

CYCLONE SEPARATOR

This invention relates to cyclone separators, and provides a modification of the type of cyclone separator which is the subject of UK Patent Nos. 1583742, 1583730 or 2102311, or UK Patent Application Nos. 8419771 and 8511149 (W086/01130) or No.8515264 (W086/07548).

The cyclone separator described in the above documents are designed to be used for the separation of a denser component of a mixture of liquids from a less dense component and are particularly suitable for the separation of oil-water mixtures.

The separator of the above type comprises an elongate separating chamber having generally the form of a volume of revolution and having an inlet portion at one end of the separating chamber of greater diameter and at least one inlet with a tangential component for introducing the mixture into the separator at said end, an overflow outlet for the less dense component at the end of greater diameter and an underflow outlet for the more dense component at the other end of the separating chamber which is of lesser diameter.

In order that the separators shall be suitable for such separation constraints are placed on various parameters of the separator.

In those cyclone separators in use, the major volumetric component is the continuous phase, with up to a few percent of less dense phase and with perhaps up to about 1 part per thousand by volume of finely divided solids or other more dense phase. Priority is usually given to the production of a

highly purified continuous phase from the underflow outlet over minimising the volume of the outlet stream containing the less dense phase. Both features, while typical of use of the cyclone separators set forth above, are most unlike the vast majority of cyclone separator technology, which is generally directed to the separation of solids from fluids.

This invention provides a cyclone separator and a method for separation of a more dense component of a mixture of liquids from a less dense component thereof and which also allows the separation from the more dense component of a minor contaminant of density greater than that of the more dense component.

According to the invention a cyclone separator comprises an elongate separating chamber having generally the form of a volume of revolution and having an inlet portion at one end of the separating chamber of greater diameter and at least one inlet with a tangential component for introducing the mixture into the separator at said end, an overflow outlet for the less dense component at the end of greater diameter and an underflow outlet for the more dense component at the other end of the separating chamber which is of lesser diameter, wherein the separating chamber has at least one slot formed in the wall thereof and leading to a third outlet or outlets through which said contaminant can be removed from said mixtures, the or each said slot being arranged such that the flow structure within the separator is not upset.

Preferably the or each slot is generally circumferential and extends at least partially around the wall of said separating chamber. In one form two slots are disposed on the same circumferential line in spaced apart relation. In another

form a single slot extends continuously around the wall of the separating chamber.

There may be further provided a valve to control the discharge of material from said third outlet so that a selected proportion of the material flowing through the chamber leaves through that outlet or outlets.

Preferably, the separating chamber comprises at least a primary portion having generally the form of a volume of revolution and having a first end and a second end, the diameter at said second end being less than at said first end, at least one inlet, the or each said inlet having at least a tangential component at or adjacent said first end for introducing feed to be separated into the cyclone separator and the separator further including at least two outlets, in which cyclone separator the following relationship applies:-

where  $d_1$  is the diameter of the said primary portion where flow enters (but neglecting any feed channel),  $d_{ix}$  is twice the radius at which flow enters the cyclone through the  $x^{th}$  inlet (i.e. twice the minimum distance of the tangential component of the inlet centre line from the axes) and

$$d_i = \frac{1}{A_i} \sum_{x=1}^{x=n} d_{ix} A_{ix}$$

where  $n$  is the number of inlets,  $A_{ix}$  is the minimum cross sectional area of the  $x^{th}$  inlet at entry to the cyclone separator in a plane parallel to the axis of the cyclone separator, and where

$$A_i = \sum_{x=1}^{x=n} A_{ix}$$

and where  $d_2$  is the diameter of the primary portion at said second end and is measured at a point  $z_2$  where the condition first applies that

$$\tan^{-1} \left( \frac{d_2 - d}{d(z - z_2)} \right) < 2^\circ$$

for all  $z > z_2$  where  $z$  is the distance along the cyclone separator axis downstream of the plane containing the inlet and  $d$  is the diameter of the cyclone at  $z$ , and further  $z = 0$  being the axial position of the weighted areas of the inlets such that the injection of angular momentum into the cyclone separator is equally distributed axially about said axial position where  $z = 0$  and being defined by

$$\frac{1}{A_i d_i} \sum_{x=1}^{x=n} z_x A_{ix} d_{ix} = 0$$

where  $z_x$  is the axial position of the  $x^{\text{th}}$  inlet and further

$$\frac{\pi d_2 d_i}{4A_i} \text{ is from 3 to 12}$$

Further according to the invention a method of separating a material containing (i) a volumetrically predominant continuous phase (ii) a dispersed phase less dense than phase (i), (iii) a dispersed phase more dense than phase (i), comprises applying the material to the inlet(s) of a cyclone separator according to the invention, phase (ii) predominantly reporting to the overflow outlet and phase (iii) predominantly reporting to the third outlet through the slot.

