

HIGH EFFICIENCY PHASE SPLITTER

BACKGROUND OF THE INVENTION

The present invention relates to an apparatus for separating a multiphase fluid, such as a mixture of oil and gas, into its constituent heavy and light phases.

5 In particular, the invention relates to a phase splitter which includes a core stabilizer for inhibiting the light phase from exiting through the heavy phase outlet in the event of fluctuations in the multiphase fluid stream.

Phase splitters are used in the hydrocarbon production industry to separate multiphase fluid streams into their different fractions or phases. For example, phase splitters are commonly used to separate the production fluid from a hydrocarbon well into separate streams of oil and gas so that these constituents can be transported and processed separately. These phase splitters operate by rotating the multiphase fluid to create centrifugal forces which cause the heavy phase to move toward the radially outer region of the fluid stream and the light phase to form a core in the radially inner region of the fluid stream.

15 In prior art phase splitters, fluctuations in the flow of the multiphase fluid stream may cause the light phase core to become unstable. This instability can be particularly severe near the distal end of the light phase core and can result in an undesirably large quantity of the light phase exiting the phase splitter through the heavy phase outlet. As a result, the separation efficiency of the phase splitter is greatly reduced.

SUMMARY OF THE INVENTION

These and other limitations in the prior art are overcome by providing an apparatus for separating a multiphase fluid into a relatively light phase and a relatively heavy phase, the apparatus comprising a separator tube which comprises a fluid inlet through which the multiphase fluid enters the apparatus, a heavy phase outlet through which the heavy phase exits the apparatus and an inner diameter surface which defines a flow bore that extends between the fluid inlet and the heavy phase outlet; a swirl element which is positioned in the flow bore downstream of the fluid inlet and which causes the multiphase fluid to rotate and separate the heavy phase from the light phase, the light phase forming an elongated core which extends axially through the flow bore radially inwardly of the heavy phase from proximate the swirl element toward the heavy phase outlet; a discharge channel through which the light phase exits the apparatus, the

discharge channel being fluidly connected to a radially inner region of the flow bore; and a core stabilizer which is positioned in the flow bore between the swirl element and the heavy phase outlet and which engages the distal end of the light phase core to thereby inhibit the light phase from exiting the apparatus through
5 the heavy phase outlet.

In accordance with one embodiment of the invention, the core stabilizer comprises a cylindrical body which is positioned coaxially within the separator tube and the body comprises a cavity which includes an upstream opening, a downstream end and an inner surface which converges radially inwardly from the
10 upstream opening to the downstream end. The inner surface may converge generally linearly from the upstream opening to the downstream end. For example, the inner surface may converge at an angle of between about 15° and about 45°. More preferably, the inner surface may converge at an angle of between about 25° and about 35°.

15 In this embodiment of the invention, the body may comprise an outer diameter which is between about 65% and about 85% of the inner diameter of the separator tube. In addition, the upstream opening may comprise a diameter which is between about 50% and about 70% of the inner diameter of the separator tube. Furthermore, the cavity may comprise an axial length from the
20 upstream opening to the downstream end which is between about 100% and 150% of the diameter of the upstream opening. Also, the axial distance between the downstream end of the swirl element and the upstream opening of the cavity is between about 4 times and about 5 times the inner diameter of the separator tube.

25 In accordance with another embodiment of the invention, the body may be supported in the separator tube by a support ring which comprises a number of axial holes through which the heavy phase flows. Alternatively, the body may be supported in the separator tube by a number of radial fins which extend between the body and the separator tube.

30 In accordance with yet another embodiment of the invention, the discharge channel may extend axially through the swirl element and comprise a discharge opening in the downstream end of the swirl element.

In accordance with an alternative embodiment of the invention, the apparatus comprises a discharge body which is positioned coaxially within the

separator tube and includes a cylindrical portion, a conical portion which comprises a base that is attached to or formed integrally with an upstream end of the cylindrical portion, and a radial shoulder which is formed between the conical portion and the cylindrical portion, wherein the core stabilizer comprises the radial
5 shoulder.

In this embodiment of the invention, the cylindrical portion may comprise an outer diameter which is between about 70% and about 90% of the inner diameter of the separator tube. In addition, the radial shoulder may comprise a radius which is between about 6% and about 18% of the outer diameter of the
10 cylindrical portion. Furthermore, the radial shoulder may comprise a radius which is between about 10% and about 22% of the outer diameter of the base of the conical portion. Also, the axial distance between the downstream end of the swirl element and the radial shoulder may be between about 4 times and about 5 times the inner diameter of the separator tube.

