

CYCLONE SEPARATOR

United States Patent 4237006 (Colman et al) describes a cyclone separator having a separating chamber having first, second and third contiguous cylindrical portions arranged in that order, the first cylindrical portion being of greater diameter than the second cylindrical portion and the third cylindrical portion being of lesser diameter than the second cylindrical portion, the first cylindrical portion having an overflow outlet at the end thereof opposite to said second cylindrical portion and a plurality of tangentially directed feed inlets, the separator being adapted to separate liquids one from the other in a mixture when infed into said separating chamber via said feed inlets, one said liquid emerging from said overflow outlet and the other emerging from an underflow outlet at the end of said third cylindrical portion remote from said first cylindrical portion.

The above separator is intended specifically, but not exclusively, for separating oil from water, the oil in use emerging from the overflow outlet and the water from said third cylindrical portion.

The aforementioned cylindrical portions may not be truly cylindrical, in the sense that they do not need in all cases to present a side surface which is linear in cross-section and parallel to the axis thereof. For example, United States Patent 4237006 describes arrangements wherein the first cylindrical portion has a frustoconical section adjacent the second cylindrical portion and which provides a taper between the largest diameter of the first cylindrical portion and the diameter of the second cylindrical portion where this meets the first cylindrical portion. Likewise, the aforementioned patent specification describes arrangements wherein a similar section of frustoconical form is provided to cause a tapering in the diameter of the second cylindrical portion from a largest diameter of the second cylindrical portion to the diameter of the third cylindrical portion. There is also described an arrangement wherein the second cylindrical portion exhibits a

constant taper over its whole length.

A difficulty has been found in operating cyclone separators of the kind described in United States Patent 4237006 in that proper and reliable separating action is not always achieved, and contamination of the heavier liquid component (that emerging from the aforementioned third cylindrical portion of the separator) with the lighter liquid component sometimes occurs. Another difficulty has been that the outlet for the lighter component will frequently become blocked by debris, thus interfering with operation of the separator.

This invention is based on the observation that for efficient operation of a cyclone separator of the type described in US 4237006 it is necessary to provide a certain resistance to flow at the underflow outlet of the separator.

The invention provides a cyclone separator for treating a mixture of liquids to separate a more dense component from a less dense component thereof, said separator having a separator chamber comprising first, second and third contiguous portions of circular cross-section and having an overflow outlet for the less dense component at the end of the first portion remote from the second portion and an underflow outlet for the more dense component at the end of the third portion remote from the second portion, the diameter of the separator decreasing from the first portion to the second portion and from the second portion to the third portion, the first portion comprising an inlet chamber with a plurality of tangentially directed feed inlets proximate to said overflow outlet, the second portion tapering over the whole of its length, and the underflow outlet being arranged to provide a resistance to flow therethrough from the third portion such that the flow through the underflow outlet expressed as a percentage $\frac{f_1}{f_2} \times 100$, where f_1 represents the restricted flow through the underflow outlet and f_2 represents the flow from the outlet of the third portion in the absence of any restriction to flow in the underflow outlet, lies within the range of from 10 to 93%.

Preferably the half angle of the second portion lies in the range of from 20' to 1°.

The aforesaid resistance to flow maybe achieved, for example, by providing a fourth portion of restricted diameter compared with the outlet diameter of the third portion such that the ratio of the minimum diameter of the fourth portion to the diameter of the third portion at its outlet, expressed as a percentage, lies in the range of from 33 1/3 to 80%. Preferably said ratio lies in the range of 33 1/3 to 66 2/3%.

The fourth portion may have a part adjacent the third portion which exhibits a decreasing diameter along its length away from the third portion to an outlet aperture at the end of the part remote from the said third portion. The fourth portion may also include an outlet pipe extending from the said outlet aperture. Said part of the fourth portion may be of generally frustoconical configuration having a maximum d_3 adjacent the junction with said third portion and equal to the diameter of the third portion at that junction and a minimum diameter d_4 . However, said part of fourth portion may exhibit other forms, such as having a side wall which exhibits a curvature such that, when viewed in cross-section, the angle which a tangent to the side wall makes with respect to the axis of the fourth portion becomes less acute in the direction away from the junction between the third portion and said fourth portion, or where such angle becomes more acute in the last-mentioned direction. The outlet pipe may be of cylindrical form having a diameter d_4 which is substantially constant.

Preferably, the half angle or angle of the interior surface of said part of said fourth portion as measured to the axis of the fourth portion may be 45°, where said part is of frustoconical form. Generally speaking, too, even where the form of the wall of said part of the fourth portion varies from frustoconical, the fourth portion may be approximately as long as it is in diameter at its maximum diameter end. The length of said part of the fourth portion should be arranged so as to cause a decrease in diameter from the

greater diameter end to the lesser diameter end which is within the range 33 1/3 to 80%.

In the United States Patent 4237006, the described cyclone separator is said to comply with a number of dimensional restrictions insofar as the relative proportions of various components thereof are concerned. These constraints are :

$$\begin{aligned} 10 &\leq l_2/d_2 \leq 25 \\ 0.04 &\leq 4A_1/\pi d_1^2 \leq 0.10 \\ 0.1 &\leq d_0/d_2 \leq 0.25 \\ d_1 &> d_2 \\ d_2 &> d_3 \end{aligned}$$

wherein d_0 is the internal diameter of said overflow outlet. d_1 is the diameter of the first portion, d_2 is the diameter of the second portion and d_3 is the diameter of the third portion, l_2 is the length of the second portion, A_1 is the total cross-sectional area of all the feed inlets measured at the points of entry into the separating chamber normal to the inlet flow.

Preferably, the dimensional constraints mentioned above are placed on the cyclone separators constructed in accordance with this invention except that it has not been found necessary to comply with the constraint concerning the ratio of the overflow outlet diameter to the diameter of the second portion. On the other hand it has been found to facilitate operation if the overflow outlet presents a stepped bore with a first bore portion adjacent the first portion being of greater diameter than a second bore portion thereof further from the first portion. The first bore portion may be of diameter in the range 0.125 to 0.625 of the diameter d_1 . The second bore portion may be of diameter .015 to .05 times the diameter d_1 .

