have a generally polygonal geometry, such as circular, square, hexagonal or octagonal, and a substantially planar configuration, such as an annular, disc-shaped, quoit-shaped, or toroid-shaped configuration. Further, the separator **450** may comprise a slanted or sloped configuration. The flow director **470** may extend in the liquid flow path between the coalescer **430** and the separator **450** and may have any suitable configuration as previously described. The flow director **470** is shown as having a substantially cylindrical configuration and a diameter less than or substantially equal to the diameter of the coalescer **430**.

In the illustrated embodiment, the separator medium **452** of the separator **450** has a generally planar, disc-shaped configuration and may be positioned within the flow director **450** substantially perpendicular to the axis of the flow director **470**. The flow director **470** and the separator **450** are preferably joined at an open end of the flow director **470** near the edge **472** of the flow director **470** either permanently or with a removable seal **457** to prevent bypass around the separator **450**. The opposite end of the

flow director 470 may be closed by a blind end of the flow director 470 or by a blind end of the coalescer 430, defining a space 474 inside the flow director 470 downstream of the separator medium 452. The separator 450 may include a fitting 458 defining an opening 460 in which the stand-off tube (not shown) may be mounted. The separator
5 450 may be sealed to the fitting 458. The interior space 474 downstream of the separator 450 fluidly communicates with the stand-off tube via the opening 460, and an O-ring or other seal 456 is preferably positioned in removable sealing engagement between the fitting 458 of the separator 450 and the stand-off tube.

Flow of the continuous phase liquid and the discontinuous phase liquid may be
10 similar to that described with respect to the other embodiments. The continuous phase liquid may flow from the downstream surface of the coalescer 430 in a curvilinear flow path around the flow director edge 472 through the separator medium 452 of the separator 450 into the interior space 474. While the flow director 470 is preferably impervious, the flow director 470 may comprise a material which resists or prevents
15 flow of the discontinuous phase liquid but is permeable to the continuous phase liquid. Thus, continuous phase liquid may flow directly through the flow director 470 and/or along the curvilinear path by making a bend around the edge 472 of the flow director 470 and passing through the disc-shaped separator medium 452. From the interior space 474, the continuous phase liquid flows through the opening 460 in the fitting 458 into
20 the stand-off tube (not shown) and hence to the continuous phase chamber (not shown) and the continuous phase outlet (not shown). The discontinuous phase liquid may flow along the flow director 470 and diverge from the curvilinear flow path of the continuous phase liquid away from the separator 450 to the bottom of the coalesced liquid chamber 422 and hence to the discontinuous phase outlet (not shown).

25 Another fluid, or liquid/liquid, treatment system 500 is illustrated in FIG. 6. This system may also include many elements, such as a housing (not shown), coalescer (not shown), separator 550 and flow director 570, which may have one or more of any of the features described with respect to the other embodiments, especially the embodiment shown in FIG. 5. For example, the flow director 570 may have a generally cylindrical
30 configuration defining a surface 571, an open end at the edge 572 of the flow director 570, and a closed end opposite the open end which may be attached to the coalescer. While the separator 550 may include a separator medium 552 having a hollow cylindrical or conical configuration, in the illustrated embodiment the separator medium

552 has a circular geometry and a generally planar configuration. The separator medium 552 may be arranged in a plane substantially perpendicular to the axis of the flow director 570. However, unlike the separator medium 452 of FIG. 5 which is substantially flush with the edge 472 of the flow director 470, the separator medium 552 of FIG. 6 is preferably positioned within the flow director 570 at a distance from the edge 572. The separator medium 552 may be disposed at any suitable distance from the edge 572 of the flow director 570 that is between the edge 572 and the closed end of the flow director 570 and may be sealed to the flow director 570 by a seal 557. The separator 550 may also include a fitting 558 defining an opening 560. The fitting 558 may have a first portion that extends into the interior space 574 formed by the downstream side of the separator medium 552 and the flow director 570, the first portion having one or more holes, such as an open end or slots or perforations in a side wall, that fluidly communicate between the interior space 574 and the opening 560 in fitting 558. The fitting 558 may also have a second portion that extends beyond, e.g., below, the separator medium 552 and is preferably impervious, defining a gap 573 between the second portion of the fitting 558, the upstream side of the separator medium 552 and the flow director 570. The second portion of the fitting 558 may be sealed to a stand-off tube (not shown) by an O-ring 556 or other seal.

Flow of the continuous phase liquid and the discontinuous phase liquid may be similar to that described with respect to the other embodiments, especially the embodiment shown in FIG. 5. The continuous phase liquid, represented by the arrows in FIG. 6, may flow from the downstream side of the coalescer (not shown) past the flow director 570 in a curvilinear flow path around the edge 572 of the flow director 570 into the gap 573. From the gap 573 the continuous phase liquid contacts the separator 550 and flows through the separator medium 552 into the interior space 574. From the interior space 574 the continuous phase liquid flows into the opening 560 of the fitting 558 through the stand-off tube (not shown) into the continuous phase chamber (not shown) and through the continuous phase outlet (not shown). The discontinuous phase liquid may flow from the downstream side of the coalescer 530 past the flow director 570. The discontinuous phase liquid may then diverge from the curvilinear flow path of the continuous phase liquid away from the separator 550 and pass to the lower portion of the coalesced liquid chamber 522 and hence to the discontinuous phase outlet (not shown).

Another fluid, or liquid/liquid, treatment system **600** is illustrated in **FIG. 7**. This system may also preferably include many elements, such as a housing (not shown), coalescer **630**, flow director **670**, and separator **650**, which may have one or more of any of the features described with respect to the other embodiments. For example, the

5 housing may include a tube sheet **614** and a process fluid chamber **620**, the coalescer **630** may include a coalescer medium **632**, and the flow director **670** may include a surface **671**. The fluid treatment system **600** includes two or more coalescers, e.g., four coalescers **630**, arranged above and in fluid communication with fewer separators, e.g., a single separator **650**. The coalescers **630** are illustrated as comprising a cylindrical

10 configuration; however, the coalescers may comprise any suitable configuration, such as conical. Further, the separator **650** is illustrated as comprising a conical configuration; however, the separator may comprise any suitable configuration, such as cylindrical or planar. In addition, more than one separator **650** may be used. A flow director **670** is illustrated as being positioned between the coalescers **630** and separator **650**. As

15 illustrated, the flow director **670** may comprise a planar configuration and a polygonal, e.g., circular, geometry. The flow director may also comprise any suitable configuration as discussed above, such as a conical or cylindrical configuration. The invention is not limited to the number of or the particular arrangement of coalescers, separators and flow director illustrated in **FIG. 7**. For example, the coalescers may be positioned in one or

20 more rows or clusters and a separator and a flow director may be associated with each row or cluster.

Flow of the continuous phase liquid and the discontinuous phase liquid may be similar to the other embodiments. Process fluid may be directed into the process fluid chamber **620** and, for example, inside-out through the coalescers **630**. The continuous

25 phase liquid, represented by the arrows in **FIG. 7**, may flow from the downstream side of the coalescers **630** in a curvilinear flow path around the edge **672** of the flow director **670** and contact the separator **650**. The continuous phase liquid may then flow through the separator medium **652** through the stand-off tube **616** into the continuous phase chamber (not shown) and hence to the continuous phase outlet (not shown). The

30 discontinuous phase liquid, represented by droplets in **FIG. 7**, may flow from the downstream side of the coalescers **630** past the edge **672** of the flow director **670**. The discontinuous phase liquid may then diverge from the curvilinear flow path of the

continuous phase liquid and pass and to the lower portion of the coalesced liquid chamber **622** and hence to the discontinuous phase outlet (not shown).

For many fluid treatment systems, the housing, as well as the coalescers and/or separators, may be oriented generally vertically. However, fluid treatment systems may also be oriented generally horizontally, as shown, for example, in **FIG. 8**. The fluid, or liquid/liquid, treatment system **700** illustrated in **FIG. 8** may include many elements, such as a housing **710**, coalescer **730**, flow director **770**, and separator **750**, which may have one or more of any of the features described with respect to the other embodiments. However, the housing **710**, one or more of the coalescers **730**, and one or more of the separators **750** are each oriented generally horizontally. Alternatively, a coalescer and/or a separator may be oriented vertically within a horizontal housing or may be oriented horizontally within a vertical housing.

The housing **710** may have a wide variety of suitable configurations and may include many of the features previously described with respect to the vertical housings in the other embodiments. For example, the housing **710** may comprise one or more fluid inlets and outlets, such as a process fluid inlet **711**, a continuous phase outlet **712**, and a discontinuous phase outlet **713**, and a removable cover **717**. Further, the housing may be divided into one or more chambers. In the illustrated embodiment, the housing **710** may include a single fluid chamber **722** e.g., a coalesced liquid chamber. However, the housing may include one or more partitions which divide the housing into two or more chambers, e.g., a process fluid chamber, a coalesced fluid chamber, and a continuous phase fluid chamber. The housing **710** preferably has a generally cylindrical configuration, the axis of the housing extending generally horizontally.

While only a single coalescer **730** and a single separator **750** are shown in the housing **710** illustrated in **FIG. 8**, the fluid treatment system **700** may include two or more coalescers and/or two or more separators, each of which are preferably oriented horizontally. The coalescer **730** may have a generally cylindrical configuration and one or more end caps, e.g., an open end cap **734** and a blind end cap **735**. Similarly, the separator **750** may have a generally cylindrical configuration and one or more end caps, e.g., a blind end cap **755** and an open end cap **754**. Alternatively, the separator **750**, as well as the coalescer **730**, may have any other suitable configuration including a conical, a circular, or a planar configuration.

The separator(s) **750** and the coalescer(s) **730** may be positioned within the housing **710** in a variety of ways. For process fluids in which the discontinuous phase liquid is heavier than the continuous phase liquid, the separator **750** is preferably positioned in a horizontal fluid treatment system laterally above the coalescer **730**, as shown in **FIG. 8**, either directly above or offset from the coalescer **730**. For process fluids in which the discontinuous phase liquid is lighter, the separator may be positioned in a horizontal fluid treatment system laterally below the coalescer. Alternatively, regardless of which phase is heavier, the separator may be positioned at the same height as the coalescer, e.g., coaxially in front of or behind the coalescer or beside the coalescer, or at a different height above or below the coalescer. The coalescer(s) and the separator(s) may be supported in the housing by any suitable support mechanism, including, for example, a tube sheet, support plate, or a mechanical connection such as a tie rod assembly. In the illustrated embodiment, the coalescer **730** and the separator **750** are supported by an inlet pipe **720** fluidly communicating between the coalescer **730** and the process fluid inlet **711** and an outlet pipe **721** fluidly communicating between the separator **750** and the continuous phase fluid outlet **712**, respectively.

