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HYDROCYCLONE FOR SEPARATING IMMISCIBLE
FLUIDS AND REMOVING SUSPENDED SOLIDS

Technical Field

This invention relates to a cyclone separator. It relates more particularly to a hydrocyclone for separating immiscible fluids, e.g. oil and water, and removing suspended solids, as well as a method for carrying out such separation.

Background Art

In heavy oil production, it is commonplace for fluids produced at the well head to contain in excess of 70 percent by volume of water, as well as varying amounts of suspended solids. In order to transport and process the oil and safely dispose of or recycle the water, it is necessary to separate these components in an efficient manner.

A variety of different cyclone separators have been developed for this purpose. For instance, Thew et al. U.S. Patent 5,017,288 describes a cyclone separator for removing oil from water having a first cylindrical section or involute followed by a pair of converging funnel shaped sections. The oil is removed through an overflow outlet at a closed end of the cylindrical section, while the water travels down the funnel shaped sections.

Kuryluk U.S. Patent 5,564,574 describes a separator for separating materials of different specific gravities, including materials of non-uniform size. That system employs a rotating agitator as a primary means of imparting rotational energy to the materials being processed. It also depends on separate injection of water and separate chambers for mixing and dilution.

It is the object of the present invention to provide a hydrocyclone which provides improved separation of oil and water, while also being capable of removing solids.



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Disclosure of the Invention

An important aspect of this invention is the design of the involute, which makes the hydrocyclone of this invention traditional hydrocyclones. The involute is, of course, the most critical area of the hydrocyclone. Firstly, the hydrocyclone of this invention has an involute that is substantially longer than that of conventional hydrocyclone. Secondly, it uses a plurality of radially balanced feed injection ports into the involute. These are arranged so that all separation of the immiscible fluids, e.g. oil and water, occurs in the involute which is the area of highest G-forces. The result is the formation of an axial low density phase which is very stable and is essentially in the form of a straight reverse axial fluid plug flow. This makes possible an exceptionally clean separation between the oil and water.

Accordingly, one aspect of the present invention relates to a cyclone separator comprising a generally cylindrical first portion or involute with an open end and a closed end. A generally axial overflow outlet is provided in the closed end. The separator includes at least two radially balanced feed injection ports in the cylindrical first portion or involute adjacent to closed end thereof. A converging tapered second section with open ends is axially flow connected to the open end of the cylindrical first portion and preferably a converging tapered third portion with open ends is axially flow connected to the tapered second portion. A fourth generally cylindrical portion preferably is axially flow connected to the third tapered portion.

An important part of the invention relates to the number and arrangement of the feed injection ports. These are located in the involute adjacent the closed end thereof and are tangentially mounted so as to provide a rapidly rotating vortex under low-shear conditions. The importance of the injection ports has

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not previously been understood. For instance, in U.S. Patent 4,722,726, two feed injection ports were used. In U.S. Patent 5,017,288, there is reference to the above patent and there is also the statement "it was
5 found that one inlet or more than two inlets could be used". This indicates that the inventors saw no significance in the number of injection ports.

However, it has now been found that by using a plurality of these injection ports together with a
10 lengthened involute, a superior separation is achieved. Particularly good results are obtained when at least four radially balanced feed injection ports are used. These are arranged as pairs of diametrically opposite ports so that, for instance, it is also possible to use
15 six or eight diametrically opposite ports depending on the size of the involute.

Through detailed studies of the flow patterns, it was found that when only one feed injection port was used the low density core that was formed in the
20 involute exhibited a generally spiral or corkscrew configuration. There were some improvements in the low density core when two or three injection ports were used, but a dramatic improvement took place when four injection ports were used arranged as two pairs of
25 diametrically opposed ports. The balanced propulsion forces generated provide improved stability of the resulting vortex, reduced turbulent energy loss and enhanced separation efficiency.

It will be appreciated that since the actual
30 separation of the immiscible fluids takes place by discharging the low density core out through the axial overflow outlet, there is great advantage in having the low density core in the form of a straight axial core with a sharp interface between it and the surrounding
35 higher density fluid. In this way the low density core is able to pass through the overflow outlet while entraining a minimum amount of surrounding high density fluid. It is this superior separation that is obtained

when using at least four injection ports together with the longer involute.

The required length for the involute is easily determined when the concept is understood. An experimental unit may be used having a transparent involute. A dye is added to the fluid mixture with the result that the separated lower density phase can be observed within the higher density phase. If the involute is too short, the axial lower density core does not form in the involute. On the other hand, when the involute has sufficient length the axial lower density core can be clearly observed as a core extending the length of the involute and passing through the axial overflow outlet.

According to a further feature of this invention, the size of the axial overflow outlet may be varied. This can be achieved by providing a movable member in association with the overflow outlet having a plurality of orifices of progressively smaller diameter than the overflow outlet. This movable member may be moved such that any selected one of the plurality of orifices may be axially aligned with the overflow outlet.

This multiple orifice system comprises a plurality of orifices of different diameters in a plate which is movably mounted on the end of the cylindrical first portion. Preferably, this plate is rotatably mounted such that it can be actuated by a powered assembly.

