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(54) **Title:** MULTI-STAGE DOWNHOLE OIL-WATER SEPARATOR

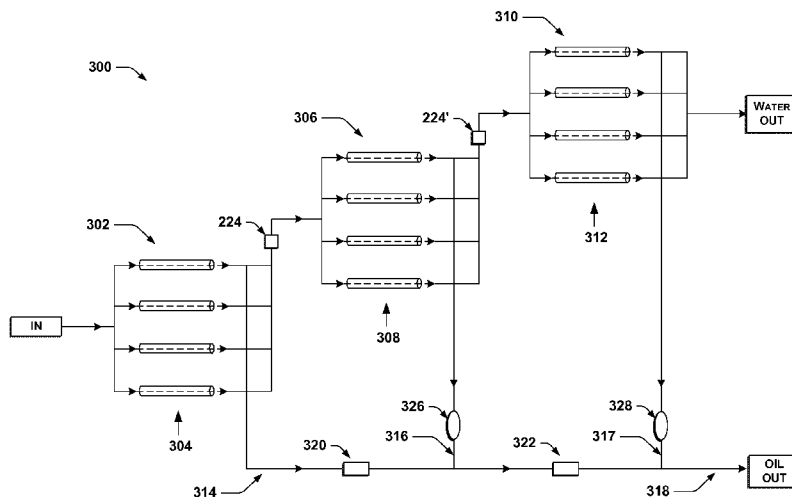


FIG. 3

(57) **Abstract:** Multi-stage downhole oil-water separators are provided. An example system includes parallel arrays of downhole hydrocyclones, with multiple of the parallel arrays connected in hydraulic series to provide successive oil-water separation stages downhole. The arrays of hydrocyclones connected in hydraulic parallel, and the parallel arrays connected in hydraulic series are flow balanced and pressure balanced with respect to each other and situated into a housing suitable for the limited space of a downhole environment. The parallel arrays provide high throughput, while the multiple stages connected in series provide high separation resulting in high oil yield and substantially clean water.

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MULTI-STAGE DOWNHOLE OIL-WATER SEPARATOR

BACKGROUND

[0001] In oil and gas wells, production tubing brings fluid hydrocarbon resources, such as oil, to the surface. The wellbore may produce liquid hydrocarbons as a water mixture. Conventionally, separation devices, such as hydrocyclones, may be used on the surface to remove the water, separating oil and water based on their different densities. Hydrocyclones may also be used downhole, but the limited cross-sectional area of a borehole conventionally limits significant cyclonic action downhole. Energy can be wasted lifting the hydrocarbon and water mixture out of the well to remove the water on the surface. It is conventionally difficult to accomplish a significant oil-water separation downhole where the water component can sometimes be stored or even utilized for pressure maintenance, and it is also conventionally difficult to achieve a downhole separation that provides environmentally pure water.

SUMMARY

[0002] Multi-stage downhole oil-water separators are provided. An example system includes parallel arrays of downhole hydrocyclones, with multiple of the parallel arrays connected in hydraulic series to provide successive oil-water separation stages downhole. The arrays of hydrocyclones connected in hydraulic parallel, and the parallel arrays connected in hydraulic series are flow balanced and pressure balanced with respect to each other and situated into a housing suitable for the limited space of a downhole environment. The parallel arrays provide

high throughput, while the multiple stages connected in series provide high separation resulting in high oil yield and substantially clean water.

[0003] This summary section is not intended to give a full description of multi-stage downhole oil-water separators. A detailed description with example embodiments follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Fig. 1 is a diagram of a section of an example parallel array of oil-water separators, such as hydrocyclones, for downhole service.

[0005] Fig. 2 is a schematic diagram of series hydraulic connection of two parallel arrays of oil-water separators for downhole service.

[0006] Fig. 3 is a diagram of an example multi-stage oil-water separation system for downhole service.

[0007] Fig. 4 is a diagram of another example multi-stage oil-water separation system for downhole service.

[0008] Fig. 5 is a diagram of a transition area and fluid flows between oil-water separators, for downhole service.

[0009] Fig. 6 is a diagram of a transition area and fluid flows between oil-water separators, for downhole service, including oil flow into a common oil line.

[0010] Fig. 7 is a flow diagram of an example method of constructing a multi-stage downhole oil-water separator.

DETAILED DESCRIPTION

Overview

[0011] This disclosure describes multi-stage downhole oil-water separators. An example system combines multiple separators, such as hydrocyclones, into a parallel array for high throughput downhole, and connects multiple instances of the parallel array in series to make separation stages, all packaged to fit in the cross-sectionally limited space of a downhole wellbore. The parallel array of multiple hydrocyclones in each separation stage ensures a high downhole flow rate through each stage, while the serial arrangement of successive hydrocyclone stages can achieve a high purity of the oil and water phases.

[0012] In an implementation, the example system packs numerous hydrocyclones into the limited bore space of a well casing by staggering the placement of individual hydrocyclones with respect to each other according to their geometry, and by interleaving, as needed, the parallel and serial fluid connections between individual hydrocyclone devices, and between serial stages.

[0013] The example system may also include flow rate mechanisms and pressure-balancing devices, especially between serial stages, that balance flow rate and pressure differences to enable the separation stages to work with each other and provide smooth and efficient oil and water phase separation. A series of flow rate controllers may govern the flow of an oil stream that has been separated off by the hydrocyclones.

[0014] This downhole “miniaturization” of an entire oil-water separation system can simplify bottleneck congestion of processing devices at surface facilities and can save the cost of energy needed for lifting an oil-water mixture to the surface before rejecting the water from the mixture.

[0015] In an implementation, the example system processes mixtures with an initial oil concentration that is between 5% and 30% of the oil-water mixture, but the example system can be used successfully for inlet oil concentrations less than 5%.

Example Systems

[0016] By adding successive stages of parallel separator arrays in series, the discharged oil-water mixture from each additional separator stage becomes more pure (contains less oil). Yet the multi-parallel hydrocyclones constituting each stage enable the flow rate of the entire system to remain substantially high. Besides concentrating the oil resource, the example system can also provide a water quality that satisfies both disposal requirements and local environmental regulations.