The horizontal fluid treatment system **700** further includes a flow director **770** which is preferably cooperatively arranged to direct the continuous phase liquid in a curvilinear flow path. The flow director **770** may thus promote separation of the discontinuous phase liquid from the continuous phase liquid, for example by diverging the flow paths of the discontinuous phase liquid from the continuous phase liquid, e.g., by directing a portion or all of the continuous phase liquid along a curvilinear flow path toward the separator **750** and by diverging a portion or all of the discontinuous phase liquid away from the separator **750**. The flow director **770** is preferably positioned between the coalescer **730** and the separator **750** such that it directs the continuous phase liquid from the downstream side of the coalescer **730** in a curvilinear flow path to the separator **750**. Further, in a horizontal embodiment, at least a portion of the flow director **770** is preferably sloped or slanted to allow discontinuous phase liquid to drain away from the separator **750** and/or flow director **770**.

The flow director may be directly associated with the separator **750** or the coalescer **730** or both the separator **750** and the coalescer **730**. For example, the flow director **770** may comprise a conical or a cylindrical configuration spaced from and extending along and around the downstream surface of the coalescer **730** or a group of

coalescers **730** and/or along and around the upstream surface of the separator **750** or a group of separators **750**. Preferably the flow director **770** comprises a partition or barrier between the coalescer **730** and the separator **750** and includes a surface **771**. The partition or barrier may, for example, have a planar, or curved configuration and may be sloped in any suitable direction to allow discontinuous phase liquid to drain away from the separator **750**. The partition or barrier may extend between the coalescer **730** and the separator **750** laterally and/or longitudinally across all or a portion of the interior of the housing **710** and/or it may have openings through which the continuous phase liquid may flow in a curvilinear flow path to the separator **750**. The flow director **770** preferably is arranged to direct liquid flowing from the coalescer **730** past the coalescer **730** toward one or both ends and/or sides of the housing or vessel **710** and then bend to the separator **750**. The flow director **770** is preferably directly associated with the housing **710**, e.g., permanently or removably positioned within the housing **710**. For example, the flow director **770** may be directly mounted to the housing **710**, e.g., as a partition within the housing **710** or may comprise a part of the housing **710**.

The fluid treatment system **700** shown in **FIG. 8** illustrates a preferred configuration where the process fluid comprises an immiscible mixture including a discontinuous phase liquid and a continuous phase liquid which is less dense than the discontinuous phase liquid. However, the invention is not limited to an embodiment for separating a denser discontinuous phase liquid from a less dense continuous phase liquid as previously explained.

A process fluid entering the system **700** may enter the housing or vessel **710** through a process fluid inlet **711** and pass through the inlet pipe **720**, isolating the process fluid from the coalesced liquid chamber **722**. The inlet pipe **720** may be associated with one or more open coalescer end caps **734**, e.g., directly or via a manifold, allowing process fluid to flow into the interior of each coalescer **730**. The fluid then flows inside-out through the coalescer medium **732** of the coalescer **730** from the upstream surface to the downstream surface of the coalescer **730**, where the small particles or droplets of the discontinuous phase liquid in the continuous phase liquid are coalesced to form larger droplets. The coalesced discontinuous phase liquid and the continuous phase liquid passing through the coalescer **730** may enter the coalesced liquid chamber **722**.

From the downstream surface of the coalescer **730** the continuous phase liquid flows along a curvilinear flow path flow, represented by the arrows in **FIG. 8**, around the flow director **770** to the separator **750**. The continuous phase liquid bends around the edge **772** of the flow director **770** and passes through the separator medium **752** through the outlet pipe **721** to the continuous phase outlet **712**. From the downstream surface of the coalescer **730** the discontinuous phase liquid may generally diverge from the continuous phase liquid. Rather than following the curvilinear flow path of the continuous phase liquid, the discontinuous phase liquid may diverge from the curvilinear flow path and pass to the lower portion of the coalesced liquid chamber **722** away from the separator **750**. Thus, the amount of discontinuous phase liquid in the vicinity of the separator **750** may be significantly reduced. Separation may be enhanced, for example, because the separator medium **752** is not blinded by the discontinuous phase liquid and/or because the continuous phase liquid may pass easily through the separator **750** without carrying or forcing significant amounts, if any, of the discontinuous phase liquid with it. In an embodiment where the flow director **770** includes a slope or slant, any discontinuous phase liquid in the vicinity of the separator **750** may be assisted in draining away from the separator **750** and back to the lower portion of the coalesced liquid chamber **722**. From the lower portion of the coalesced liquid chamber **722**, the discontinuous phase liquid exits the housing or vessel **710** via the discontinuous phase outlet **713**.

Another horizontal fluid, or liquid/liquid, treatment system **800** is shown in **FIG. 9**. This system may include many elements, such as a housing (not shown), coalescer **830**, separator **850** and flow director **870**, which may have one or more of any of the features described with respect to the other embodiments, especially the embodiment shown in **FIG. 8**. For example, the coalescer **830** may be supported by an inlet pipe **820** and may include a coalescer medium **832**. A horizontal separator **850** may be arranged laterally above the horizontal coalescer **830**, and the flow director **870** may be disposed between them. However, in the fluid treatment system **800** shown in **FIG. 9**, the flow director **870** may have a generally cylindrical configuration and may be cooperatively associated with, e.g., attached coaxially to, the separator **850**. The separator **850** may have a generally conical configuration, and a horizontally oriented conical separator **850** may have advantages similar to those described with respect to the vertically oriented conical separator **350** of the embodiment shown in **FIG. 4**. Alternatively, the flow

director and the separator may have any other suitable configuration. For example, the flow director may have a conical configuration and/or the separator may have a cylindrical or generally planar configuration.

The flow director **870** may surround the separator **850**, e.g., as a skirt or shroud, and define a surface **871** and a gap **873** between the flow director **870** and the separator **850**, e.g., a tapered gap **873**. The flow director **870** preferably extends axially substantially the full length or more of the separator **850**. The flow director **870** may also extend axially substantially the full length or more of the coalescer **830**. In the illustrated embodiment, the separator **850** preferably has an open end fluidly communicating with outlet pipe **821** and an opposite closed end, and the flow director **870** preferably has a closed end at the outlet pipe **821** and an opposite open end. The lower region of the flow director **870** may be sloped downward toward the open end to allow any discontinuous phase liquid that may enter the open end of the flow director **870** to drain from the interior of the flow director **870**. The flow director **870** and the separator **850** may be attached, for example, to the outlet pipe **821** in various ways, e.g., by a mechanical connection, such as a tie rod assembly or a screw-on attachment.

Flow of the continuous phase liquid and the discontinuous phase liquid may be similar to that described with respect to the other embodiments, especially the embodiment shown in **FIG. 8**. The continuous phase liquid may flow from the downstream side of the coalescer **830** in a curvilinear path around the edge **872** of the flow director **870** into the gap **873**. From the gap **873**, the continuous phase liquid may contact the upstream side of the separator **850**, flow through the separator medium **852** into the interior of the separator **850**, and pass through the open end of the separator **850** into outlet pipe **821** and hence to the continuous phase outlet (not shown). The discontinuous phase liquid may diverge from the curvilinear flow path of the continuous phase liquid, e.g., at or near the edge **872** of the flow director **870**, and pass to the bottom of the coalesced liquid chamber **822**, where it exits the housing or vessel (not shown) via the discontinuous phase outlet (not shown).

Each of the previous fluid treatment systems preferably includes a separator. However, in accordance with a second aspect of the invention, a fluid treatment system may comprise a flow director downstream of a coalescer but be free of a separator. Fluid treatment systems comprising a flow director but no separator may be advantageous for many types of immiscible liquid/liquid mixtures, including mixtures in

which the continuous phase liquid and the discontinuous phase liquid have significantly different specific gravities. For example, the specific gravities may differ by about 10% or more with respect to the smaller specific gravity.

One example of a fluid, or liquid/liquid, treatment system **900** comprising a flow director **970** and without a separator is shown in **FIG. 10**. The system **900** may include many elements, such as a housing (not shown), coalescer **930**, and flow director **970**, which may have one or more any of the features described with respect to the other embodiments, except this system does not have a separator.

The coalescer **930** may be variously configured but preferably comprises a hollow conical or cylindrical configuration, including a coalescer medium **932** extending between an open end cap **934** and a blind end cap **935**. The interior of the coalescer **930** fluidly communicates with the process fluid chamber **920** via the open end cap **934**. The flow director **970** also preferably has a hollow conical or cylindrical configuration, including a blind end, which may abut the closed end cap **935** of the coalescer **930**, and an open end, which may be spaced axially from and open away from the coalescer **930**. Preferably, the coalescer **930** and the flow director **970** are permanently or removably attached as an integral unit and may be mounted to or removed from the housing as an integral unit. For example, the coalescer **930** and the flow director **970** may have diameters which enable them to be mounted to the tube sheet **914** by slipping them through the opening in the tube sheet **914**, similar to the previous embodiments.

The continuous phase chamber preferably communicates with an interior space **974** of the flow director **970**, for example, via a stand-off tube **916**. The stand-off tube **916** preferably contacts and is secured to the flow director **970**. For example, the flow director **970** may include a fitting **975** similar to the fitting **458** of **FIG. 5** or the fitting **558** of **FIG. 6**. A perforated structural member **977**, such as a spider or a perforated plate, may join the fitting **975** to the side wall of the flow director **970**, either at the edge **972** of the flow director **970** as shown in **FIG. 10** or inward from the edge **972**. For example, a perforated structural member may be substituted for the separator medium **552** shown in **FIG. 6**. The fitting **975** may be sealed to the stand-off tube **916**, for example, via an O-ring or other seal **979**.

As another example, the flow director may have a planar configuration and a polygonal geometry, e.g., a disc-shaped configuration and a circular geometry. One or more coalescers may be positioned on one side of the flow director, e.g., above the flow

director. For example, the planar flow director may be attached to the blind ends of one or more coalescers perpendicular to the axes of the coalescers, the diameter of the flow director preferably being larger than the diameter of the coalescer or the cluster of the coalescers. A stand-off tube may open into the coalesced liquid chamber near the flow director, e.g., near the center below the flow director. This embodiment may be similar to the embodiment shown in **FIG. 7** without the separator **650**.