In accordance with still another embodiment of the invention, the discharge channel extends axially through the discharge body and comprises a discharge opening in the upstream end of the conical portion. In this embodiment, the axial distance between the downstream end of the swirl element and the discharge opening may be between about 2 times and 3 times the inner
15 diameter of the separator tube. In addition, the axial length of the conical portion may be between about 2 times and 3 times the inner diameter of the separator tube.

Thus, the present invention provides a core stabilizer which engages the distal end of the light phase core and inhibits the light phase from exiting the
25 separator tube through the heavy phase outlet even under the influence of fluctuations in the flow of multiphase fluid through the fluid inlet. As a result, the separation efficiency of the phase splitter is greatly improved.

These and other objects and advantages of the present invention will be made apparent from the following detailed description, with reference to the
30 accompanying drawings. In the drawings, the same reference numbers may be used to denote similar components in the various embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross sectional representation of a phase splitter in accordance with one embodiment of the present invention;

Figure 1A is an enlarged view of a portion of the phase splitter of Figure 1 showing more clearly the core stabilizer component of this embodiment of the invention;

Figure 2 is an illustration obtained from a computational fluid dynamics simulation of the phase splitter shown in Figure 1;

Figure 3 is an illustration obtained from a computational fluid dynamics simulation of a phase splitter similar to the phase splitter of Figure 1 but without the core stabilizer component of the invention;

Figure 4 is a cross sectional representation of a phase splitter in accordance with another embodiment of the present invention;

Figure 4A is an enlarged view of a portion of the phase splitter of Figure 4 showing more clearly the core stabilizer component of this embodiment of the invention;

Figure 5 is an illustration obtained from a computational fluid dynamics simulation of the phase splitter shown in Figure 4; and

Figure 6 is an illustration obtained from a computational fluid dynamics simulation of a phase splitter similar to the phase splitter of Figure 4 but without the core stabilizer component of the invention;

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a phase splitter for separating out the individual phases of a multiphase fluid. In the hydrocarbon production industry, for example, the fluid produced from a subterranean well may comprise a mixture of a relatively light phase such as gas and a relatively heavy phase such as oil. In this situation, a common objective is to separate the gas from the oil so that these separate phases may be transported and processed separately. Although the invention can be used with a number of multiphase fluids and in a variety of industries, for purposes of simplicity it will be described herein in the context of a device for separating gas from oil.

Referring to Figure 1, one embodiment of a phase splitter in accordance with the present invention, which is indicated generally by reference number 10, is shown to comprise an elongated separator tube 12 which includes a first or upstream end 14, a second or downstream end 16 and an inner diameter surface 18 which defines a flow bore 20 that extends between the first and second ends. In use, the first and second ends 14, 16 may be connected to corresponding

sections of a pipeline which is connected to, e.g., a hydrocarbon production facility.

In this embodiment of the invention, the multiphase fluid (represented by the arrow A) enters the separator tube 12 through a fluid inlet 22 which is located in the first end 14, the relatively heavy phase (represented by the arrow B) exits the separator tube through a heavy phase outlet 24 which is located in the second end 16, and the relatively light phase (represented by the arrow C) exits the separator tube through a discharge channel 26 which in this illustrative embodiment of the invention extends through a discharge pipe 28. As shown in Figure 1, the discharge pipe 28 includes a first section 30 which extends axially through the flow bore 20 and a second section 32 which extends transversely through the separator tube 12. The discharge pipe 28 may be supported in the separator tube 12 by a gland nut 34 which is threaded into a collar 36 that is attached such as by welding to the separator tube.

The phase splitter 10 also includes a swirl element 38 which is positioned in the flow bore 20 downstream of the fluid inlet 22. In the embodiment of the invention shown in Figure 1, the swirl element 38 is mounted in the flow tube 12 and is connected to the upstream end of the discharge pipe 28. As is well understood in the art, the swirl element 38 sets the multiphase fluid into rotation, and the resulting centrifugal forces acting on the multiphase fluid cause the heavy phase to move to the radially outer region of the flow bore 20 and the light phase to move to the radially inner region of the flow bore. The light phase will thus form an elongated core 40 which extends axially through the flow bore radially inwardly of the heavy phase from proximate the swirl element 38 toward the heavy phase outlet 24. The light phase exits the flow bore 20 through the discharge channel 26, which in this embodiment of the invention extends axially through the swirl element 38 to a discharge opening 42 in the downstream end of the swirl element.