Preferably a valve is provided to control the third outlet , so that a desired proportion (such as up to 15% by volume) of the material flowing through the cyclone leaves through that exit. The slot is preferably not wider (measured axially) than 10% of  $d_2$ . Preferably the slot extends radially outwardly, with substantially planar edges, and free from radially inwards protrusions into the body of the cyclone separator.

Preferably higher pressure is applied at the inlets than exists at the outlets.

Preferably, the dispersed phase (ii) is under 5% by volume (more preferably under 1%) of the material, and may for example be hydrophobic such as oil.

For example the phase (i) is aqueous.

For example the phase (iii) is solids, preferably not exceeding 1 part per thousand by volume of the material and may for example be sand, quartz or clay. Preferably its kinetic energy on leaving the cyclone separator is recovered.

The invention will now be described by way of example, with reference to the accompanying drawing, which shows, schematically, a cyclone separator according to the invention. The drawing is not to scale.

Except as explained hereafter, the illustrated cyclone separator is identical to that disclosed and claimed in UK Patent 2102311, to which the reader is referred. Identical reference numbers have been used as far as possible. Where the flow-smoothing taper  $T_2$  of the separation portion 2 merges at its downstream end with the cylindrical third portion 3, a circumferential slot 20 is cut, leading to an annular gallery 21 which has occasional generally radial drains 22 controlled by valves 23. The slot width (measured axially) is 3mm, i.e. about 8% of the diameter  $d_2$  (38mm) of the separation portion 2.  $d_3$  is 19 mm.

In treating oily water, the oil removal efficiency remained satisfactory over a large range of split ratios at small volumetric flow rates through the slot 20, i.e. up to about 15% of the flow entering the cyclone separator. When the valves 23 were fully

closed, the cyclone separator operated as if the slot 20 were absent.

The slot itself could be located anywhere along the taper  $T_2$  where the flow was generally convergent. In a curved-wall cyclone, this would also apply, that is, the slot 20 could be located at any location where the flow structure was characteristic of a convergence towards the downstream outlet.

Slot widths grossly exceeding 10% of  $d_2$  or having radially inwardly protruding lips, guides or other discontinuities were found to upset the flow structure in the cyclone separator.

The effect of the slot 20, when the valves 23 are appropriately open, is to form a third exit from the cyclone separator. This is especially suitable where it is desired to treat a continuous liquid phase (e.g. water) containing two low-concentration dispersed phases, one denser and one less dense than the continuous phase, e.g. solids and oil. The solids may in practice comprise sand (e.g. quartz) or clay or chalk, up to about 1 part per thousand by volume. It is this denser phase which, centrifugally thrown radially outwardly towards the wall of the cyclone separator, is extracted through the slot 20. The particle size of such solids, in two examples, is 20 microns and 100 microns; these simply move into the slot. Some particles may be carried past the slot by the flow, but this is acceptable since, for most applications, removal of say three-quarters of the solids is sufficient.

Within the scope of this invention, the slot 20 may be applied to other cyclone separators than that in the drawing. Thus, for example, the slot 20 could

be applied to the cyclone separator disclosed and claimed in UK Patent 1583742, making it possible to treat materials containing higher proportions of less dense phase, such as up to 5%.

More than one slot 20 may be provided at different axial positions ( $z > z_2$ ).

The slot(s) thus permit a three-way separation of material at similar energy cost as conventional two-way separation in a cyclone separator. The pressure drop in the slotted cyclone separator is similar to that in an unslotted one, and the need for extra energy-consuming sand-removal cyclones, as used conventionally, is obviated. Moreover, the kinetic energy may (at least to some extent) be recovered from the exit, by using a suitable form of spiral or tangential connection instead of exactly radial drains 22 from the slot 20; alternatively a diffusing action in the slot 20 itself may be exploited to recover this energy.