Flow of the continuous phase liquid and the discontinuous phase liquid may be similar to that described with respect to the other embodiments, especially the embodiments shown in **FIGS. 5** and **6**, except the continuous phase liquid does not flow through a separator. The continuous phase liquid may flow from the downstream side of the coalescer **930** in a curvilinear flow path around the edge **972** of the flow director **970**. The continuous phase liquid may, for example, flow away from the coalescer **930** generally axially along the side wall of the flow director, bending around the edge **972** of the flow director **970**. The continuous phase liquid then passes axially in the opposite direction into the interior space **974** and then through the fitting **977** to the stand-off tube **916**. As another example, the continuous phase liquid may flow away from the coalescer or cluster of coalescers generally radially outwardly along the flow director bending in a curvilinear flow path around the outer edge of the flow director. The continuous phase liquid then passes in the opposite direction radially inwardly along the opposite side of the flow director to the stand-off tube. From the stand-off tube **916**, the continuous phase liquid passes into the continuous phase chamber (not shown) and hence to the continuous phase outlet (not shown). The discontinuous phase liquid may flow from the downstream side of the coalescer **930** (or cluster or coalescers) past the edge **972** of the flow director **970** and diverge from the curvilinear flow path of the continuous phase liquid, passing away from the opening in the stand-off tube **916** to the lower portion of the coalesced liquid chamber **922** and hence to the discontinuous phase outlet (not shown).

Each of the previous fluid treatment systems preferably includes a flow director. However, in accordance with a third aspect of the invention, a fluid treatment system may comprise a separator downstream of a coalescer but be free of a flow director. One example of a fluid, or liquid/liquid, treatment system **1000** comprising a coalescer **1030** and a separator **1050** without a flow director is shown in **FIG. 11**. The system **1000** may include many elements, such as a housing (not shown), coalescer **1030** and separator

1050, which may have one or more of all the features described with respect to the other embodiments, except this system **1000** does not have a flow director.

The coalescer **1030** may be variously configured but preferably comprises a hollow conical or cylindrical configuration having an interior. A coalescer medium **1032**, which may be pleated or nonpleated, may be disposed between first and second open end caps **1034**, **1035** at opposite first and second open ends of the coalescer **1030**. One of end caps, e.g., the first end cap **1034**, may be sealed to the housing e.g., may be sealingly mounted the tube sheet **1014**. The coalescer medium **1032** has an interior surface facing the interior of the coalescer **1030**, which is preferably an upstream surface, and an exterior surface facing away from the interior of the coalescer **1030**, which is preferably a downstream surface. The coalescer **1030** may also include one or more additional elements as previously described.

The separator **1050** is preferably positioned at least partially within, more preferably substantially entirely within, and even more preferably entirely within the hollow coalescer **1030**. The separator **1050** and the coalescer **1030** are preferably permanently or removably attached as an integral unit which can be conveniently mounted to or removed from a housing. By positioning the separator **1050** within the coalescer **1030**, the arrangement of the coalescer **1030** and the separator **1050** may be more compact, e.g., shorter, enabling the coalescer and the separator to be housed within a smaller housing or vessel.

The separator **1050** may be variously configured and may include one or more of the elements previously described. For example, the separator **1050** may include a separation medium **1052**, and the separation medium **1052** may be disposed at an angle A to the longitudinal axis of the separator **1050**. The angle A may be in the range from about 0° to about 180° , the separation medium **1052** having a hollow generally cylindrical configuration where the angle A equals about 0° (or 180°) or a hollow, generally planar configuration where the angle A equals about 90° . Preferably, the separation medium has a nonpleated, hollow, generally conical configuration and the angle A is in the range from about 30° to about 60° , e.g., about 45° . Preferably, the apex of the conical separator **1050** points toward the second open end of the coalescer **1030**.

The separator **1050** may also include a fitting **1058** which may be sealed to the separation medium **1052**, e.g., at any suitable distance from the end of the coalescer **1030**. The fitting **1058** preferably defines an opening **1060** that fluidly communicates

with the downstream side of the separator medium **1052**, e.g., via an open end of the fitting **1058** or via perforations or slots in the fitting **1058**. The fitting **1058** may be attached to a stand-off tube **1016** and sealed to the stand off tube **1016**, for example, via an O-ring or other seal **1056**, allowing fluid communication between the stand-off tube
5 **1016** and the opening **1060** in the fitting **1058**. The fitting **1058** may also be attached to the coalescer **1030**, for example, via a spider or a perforated plate **1062**.

A barrier assembly **1090** is preferably positioned within the coalescer **1030** between the coalescer medium **1032** and the separation medium **1052**. The barrier assembly may have a one-piece or a multipiece construction and may be a separate
10 element or may be part of the coalescer or the separator. The barrier assembly **1090** serves as a barrier between process fluid which enters, for example, the first open end of the coalescer **1030** and the continuous phase liquid which enters, for example, the second open end of the coalescer **1030**. The barrier assembly isolates the separator from the open end or open end cap through which the process fluid enters the coalescer and
15 from the upstream side of the coalescer. Consequently, the barrier assembly **1090** preferably comprises an impervious material such as an impervious metal or plastic.

The barrier assembly **1090** may be configured in a wide variety of ways. For example, the barrier assembly **1090** may have a generally cylindrical or a generally conical configuration. As shown in **FIG. 11**, the conical barrier assembly is preferably
20 oriented with the apex pointing toward the first open end of the coalescer and may be truncated. The barrier assembly **1090** is preferably sealed against both the coalescer **1030** and the separator **1050** and may be attached to one or more of the housing, the coalescer **1030** and the separator **1050**. In the illustrated embodiment, the barrier assembly **1090** may be attached and sealed to the second end cap **1035** of the coalescer
25 **1030** and to the separation medium **1052**, terminating beyond the separation medium **1052**. Alternatively, the separator may include a blind end cap attached to the separator medium and the barrier assembly may extend between the second open end cap of the coalescer and the blind end cap of the separator. Within the coalescer **1030**, the barrier assembly **1090** and the separator **1050** define a gap **1093** upstream of the separator
30 medium **1050** and an interior space **1094** downstream of the separator medium **1052**.

Flow of the continuous phase liquid and the discontinuous phase liquid may be similar to that described with respect to the other embodiments, except the continuous phase liquid does not flow along or around a flow director. Process fluid may enter the

interior of the coalescer **1030**, for example, from the process fluid chamber **1020** through the first open end cap **1034** at the first open end of the coalescer **1030** and pass along one side of the barrier assembly **1090** to the coalescer medium **1032**. The conical configuration of the barrier assembly **1090** may enhance distribution of process fluid to the coalescer medium **1032**. The process fluid then flows inside-out from the upstream surface, e.g., the interior surface, of the coalescer **1030** to the downstream surface e.g., the exterior surface, through the coalescer medium **1032**, where the small particles or droplets of the discontinuous phase liquid are coalesced to form larger droplets.

From the downstream surface of the coalescer **1030** the continuous phase liquid flows in a curvilinear flow path around the second open end cap **1035** and, preferably back through the second open end of the coalescer **1030**. The continuous phase liquid then flows into the interior of the coalescer **1030** in the gap **1093** along the other side of the barrier assembly **1090** to the separation medium **1052** of the separator **1050**, which is isolated from the upstream side of the coalescer **1030**. From the gap **1093** the continuous phase liquid **1052** flows through the separator medium **1052**, which resists passage of any discontinuous phase liquid, and into the interior space **1094** downstream from the separator medium **1052**. From the interior space **1094** the continuous phase liquid flows through the opening **1060** in the fitting **1058** through the stand-off tube **1016** into the continuous phase chamber **1021** and hence to the continuous phase outlet (not shown). The discontinuous phase liquid may flow from the downstream side of the coalescer **1030** past the coalescer medium **1032** and the second end cap **1035**. The discontinuous phase liquid may then diverge from the curvilinear flow path of the continuous phase liquid away from the separator **1050** and pass to the lower portion of the coalesced liquid chamber **1022**. Any discontinuous phase liquid which reaches the separator **1050** may drain from the separator medium **1052**, especially the conically-shaped separator medium **1052**, and pass to the lower portion of the coalesced liquid chamber **1022**. From the lower portion of the coalesced liquid chamber **1022**, the discontinuous phase liquid may pass to the discontinuous phase outlet (not shown).

Another fluid, or liquid/liquid, treatment system **1100** is illustrated in **FIG.12**. This system may also include many elements, such as a housing (not shown), coalescer **1130** and separator **1150**, which may have one or more of any of the features described with respect to the other embodiments, especially the embodiments shown in **FIG. 4** and **FIG. 11**, except this system **1100** does not include a flow director. Further, the separator

1150 in this system **1100** is preferably disposed substantially outside of, more preferably completely outside of, the coalescer **1130**.

The coalescer **1130** may have a hollow, generally cylindrical or conical configuration and a coalescer medium **1032** extending between first and second end caps **1134**, **1135**. The first end cap **1134** is preferable open, while the second end cap **1135** is preferably blind.

The separator **1150** is disposed downstream of the coalescer **1130** and may be permanently or removably mounted to the housing, e.g., a stand-off tube, or, preferably, the coalescer **1130**, e.g., to the blind end cap **1135** of the coalescer **1130**. While two or more coalescers may be associated with each separator, each coalescer **1130** is preferably associated with a single separator **1150**. The separator **1150** and the coalescer **1130** are preferably arranged coaxially, and the diameter of the separator **1150** is preferably substantially equal to or less than the diameter of the coalescer **1130**, enabling them to be mounted or removed through an opening in the housing, for example, through an opening in a tube sheet **1114**, as an integral unit. While the coalescer **1130** and separator **1150** may be oriented horizontally, they are preferably oriented vertically.

While the separator **1150** may have any suitable configuration, a nonpleated, conical configuration where the apex of the conical separator **1150** points away from the coalescer **1130** is most preferred. The separator **1150** may include any of the elements previously described, including a separator medium **1152** and a blind end cap mounted to one end of the separator medium **1152**. The blind end cap of the separator **1150** may be attached to the blind end cap **1135** of the coalescer **1130**. Alternatively, the separator medium may be mounted directly to the blind end cap of the coalescer. The separator **1150** may also include a fitting **1158** joined to the other end of the separator medium **1152** and defining an opening **1160** which fluidly communicates between the downstream side of the separator medium **1152** and a continuous phase chamber, e.g., via a stand-off tube. The fitting **1158** may be sealed to the stand-off tube (not shown) by an O-ring or other seal **1156**.

Process fluid may be introduced to the coalescer **1130**, preferably, into the interior of the coalescer **1130** through the first open end cap **1134** at the first open end. The process fluid then flows from the upstream surface, e.g., the interior surface, of the coalescer **1130** to the downstream surface, e.g., the exterior surface, through the coalescer medium **1132**. As the process fluid flows through the coalescer medium **1132**,

small particles or droplets of discontinuous phase liquid are coalesced to form larger droplets.