In prior art phase splitters, fluctuations in the flow of multiphase fluid through the fluid inlet 22 may cause the light phase core to become unstable. This instability can be particularly severe near the distal end of the light phase core, i.e., the end of the light phase core closest to the heavy phase outlet 24, and can result in an undesirably large quantity of the light phase exiting the separator tube through the heavy phase outlet 24.

According to the present invention, the phase splitter 10 includes a core stabilizer for stabilizing the light phase core 40. The core stabilizer, two exemplary embodiments of which will be described below, is positioned in the flow bore 20 between the swirl element 38 and the heavy phase outlet 24. In operation of the phase splitter 10, the core stabilizer engages the distal end of the light phase core and inhibits the light phase from exiting the separator tube 12 through the heavy phase outlet 24 even under the influence of fluctuations in the flow of multiphase fluid through the fluid inlet 22. As a result, the separation efficiency of the phase splitter is greatly improved.

In the embodiment of the invention shown in Figures 1 and 1A, the core stabilizer, generally 44, is shown to comprise a cylindrical stabilizer body 46 which is positioned coaxially within the separator tube 12 and includes a cavity 48 that extends partially therethrough. The cavity 48 comprises an upstream opening 50, a downstream end 52 and an inner surface 54 which converges radially inwardly from the upstream opening to the downstream end. In the embodiment of the core stabilizer 44 shown in Figures 1 and 1A, the inner surface 54 converges generally linearly from the upstream opening to the downstream end. For example, the inner surface 54 may converge at an angle α of between about 15° and about 45°. More preferably, the inner surface 54 may converge at an angle α of between about 25° and about 35°. Alternatively, the inner surface 54 may converge non-linearly so as to provide the cavity 48 with, e.g., a hemispherical or parabolic shape, among others.

The dimensions of the cavity 48 and the distance of the stabilizer body 46 from the swirl element 38 depend on the flow rate of the multiphase fluid entering the phase splitter 10 and the approximate percentage of light phase in the multiphase fluid. Although the ideal dimensions of the cavity 48 and distance of the stabilizer body 46 from the swirl element 38 may be determined empirically for a given separation application, the inventors have discovered that for most applications they may be determined using the following relationships. The inner diameter D_t of the separator tube 12 depends in large part on the flow rate of the multiphase fluid entering the phase splitter 12. Once the inner diameter D_t of the separator tube 12 is determined, the outer diameter D_b of the stabilizer body 46 may be chosen to be between about 65% and about 85% of the inner diameter D_t , the diameter D_c of the upstream opening 50 of the cavity 48 may be chosen to

be between about 50% and about 70% of the inner diameter D_t , and the axial length L_c of cavity from the upstream opening to the downstream end 52 may be chosen to be between about 100% and 150% of the diameter D_c of the upstream opening. In addition, the axial distance L between the downstream end of the swirl element 38 and the upstream opening 50 of the cavity 48 may be chosen to be between about 4 times and about 5 times the inner diameter D_t of the separator tube.

The stabilizer body 46 may be supported in the separator tube 12 by any suitable means. In the embodiment of the invention shown in Figures 1 and 1A, for example, the stabilizer body 46 is supported in the separator tube 12 by a support ring 56 which comprises a number of axial holes 58 through which the heavy phase may flow. Alternatively, the stabilizer body 46 may be supported in the separator tube 12 by a number of radial fins which extend between the body and the separator tube.

The effect that the core stabilizer 44 has on the light phase core 40 can be seen by comparing Figure 2 with Figure 3. Figure 2 is an illustration obtained from a computational fluid dynamics ("CFD") simulation of the phase splitter 10. As shown in Figure 2, the core stabilizer 44 engages the distal end of the light phase core 40 and prevents the light phase from exiting the separator tube 12 through the heavy phase outlet 24. By comparison, Figure 3 is an illustration obtained from a CFD simulation of a phase splitter similar to the phase splitter 10 but without the core stabilizer 44. As is apparent from Figure 3, the distal end of the light phase core 40 is unrestrained. As a result, a significant percentage of the light phase is permitted to exit the separator tube through the heavy phase outlet.