In an alternative form of the invention the underflow outlet may be of cylindrical or other configuration of constant or varying cross-sectional area throughout its length but so arranged that it

nevertheless presents a resistance to flow therethrough. For example, it may be provided with flow inhibiting baffles or other flow resistance elements such as particulate material or other porous material. In a preferred form, control means is provided for sensing liquid pressure in the cyclone separator and responsive to that pressure for varying the degree of resistance to flow presented by said fourth portion. Thus liquid pressure may be sensed at a location reached by the liquid before emerging from the separator such as at the fourth portion itself or at an upstream location such as at the third portion. Preferably the control means is responsive to decrease the flow resistance when there is a rise in sensed pressure and to increase the resistance when there is a drop in sensed pressure. The variation of flow resistance may be effected by varying the cross-sectional area of the fourth portion such as by making the wall of the fourth portion wall so that it can be deformed, and providing means for exerting external pressure on the wall to effect deformation. Where two or more cyclone separators are connected in series, such as to facilitate separation, the above described flow restriction means may for the first of the separators simply comprise the second separator.

Preferably the overflow outlet of the separator is provided with means selectively operable to vary the cross-sectional area of the outlet for permitting clearing of a blockage when occurring in the outlet. It is preferred that flow sensitive means be provided positioned and operable for detecting a decrease in flow through the outlet and for operating said area varying means for increasing the cross-sectional area for clearing the blockage.

The overflow outlet may, for example, be in the form of an outlet pipe and the cross-sectional area varying means may comprise a mechanism including a portion of the wall of the pipe which is so movable as to open the side of the pipe to the exterior thereof. More particularly, said portion of said side wall of the pipe may be a side segment of the pipe which is movable outwardly away from the remainder of the pipe under influence of said mechanism. The mechanism may, for example, include an electromagnet and the said

flow sensitive means may operate to apply electric current to said electromagnet for effecting movement of the segment away from the remainder of the pipe on said detecting of decrease in flow. The segment may have opposed end surfaces which, reckoned in the direction of flow through the pipe are angled relative to the axis of the pipe when viewed in radial section. The direction of movement of the segment may be correspondingly angled relative to the axis.

The pipe wall portion may be pivotally movable away from the remainder of the pipe. Thus, the wall portion may be pivoted about an axis transverse to the direction of extent of the outlet pipe at a relatively downstream end of the portion. More preferably, the pipe wall portion is arranged to be subject, in use, to a bias such as gravitational bias or spring bias, towards a position effecting said opening of the side of the pipe, and flow sensitive means is positioned to be normally acted upon directly by flow through the pipe to impart a force thereon which is directed against the outlet pipe wall portion to maintain it closed, said force, however, being reduced in the case of reduced flow through the pipe due to blockage whereby the aforementioned bias effects movement to open the side of the pipe. The flow sensitive means may comprise a pivotal lever having two arms extending from a location at which the lever is pivotal to said remainder of said pipe one said arm being formed with means in use subjected to flow thereon to form the separator and the other engaging the said pipe wall portion. The said one arm, alternatively, may carry a vane or plate positioned exteriorly of the outlet pipe to be subjected to flow from the pipe.

The invention is further described with reference to the accompanying drawings in which :

Figure 1 is a cutaway perspective view of a cyclone separator constructed in accordance with this invention;

Figure 2 is a fragmentary lengthwise section of a modified cyclone separator in accordance with the invention;

Figure 3 is a fragmentary lengthwise section of another modified cyclone separator in accordance with the invention;

Figure 4 is a scrap view corresponding to part of Figure 3, but showing the separator in use.

Figure 5 is a fragmentary perspective view of the cyclone separator of Figure 1 showing outlet area varying means in accordance with the invention;

Figure 6 is a view like Figure 5 but showing the outlet area varying means operated;

Figure 7 is a cross-section showing part of the cyclone separator of Figure 5, and outlet thereof, and the area varying means when conditioned in the same condition as Figure 5;

Figure 8 is a view like Figure 7 but showing the outlet area varying means in the condition of Figure 6;

Figure 9 is an electric circuit diagram of electric control means associated with the area varying means;

Figure 10 is a partly sectioned perspective view of an alternative form of area varying means constructed in accordance with the invention;

Figure 11 and 12 are cross-sectional views of the area varying means of Figure 10 shown, respectively, in closed and open conditions,

Figure 13 is a side view of a still further form of area varying means constructed in accordance with the invention;

Figure 14 is an end view of the area varying means of Figure 13,

Figure 15 is a plan view of the area varying means of Figure 13;

5 Figures 16 and 17 are respective axial cross-sections of the area varying means of Figure 13, in two different operative conditions,

10 Figure 18 is a graph illustrating influence of outlet constriction on separating performance of the separator of Figure 1,

Figure 19 is a graph illustrating influence of outlet constriction on delivery flow from the separator of Figure 1,

15 Figure 20 is a diagram showing interconnection of two cyclone separators, in accordance with this invention,

Figure 21 is a fragmentary axial cross section showing an alternative form of overflow outlet pipe for the cyclone separator of Figure 1,

20 Figure 22 is an end view of a bank of separators as shown in figure 1,

Figure 23 is a diagrammatic opposite end view of one row of separators in the bank of separators shown in figure 22, and

5 Figure 24 is a diagrammatic cross section of the bank of separators of figure 22, taken approximately on the line 24-24 in figure 22.

The separator 10 shown in Figure 1 has a separating chamber 25 having first, second and third portions 12, 14 and 16 coaxially arranged
10 in that order.

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The first cylindrical portion 12 has two feed pipes 26, 28 associated therewith, these being arranged to feed tangentially into the
20 portion 12 via respective inlet apertures of which only one aperture, namely aperture 30 associated with pipe 26, is visible in the drawing. The two feed inlet apertures are diametrically arranged one relative to the other and positioned close to the end
25 of portion 12 remote from portion 14. The end of portion 12 remote from portion 14 also has a circular outlet opening 32 which leads to an overflow outlet pipe 34.

Portion 12 is not of constant diameter over its whole length, the part 12a thereof adjacent portion 14 exhibiting a taper towards the second portion 14.

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The second portion 14 exhibits a taper over its length, tapering from a diameter at the end adjacent section 12 equal to the diameter of
10 portion 12 at the junction between the two portions to a somewhat lesser dimension at its opposite end.