This adjustable overflow outlet has important advantages in commercial operations. Thus, the fluids being separated may be quite variable in concentrations. For instance, it may change from oil content of 10% to an oil content of 20%. The only way that the system can adapt for this is to increase the size of the overflow outlet. Otherwise, much of the oil remains with the water. With the variable size overflow outlet of the invention, this outlet size can be adjusted either manually or automatically based on the composition of the fluids being separated.

Because of the very efficient separation of immiscible fluids that is possible according to this invention, it is capable of use in a great variety of situations. Thus, it is capable of removing very small quantities of oil, e.g. 1 to 2%, from water and it is able to separate very difficult fluid mixtures. For instance, it may be used to separate oil which is emulsified with very small droplet sizes and has also separated fluids having density differences of as little as 0.05. Also, because such a stable low density core is formed with the hydrocyclone of this invention, it can be installed for separating a fluid mixture of known composition in a pipeline in a remote location. Separation efficiencies have been as high as 98%.

Another unique feature of the present invention is a cooperating means for removing particulate material in the feed stream. This is accomplished by arranging the fourth generally cylindrical portion as a pair of radially aligned tubes with an axial gap therebetween. This gap is in turn enclosed by an outer tubular portion providing an annular flow chamber connected to a discharge outlet. Because of the centrifugal forces within the fourth generally cylindrical portion, the denser particulate material travelling along the outer wall of the cylindrical portion passes through the gap between the tubes and into the annular chamber to be discharged through the discharge outlet. The water in the cylindrical portion does not tend to pass through the gap but instead continues on down through the second tubular portion for discharge.

Brief Description of the Drawings

A presently preferred embodiment of the cyclone separator of the present invention will now be described in conjunction with the accompanying drawings, in which:

Fig. 1 is an elevational view, partly in cross section of a separator according to the invention;

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Fig. 2 is an enlarged portion of the embodiment of Fig. 1;

Fig. 3 is an end elevation of an orifice plate;

Fig. 4 is a partial sectional view of an orifice plate;

Fig. 5 is an end elevation of the closed end of the hydrocyclone;

Fig. 6 is an elevational view in cross section showing the cylindrical first portion; and

Fig. 7 is an elevational view in cross section showing an outer casing and water jacket assembly.

Best Modes for Carrying Out the Invention

As seen in Figs. 1 and 2, the hydrocyclone assembly of the invention includes a generally cylindrical first portion or involute 10, a first tapered section 11 axially aligned with the involute 10, a second tapered section 12 axially aligned with section 11 and a tubular barrel 13 axially aligned with tapered section 12. Connected to the end of tubular barrel 13 is a water collection tube 14.

The involute 10 includes a body portion 15 with a closed end wall 16. An orifice 17 is located axially in the end wall 16. The involute section 10 also includes a plurality (preferably at least four) feed injection ports 25 which are tangentially mounted and equally spaced around the circumference thereof.

When a feedstock containing oil and water is fed through inlet 24 and injection ports 25, a rapidly rotating vortex is formed under low-shear conditions. The centrifugal forces generated by the vortex act differently on the denser (water) phase and the less-dense (oil) phase such that the oil phase is displaced toward the central axis of the cyclone and forms a reverse flow towards the overflow orifice 17. Because it has been found advantageous to be able to adjust the size of the orifice 17 depending on the nature of the feedstock to optimize separation, a further feature of the present invention is a system for adjusting the

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effective orifice size. This is accomplished by means of a rotatable plate 18 (as shown in Figs. 3 and 4) having a plurality of orifices of different size 19. This plate 18 can be rotated either manually or by means of a power unit 20 via drive shafts 21. By this power means, any selected one of the orifices 19 in rotatable plate 18 is brought into axially alignment with orifice 17 to thereby effectively change the diameter of the orifice 17.

10 The first tapered section 11 includes a body portion 29 screw connected to the body portion 15 of the involute 10. Surrounding these is an outer wall 27 through which the inlet 24 passes and to which is connected a flange plate 28. The body portion 29 also has a flange plate 30 which is connected to flange plate 28.

15 The second tapered section 12 is screw connected to the body portion 29 of the first tapered section 11 and this in turn is connected to the water barrel or tube 13 by means of connector assembly 31.

20 At the downstream end of barrel 13 is a further assembly for separating solid particles from the water being carried down barrel 13. This includes a water collection tube 14 which is axially spaced from the end of barrel 13 by a gap 33 as best seen in Fig. 7. The barrel 13 and tube 14 are held in this spaced relationship by means of an outer tube 34, a T-assembly 36 and connector flanges 35, 37 and 38. This arrangement provides an annular chamber 39 surrounding the gap 33 and surrounding tube 13. Since the density of the solids is greater than that of water, the solids tend to migrate to the outer edges of the vortex flow in barrel 13 so that when they reach the gap 33, the particles tend to pass through the gap and into the annular chamber 39 while the bulk of the water continues to flow into the water collection

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tube 14, with the solids being collected at outlet 40. The water, free of particles and oil discharges through outlet 47.