[0017] Fig. 1 shows an example section of a parallel array 100 of separators, such as oil-water hydrocyclone separators. The example section of the parallel array 100 may contain "n" separators in parallel, although two separators 102 & 104 are shown in the example section of a parallel array 100 in Fig. 1. The example section of a parallel array 100 thus represents a section of a longer assembly that includes n separators arranged longitudinally (e.g., n = 5 hydrocyclones). Using hydrocyclones as an example of a separator type, each hydrocyclone separator is connected in parallel fluid communication with the other hydrocyclone separators in the parallel array 100. Parallel fluid communication or connection in parallel means that at least the inputs 106 & 108 of each hydrocyclone separator 102 & 104 in the parallel array 100 are connected together for common fluid flow via a common tube, space 110 or manifold. Likewise, the oil outputs 112 & 114 of each separator 102 & 104 in the parallel array 100 may be fluidly connected together, either at a common tube 116, space, or manifold. The water outputs 118 & 120 of each separator 102 & 104 in the parallel array 100 are preferably

assigned separate individual tubes 138 & 140 for each hydrocyclone, but may also be connected together, if the hydrostatics allow, either at a common tube, space or manifold.

[0018] The example section of a parallel array 100 includes a housing 124 that may define the section and may provide a modular parallel array 100 that can be interchanged in a longer assembly. Or the housing 124 may be one long casing for several fixed arrays. The housing has an inlet end 126 for receiving a fluid mixture and an outlet end 128 that includes a discharge head 130 having an overflow port 132 (for separated oil) and two underflow ports 134 and 136 (for the water or water mixture that has been deoiled). In Fig. 1, only two underflow ports 134 and 136 are shown. However, in a separator assembly with more hydrocyclones than shown, there may be more overflow ports.

[0019] Inside housing 124, two hydrocyclones 102 & 104 are shown as arranged in the same general orientation for separating phases of the fluid mixture. In a given parallel array 100, however, the hydrocyclone separators do not necessarily have to be placed in the same orientation.

[0020] Each hydrocyclone 102 & 104 has an inlet 106 & 108 that is at least fluidly connected to the housing inlet end 126. Hydrocyclones 102 & 104 have overflow exits 112 & 114 for withdrawing overflow fractions (oil), and underflow exits 118 & 120 for withdrawing underflow fractions (water). The overflow exits 112 & 114 of hydrocyclones 102 & 104 are connected into a tubing 116, which leads to the overflow port 132 on the discharge head 130. The underflow exits 118 & 120 of hydrocyclones 102 & 104 are fluidly connected to tubings 138 & 140, respectively. The tubing 138 & 140 from underflow exits 118 & 120 are fluidly connected to the underflow ports 134 & 136 on the discharge head 130.

[0021] An oil-water mixture enters the hydrocyclone separators 102 & 104 through the housing inlet end 126. The oil-water mixture flows

through the hydrocyclone separators 102 & 104 and is separated into phases by cyclonic action based on the relative densities of the components to provide an oil-rich flow at the overflow exits 114 & 116 and a water-rich flow at the underflow exits 118 & 120. The underflow may be substantially clean water after being deoiled by a series of the parallel arrays 100, or contain a sufficiently small quantity of oil to be returned to a geological stratum of the well for disposal. In some cases, the water may be used for well pressure maintenance.

[0022] The water-bearing underflows 118 & 120 from individual hydrocyclones 102 & 104 have separate tubings 138 & 140 leading to the discharge head 130, while the oil-bearing overflows 112 & 114 from individual separators 102 & 104 are connected into the same tubing 116 to the discharge head 130. This configuration is advantageous for fluid dynamics because the underflow (e.g., water) is relatively dense and more viscous as compared to the hydrocarbons, and there is more fluid in the water phase traversing the series of parallel arrays 100.

[0023] Fig. 2 shows an example schematic diagram 200 for connecting multiple instances of the example parallel array 100 of Fig. 1 in series, downhole. Series connection means that the water-rich output (e.g., hydrocyclone underflow) from a previous parallel array 100 becomes the input for a next instance of the parallel array 100', while the oil-rich output (e.g., hydrocyclone overflow) may be transported away in a common tube 116, separately.

[0024] Downhole oil-water separation may be either static separation, utilizing for example one or more hydrocyclone "liners," or dynamic separation which utilizes a centrifuge separator rotating at the same operating speed as an electrical submersible pump (ESP). Hydrocyclone liners are available in different diameters. Small diameter liners, known as deoilers, have high-quality separation performance but are flow rate limited. To overcome the flow rate limitation of small

deoilers, a greater number of multiple deoilers are operated in hydraulic parallel in a respective parallel array 100. For example, an individual deoiler hydrocyclone (e.g., 1 inch (2.54 cm) diameter) may pass a few hundred barrels (bbl) per day (bpd), but multiple instances of the small deoiler hydrocyclones connected in parallel may handle the flow rate of a well pumped by artificial lift.

[0025] Fig. 2 shows a serially connected system 200 of only two parallel arrays 100 & 100' (each parallel array 100 represented by a single symbol), but an example multi-stage downhole separation system (300 in Fig. 3) may have three or more parallel arrays 100 in series.

[0026] System 200 includes a first parallel array 100 of separators that provides a stage of separation (e.g., bulk separation of oil from water) and a second parallel array 100' of separators, fluidly connected in hydraulic series. The total inlet fluid 202 (e.g., wellbore fluid or formation fluid) is drawn (e.g., pumped) into the first parallel array 100 through inlet 204. The first parallel array 100 separates the inlet fluid stream 202 into a first output stream 206 richer in water than inlet stream 202 and a first production stream 208 richer in hydrocarbon (e.g., oil) than the inlet stream 202. The first production stream 208 is discharged from an outlet 210 (e.g., oil outlet, production outlet) and may be directed to the surface as production outlet stream 116. The first water stream 206 is discharged from an outlet 212 (e.g., water outlet, injection outlet) to become the inlet stream (via inlet 214) for the second stage parallel array 100'. At the second parallel array 100', the first water stream 206 is separated into the second water stream 216 and a second production stream 218. The second water stream 216 is discharged from an outlet 220 into succeeding stages (not shown) to become the water-rich final output of the system, with most oil removed. The second production stream 218 is discharged through an outlet 222 and may be produced to the surface in common line 116.