Another embodiment of a phase splitter in accordance with the present invention is shown in Figures 4 and 4A. The phase splitter of this embodiment of the invention, generally 100, is similar to the phase splitter 10 described above in that it comprises an elongated separator tube 12 which includes a first or upstream end 14, a second or downstream end 16 and an inner diameter surface 18 which defines a flow bore 20 that extends between the first and second ends.

In this embodiment, the multiphase fluid (represented by the arrow A) enters the separator tube 12 through a fluid inlet 22 which is located in the first end 14, the relatively heavy phase (represented by the arrow B) exits the

separator tube through a heavy phase outlet 24 which is located in the second end 16, and the relatively light phase (represented by the arrow C) exits the separator tube through a discharge channel 26 which extends through a discharge body 102. The discharge body 102 is positioned coaxially within the separator tube and includes a cylindrical portion 104, a conical portion 106 which comprises a base that is attached to or formed integrally with an upstream end of the cylindrical portion, and a outlet portion 108 which extends transversely from the downstream end of the cylindrical portion through the separator tube 12. The discharge body 102 may be supported in the separator tube 12 by a gland nut 110 which is threaded into a collar 112 that is attached such as by welding to the separator tube.

The phase splitter 100 also includes a swirl element 38 which is positioned in the flow bore 20 downstream of the fluid inlet 22. As in the prior embodiment, the swirl element 38 sets the multiphase fluid into rotation, and the resulting centrifugal forces acting on the multiphase fluid cause the heavy phase to move to the radially outer region of the flow bore 20 and the light phase to move to the radially inner region of the flow bore. The light phase thus forms an elongated core 40 which extends axially through the flow bore radially inwardly of the heavy phase from proximate the swirl element 38 toward the heavy phase outlet 24. The light phase exits the flow bore 20 through the discharge channel 26, which in this embodiment of the invention includes a discharge opening 114 in the upstream end of the conical portion 106.

In this embodiment of the invention, the cylindrical portion 104 of the discharge body 102 comprises a diameter D_1 , the base of the conical portion 106 of the discharge body comprises a diameter D_2 which is smaller than the diameter D_1 , and the core stabilizer comprises a radial shoulder 116 which is formed between the cylindrical portion and the base of the conical portion.

As with the previous embodiment, the size of the core stabilizer 116 and the axial spacing of the core stabilizer and the other components of the flow body 102 from the swirl element 38 depend on the flow rate of the multiphase fluid entering the phase splitter 100 and the approximate percentage of light phase in the multiphase fluid. Although these dimensions may be determined empirically for a given separation application, the inventors have discovered that for most applications the cylindrical portion 104 may comprise a diameter D_1 which is

between about 70% and about 90% of the inner diameter D_t of the separator tube 12 and the core stabilizer 116 may comprise a radius R which is between about 6% and about 18% of the diameter D_1 of the cylindrical portion. In addition, the radius R of the core stabilizer 116 may be between about 10% and about 22% of the outer diameter D_2 of the base of the conical portion 106.

Furthermore, the axial distance L_1 between the downstream end of the swirl element 38 and the core stabilizer 116 may be between about 4 times and about 5 times the inner diameter of the separator tube, the axial distance L_2 between the downstream end of the swirl element and the discharge opening 114 may be between about 2 times and 3 times the inner diameter of the separator tube 12, and the axial length L_3 of the conical portion 106 may be between about 2 times and 3 times the inner diameter of the separator tube.

The effect that the core stabilizer of this embodiment of the invention has on the light phase core 40 can be seen by comparing Figure 5 with Figure 6. Figure 5 is an illustration obtained from a CFD simulation of the phase splitter 100. As shown in Figure 5, the core stabilizer 116 engages the distal end of the light phase core 40 and prevents the light phase from exiting the separator tube 12 through the heavy phase outlet 24. By comparison, Figure 6 is an illustration obtained from a CFD simulation of a phase splitter similar to the phase splitter 100 but without the core stabilizer 116. As is apparent from Figure 6, the distal end of the light phase core 40 is unrestrained. As a result, a significant percentage of the light phase is permitted to exit the separator tube 12 through the heavy phase outlet.