C L A I M S

1. A cyclone separator for separation of a more dense component of a mixture of liquids from a less dense component thereof and which also allows the separation from the more dense component of a minor contaminant of density greater than that of the more dense component, which comprises an elongate separating chamber having generally the form of a volume of revolution and having an inlet portion at one end of the separating chamber of greater diameter and at least one inlet with a tangential component for introducing the mixture into the separator at said end, an overflow outlet for the less dense component at the end of greater diameter and an underflow outlet for the more dense component at the other end of the separating chamber which is of lesser diameter, wherein the separating chamber has at least one slot formed in the wall thereof and leading to a third outlet or outlets through which said contaminant can be removed from said mixtures, the or each said slot being arranged such that the flow structure within the separator is not upset.

2. A cyclone separator according to claim 1 wherein the or each said slot is generally circumferential and extends at least partially around the wall of said separating chamber.

3. A cyclone separator according to claim 2 wherein two said slots are disposed on the same circumferential line in spaced apart relation.

4. A cyclone separator according to claim 2 wherein a sinngle slot extends continuously around the wall of said separating chamber.



5. A cyclone separator according to any preceding claim further including a valve to control the discharge material from said third outlet or outlets so that a selected proportion of the material flowing through the chamber leaves through that outlet or outlets.

6. A cyclone separator according to any one of claims 1 to 5 wherein up to 15% by volume of the mixture introduced into the separator leaves through the third outlet(s).

7. A cyclone separator according to any preceding claim wherein the or each said slot extends radially outwardly with substantially planar edges and free from radially inwardly extending protrusions into the body of the cyclone separator.

8. A cyclone separator according to claim 1 wherein said separating chamber comprises at least a primary portion having generally the form of a volume of revolution and having a first end and a second end the diameter at said second end being less than at said first end, at least one inlet having at least a tangential component at or adjacent said first end for introducing feed to be separated into the cyclone separator and the separator further including at least two outlets, in which cyclone separator the following relationship applies:

where  $d_1$  is the diameter of the said primary portion where flow enters (but neglecting any feed channel),  $d_{ix}$  is twice the radius at which flow enters the cyclone through the  $x^{\text{th}}$  inlet (i.e. twice the minimum distance of the tangential component of the inlet centre line from the axes)

and

$$d_j = \frac{1}{A_j} \sum_{x=1}^{x=n} d_{ix} A_{ix}$$



where  $n$  is the number of inlets,  $A_{ix}$  is the minimum cross sectional area of the  $x^{\text{th}}$  inlet at entry to the cyclone separator in a plane parallel to the axis of the cyclone separator, and where

$$A_i = \sum_{x=1}^{x=n} A_{ix}$$

and where  $d_2$  is the diameter of the primary portion at said second end and is measured at a point  $z_2$  where the condition first applies that

$$\tan \left( \frac{-1}{2(z-z_2)} \frac{d_2 - d}{1} \right) < 2^\circ$$

for all  $z > z_2$  where  $z$  is the distance along the cyclone separator axis downstream of the plane containing the inlet and  $d$  is the diameter of the cyclone at  $z$ , and further  $z=0$  being the axial position of the weighted areas of the inlets such that the injection of angular momentum into the cyclone separator is equally distributed axially about said axial position where  $z = 0$  and being defined by

$$\frac{1}{A_i d_i} \sum_{x=1}^{x=n} z_x A_{ix} d_{ix} = 0$$

where  $z_x$  is the axial position of the  $x^{\text{th}}$  inlet, and further



$\pi$

$d_2 \ d_1$

is from 3 to 12

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$4A_1$

9. A method of separating a material containing (i) a volumetrically predominant continuous phase, (ii) a dispersed phase less dense than phase (i), and (iii) a dispersed phase more dense than phase (i) comprising applying the material to the inlet(s) of a cyclone separator according to any one of claims 1 to 8, phase (ii) predominantly reporting to the overflow outlet and phase (iii) predominantly reporting to the third outlet through the or each slot.

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