[0027] The first production stream 208 (oil) may bypass the second parallel array 100' and be produced directed to the surface (e.g., production stream 116) or it may be combined with the second production stream 218 (as shown) for transport to the surface. Due to the additional pressure drop from the second parallel array 100' separator stage, the second stage production stream 218 will have a lower pressure than the first production stream 208. Before production streams 208 & 218 can be combined, the pressures must be balanced, for example via pressure-balancing device 224. Pressure-balancing device 224 is an apparatus for controlling or regulating fluid pressure, for example, by reducing the flow rate of the first production stream 208 and/or increasing the pressure of second production stream 218. For example, device 224 may be a pump for boosting the pressure of second production stream 218. The pressure-balancing device 224 may be a valve (e.g., fixed or adjustable) to provide a pressure drop for first production stream 208. The pressure-balancing device 224 may also be a check valve combined with one or more sensors (e.g., gauges) such as flow rate sensors, pressure sensors, or oil-water concentration gauges.

[0028] The pressure-balancing device 224 that reduces pressure of first production stream 208 may be integrated, for example, in the first parallel array 100 or the second parallel array 100', or provided in a separate module.

[0029] The first stage parallel array 100 of separators and the second parallel array 100' of separators may be of the same type of separator (e.g., static, hydrocyclone) or may be different types of separators.

[0030] Fig. 3 shows an example multi-stage downhole separation system 300, wherein each stage 302 is a parallel array 304 of separators. In an implementation, the example multi-stage downhole separation system 300 includes three different interconnecting stages 302 & 306 &

310. In the following description, components described as lower are further downhole, while upper or uphole components are closer to the surface within the wellbore.

[0031] Separators for the various serial stages of the multi-stage downhole separation system 300 may include different types and geometries of separators, such as bulk oil-water hydrocyclone separators designed to operate on mixtures that have a relatively high concentration of oil with respect to the water present; or pre-deoiler separators designed to separate oil from a mixture that already has a lower concentration of oil than initially, such as the water and oil mixture that is discharged from the previous bulk oil-water separators and has most of the oil already removed; or deoiler separators designed to separate traces of oil from a mixture containing a very low concentration of oil and to discharge water that is substantially clean into the environment.

[0032] In an implementation, a lower tandem separator stage 302 has an inlet that connects directly to a pumped source of the oil-water mixture. For example, the lower tandem separator stage 302 may connect directly to the discharge of a pump to receive pumped well fluid. The lower tandem separator stage 302 performs an initial oil-water bulk separation. The bulk separation stage results in a discharged oil-water mixture that has a low concentration of oil, for example, approximately 500 – 3000 parts per million (ppm).

[0033] In an implementation, the example lower tandem separator stage 302 may use an arrangement of separators in a parallel array 100, such as that described in U.S. Patent No. 8,261,821 to Hackworth et al., which is incorporated herein by reference in its entirety. In the Hackworth reference, separators, such as hydrocyclones, are disposed along the same orientation within a longitudinal housing, and a discharge head at one end of the longitudinal housing has at least one overflow port (for the hydrocarbon) and at least one underflow port (for the phase that is mainly

water). The hydrocyclones each have an overflow exit (for the separated oil or hydrocarbon) connected to a common tubing that is connected to the overflow port on the discharge head.

[0034] Each hydrocyclone has an underflow exit too (for the water-heavy oil-water mixture), which is preferably connected to one separate tube for each hydrocyclone, each tube leading to an underflow port of the discharge head, but these underflow exits can also be connected to a common tubing leading to the discharge head if the hydrostatics allow. The overflow tubes (for oil) are separate from the underflow tube(s) (water-heavy mixture). In general, because the overflow fluids (e.g., hydrocarbons) are relatively less demanding in terms of hydrodynamics, they can more easily share a common tubing in a downhole packaging scheme for the multi-stage separation system 300.

[0035] The example lower tandem separation stage 302 packages the participating hydrocyclones, connected in hydraulic parallel, into a very confined space. Thus, for efficiency and packing, the parallel array 100 may have the multiple hydrocyclones connected in a same orientation and plumbing that is designed to properly manage the fluid flows coming from multiple hydrocyclones in order to prevent erosion and properly balance the performance of each individual hydrocyclone. The example lower tandem separation stage 302, properly pressure-balanced, removes most of the oil in the incoming mixture, while rejecting the most water possible, and while maintaining a significant fluid volume flow downhole.

[0036] A center tandem stage 306 receives the discharge from the lower tandem separator stage 302. In an implementation, the center tandem stage 306 consists of another parallel array 308 of hydrocyclones, which may be of a different type or geometry than the separators used for the lower tandem separation stage 302. The center tandem stage 306 provides a first polishing separation stage, which

removes even more of the (residual) oil from the water phase. Suitable separators for use in the center tandem stage 306 and the other tandem stages of the separator system 300 are described at least in U.S. Patent Application Publication 20110146977 to Fielder et al., which is incorporated herein by reference in its entirety. Since the center tandem stage 306 applies a first polishing separation instead of a bulk separation, the individual separators used, such as pre-deoiler hydrocyclones, are generally smaller than the larger bulk separation hydrocyclones used in the preceding lower tandem separation stage 302. To match the output pressure and volume discharged from the lower tandem separation stage 302, the center tandem stage 306 includes enough smaller hydrocyclones in the parallel array 308 to match the incoming pressure and volume. Alternatively, a pressure regulating device 224 may be used between the lower tandem separation stage 302 and the center tandem stage 306 to match the input capacity of the center tandem stage 306 with the output pressure and volume of the lower tandem separation stage 302.