From the downstream side of the coalescer **1130**, the continuous phase liquid flows past the coalescer **1130** to the separator **1150**. However, continuous phase liquid
5 does not pass along or around a flow director. Further, unlike many previous embodiments where much or all of the continuous phase liquid may bend through about 90° or more, e.g., about 180° or more, before contacting a separator, the continuous phase liquid in the fluid treatment system **1100** shown in **FIG. 12** may bend through less than 90°, e.g., generally about 45°, to contact the separator **1150**. The continuous phase
10 liquid then passes through the separator medium **1152** through the opening **1160** in the fitting **1158** and into the stand-off tube (not shown). From the stand-off tube, the continuous phase liquid may pass into the continuous phase chamber (not shown) and hence to the continuous phase outlet (not shown). The discontinuous phase liquid also flows past the coalescer **1130**. Some of the discontinuous phase liquid may then flow
15 past the separator **1150** to the lower portion of the coalesced liquid chamber and some of discontinuous phase liquid may pass in the vicinity of e.g., contact, the separator **1150**. As previously described, a separator having a conical, nonpleated configuration may facilitate drainage of the discontinuous phase liquid from the surface of the separator. The discontinuous phase liquid which drains from the separator **1150** may also flow to
20 the lower portion of the coalesced liquid chamber **1122**. From the lower portion of the coalesced liquid chamber, the discontinuous phase liquid may pass through the discontinuous phase outlet (not shown).

While the invention has been described in some detail by way of illustration and example, the invention is susceptible to various modifications and alternative forms and
25 is not restricted to the specific embodiments set forth. One or more of the features of one embodiment may be combined with one or more of the features of another embodiment. For example, the generally planar flow director of **FIG. 3** may be combined with the generally cylindrical or conical flow director of, e.g., **FIG. 1**, **FIG. 2**, or **FIG. 3** to form a flow director comprising a larger diameter planar flange and a
30 smaller diameter cylindrical or conical skirt depending from the flange. One or more of the features of any embodiment may be modified. For example, the horizontal fluid treatment system **700** shown in **FIG. 8** may be modified to form a vertical fluid, or liquid/liquid, treatment system **1200** as shown in **FIG. 13**. This system **1200** may

include many elements, such as a housing **1210**, coalescer **1230**, flow director **1270** and separator **1250**, which may have one or more of the features described with respect to the other embodiments, especially the embodiment shown in **FIG. 8**. For example, the housing **1210** may include a process fluid inlet **1211**, a continuous phase outlet **1212**, an inlet pipe **1220**, and an outlet pipe **1221**; the coalescer **1230** may include a coalescer medium **1232** extending between an open end cap **1234** and a blind end cap **1235**; and the separator **1250** may include a separator medium **1252** extending between an open end cap **1254** and a blind end cap **1255**. However, the fluid treatment system **1200** is preferably oriented vertically with the cover **1217** on top. The flow director **1270** preferably comprises a barrier partition which is sealed to the cover **1214** and which extends to a perforated support plate **1215** in the lower portion of the housing **1210**. Further, the discontinuous phase outlet **1213** is disposed in the lower portion of the coalesced liquid chamber **1222**. After the process fluid flows through the coalescer **1230**, the continuous phase liquid flows from the downstream side of the coalescer **1030** in a curvilinear flow path through the perforated support plate **1215** around the lower edge **1272** of the flow director **1270** and up to the separator **1250**. The discontinuous phase liquid diverges from the curvilinear flow path of the continuous phase liquid and passes to the lower portion of the coalesced liquid chamber **1222** and hence to the discontinuous phase outlet. Further, one or more of the features of any embodiment may be omitted. For example, the flow director **670** of the embodiment shown in **FIG. 7** may be omitted. The conical separator **650** may be attached, for example, to the stand-off tube **616** at one end and have a blind end cap attached to the opposite end. The conical separator **650** may then function with two or more coalescers **630** in a manner similar to that of the conical separator **1150** with the single coalescer **1130** shown in **FIG. 12**. Thus, the described and illustrated embodiments are not intended to limit the invention but, on the contrary, are intended to suggest all modifications, equivalents, and alternatives falling within the spirit and scope of the invention defined in each of the following claims.

All of the information cited herein, including publications, patents, and patent applications, are hereby incorporated in their entireties by reference.

WHAT IS CLAIMED IS:

1. A liquid/liquid separation arrangement for separating a discontinuous phase liquid from a continuous phase liquid comprising:
 - 5 a separator including an upstream surface, wherein the separator resists passage of the discontinuous phase liquid and allows passage of the continuous phase liquid; and
 - a flow director cooperatively arranged with the separator to direct the continuous phase liquid in a curvilinear flow path to the upstream surface of the separator.
- 10 2. The liquid/liquid separation arrangement according to claim 1, wherein the separator comprises a conical configuration.
3. The liquid/liquid separation arrangement according to claim 1 or 2, wherein the flow director surrounds the separator.
- 15 4. The liquid/liquid separation arrangement according to any one of claims 1-3, wherein the flow director defines a gap upstream of the separator.
5. The liquid/liquid separation arrangement according to claim 4, wherein the gap is
- 20 uniform.
6. The liquid/liquid separation arrangement according to claim 4, wherein the gap is tapered.
- 25 7. The liquid/liquid separation arrangement according to any one of claims 1-6, wherein the length of the flow director is greater than or substantially equal to the length of the separator.
8. The liquid/liquid separation arrangement according to any one of claims 1-7, wherein
- 30 the flow director is attached to the separator.
9. The liquid/liquid separation arrangement according to claim 8, wherein the flow director is attached to an end of the separator.

10. A liquid/liquid separation arrangement for separating a discontinuous phase liquid from a continuous phase liquid comprising:

- 5 a separator including a separator medium and
 a flow director mounted to the separator.

11. The liquid/liquid separation arrangement according to claim 10, wherein the separator comprises a conical configuration.

10 12. The liquid/liquid separation arrangement according to claim 10 or 11, wherein the flow director surrounds the separator.

13. The liquid/liquid separation arrangement according to any one of claims 10-12, wherein the flow director defines a gap upstream of the separator.

15

14. The liquid/liquid separation arrangement according to claim 13, wherein the gap is uniform.

15. The liquid/liquid separation arrangement according to claim 13, wherein the gap is
20 tapered.

16. The liquid/liquid separation arrangement according to any one of claims 10-15, wherein the length of the flow director is greater than or substantially equal to the length of the separator.

25

17. The liquid/liquid separation arrangement according to any one of claims 10-15, wherein the length of the flow director is less than the length of the separator.

18. The liquid/liquid separation arrangement according to any one of claims 10-17,
30 wherein the flow director is mounted to an end of the separator.

19. A liquid/liquid coalescing arrangement for separating a discontinuous phase liquid from a continuous phase liquid comprising:

a coalescer including a downstream surface, wherein the coalescer forms smaller particles of the discontinuous phase liquid into larger droplets; and

a flow director cooperatively arranged with the coalescer to direct the continuous phase liquid in a curvilinear flow path away from the downstream surface of the
5 coalescer.

20. A liquid/liquid coalescing arrangement for separating a discontinuous phase liquid from a continuous phase liquid comprising:

a coalescer including a coalescer medium and
10 a flow director mounted to the coalescer.

21. The liquid/liquid separation arrangement according to claim 19 or 20, wherein the flow director is mounted to an end of the coalescer.

15 22. The liquid/liquid separation arrangement according to any one of claims 19-21, wherein the flow director comprises a hollow configuration.

23. The liquid/liquid separation arrangement according to any one of claims 19-22, wherein the flow director comprises an open end which opens away from the coalescer.
20

24. The liquid/liquid separation arrangement according to any one of claims 19-23, wherein the diameter of the flow director is less than or substantially equal to the diameter of the coalescer.

25 25. A liquid/liquid treatment arrangement for separating a discontinuous phase liquid from a continuous phase liquid comprising:
a coalescer including a downstream surface;
a separator including an upstream surface; and
a flow director disposed between the downstream surface of the coalescer and the
30 upstream surface of the separator.

26. The liquid/liquid treatment arrangement according to claim 25, wherein the coalescer, the separator, and the flow director are attached as an integral unit.

27. The liquid/liquid treatment arrangement according to claim 25 or 26, wherein the diameter of the flow director is less than or substantially equal to the diameter of the coalescer.

5

28. The liquid/liquid treatment arrangement according to any one of claims 25-27, wherein the separator comprises a conical configuration.

29. The liquid/liquid treatment arrangement according to any one of claims 25-27,

10 wherein the separator comprises a planar configuration.

30. The liquid/liquid treatment arrangement according to any one of claims 25-29, wherein the flow director comprises a hollow configuration and surrounds the separator.

15 31. The liquid/liquid treatment arrangement according to any one of claims 25-30, wherein the flow director defines a gap upstream of the separator.

32. The liquid/liquid treatment arrangement according to claim 31, wherein the gap is tapered.

20

33. The liquid/liquid treatment arrangement according to any one of claims 25-32, wherein the flow director is attached to a blind end of the coalescer.

34. The liquid/liquid treatment arrangement according to any one of claims 25-32,

25 wherein the flow director is attached to a blind end of the separator.

35. The liquid/liquid treatment arrangement according to claim 25, wherein the flow director comprises a generally planar configuration and a diameter greater than the diameter of the coalescer.

30

36. The liquid/liquid treatment arrangement according to any one of claims 25-35, wherein the coalescer and the separator are oriented vertically.

37. The liquid/liquid treatment arrangement according to any one of claims 25-35, wherein the coalescer and the separator are oriented horizontally.

38. A liquid/liquid treatment arrangement for separating a discontinuous phase liquid
5 from a continuous phase liquid comprising:
a hollow coalescer including an interior, an upstream side facing the interior of the coalescer and a downstream side facing away from the interior of the coalescer and
a separator positioned in the interior of the hollow coalescer and isolated from the upstream side of the coalescer.

10

39. The liquid/liquid treatment arrangement according to claim 38, further comprising a barrier assembly disposed in the interior of the hollow coalescer, the barrier assembly isolating the upstream side of the coalescer from the separator.

15 40. The liquid/liquid treatment arrangement according to claim 39, wherein the barrier assembly comprises a conical configuration.

41. The liquid/liquid treatment arrangement according to any one of claims 38-40, wherein the separator is disposed substantially entirely within the interior of the
20 coalescer.

42. The liquid/liquid treatment arrangement according to any one of claims 38-41, wherein the separator comprises a conical configuration.

25 43. The liquid/liquid treatment arrangement according to any one of claims 38-42, wherein the coalescer comprises first and second opposite open ends.