Portion 16 has a constant diameter equal to the minimum diameter of portion 14.

In the drawing, the length l_1 of portion 12, its
15 diameter d_1 , the taper angle α of the tapered part of cylindrical portion 12, the internal diameter d_0 of the outlet pipe 34, the length and diameter l_2 , d_2 of the second portion 14, the taper angle β of the second
20 portion 14 and the length l_3 and diameter d_3 of the third cylindrical portion, as well as the total area A_1 of the two feed inlet apertures 30 may all be selected in accordance with the parameters mentioned
25 in United States patent 4,237,006 save that the outlet diameter d_0 need not be constrained to be within limits as described therein.

In accordance with this invention, a fourth portion is added to the separating chamber 25, this portion being designated by reference numeral 18 in

Fig. 1. Portion 18 has a part 18a adjacent portion 16 which is of frustoconical configuration, tapering from a maximum diameter equal to d_3 at its end closest to and adjoining to the outlet end of cylindrical portion 16, to a diameter d_4 at its outlet end. At the outlet end of part 18a, fourth portion 18 includes an outlet pipe 18b which is of internal diameter d_4 .

Preferably, the angle γ , being the conicity or half-angle of the frustoconical surface of part 18a is about 45° , although angles in the range 30° to 60° are generally satisfactory. In any event, it is preferred that the ratio $\frac{d_4}{d_3}$ be in the range 1:3 to 2:3. The length of part 18a is not critical to the invention and in any event is normally fixed by the selection of the aforementioned ratio of diameters d_4 to d_3 . Likewise, the length of the pipe 18b has not been found to be important to the operation of the invention.

Although part 18a is shown as having a truly frustoconical cross-sectional form (that is to say it is shown as having a side surface which exhibits a linear sloping configuration relative to the axis of the portion when viewed in section) this is not essential. The part 18a may have a conicity angle which varies along the length thereof such as either increasing or decreasing in the direction from the greater diameter end to the lesser diameter end thereof. It is preferred that the

length of the part 18 be roughly the same as the maximum diameter thereof.

In use, liquid to be separated is admitted tangentially to the interior of portion 12 via feed pipes 26, 28, the denser component of the liquid then travelling lengthwise through the separator to emerge from pipe 18b, whilst the lighter component emerges from pipe 34.

Figures 18 and 19 show experimental results obtained by operating an experimental oil separator of the form shown in figure 1 with various fourth portions 18 presenting different end diameters d_4 . The third portion 16 of this separator had a diameter d_3 of 29mm. Under operating conditions, with the fourth portion 18 removed, the exit flow rate from the separator when separating an oil-water mixture was 200 litre/minute. The experimental separator was tested using a mixture of oil and water with the oil concentration being approximately 7500 p.p.m.

As shown in figure 18, the separating action of the separator was found to be heavily dependent on the exit diameter d_4 . Only when diameter d_4 was reduced to give a ratio $\frac{d_4}{d_3}$ of 80% or less did the residual oil concentration in water exiting from the portion 18 exhibit a magnitude (130p.p.m) which was judged satisfactory. Further decrease in the ratio $\frac{d_4}{d_3}$ brought about a corresponding decrease in residual oil concentration until a minimum residual concentration

- of about 35p.p.m. was achieved at a diameter ratio of about 76%. Further decrease in the diameter ratio caused decreased separation efficiency, the residual oil concentration rising with diameter ratio decrease until a diameter ratio of about 66% was reached, at which the residual oil concentration was about 130p.p.m. On further decrease in the ratio $\frac{d_4}{d_3}$ the residual oil concentration again fell, the concentration being about 45p.p.m. at a ratio of 55%.
- 10 The aforementioned range 1:3 to 2:3 for the ratio $\frac{d_4}{d_3}$, represented in figures 18 and 19 as range R_1 , has been found satisfactory in many applications giving good separation, whilst ensuring reliable operation, where operating considerations do not require maintenance of highest flow rates through the separator. As shown in figure 19, the flow rate through the experimental separator was found to exhibit relatively small fall off where the ratio $\frac{d_4}{d_3}$ was large. However the flow rate falls rapidly once the ratio falls below about 55% at which ratio the flow rate was found to be one half of that prevailing when no fourth portion 18 was provided. The lower limit of the range R_1 for ratio $\frac{d_4}{d_3}$ is established at $33\frac{1}{3}\%$ based on the observation that below this ratio insufficient flow could be achieved through the separator for effective operation to occur. As evident from figure 19, the flow rate at this value for $\frac{d_4}{d_3}$ was about 20 litre/minute in the experimental separator giving a flow rate of some 10% of the flow rate with no portion 18 provided. The preferred upper limit of $66\frac{2}{3}\%$ for R_1 is

established on the basis that although good separating operation can be achieved above this level, care in operating is necessary to ensure that transitory fluctuations in flow do not cause higher levels of retained oil. Notwithstanding this, however, it has been found that where efficient separation is needed together with preservation of high flow through the separator, operation in the range R_2 shown for the ratio $\frac{d_4}{d_3}$ is preferable. The lower limit for Range R_2 is established at a value of $\frac{d_4}{d_3}$ equal to 55%, being the value at which the flow rate is still one half of that prevailing with no portion 18 provided. The upper limit for range R_2 is established at a value of ratio $\frac{d_4}{d_3}$ equal to about 80%, this representing the maximum value at which adequate oil separating efficiency is retained. At this ratio, the flow rate through the experimental separator was largely unaffected by the presence of portion 18, being about 185 litre/minute or some 93% of the original rate, as evident from figure 19. At that ratio, the residual oil concentration was as mentioned about 130p.p.m. Thus, the overall range of ratios $\frac{d_4}{d_3}$ for possible operation is the range R_3 shown, extending from about $33\frac{1}{3}\%$ to about 80%. The ranges R_1 , R_2 , R_3 may alternatively be expressed in terms of ratios of cross sectional areas of the portions 18 and 16 (i.e. as ratios $\left(\frac{d_4}{d_3}\right)^2$). Figure 19 has a scale marked in area ratios from which the area ratios corresponding to given ratios $\left(\frac{d_4}{d_3}\right)$ may be approximated. The ranges R_1 , R_2 , R_3 when so expressed in area ratios $\left(\frac{d_4}{d_3}\right)^2$