[0037] Fig. 4 shows a variation of the multi-stage downhole separation system 400, in which the center tandem stage 406 is a transfer and coalescence stage for physical phase resolution within the moving fluid instead of a separator stage. In this variation, transition tubing or another fluid chamber 408 intervenes to transfer the previously separated fluid from the lower tandem separation stage 302 to the next stage, while allowing a transit time for the water phase to coalesce, with or without the aid of a chemical injection. In this implementation, the center tandem stage 406 can be considered similar to a fluid settling area. Here the rejected water from the lower tandem separation stage 302 enters a housing where a reduction in fluid velocity slows the mixture to decrease turbulence and establish laminar flow of the phases that favors coalescence before the next separation stage. This type of center

tandem stage 406 may enable small droplets of oil in the water to coalesce with large droplets, making them more separable. Also, such a stage 406 may provide chemical agents time to work, further reducing the quantity of oil contained in very small droplets.

[0038] Returning to Fig. 3, an upper tandem separation stage 310 provides a final polishing oil-water separation and refinement. The hydrocyclones used in the parallel array 312 of the upper tandem separation stage 310 may be of a different type and geometry than those used in the center tandem stage 306 and the lower tandem separation stage 302. For example, the upper stage 310 may use more separators each having a smaller bore in the respective parallel array 312. This final polishing stage 310 may result in a discharged oil-water mixture with almost no remaining residual oil, for example less than 100 parts per million (ppm).

[0039] Multiples of the three separation stages 302 & 306 & 310 can be combined into a complete downhole oil-water separator system 300. In the tandem connections, each separation stage 302 & 306 & 310 may be constructed so that an output oil stream 314 from a previous separator stage 302 discharges into the same manifold as the output oil streams 316 & 317 of following separator stages 306 & 310. This common oil manifold 318 has the effect of always keeping the oil-rich phase of each stage away from the rejected water, which is fed into the inlets of succeeding separator stages.

[0040] A common oil (i.e., production) manifold 318 may employ pressure regulating devices when branch lines from the parallel arrays 308 & 312 join the oil manifold 318. Because of the pressure drop from one stage to the next, the second stage production stream 316 has a lower pressure than that of first production stream 314. Before production streams, 314 and 316 can be combined in the manifold 318, the pressures must be balanced, for example by one or more pressure-

balancing devices 224. A series of flow restrictors 320 & 322 can be used to equalize pressure by restricting a preceding flow along the common oil manifold 318 when a lower pressure line joins, or alternatively, a series of pumps 326 & 328 can be used to boost the pressure of succeeding oil lines that join the oil manifold 318. As described above, such pressure-balancing devices 224 can be a pump for boosting the pressure, a valve (e.g., fixed or adjustable) to provide the pressure drop for a preceding production stream 314, or a check valve combined with one or more sensors (e.g., gauges) such as flow rate sensors, pressure sensors, and oil-water concentration gauges, and so forth.

[0041] When passing from one parallel array 100 of hydrocyclones to the next, the inlet capacity of a succeeding parallel array 308 is preferably sized to match the output pressure and volume of the preceding parallel array 302. Alternatively, at least one pressure-balancing device 224 & 224' may be used for balancing the pressure losses between the different parallel arrays 302 & 306, and 306 & 310 to ensure proper flow splits.

[0042] Fig. 5 shows an example transition between separators. A water flow 502 leaves one separator and passes into the next separator, keeping separated from the oil flow. The oil phase 504 leaves one separator and flows through dedicated oil tubing to the next separator, where additional oil-phase flow will be added. A pressure loss device 506 may be included as needed to balance pressure along the oil tubing.

[0043] Fig. 6 shows another example transition between separators. A water flow 602 leaves one separator and passes into the next. The water flow 602 then enters the hydrocyclones of the uphole stage for further refinement. Oil flow 604 passes from one separator to the next. More oil phase fluid 604 is added by the uphole stage to the common oil line. A pressure loss device 606 may be included as needed

to balance pressure along the oil line, so that oil will flow in a desired direction from all parts of the system.

Example Method

[0044] Fig. 7 shows an example method 700 of constructing a multi-stage downhole oil-water separator. In the flow diagram, the operations are summarized in individual blocks.

[0045] At block 702, downhole hydrocyclones are connected in hydraulic parallel to make a parallel array stage for downhole oil-water separation.

[0046] At block 704, multiple instances of the parallel array stage are connected in hydraulic series for downhole oil-water separation.

[0047] At block 706, flow rates and fluid pressures are balanced between the multiple instances of the parallel array stage so that fluids will flow through all parts of the parallel array stages connected together in series.

Conclusion

[0048] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from the subject matter of multi-stage downhole oil-water separators. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. It is the express intention of the applicant not to invoke 35 U.S.C. § 112, paragraph 6 for any limitations of any of the claims herein,

except for those in which the claim expressly uses the words 'means for' together with an associated function.

CLAIMS

1. A system, comprising:
 - a housing insertable into a wellbore for downhole service;
 - multiple oil-water separator stages hydraulically connected in series in one or more instances of the housing;
 - each oil-water separator stage comprising a parallel array of oil-water separators hydraulically connected in parallel; and
 - at least one pressure-balancing device to control a flow of oil into a common line from each of the multiple oil-water separator stages.

2. The system of claim 1, wherein the housing is sized to fit inside a wellbore casing having an outside diameter selected from the group consisting of 4.5 inches, 5 inches, 5.5 inches, 6 and 5/8 inches, 7 inches, 7 and 5/8 inches, 8 and 5/8 inches.

3. The system of claim 1, wherein each parallel array of oil-water separators resides in a modular housing connectable to other modular housings of other parallel arrays of oil-water separators.

4. The system of claim 1, wherein a placement of each oil-water separator is staggered or interleaved in the housing with other oil-water separators to fit in the housing.

5. The system of claim 1, wherein a first quantity comprising a number of the oil-water separators in each parallel array is selected to achieve an overall flow rate of the system; and
 - wherein a second quantity comprising a number of the oil-water separator stages in the series is selected to improve a quality or a purity of an output oil or of an output water.

6. The system of claim 1, further comprising three oil-water separator stages hydraulically connected in series;

a first stage of the three oil-water separator stages including a parallel array of oil-water separators providing a bulk separation of the oil and the water; and

a third stage of the three oil-water separator stages including a parallel array of oil-water separators matched to receive an outflow from a previous separation stage, to provide a polishing separation of the oil, and to provide substantially clean water.

7. The system of claim 6, further comprising a second stage of the three oil-water separator stages including a parallel array of oil-water separators providing an additional separation of the oil and the water.