It is possible to enhance the separation by heating the liquids being processed, thereby reducing the viscosity of the oil and increasing separation efficiency. This heat can be provided by means of a heating jacket formed by outer shell 41, having an inlet port 42 and an outlet port 43 for heating liquids. The downstream end of the outer shell 41 is connected to a flange 44, which in turn connects to a flange 45 which holds the outer end of the water collection tube 14.

A hydrocyclone was constructed as shown in the above drawings. The involute 10 had a length of 4.0 cm and an interior diameter of 4.0 cm. The first tapered section 11 was 5.7 cm long with a large diameter of 2.0 cm. The second tapered section 12 had a length of 38.8 cm, with a large diameter of 2.0 cm and a small end diameter of 1.0 cm.

Example 1

The above hydrocyclone was used at a heavy oil production site to separate a well head stream (from horizontal well production) containing 20-25% by volume of oil in water. The hydrocyclone product stream (overflow) contained as much as 85% oil, while the oil content in the water stream (underflow) contained as little as 150 ppm oil. The feed flowrate varied between 35 and 50 L/min depending on pressure settings. It was found that higher feed temperatures improved separation, with a temperature of at least 40°C being preferred. In comparison, a corresponding gravity separation, such as Free Water Knockout, requires a temperature in the order of 50-75°C.

Example 2

A further test was conducted using as feed a high-water-cut production fluid containing about 2-3% by volume of oil in brine. This was separated into a

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clean water stream (underflow) containing no more than 100 ppm oil and an oil-rich stream (overflow) containing 5-20% oil, depending on the oil concentration of the feed. The feed was at a temperature of 60-65°C and the underflow discharge rate varied from 95-99% of the feed rate.

Claims:

1. A cyclone separator for separating immiscible fluids comprising a generally cylindrical first portion or involute with an open end and a closed end, a
5 generally axial overflow outlet in said closed end, at least four radially balanced feed injection ports in said cylindrical first portion adjacent the closed end thereof, at least one converging tapered portion with open ends axially flow connected to the open end of the
10 cylindrical first portion, and a generally cylindrical discharge portion axially flow connected to said tapered portion, wherein the combination of the multiple injection ports and the length of the cylindrical first portion or involute being adapted to
15 fully separate the fluids within the involute into a straight reverse axial flow of a lower density phase within a forward flow of higher density phase.

2. A separator according to Claim 1 wherein the injection ports are tangentially mounted to provide a
20 rapidly rotating vortex under low-shear conditions.

3. A separator according to Claim 2 wherein the injection ports are arranged in diametrically opposed pairs.

4. A separator according to Claim 1, 2 or 3 which
25 includes a converging tapered second portion with open ends axially flow connected to the open end of the cylindrical first portion and a converging tapered third portion with open ends axially flow connected to said tapered second portion.

30 5. A cyclone separator for separating immiscible fluids comprising a generally cylindrical first portion or involute with an open end and a closed end, a generally axial overflow outlet in said closed end, a moveable member associated with said closed end having

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a plurality of orifices of progressively smaller diameter than the overflow outlet, said moveable member being moveable such that any selected one of said plurality of orifices is axially aligned with said overflow outlet, at least two radially balanced feed injection ports in said cylindrical first portion adjacent the closed end thereof, a converging tapered second portion with open ends axially flow connected to the open end of the cylindrical first portion, a converging tapered third portion with open ends axially flow connected to said tapered second portion and a fourth generally cylindrical portion axially flow connected to said tapered third portion.

6. A separator according to Claim 1 or 5 wherein the fourth generally cylindrical portion comprises a pair of radially aligned tubes with a gap therebetween, said gap being enclosed by an outer tubular portion providing an annular flow chamber and a discharge outlet associated with said annular chamber whereby solid particles carried in a liquid stream travelling through said fourth generally cylindrical portion are removed through said gap and discharge outlet.

7. A separator according to Claim 6 wherein said plurality of orifices are provided in a plate rotatably mounted on the end of said cylindrical first portion.

8. A separator according to Claim 7 wherein the plate is rotated by powered assembly.

9. A separator according to Claim 1 or 5 which includes an outer casing forming a heating chamber surrounding the cyclone.

10. A method for separating a mixture immiscible fluids of differing densities, comprising feeding said mixture into a cyclone separator comprising a generally

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5 cylindrical first portion or involute with an open end
and a closed end, a generally axial overflow outlet in
said closed end, at least four radially balanced feed
injection ports in said cylindrical first portion
adjacent the closed end thereof, at least one
converging tapered portion with open ends axially flow
connected to the open end of the cylindrical first
portion, and a generally cylindrical discharge portion
axially flow connected to said tapered portion, the
10 mixture being fed into the cylindrical first portion or
involute whereby the fluids of differing densities
separate within the involute into a straight reverse
axial flow of a lower density phase and a forward flow
of a higher density phase, removing the lower density
15 phase through the axial overflow outlet and removing
the higher density phase through the cylindrical
discharge.

11. A method according to Claim 10 wherein the mixture
of immiscible fluids is a mixture of oil and water.

20 12. A method according to Claim 11 wherein the mixture
contains up to 30% oil.

13. A method according to Claim 11 wherein the mixture
contains about 1-2% oil.

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