have the following limits:

$$R_1; \left(\frac{d_4}{d_3}\right)^2 = 10\% \text{ to } 45\%$$

$$R_2; \left(\frac{d_4}{d_3}\right)^2 = 30\% \text{ to } 65\%$$

$$R_3; \left(\frac{d_4}{d_3}\right)^2 = 10\% \text{ to } 65\%.$$

- 5 Furthermore, the ratios $\frac{d_4}{d_3}$ and $\left(\frac{d_4}{d_3}\right)^2$ are measures of the resistance to flow through portion 18. This resistance may also be expressed as a percentage $\frac{f_1}{f_2}$ of the flow which would prevail if no portion 18 were provided, "f₁" representing the
 10 flow with portion 18 and f₂ the flow when there is no portion 18. The ranges R₁, R₂, and R₃ have the following limits, ascertainable from figure 19, when expressed in terms of such percentage flow:

$$R_1; \frac{f_1}{f_2} = 10\% \text{ to } 50\%$$

$$15 \quad R_2; \frac{f_1}{f_2} = 50\% \text{ to } 93\%$$

$$R_3; \frac{f_1}{f_2} = 10\% \text{ to } 93\%.$$

- The modified cyclone separator 110 shown in Figure 2 is identical to that shown in Figure 1 save that the pipe 18b is omitted and a modified fourth
 20 portion 118 is provided instead of portion 18. Portion 118 is of the same diameter as portion 16 but is filled with sand particles 119 whereby to provide

resistance to flow therethrough. The size and density of packing of sand particles and the length of portion 118 are selected to provide a resistance to flow similar to that provided by portion 18.

- 5 Where the separator 110 is vertical, the sand may be supported on a suitable meshing such as the meshing 12 shown. Otherwise suitable retaining meshing may be provided at either end of portion 118.

- 10 In a still further alternative construction (not shown) resistance to flow through portion 118 is provided by partial flattening of portion 118 or by retaining a suspended ball in a cage therein.

- 15 In the modification shown in Figures 3 and 4, the pipe 18b is formed of a flexible tube. A pressure sensor 140 is provided connected to be sensitive to fluid pressure at the inlet end of the pipe 18b and to provide an electrical signal at its output which is representative of that pressure. A control circuit 142 is connected to receive signal from sensor 140 and to provide an output signal which is coupled to an electromechanical transducer 144 via lines 146 as shown. Transducer 144 might, for example, be in the form of a solenoid but in any event is of a kind having an element 148 which is capable of movement under control of the control circuit 142 so as to adopt a position which is dependent upon the fluid pressure as sensed by sensor 140. Element 148 is disposed to one side of the tube comprising pipe 18b and a fixed element 150 of somewhat similar
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configuration is provided immediately opposite element 148 and to the opposite side of the tube defining pipe 18b. The arrangement is such that, on detection of decrease of fluid pressure as sensed by sensor 140, control circuit 142 controls transducer 144 to move element 148 inwardly towards element 150 to constrict the pipe 18b, by deformation of the wall of the tube thereof as shown in Figure 4. Thus, on detection of fluid pressure decrease, the cross-sectional area of pipe 18b is decreased. Correspondingly, if increase of pressure is detected by sensor 140, control circuit 142 moves element 148 away from element 150 to release the constriction to some extent. By this means, the resistance to flow presented by the pipe 18b can be varied in accordance with the determined pressure at the inlet end of the pipe 18b.

The above described arrangements for providing restriction to outflow from the separator have been found to be effective in ensuring adequate operation of the separator. More particularly, in the absence of such constriction, it is observed that, generally, the outflow via portion 16, which should, for effectiveness of the separator, comprise only the more dense component of the liquids to be separated, will tend to be contaminated with the lighter component liquid. It is believed that this effect arises because it is necessary to provide a "back pressure", by inducing flow restriction, for outflow via portion 16 and the described constrictions effectively provide such back pressure.

In cases where two or more separators are coupled in series it has been found sufficient that the second separator only be provided with a specific flow restriction device since the second separator itself
5 can satisfactorily act as a flow restriction device for the first separator. Figure 20 shows two separators 300, 312 of which separator 312 is of the form shown in figure 1. The feed pipes 26, 28 for separator 312 are however coupled by a branched pipe
10 308 to the outlet end of a separator like the separator of Figure 1, save that the portion 18 is omitted. In use oil-water mixture is introduced first into separator 300, separated oil leaving via outlet 34 thereof. The water component,
15 possibly still with some oil content, is taken from the outlet of the separator provided by portion 16 thereof via pipe 308 to the separator 312. Further oil is separated by the separator 312, leaving via the outlet 34 thereof. Water is exited from
20 separator 312 via portion 18 thereof. In this arrangement, separator 312 provides the flow restriction necessary for proper operation of separator 300.

As best shown in Figures 5 to 8, the outlet pipe
25 34 of the separator of figure 1 may be provided with an area varying means 23 constructed in accordance with this invention. More particularly, the area varying means includes a segment 29 of the pipe 34 which is constructed so as to be removable from the
30 remainder 31 of the pipe 34. Segment 29 has part

frustoconical end surfaces 33, 35 which in the closed condition of the segment shown in Figures 5 and 6 mate with corresponding part frustoconical surfaces 36, 38 of the remainder 31 of the pipe 34. The segment 29
5 also has two opposed side edge surfaces 40, 42 which mate with corresponding lengthwise extending edge surfaces 44, 46 on the pipe remainder 31.

A rod 48 is connected to the exterior of segment 29 and extends away therefrom at an angle relative to
10 the axis of pipe 34, this angle corresponding roughly to the angle of surfaces 33, 35 as presented to the axis of the pipe 34 in a generally radial plane in which the rod 48 is contained. At its opposite end, rod 48 is connected to the plunger 50a of an
15 electromagnet 50. A spring 54 is interposed between the body of the magnet 50 and an outstanding flange 48a on rod 48 and normally urges rod 48 away from the electromagnet 50 to the condition shown in Figures 5 and 6 at which the segment 29 neatly fits into the
20 space in the pipe 34 defined by the surfaces 36, 38, 44 and 46. Although not shown, in order to facilitate sealing, the surfaces 33, 35 of the segment 29 may be made slightly convergent in the direction away from the outside surface of the segment 29 towards the axis
25 of the pipe 34. Similarly, the surfaces 40 and 42 may be made convergent in the direction away from the outer surface of the segment 29 towards the axis of the pipe 34.