44. A liquid/liquid treatment arrangement for separating a discontinuous phase liquid from a continuous phase liquid comprising:
30 a hollow coalescer including an interior and first and second opposite open ends and
a separator positioned in the interior of the hollow coalescer and isolated from one of the open ends of the coalescer.

45. The liquid/liquid treatment arrangement according to claim 44, further comprising:
a barrier assembly disposed in the interior of the coalescer, the barrier assembly
isolating the first or second open end of the coalescer from the separator.

5

46. The liquid/liquid treatment arrangement according to claim 45, wherein the barrier
assembly comprises a conical configuration.

47. The liquid/liquid treatment arrangement according to any one of claims 44-46,
10 wherein the separator comprises a conical configuration.

48. The liquid/liquid treatment arrangement according to any one of claims 44-47,
wherein the separator is disposed substantially entirely within the interior of the
coalescer.

15

49. A liquid/liquid treatment arrangement for separating a discontinuous phase liquid
from a continuous phase liquid comprising:

a coalescer including a coalescer medium and

a separator including a separator medium, wherein the separator comprises a

20 conical configuration and the conical separator points away from the coalescer.

50. The liquid/liquid treatment arrangement according to claim 49, wherein the coalescer
and the separator are oriented vertically.

25 51. The liquid/liquid treatment arrangement according to claim 49, wherein the coalescer
and the separator are oriented horizontally.

52. The liquid/liquid treatment arrangement according to any one of claims 49-51,
further comprising a plurality of coalescers.

30

53. The liquid/liquid treatment arrangement according to any one of claims 49-52,
further comprising a flow director disposed between the coalescer and the separator.

54. A method for separating a discontinuous phase liquid from a continuous phase liquid comprising:

directing the continuous phase liquid from a coalescer in a curvilinear flow path to a separator.

5

55. The method for separating a discontinuous phase liquid from a continuous phase liquid according to claim 54, wherein directing the continuous phase liquid from the coalescer in the curvilinear flow path to the separator includes passing the continuous phase liquid around a flow director.

10

56. The method for separating a discontinuous phase liquid from a continuous phase liquid according to claim 54 or 55, wherein directing the continuous phase liquid from the coalescer in the curvilinear flow path to the separator includes diverging the discontinuous phase liquid from the curvilinear flow path of the continuous phase liquid.

15

57. A method for separating a discontinuous phase liquid from a continuous phase liquid comprising:

diverging the flow paths of the continuous phase liquid from the discontinuous phase liquid, including directing the continuous phase liquid along a curvilinear flow path.

20

58. The method for separating a discontinuous phase liquid from a continuous phase liquid according to claim 57, wherein directing the continuous phase liquid along the curvilinear flow path includes passing the continuous phase liquid around a flow director.

25

59. The method for separating a discontinuous phase liquid from a continuous phase liquid according to claim 57 or 58, further comprising passing the continuous phase liquid through a separator.

30

60. A method for separating a discontinuous phase liquid from a continuous phase liquid comprising:

directing a mixture of the continuous phase liquid and the discontinuous phase

liquid into the interior of a hollow coalescer and inside-out from an upstream side of the coalescer to a downstream side through a coalescer medium and

directing the continuous phase liquid into the interior of the hollow coalescer and through a separator which is isolated from the upstream side of the coalescer.

5

61. The method for separating a discontinuous phase liquid from a continuous phase liquid according to claim 60, wherein directing the continuous phase liquid into the interior of the hollow coalescer includes passing the continuous phase liquid in a curvilinear flow path into the interior of the coalescer.

10

62. A method of separating a discontinuous phase liquid from a continuous phase liquid comprising:

directing a mixture of the continuous phase liquid and the discontinuous phase liquid through a first open end of a hollow coalescer and inside-out through a coalescer

15 medium and

directing the continuous phase liquid through an opposite open end of the hollow coalescer and through a separator which is isolated from the first open end of the coalescers.

20

63. The method for separating a discontinuous phase liquid from a continuous phase liquid according to claim 62, wherein directing the continuous phase liquid through an opposite open end of the hollow coalescer includes passing the continuous phase liquid in a curvilinear flow path.