8. The system of claim 6, further comprising a second stage of the three oil-water separator stages including a transfer chamber between the first stage and the third stage for droplets of the oil to coalesce.

9. A downhole oil-water separation apparatus, comprising:

a housing to fit downhole in a well casing;

multi-parallel hydrocyclone separators, each multi-parallel hydrocyclone separator including individual hydrocyclones situated in the housing and fluidly connected in parallel;

a series array of the multi-parallel hydrocyclone separators situated in the housing and fluidly connected in series; and

at least a flow-balancing device to control a pressure of a fluid flow between the multi-parallel hydrocyclone separators in the series.

10. The downhole oil-water separator of claim 9, wherein a placement of each hydrocyclone separator is staggered or interleaved with respect to other hydrocyclone separators to fit in the housing.

11. The downhole oil-water separator of claim 9, wherein the housing comprises a modular housing section for each multi-parallel hydrocyclone separator including individual hydrocyclones situated in the modular housing section and fluidly connected in parallel.

12. The downhole oil-water separator of claim 9, further comprising three multi-parallel hydrocyclone separators in the series array and fluidly connected in series;

a first multi-parallel hydrocyclone separator in the series array including a parallel array of hydrocyclones providing a bulk separation of the oil and the water;

a second multi-parallel hydrocyclone separator in the series array including a parallel array of hydrocyclones providing an additional separation of the oil and the water; and

a third multi-parallel hydrocyclone separator in the series array including a parallel array of hydrocyclones providing a final polishing separation of the oil and substantially clean water.

13. The downhole oil-water separator of claim 12, further comprising at least one transfer tube between the first multi-parallel hydrocyclone separator in the series array and the third multi-parallel hydrocyclone separator in the series array for droplets of the oil to coalesce or for a chemical injection to encourage the droplets of the oil to coalesce.

14. The downhole oil-water separator of claim 12, wherein for each successive multi-parallel hydrocyclone separator in the series array, the number of individual hydrocyclones increases to maintain a flow through the series array while the bore size of each individual hydrocyclone decreases to apply a more refined separation of the oil and the water.

15. A method, comprising:

connecting downhole hydrocyclones in hydraulic parallel to construct a parallel array stage for downhole oil-water separation;

connecting multiple instances of the parallel array stage in hydraulic series for the downhole oil-water separation; and

balancing flow rates and fluid pressures between the multiple instances of the parallel array stages in hydraulic series.

16. The method of claim 15, further comprising controlling a flow between the multiple parallel array stages to match output and inlet pressures between the multiple parallel array stages.

17. The method of claim 15, further comprising collecting an oil from the downhole oil-water separation in a common oil manifold between the multiple parallel array stages; and

maintaining the common oil manifold in separation from a flow of a water or a flow of an oil-water mixture.

18. The method of claim 15, wherein connecting the multiple parallel array stages in hydraulic series for the downhole oil-water separation further comprises:

connecting a first parallel array stage in the hydraulic series to provide a bulk separation of the oil and the water;

connecting a second parallel array stage in the hydraulic series to provide an additional separation of the oil and the water; and

connecting a third parallel array stage in the hydraulic series to provide a final polishing separation of the oil and the water.

19. The method of claim 15, further comprising connecting the downhole hydrocyclones into a network of separators;

balancing pressures of each flow split in the network to maintain an overall flow through the network; and

placing different types of downhole hydrocyclones in the network to refine an input mixture of oil and water through a bulk separation stage and through successive separation refinement stages.

20. The method of claim 19, further comprising collecting an oil production from the downhole hydrocyclones in a common oil manifold having an oil flow separate from the overall flow through the network.