In the condition of Figures 5 and 7, the cyclone separator can operate normally, one of two components of the liquid admitted via pipes 26 and 28 being delivered, as previously described, from the

5 portion 12 through the outlet constituted by the pipe 34 and its interior opening 34a with the interior of portion 12. The liquid flow under these conditions is shown by arrows 56.

10 Under the condition that the outlet constituted by pipe 34 and outlet opening 34a should become blocked, it is possible, by energizing of
electromagnet 50, to withdraw the rod 48 into the body
of the electromagnet against the resilient bias
15 applied by spring 54. Under this condition, then, the segment 29 is correspondingly moved outwardly of the remainder 31 of the pipe 34 so that an enlarged
opening 68 then defined by the aforementioned surfaces
36, 38, 44, 46 is provided for egress of material from
20 the separator. By this means, obstructions such as stones or the like may be readily cleared from pipe 34 and/or opening 34a. The flow of such egress is indicated by the arrows 70 in Figures 6 and 8.

In order to provide for automatic operation, the
25 area varying means of the invention may, as shown in Figures 7 and 8, include a flow sensitive device 72. Device 72 includes a light planar vane 74 positioned within pipe 34 and connected to a shaft 76 which is mounted for free rotation in a bearing (not shown) in

the side wall of the pipe 34. Shaft 76 extends, from
an inner end within the pipe 34, exteriorly of the
pipe 34. The shaft is mounted so that it is rotatable
about an axis which extends generally radially to the
5 direction of extent of the pipe 34. At its outer end,
shaft 76 has two radial arms 78, 80 which extend
oppositely therefrom. Arm 80 is located adjacent a
free end of an operating button 90a of a switch 90.
Arm 78 is connected, at its end remote from shaft 76,
10 to a tension spring 92. Spring 92 is arranged to
normally bias arm 78 and shaft 76 to a position such
that arm 80 assumes the position shown in Figure 8 at
which the arm 80 is positioned at a limit distance
away from the body of the switch 90. The operating
15 button 90a of the switch 90 is resiliently biased away
from the body of the switch and thus, at this
condition, is at an extreme extension from the body.
Under this condition, the switch 90 is closed. It
will be noted from Figure 8, too, that the vane 74 is
20 so located relative to the shaft 76 that under the
condition of Figure 8 the vane does not extend in the
axial direction of the shaft 34 but is angularly
displaced relative thereto.

Under the condition of flow through pipe 34, the
25 flow so acts on vane 74 as to cause the shaft 76 to be
rotated to the condition shown in Figure 7. During
this rotation, which occurs against spring bias of
spring 92, the arm 80 is brought to bear on the button
90a so as to axially move the button towards the body

of switch 90 at which condition the switch 90 is arranged to be open.

As shown in Figure 9, the switch 90 is arranged in an electric circuit 94 so that when closed it operates to effect energization of a relay coil 94a from a low voltage source 96. Electric contacts 95b associated with a relay coil 95a are likewise arranged in an electric circuit 98 so that when closed the contacts ensure energization of the winding 50b of electromagnet 50 from an electric source 100. The arrangement is such that, under normal conditions of flow through pipe 34, switch 90 is not actuated, the vane 74 assuming the position shown in Figure 7. Under conditions of flow blockage however, there will be reduced flow through pipe 34 with the result that there is insufficient fluid pressure to maintain the vane 74 in the generally axial direction of the pipe 34, against the bias of spring 92, whereupon the spring 92 operates as just described to rotate the shaft 76 and thereby effect closing of switch 90. Resultant operation of the electromagnet 50 causes withdrawal of the plunger 50a, so conditioning the means 23 as shown in Figure 8 to permit clearance of the blockage. After clearance as shown in Figure 8, resumption of flow through the pipe 34 will occur and the apparatus will be conditioned again to the condition of Figure 7. In order to facilitate reversion back to the condition of Figure 7, it is possible to modify the circuit of Figure 9 to include timing and resetting means such that the contacts 95a

remain closed only for a predetermined time following an initiation of closing pursuant to closing of switch 90.

Referring now to Figure 10, a modified area
5 varying means 124 is shown for use in conjunction with an outlet pipe 120 of a cyclone separator 110. The separator 110 is, aside from the different form of the area varying means similar to the separator 10 previously described, the outlet pipe 120
10 corresponding in function generally to the outlet pipe 34 previously described, and extending away from an outlet opening 122 generally performing the same function as the outlet opening 34a previously described.

15 The pipe 120 has a movable portion 128 which forms one segment of the total periphery of the pipe and which is pivotally secured to the remainder 130 of the pipe. Remainder 130 is secured, such as by welding, to the end wall 125 of the separator, about
20 opening 122. Portion 128 is pivoted, at a location downstream of opening 122, to the remainder 130 of pipe 120 by coaxial pivot pins 127, 129 which extend through lugs 131, 133 on the pipe remainder. At locations adjacent the outlet 122, the remainder 130
25 and pipe portion 128 are of generally arcuate configuration when viewed in cross-section, fitting together, in the operative position of the means 124, in the fashion shown in Figures 10 and 11 to define a substantially circular cross-sectioned flow path for

fluid flow from outlet 122. As shown in Figure 12, however, the portion 128 is swingable about the common axis of the pins 127, 129 so that, adjacent the opening 122, the portion 128 is swung outwardly to increase the space between the portion 128 and remainder 130 of pipe 120 so increasing the outflow area and permitting clearance of blockages.