25

FIG. 1

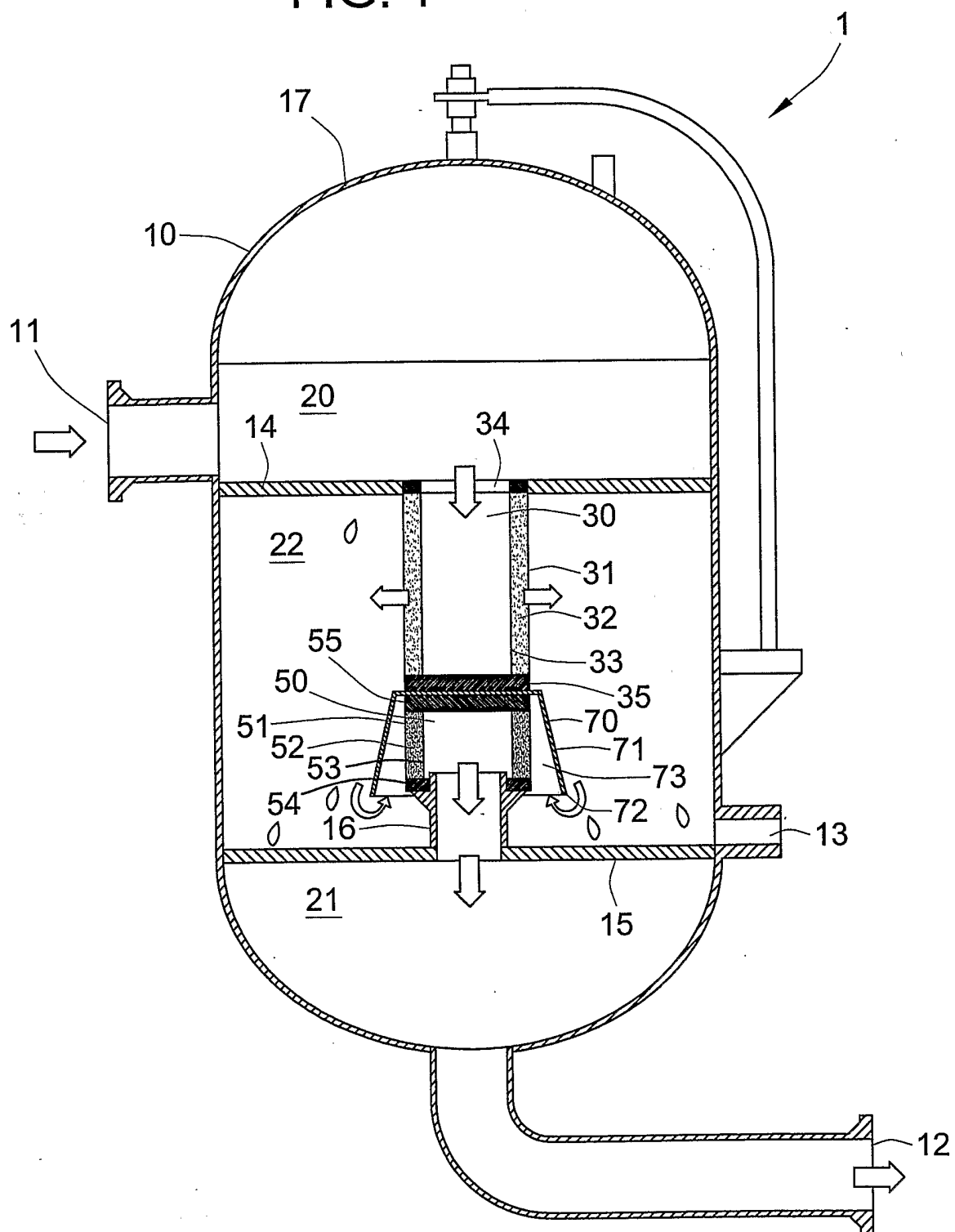


FIG. 2

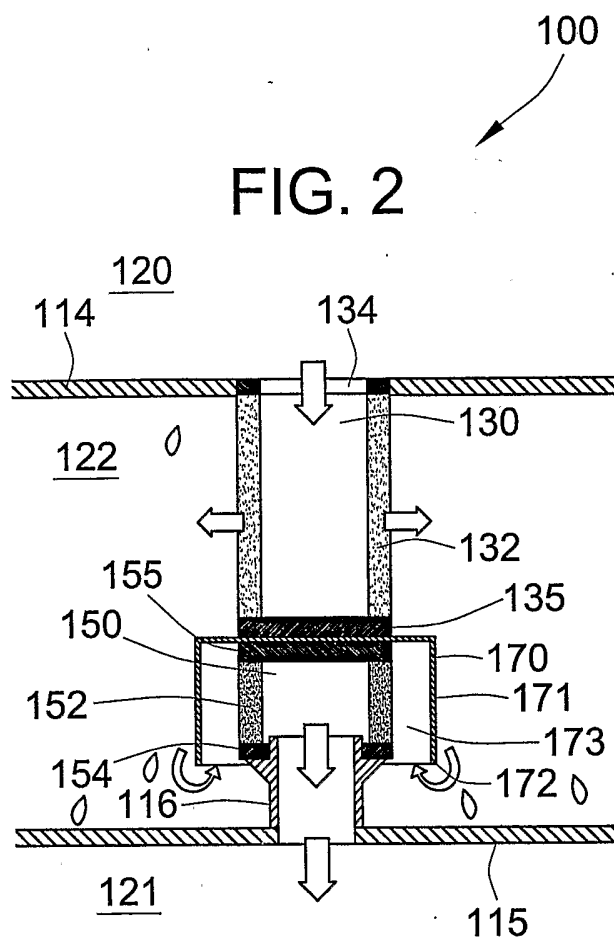


FIG. 3

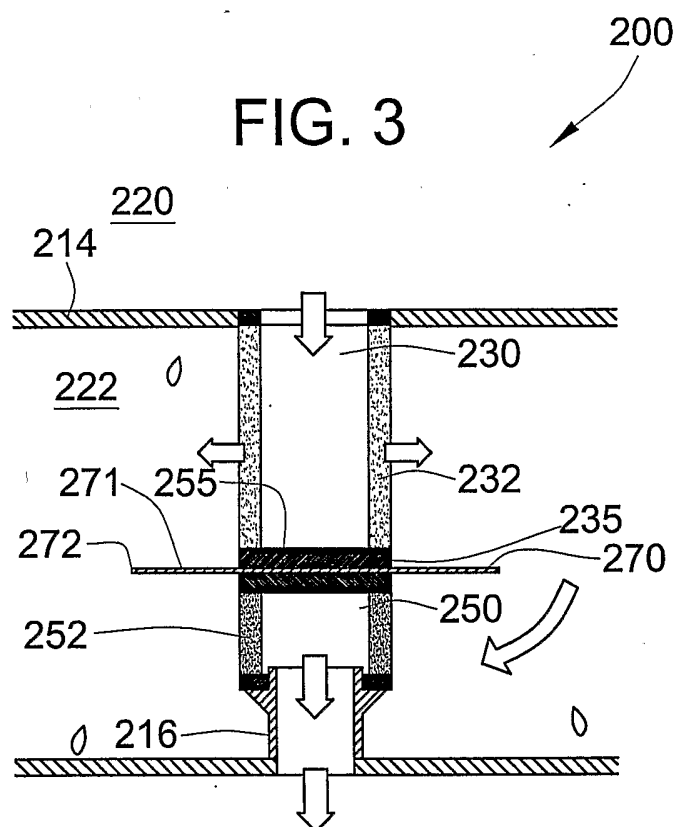


FIG. 4

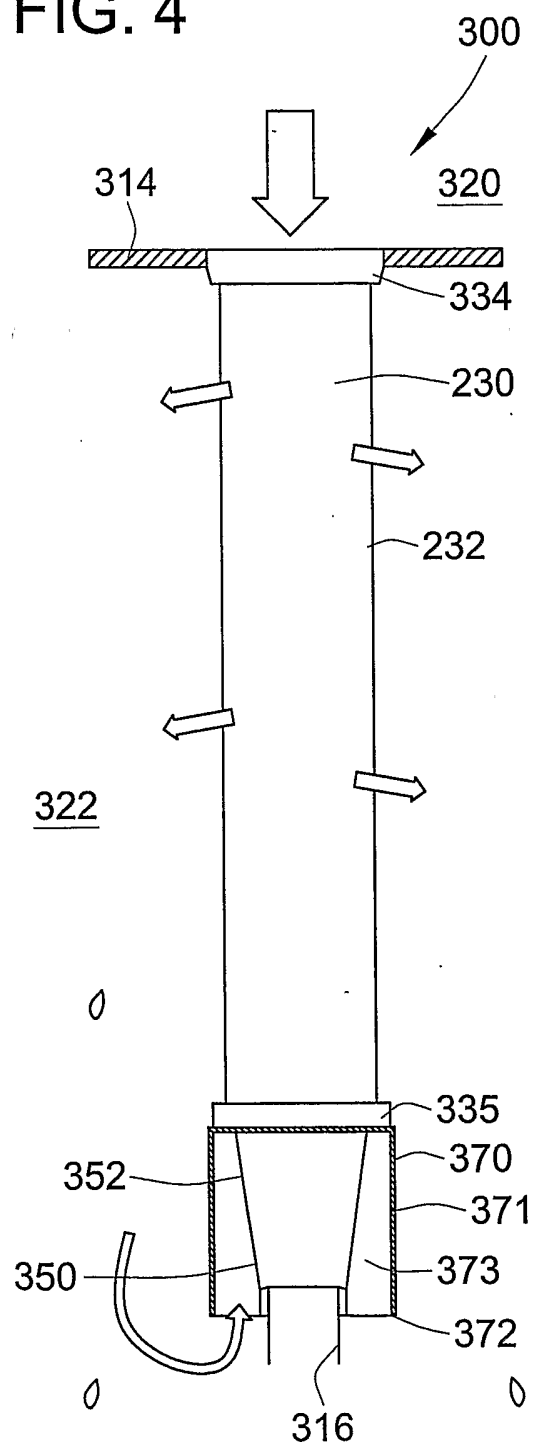


FIG. 5