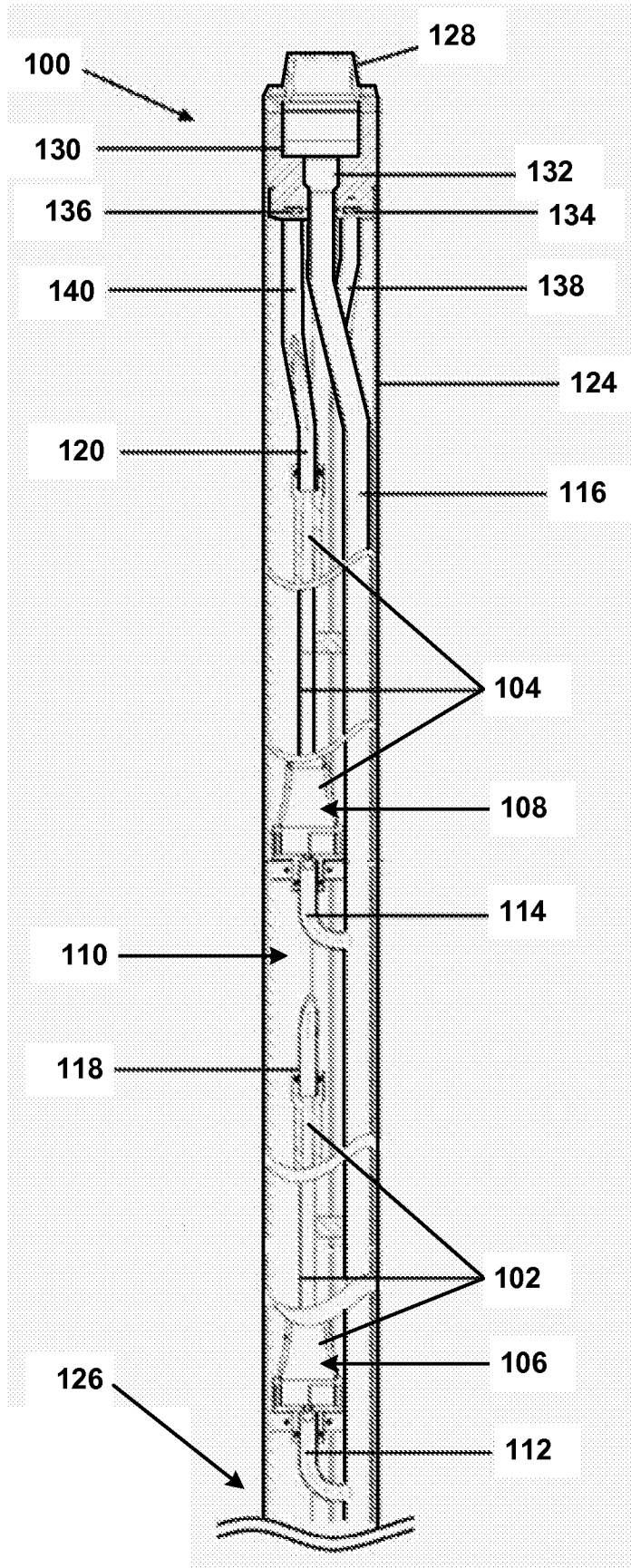


FIG. 1

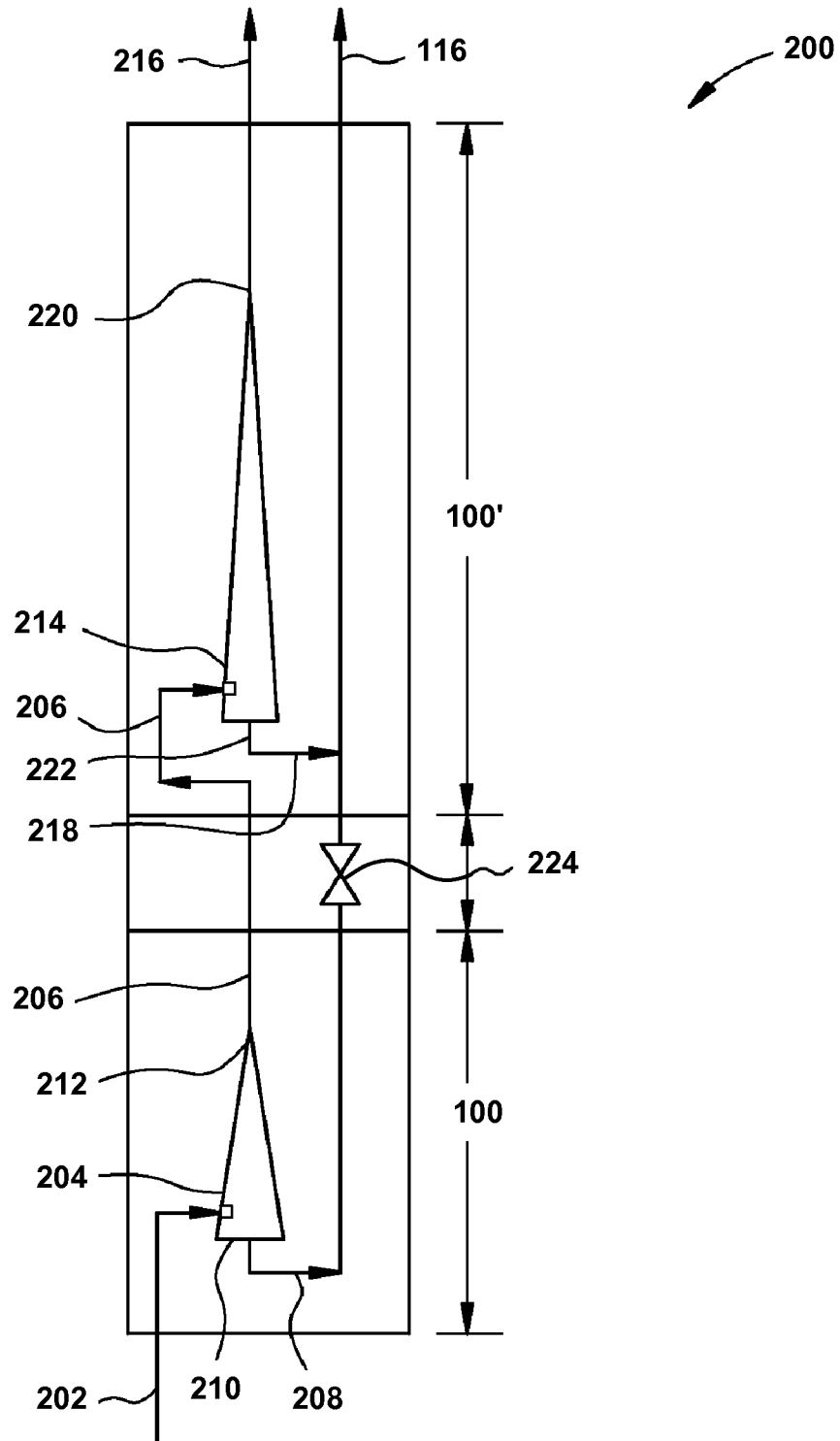


FIG. 2

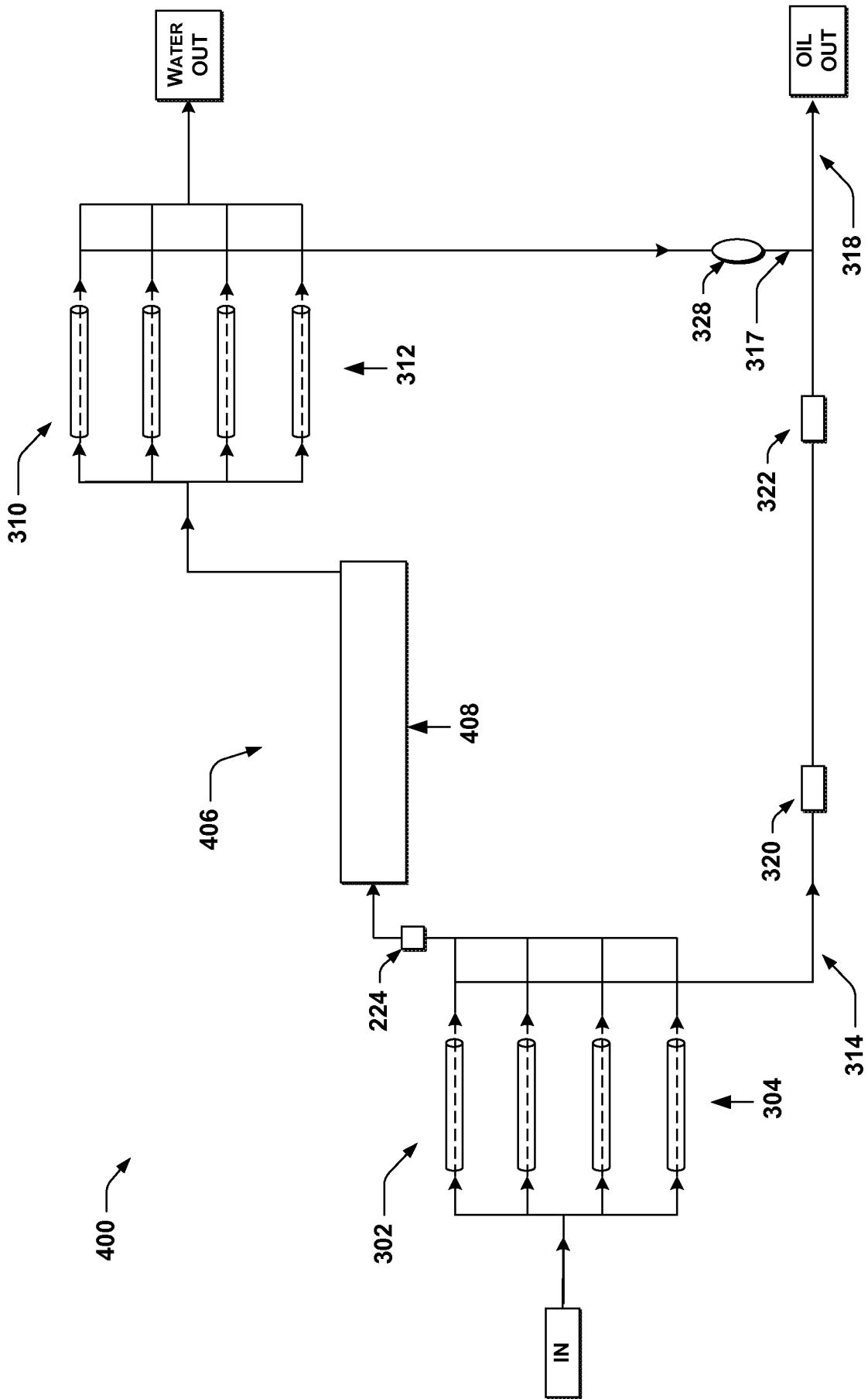


FIG. 4

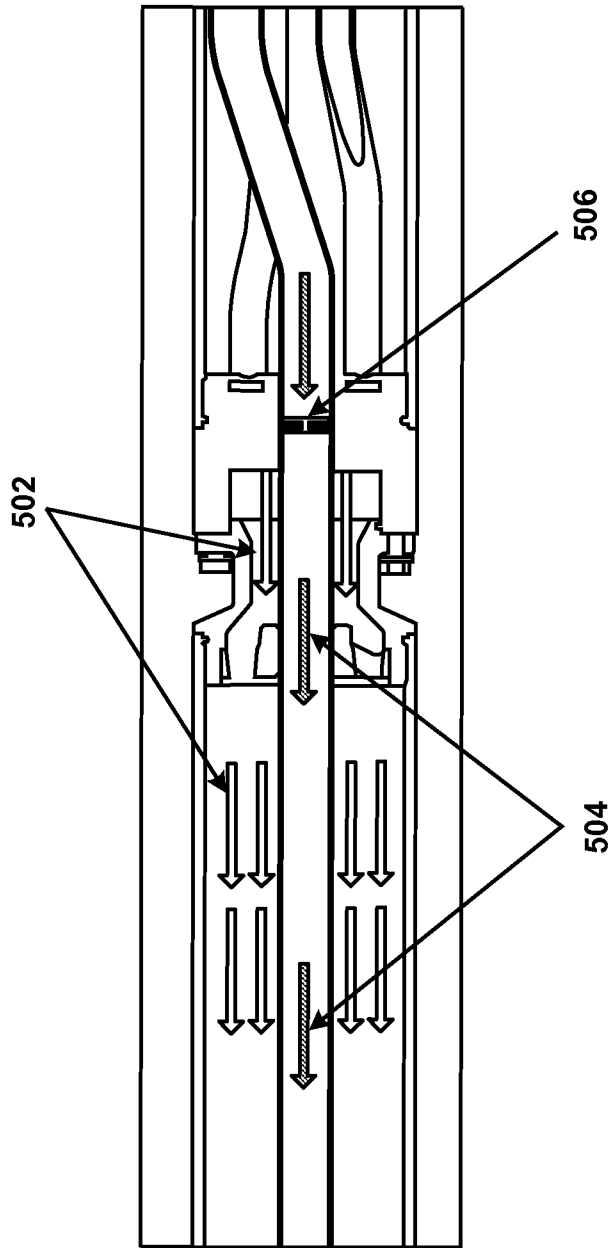


FIG. 5

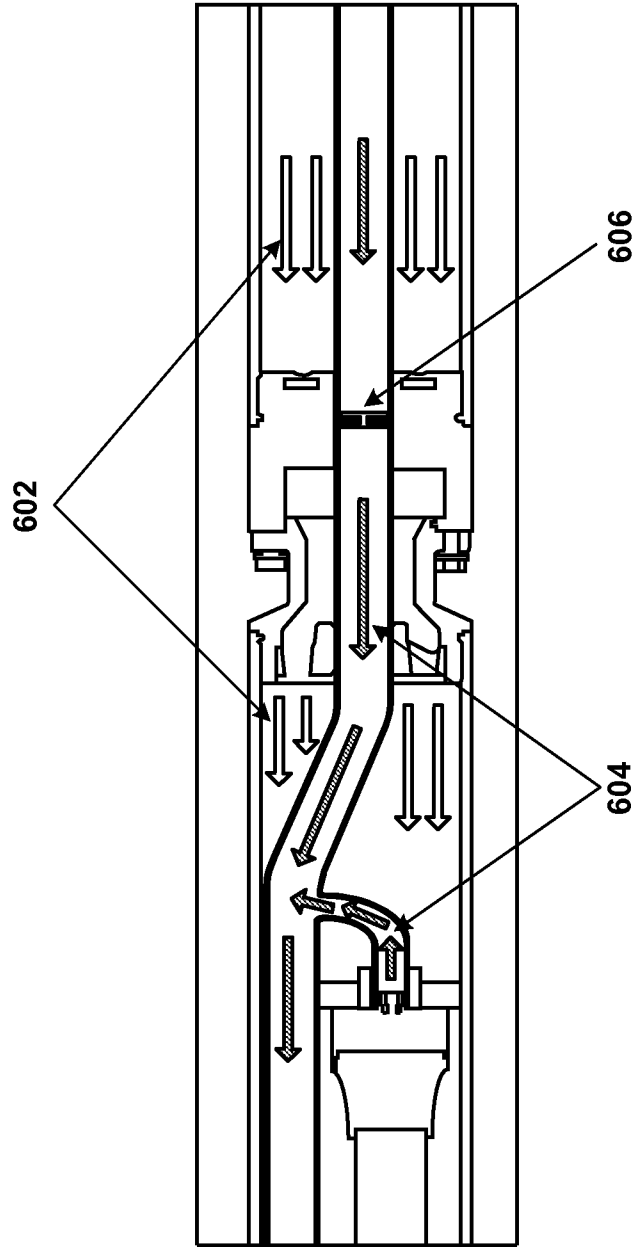


FIG. 6

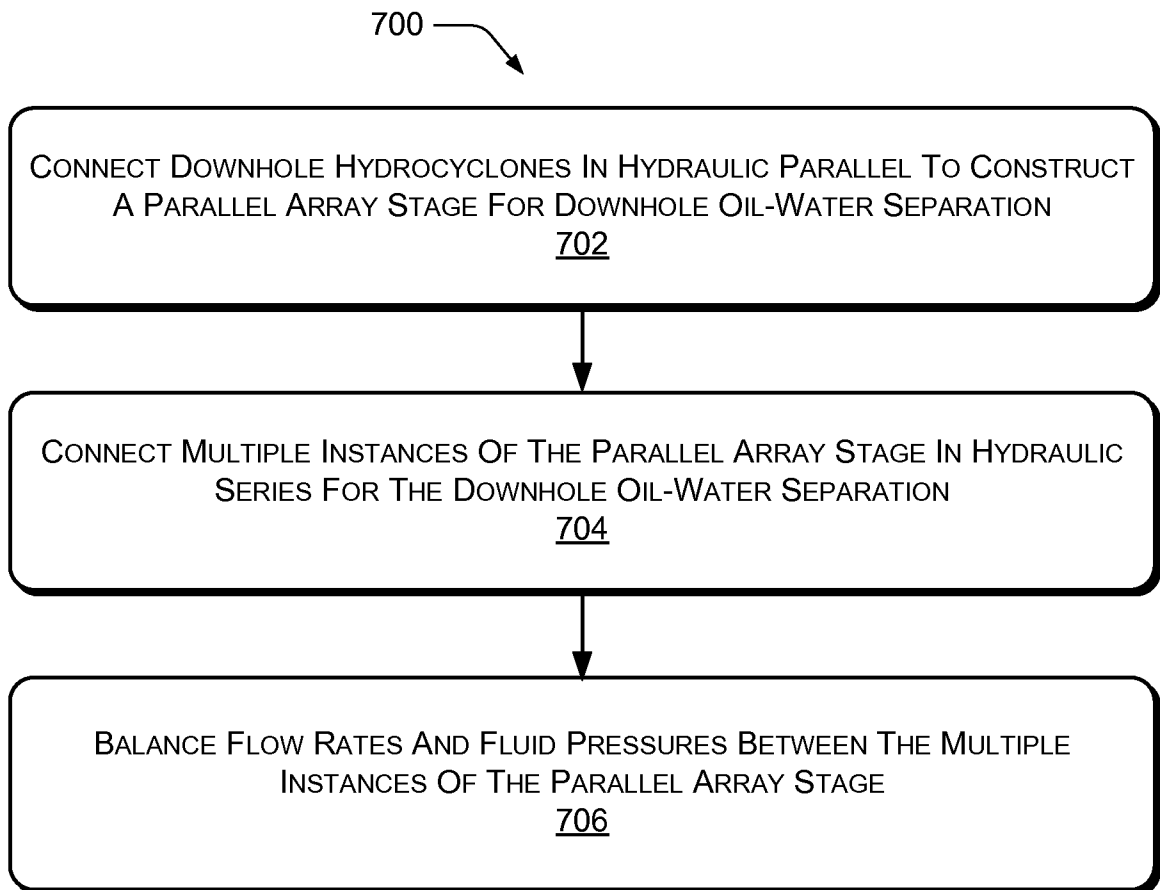


FIG. 7

A. CLASSIFICATION OF SUBJECT MATTER**B01D 17/038(2006.01)i, B04C 5/28(2006.01)i, E21B 43/34(2006.01)i**

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)

B01D 17/038; B01D 21/26; B04C 5/28; E21B 43/00; E21B 43/48; E21B 43/38; B01D 17/02; E21B 43/34

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords:separator, parallel, series, array, pressure-balance, wellbore, downhole

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011-0146977 A1 (FIELDER, L. I. et al.) 23 June 2011 See abstract; paragraphs [0020]-[0025] and figure 1.	1-20
A	WO 03-062597 A1 (KVAERNER OILFIELD PRODUCTS AS) 31 July 2003 See abstract; pages 8, 10, 14, 15; and figure 1.	1-20
A	US 5693225 A (LEE, L. C.) 02 December 1997 See abstract; claim 1; column 2; and figure 2.	1-20
A	US 6627081 B1 (HILDITCH, M. et al.) 30 September 2003 See abstract; columns 3-5; and figures 1, 2.	1-20
A	US 8261821 B2 (HACKWORTH, M. et al.) 11 September 2012 See abstract; claims 1, 8; and figure 1A.	1-20

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

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"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

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"&" document member of the same patent family


Date of the actual completion of the international search

04 July 2014 (04.07.2014)

Date of mailing of the international search report

07 July 2014 (07.07.2014)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2014/027501

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