A light helical tension spring 135 is provided between the lower end of portion 128 and an outer flow collecting pipe 145 secured to separator wall 125 in coaxial spaced relationship around pipe 120. Spring 135 provides a resilient bias so directed as to tend to cause the portion 128 to assume the open condition shown in Figure 11. However, in normal use, with fluid flow through outlet 122 into the pipe 120, the portion 128 is held biased in its closed position by fluid pressure force acting on a lever 147. Lever 147 has two arms 149, 151 each radiating from a central portion of the lever. The lever is pivotally mounted to the pipe 145 at that central portion by means of a pin 153 passing through lugs 155 on the interior surface of the pipe 145. Arm 151 extends generally against the flow direction in pipe 130 from pin 153 to an outer end which engages the exterior of portion 128 at a location well away from its pivot axis about pins 127, 129. Arm 149 extends away from pin 153, through a clearance slot 159 in portion 128 and thence generally transversely across the interior of the pipe 120 between the portion 128 and the remainder 130 of the pipe.

In the absence of flow from outlet 122 through pipe 120, lever 147 is positioned as shown in Figure 12, with the free end of the arm 151 against the exterior surface of portion 128. However, when flow occurs through the pipe 120 the flow impinges upon the arm 149 of lever 147 thus subjecting it to a pressure force which is directed away from the opening 122 in the direction of flow of the liquid through pipe 120. The force is arranged to be sufficient to cause movement of the arm 149 and thus of the lever 147 so that the lever is pivoted in the clockwise direction from the position as shown in Figure 12, so that the pressure force acting on arm 149 is transferred through the lever to apply a force at the opposite end thereof, namely at the free end of arm 151, against portion 128 thus causing the portion to be pivoted, with corresponding pivotal movement of the lever 147, to close the gap between the portion 128 and the remainder 130. That is to say, the action is thus to move the portion 128 from the condition shown in Figure 12 to that shown in Figure 11, against the bias of spring 135. By this means, in normal use, the portion 128 is maintained closed, only opening under condition where, due to blockage, there is no flow through the pipe 120 whereupon the pressure force acting on arm 149 is reduced to the extent that the spring 135 can operate to bias the portion 128 open. This arrangement has the advantage that it has no electrical parts and is mechanically simple, whilst nevertheless operating automatically to increase the area for outflow of the fluid under blockage

conditions and to again decrease the area for outflow to a normal condition on clearing the blockage.

Referring now to Figures 13 to 17, the modified area varying means 224 shown therein is for use in conjunction with an outlet pipe 220 of a cyclone separator, such as the separator 10. The outlet pipe 220 performs the function of the earlier described outlet pipe 34. The area varying means 224 has a circular plate 221 adapted for securement to a transverse end wall of the separator so that an outlet opening 222 through the plate 221 and leading to the interior of the pipe 220 then performs the function of the previously described outlet opening 34a.

Pipe 220 has a removable portion 228 which forms one segment of the total periphery of the pipe and which is pivotally secured to the remainder 230 of the pipe. The pivotal securement is effected by means of two lugs 233, 235 secured to the portion 228 and pivoted to the pipe remainder 230 by means of pivot pins 237 arranged on a common side-to-side pivot axis on the remainder 230. The pipe 220 has an interior bore extending from opening 222 to an outlet aperture 271 at the end of the pipe remote from plate 221. As best seen from Figures 16 and 17 this bore has two sections, a larger diameter bore section 273 adjacent opening 222 and a lesser diameter section 275 adjacent aperture 271. Remainder 230 of pipe 220 is formed with lengthwise extending surfaces 279, 281 which are disposed to opposite sides of bore section 275 and

portion 228 has corresponding lengthwise extending surfaces 283, 285 which, in the closed condition of the area varying means, sealingly engage the respective surfaces 279, 281. The bore section 275 is, for one lengthwise extending half thereof, defined within remainder 230 and for the other lengthwise extending half, defined within portion 228. At a portion of the larger diameter bore section 273 adjacent the junction between sections 273 and 275, the portion 230 has a transverse, planar, somewhat U-shaped surface 287 which extends, at opposite ends of that surface, to meet respective ones of the surfaces 279 and 281 and thence extends obliquely to the top of the outer surface of the remainder 230 as viewed in the sections of Figures 16 and 17. The U-shaped configuration of the surface 287 can, however, be appreciated from Figure 15. The portion 228 has a similar U-shaped surface 289 which in the closed position of the area varying means engages with surface 287.

Plate 221 carries a generally U-shaped bracket 290 and a shaft 292 extends between the opposed arm portions thereof and is retained therein so as to be freely rotatable about an axis extending transversely of the pipe 220 and generally parallel to the plane containing surfaces 279, 281. Shaft 292 has secured thereto two elongate arms 294, 296 which extend away from the shaft to free ends positioned over the end of pipe 220 remote from opening 222. A plate 297 is secured to the free ends of the arms 294, 296 and

extends generally transversely thereto to the directions of extent of the arms. Intermediate the ends of the shaft 292, the shaft is provided with a downwardly depending cam element 298 which is secured
5 for rotation with the shaft. Cam element 298 has a lower cam surface 298a which is of arcuate form and which co-operates with an arcuately curved cam surface 300a on a projection 300 extending upwardly from portion 228.

10 In normal operation of the device 224 the portion 228 occupies the position shown in Figures 13 and 16 where the portion 228 is engaged with the remainder 230 so as to fully define the two bore sections 273,
15 275. Liquid leaving the cyclone separator passes through opening 222 thence through bore section 273 and then through bore section 275 to exit via aperture 271. The bore section 275 is of relatively small diameter to provide proper operation of the separator. Liquid egressing from aperture 271 strikes plate 297
20 and exerts sufficient force thereon to normally cause the arms 294, 296 to pivot such that the plate 297 is held away from the aperture 271, as shown in Figure 13. Under this condition, the cam surface 298a on element 298 engages cam surface 300a on portion 228 in
25 such a fashion as to cause force exerted by the egressing liquid on the plate 296 and transferred through the arms 294, 296 to the element 298, to press on the portion 228 so maintaining it in the position of Figures 13 and 16. Under the condition, however,
30 where blockage of outlet 222 occurs and there is