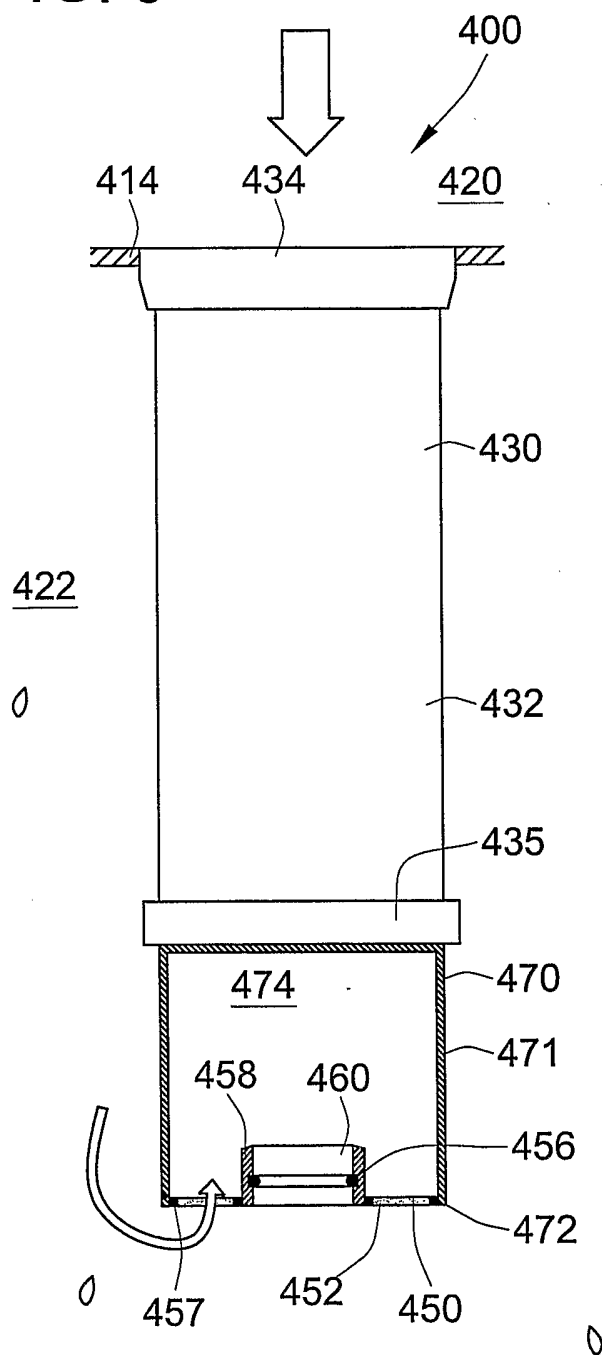


FIG. 6

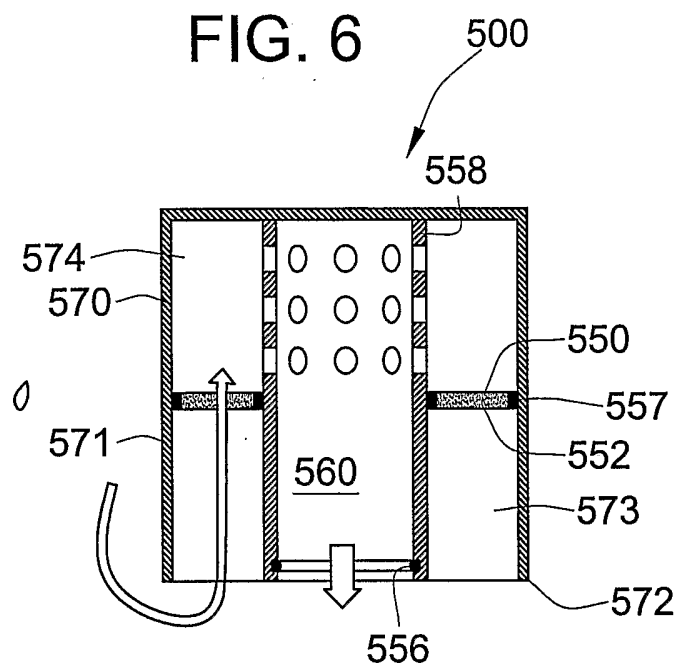
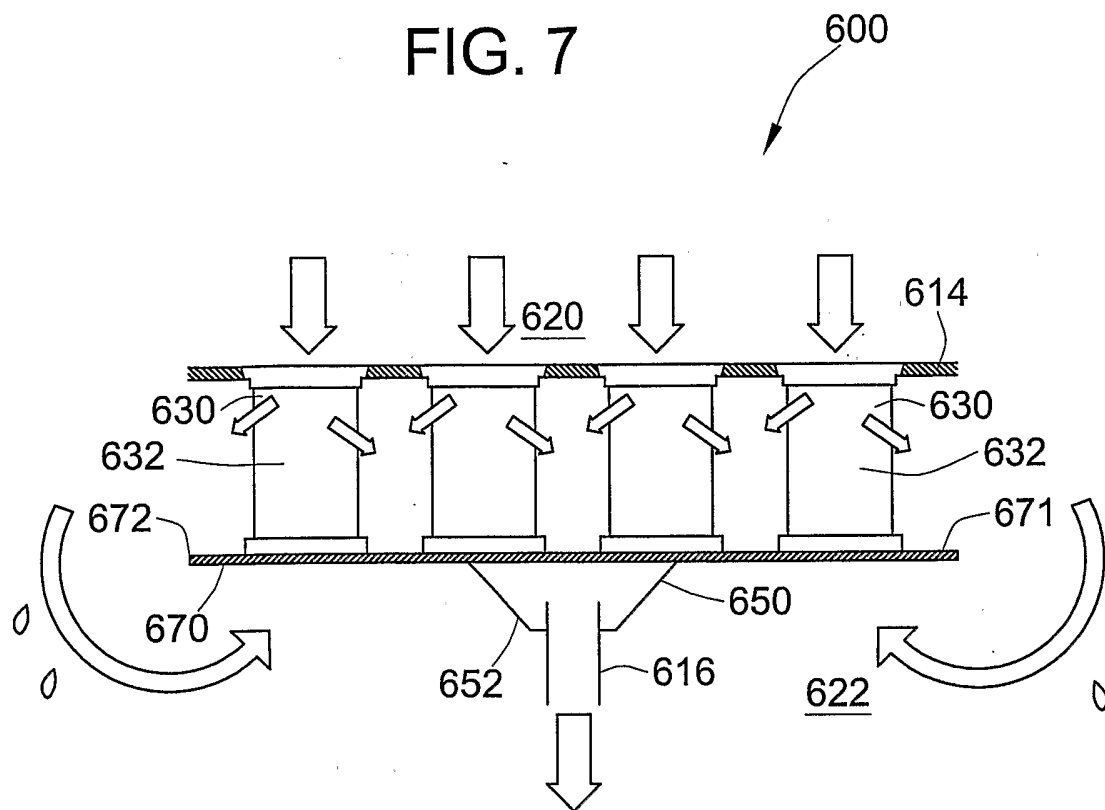
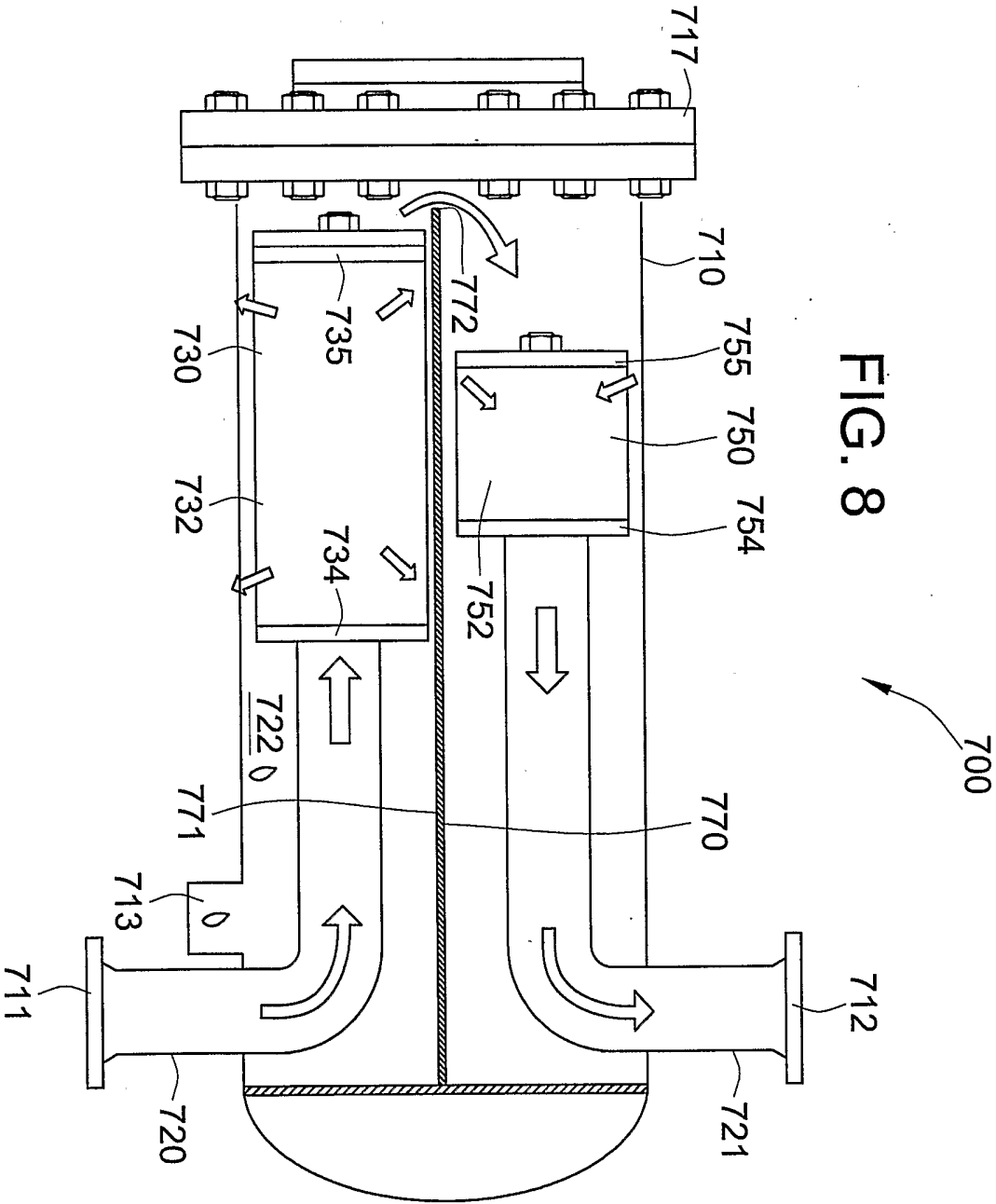
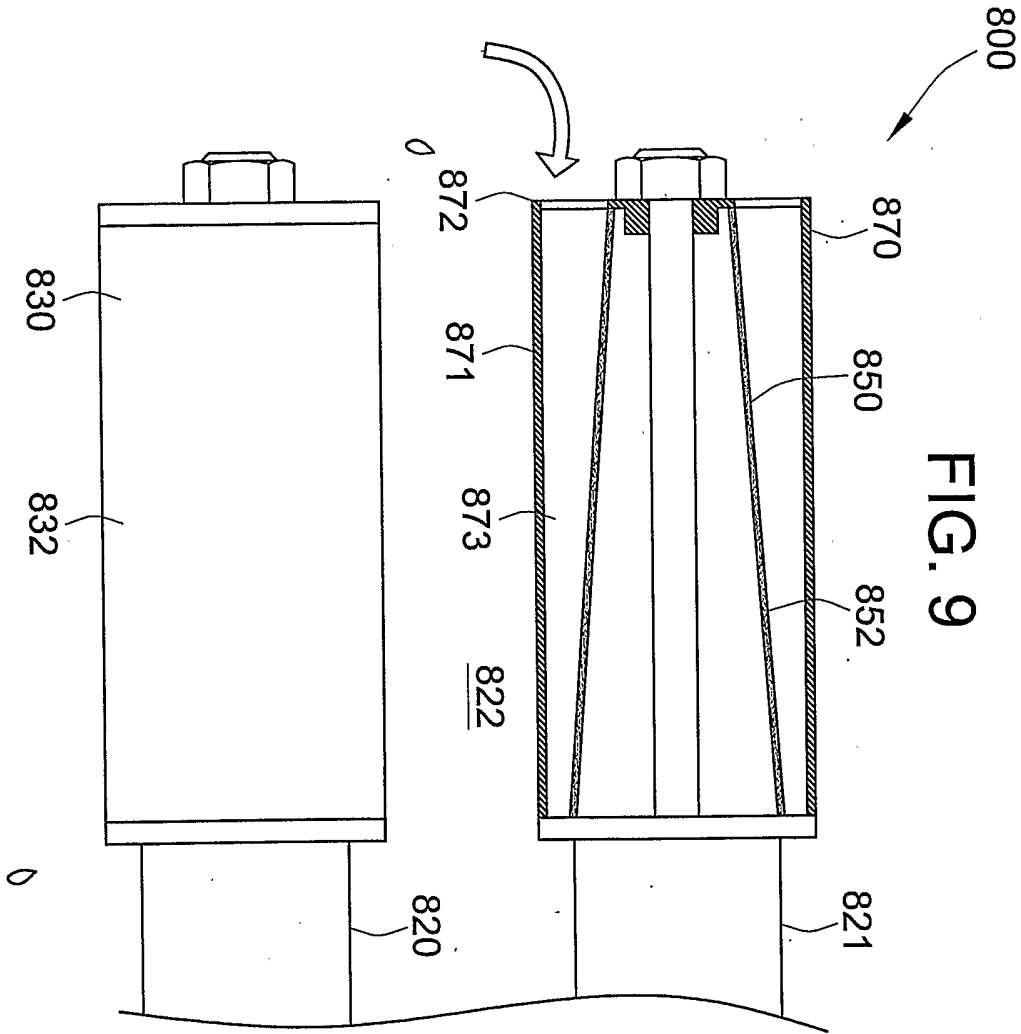