It should be recognized that, while the present invention has been described in relation to the preferred embodiments thereof, those skilled in the art may develop a wide variation of structural and operational details without departing from the principles of the invention. Therefore, the appended claims are to be construed to cover all equivalents falling within the true scope and spirit of the invention.

What is Claimed is:

1. An apparatus for separating a multiphase fluid into a relatively light phase and a relatively heavy phase, the apparatus comprising:
 - a separator tube which comprises a fluid inlet through which the
 - 5 multiphase fluid enters the apparatus, a heavy phase outlet through which the heavy phase exits the apparatus and an inner diameter surface which defines a flow bore that extends between the fluid inlet and the heavy phase outlet;
 - a swirl element which is positioned in the flow bore downstream of the fluid inlet and which causes the multiphase fluid to rotate and separate the
 - 10 heavy phase from the light phase, the light phase forming an elongated core which extends axially through the flow bore radially inwardly of the heavy phase from proximate the swirl element toward the heavy phase outlet;
 - a discharge channel through which the light phase exits the apparatus, the discharge channel being fluidly connected to a radially inner
 - 15 region of the flow bore; and
 - a core stabilizer which is positioned in the flow bore between the swirl element and the heavy phase outlet and which engages the distal end of the light phase core to thereby inhibit the light phase from exiting the apparatus through the heavy phase outlet.
- 20 2. The apparatus of claim 1, wherein the core stabilizer comprises a cylindrical body which is positioned coaxially within the separator tube, the body comprising a cavity which includes an upstream opening, a downstream end and an inner surface which converges radially inwardly from the upstream opening to the downstream end.
- 25 3. The apparatus of claim 2, wherein the inner surface converges generally linearly from the upstream opening to the downstream end.
4. The apparatus of claim 3, wherein the inner surface converges at an angle of between about 15° and about 45°.
5. The apparatus of claim 4, wherein the inner surface converges at
- 30 an angle of between about 25° and about 35°.
6. The apparatus of claim 2, wherein the body comprises an outer diameter which is between about 65% and about 85% of the inner diameter of the separator tube.

7. The apparatus of claim 2, wherein the upstream opening comprises a diameter which is between about 50% and about 70% of the inner diameter of the separator tube.

5 8. The apparatus of claim 2, wherein the cavity comprises an axial length from the upstream opening to the downstream end which is between about 100% and 150% of the diameter of the upstream opening.

9. The apparatus of claim 2, wherein the axial distance between the downstream end of the swirl element and the upstream opening of the cavity is between about 4 times and about 5 times the inner diameter of the separator
10 tube.

10. The apparatus of claim 2, wherein the body is supported in the separator tube by a support ring which comprises a number of axial holes through which the heavy phase flows.

11. The apparatus of claim 2, wherein the body is supported in the
15 separator tube by a number of radial fins which extend between the body and the separator tube.

12. The apparatus of claim 2, wherein the discharge channel extends axially through the swirl element and comprises a discharge opening in the downstream end of the swirl element.

20 13. The apparatus of claim 2, further comprising a discharge body which is positioned coaxially within the separator tube and which includes a cylindrical portion, a conical portion which comprises a base that is attached to or formed integrally with an upstream end of the cylindrical portion, and a radial shoulder which is formed between the conical portion and the cylindrical portion,
25 wherein the core stabilizer comprises the radial shoulder.

14. The apparatus of claim 13, wherein the cylindrical portion comprises an outer diameter which is between about 70% and about 90% of the inner diameter of the separator tube.

15. The apparatus of claim 14, wherein the radial shoulder comprises a
30 radius which is between about 6% and about 18% of the outer diameter of the cylindrical portion.

16. The apparatus of claim 14, wherein the radial shoulder comprises a radius which is between about 10% and about 22% of the outer diameter of the base of the conical portion.

17. The apparatus of claim 13, wherein the axial distance between the downstream end of the swirl element and the radial shoulder is between about 4 times and about 5 times the inner diameter of the separator tube.

18. The apparatus of claim 13, wherein the discharge channel extends
5 axially through the discharge body and comprises a discharge opening in the upstream end of the conical portion.

19. The apparatus of claim 18, wherein the axial distance between the downstream end of the swirl element and the discharge opening is between about 2 times and 3 times the inner diameter of the separator tube.

20. The apparatus of claim 19, wherein the axial length of the conical
10 portion is between about 2 times and 3 times the inner diameter of the separator tube.