reduced flow through the bore sections 273 and 275, the force exerted by liquid emerging from aperture 271 will be insufficient to maintain the plate 297 clear of the aperture whereupon arms 294, 296 pivot clockwise as shown in Figure 13 so that plate 297 moves downwardly as viewed in Figure 13. This causes the cam surface 298a to be moved, by corresponding clockwise pivoting of element 298, away from cam surface 300a, thus removing constraint against pivoting of the portion 228 about the axis of pins 237. Under this condition, then, liquid pressure in the bore section 273 may bear against the portion 228 in such a fashion as to effect anti-clockwise pivoting of portion 228 as viewed in Figure 13 so as to bring portion 228 to the condition shown in Figure 17 whereupon the surfaces 279, 281 and 287 on remainder 230 of pipe 220 are well cleared from the corresponding surfaces 283, 285 and 289 on portion 228, so as to present a substantial gap therebetween, such gap being indicated by reference numeral 295 in Figure 17. Thus, material causing a blockage in the outlet 222 may be readily cleared by outflow of liquid through that gap. Once such clearance has occurred, the portion 228 may revert to the initial condition shown in Figure 16 under gravitational action, accompanied by clockwise rotation about the axis of the pins 237. If desired, in order to facilitate the return action, a resilient tension spring may be provided acting between portion 228 and remainder 230. Alternatively, in order to facilitate the action of the cam surface 298a, a spring may be provided between

the projection and say, the plate 221 to lightly bias the element 298 for clockwise rotation about the axis of shaft 292.

5 In order to improve sealing between portion 228 and remainder 230 of pipe 220, the surfaces 279, 281 and 287 thereof may have suitable sealant strips positioned therein. Two such strips, designated by respective reference numerals 301, 303, are shown in Figure 14 as set into surfaces 279, 281. The strips
10 may be formed, for example, of neoprene.

Figure 21 shows a modified overflow outlet pipe 34 usable instead of the overflow outlet pipe 34 in the construction of figure 1. In this case the pipe has a stepped interior bore leading from outlet
15 opening 32. More particularly, the bore has a first portion 34' adjacent outlet 32 of diameter equal to the diameter of outlet 32 and a second portion 34" away from outlet 32 of lesser diameter than bore portion 34'. Bore portion 34' may be of diameter in
20 the range 0.125 to 0.625 preferably 0.017 to 0.47 times the diameter d_1 of portion 12 of the separating chamber 25. Bore portion 34" may be of diameter 0.015 to .05 preferably .025 to .035 times the diameter d_1 of portion 12 of the separating chamber 25. The
25 lengths of the bore portions 34' and 34" are not important.

Figures 22 to 24 show an arrangement of sixteen separators 10 and 10' in a bank 370. These are

arranged in two vertical rows 372, 374 of eight separators each. A single main inlet feed pipe 376 is provided, this having three upright parallel secondary feed pipes 378, 380, 382 extending therefrom at spaced locations along the length thereof. The inlet pipes 26, 28 of four of the separators, separators 10, in row 372 are connected respectively to pipes 378 and 380 whilst the inlet pipes 26, 28 of four of the separators, also separators 10, in row 374 are connected respectively to pipes 380, 382.

The separators 10' are arranged four in each of the two rows 372, 374, three between each adjacent pair of separators 10 in the row and one above the uppermost 10 in each row. The separators 10' are arranged with their outlet ends of their portions 16 oppositely directed to those of the separators 10.

The separators 10 and 10' in this case are not provided with fourth portions 18 but are arranged with the third portions 16 at the outlets thereof.

As is best seen from figure 24, the portions 18 of the separators 10 are connected by branched pipelines 390 to the inlet pipes 26, 28 of the separators 10'. In the case of the uppermost three separators 10 in each row 372, 374, the portion 16 of each extends via the associated branched pipeline 390 to communicate with the inlet pipe 26 of the separator 10' immediately above and the inlet pipe 28 of the

separator 10' immediately below. The lowermost separator 10 in each row provides communication via the pipeline 390 thereof with the inlet pipe 20 of the separator 10' immediately above and with the inlet
5 pipe 28 of the uppermost separator 10'. The last mentioned pipeline 390 for each row is thus longer than the remaining pipelines 390.

The outlets at portions 16 of separators 10' in row 372 are connected to a common outlet line 398. A
10 similar outlet line 400 interconnects the outlets at portions 16 of separators 10' in row 374 and these outlet lines 398 and 400 may be connected together as shown. Although not shown, for clarity, the outlet
15 pipes 34 of all of the separators 10, 10' in both rows may be connected to a common line.

In use of the bank 370, oil-water mixture is fed to the main inlet feed pipe 376 and thence via the secondary feed pipes 378, 380, 382 to the separators 10 in each of the rows 372, 374. This then flows
20 through separators 10 of each bank. One half of the separated water component from each separator 10, appearing at the outlet of portion 16, is then fed to a separator 10' in that row, whilst the again separated water from the separators 10' is taken from
25 the bank via the lines 398, 400. Separated oil emerging from the separators 10, 10' is collected such as in a single collector pipeline. By this arrangement, oil-water mixture is passed in succession through to separators before reaching the water outlet

from the bank. This arrangement has been found to be very satisfactory in use.

In the described arrangement, although no specific provision is provided to generate back pressure in the
5 separators 10, 10' so as to cause flow constriction, such back pressure and flow restriction is provided, for the separators 10, by the separators 10' themselves which are connected to the portions 16 of
10 separators 10, and, for the separators 10', by the outlet lines 398, 400 which are suitably dimensioned for the purpose. If necessary, however, a common flow constriction device could be inserted at an outlet pipe providing connection to both of lines 398, 400.

Patent Application GB 8522346 is divided herefrom.



C L A I M S

1. A cyclone separator for treating a mixture of liquids to separate a more dense component from a less dense component thereof, said separator having a separator chamber comprising first, second and third contiguous portions of circular cross-section and having an overflow outlet for the less dense component at the end of the first portion remote from the second portion and an underflow outlet for the more dense component at the end of the third portion remote from the second portion, the diameter of the separator decreasing from the first portion to the second portion and from the second portion to the third portion, the first portion comprising an inlet chamber with a plurality of tangentially directed feed inlets proximate to said overflow outlet, the second portion tapering over the whole of its length, and the underflow outlet being arranged to provide a resistance to flow therethrough from the third portion such that the flow through the underflow outlet expressed as a percentage $\frac{f_1}{f_2} \times 100$, where f_1 represents the restricted flow through the underflow outlet and f_2 represents the flow from the outlet of the third portion in the absence of any restriction to flow in the underflow outlet, lies within the range of from 10 to 93%.
2. A cyclone separator according to claim 1, wherein the half angle of the second portion lies in the range of from 20' to 1°.
3. A cyclone separator according to claim 1 or claim 2, wherein the restriction to flow is provided by a fourth portion of restricted diameter compared with the outlet diameter of the third portion such that the ratio of the minimum diameter of the fourth portion to the diameter of the third portion at its outlet, expressed as a percentage, lies in the range of from 33 1/3 to 80%.
4. A cyclone separator according to claim 3, wherein the said ratio, expressed as a percentage, lies in the range of 33 1/3 to 66 2/3%.
5. A cyclone separator according to claim 3 or claim 4, wherein said fourth portion is connected to said third portion by a frusto



conical section.