FIG. 7







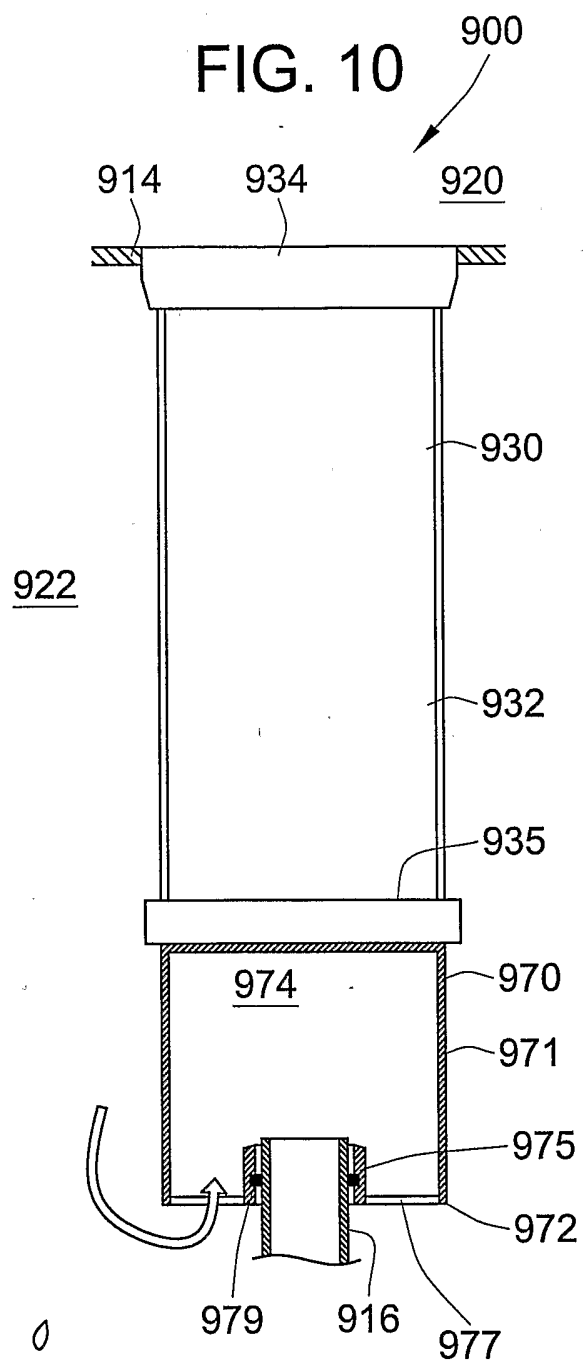


FIG. 11

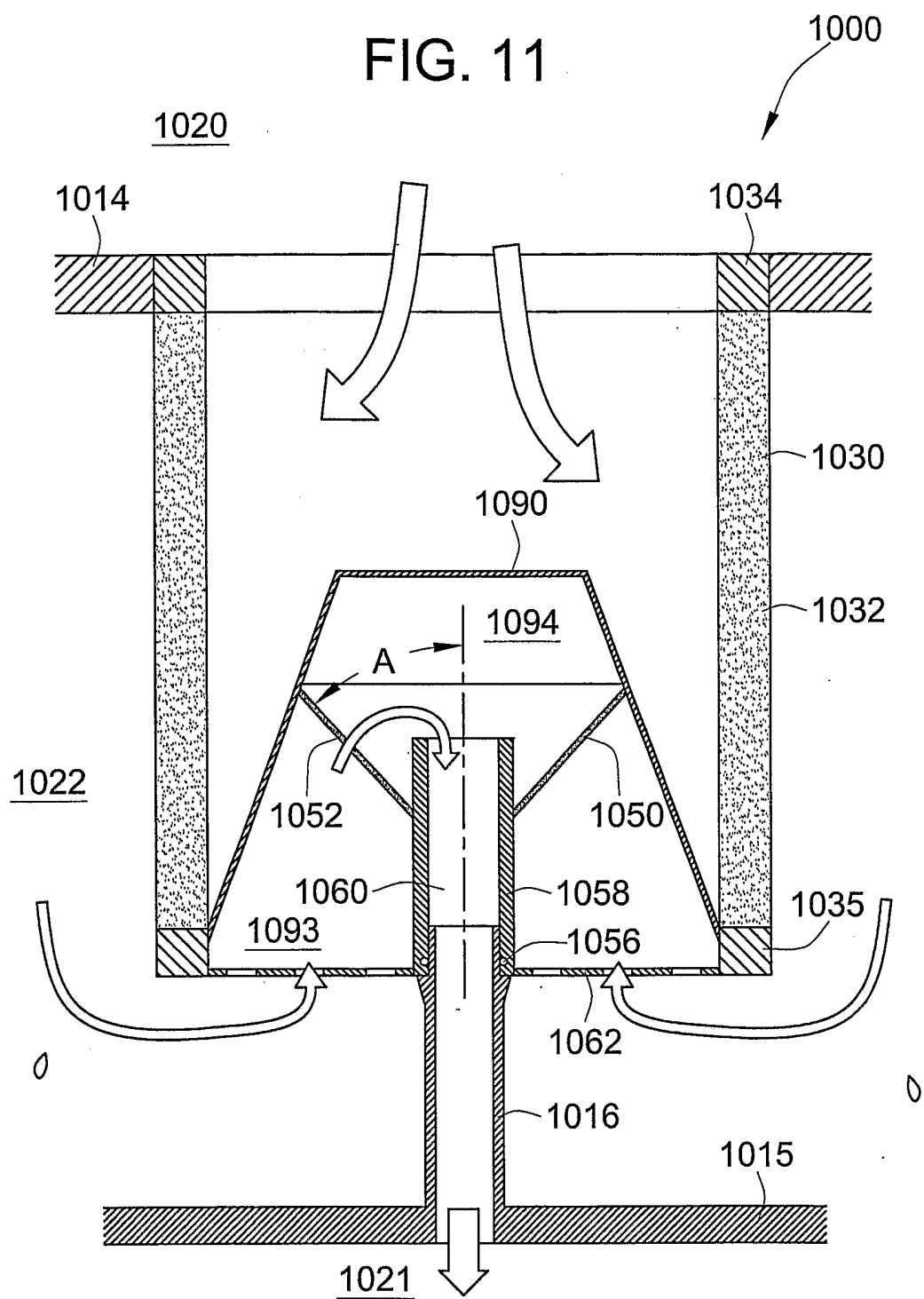


FIG. 12

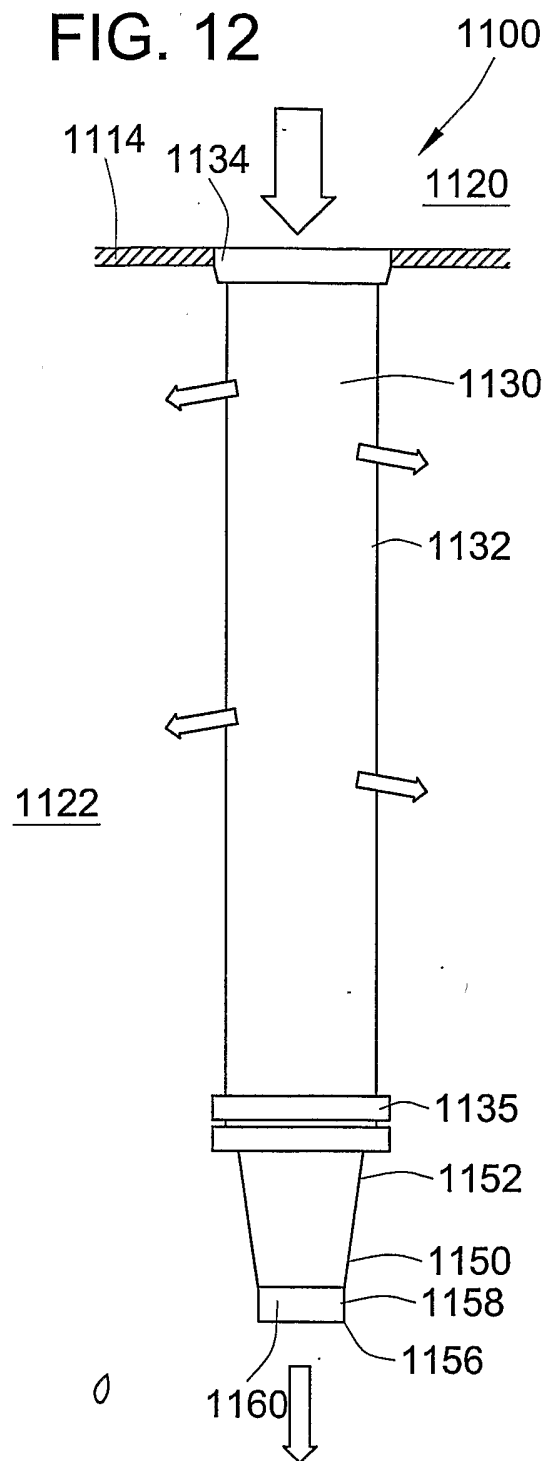
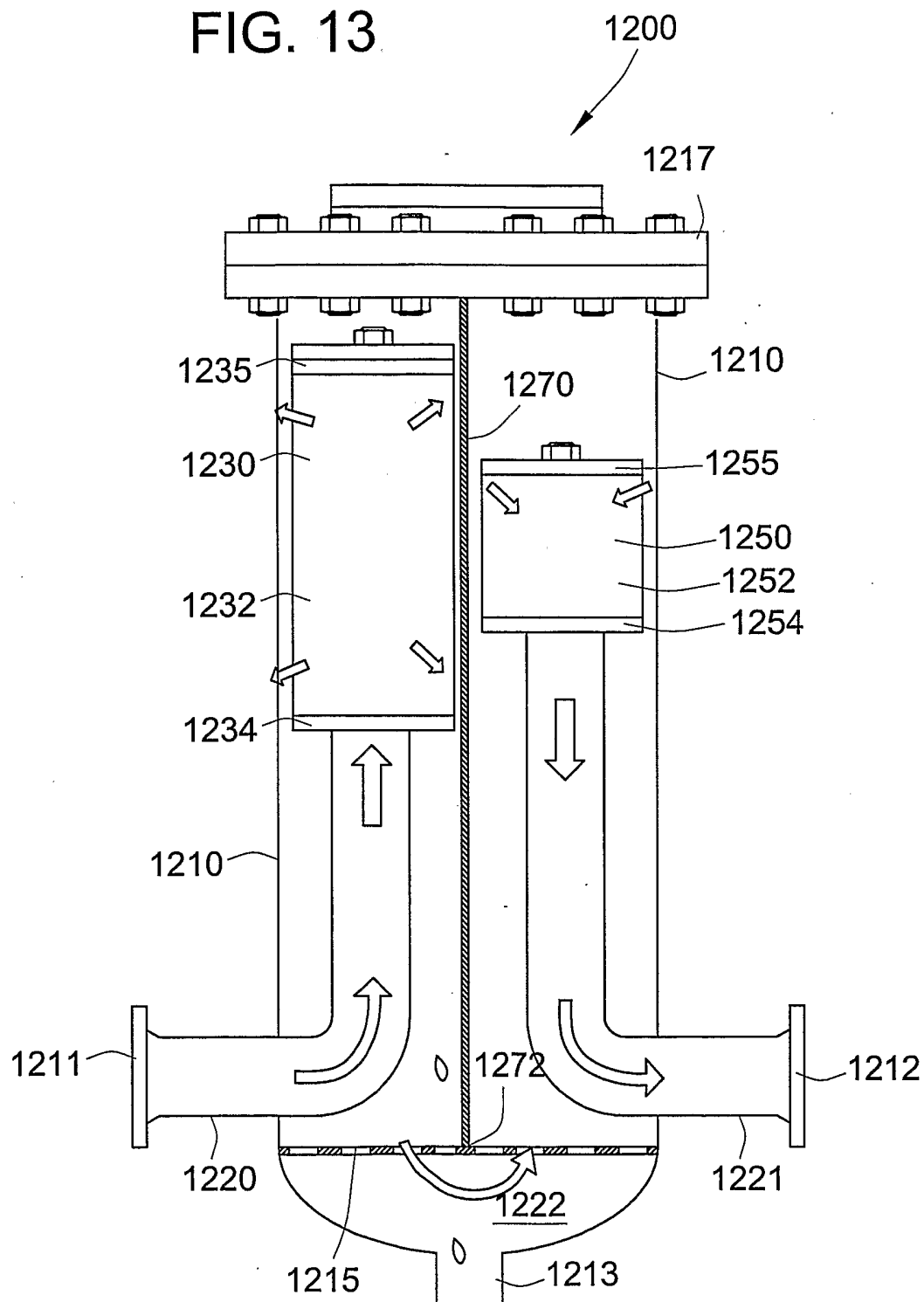


FIG. 13



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/03331

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : B01D 29/50, 29/56, 29/58

US CL : Please See Extra Sheet.

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)

U.S. : 210/295, 314, 316, 323.2, 416.4, 435, 456, 488, 489, 492, 502.1, DIG. 5

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,443,724 A (WILLIAMSON et al) 22 August 1995 (22.08.95), see entire document.	1-3, 10-12, 19-21, 25-27, 38-41, 44-47, 49-52, 54-63
Y	US 4,511,537 A (FIOCCO et al) 16 April 1985 (16.04.85), see entire document.	1, 10, 19-21, 25, 38, 44, 54
Y	US 4,369,047 A (ASRSCOT et al) 18 January 1983 (18.01.83), see entire document.	1, 10, 19-21, 25, 38, 44, 54

☐ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	"I" 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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier document published on or after the international filing date	"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
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

01 MAY 2002

Date of mailing of the international search report

23 MAY 2002
 Name and mailing address of the ISA/US
 Commissioner of Patents and Trademarks
 Box PCT
 Washington, D.C. 20231

Facsimile No. (703) 305-3230

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Telephone No. (703) 308-0661

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/03331

A. CLASSIFICATION OF SUBJECT MATTER:

US CL :

210/295, 314, 316, 323.2, 416.4, 435, 456, 488, 489, 492, 502.1, DIG. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/03331

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 4-9, 13-18, 22-24, 28-37, 42-43, 48, 53
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.