6. A cyclone separator according to claim 1, wherein said resistance to flow is provided by porous flow resistance means in the underflow outlet.

7. A cyclone separator according to claim 1, wherein the underflow outlet is provided with flow inhibiting baffles or other flow resistance elements.

8. A cyclone separator according to claim 1, wherein the underflow outlet is provided with a flexible wall in a tubular portion thereof with means for exerting external pressure on the wall to effect deformation thereof whereby the resistance to flow is variable within said range.

9. A cyclone separator according to claim 8, wherein control means are provided for sensing liquid pressure in the cyclone separator and for varying the degree of resistance to flow responsive to the sensed pressure.

10. A cyclone separator according to claim 9, wherein the control means are responsive to decrease flow resistance when there is a rise in sensed pressure and to increase flow resistance when there is a drop in sensed pressure.

11. A cyclone separator according to any one of claims 1 to 10, wherein the length of the second portion is at least 10 times its maximum diameter.

12. A cyclone separator according to any one of claims 1 to 11, wherein :-

$$\begin{aligned} 10 &\leq l_2/d_2 < 25 \\ 0.04 &\leq 4A_1/\pi d_1^2 < 0.10 \\ d_1 &> d_2 \\ d_2 &\approx d_3 \end{aligned}$$



wherein, d_1 is the diameter of the first portion at the level of the feed inlets, d_2 is the maximum diameter of the second portion and d_3 is the diameter of the third portion at its outlet, l_2 is the length of the second portion and, A_1 is the total cross-sectional area of all the feed inlets measured at the points of entry into the separating chamber normal to the inlet flow.

13. A cyclone separator according to claim 12, wherein :-

$$0.1 \leq \frac{d_o}{d_2} \leq 0.25$$

wherein d_o is the diameter of said overflow outlet.

14. A cyclone separator according to any preceding claim, wherein the overflow outlet is provided with means selectively operable to vary the cross-sectional area of the outlet for permitting clearing of a blockage occurring in the outlet.

15. A cyclone separator according to claim 14, wherein flow sensitive means is provided, positioned and operable for detecting a decrease in flow through said outlet and for operating said area varying means for increasing the cross-sectional area for said clearing.

16. A cyclone separator according to claim 15, wherein said outlet is in the form of an outlet pipe and the cross-sectional area varying means comprises a mechanism including a portion of the wall of the pipe which is so movable as to open the side of the pipe to the exterior thereof.

17. A cyclone separator according to claim 16, wherein said portion is a side segment of the pipe which is movable outwardly away from the remainder of the pipe under influence of said mechanism.



18. A cyclone separator according to claim 16 or claim 17, wherein said mechanism includes an electromagnet and the said flow sensitive means operates to apply electric current to said electromagnet for effecting movement of the wall portion away from the remainder of the pipe on said detecting of decrease in flow.

19. A cyclone separator according to claim 16, wherein the pipe wall portion is pivotally movable away from the remainder of the pipe.

20. A cyclone separator according to claim 19, wherein the pipe wall portion is arranged to be subject, in use, to a bias towards a position effecting said opening of the side of the pipe, and said flow sensitive means is positioned to be normally acted upon directly by flow through the pipe to impart a force thereon which is directed against the outlet pipe wall portion to maintain it closed, said force, however, being reduced in the case of reduced flow through the pipe due to blockage whereby the aforementioned bias effects movement to open the side of the pipe.

21. A cyclone separator according to claim 20, wherein the flow sensitive means comprises a pivotal lever having two arms extending from a location at which the lever is pivotal to said remainder of said pipe, one said arm being formed with means in use subjected to flow thereonto from the separator and the other engaging the said pipe wall portion.

22. A cyclone separator according to any one of claims 1 to 21, wherein said overflow outlet presents a stepped bore with a first bore portion adjacent the first portion being of greater diameter than a second bore portion thereof further from the first portion.

23. A cyclone separator according to claim 22, wherein said first bore portion is of a diameter in the range 0.125 to 0.625 of the diameter d_1 .

24. A cyclone separator according to claim 22 or claim 23, wherein



said second bore portion is of diameter 0.015 to 0.05 times the diameter d_1 .

25. A cyclone separator according to claim 1, substantially as described herein with reference to the drawings.

26. A cyclone separator assembly comprising two cyclone separators in accordance with claim 1 arranged in series with the underflow outlet of the first separator connected to at least one of the inlets of the second separator, the second separator providing said resistance to flow from the underflow outlet of the first separator.

27. A cyclone separator assembly according to claim 26, substantially as described herein with reference to Fig. 20 of the drawings.

28. A cyclone separator bank comprising a plurality of cyclone separators in accordance with claim 1 arranged in a plurality of rows of separators, a main feed inlet pipe and a plurality of generally parallel secondary inlet pipes extending from the main inlet pipe at spaced locations along the length thereof, the rows of separators lying between adjacent pairs of secondary inlet pipes with one inlet of each separator being connected to one secondary inlet pipe and the other inlet of each separator being connected to the other secondary inlet pipe of the adjacent pair of secondary inlet pipes.

29. A cyclone separator bank according to claim 28, including a plurality of rows of second separators, the underflow outlet of each first separator being branched with one branch being connected to one inlet of a second separator and the other branch being connected to one inlet of an adjacent second separator, the second separators providing said resistance to flow from the underflow outlet of the first separators.

30. A cyclone separator bank according to claim 28, substantially as described herein with reference to Figs 22 to 24 of the drawings.
