Phase separation in centrifugal fields with emphasis on the rotational particle separator

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Abstract

The separation of heavy or light phases and particulate matter from fluids by centrifugation is considered. Emphasis is laid on the newly developed and patented technique of the rotational particle separator. This technique is used in areas ranging from the treatment of fluids in industrial processes to the filtering of air to protect men to respiratory allergic reactions. Principles of centrifugation, fluid forces on objects and kinematics of phases and particles in laminar flow are treated to obtain analytical expressions for parameters of separation performance. Conditions for stability of laminar flow in rotating configurations are specified; secondary flows induced by Coriolis forces and their effect on separation performance are quantified. Results of measurements are compared with theoretical predictions. Designs which have materialized in the various areas of application are discussed. © 2002 Elsevier Science Inc. All rights reserved.

1. Introduction

There is considerable societal interest in techniques to separate dispersed phases and particulate matter from fluids. Interest stems from needs to recover products from fluids in technical processes and from desires to reduce emissions of pollutants to the environment. Several methods exist to perform the separation function [1]. Each of these methods is based on application of specific physical principles and each of them has its pros and cons (see Table 1).

A new method concerns the rotational particle separator [2]. In this patented technique [3,4] the principles of centrifugation are exploited to enhance the separation of small-sized phases and particulate matter of density different from the carrier fluid. Main objective of this paper is to elucidate the phenomena and features of fluid flow and separation apparent in centrifugal fields and encountered in the technique of the rotational particle separator.

2. Working principles of the rotational particle separator

Phase separation by centrifugation in the rotational particle separator involves the application of a separation element which is cylindrical in shape and which rotates around its axial symmetry-axis: Fig. 1. The element consists of a large number of small channels, typically 1 mm in diameter, which are arranged in parallel to the symmetry and rotation axis. When fluid is led through the channels, phases and particles entrained in the fluid are driven by the centrifugal force to the walls; to the outer walls if the phases or particles are heavier than the carrier fluid: Fig. 2, to the inner walls if lighter. As the radial distances over which phases and particles have to move to arrive at the collecting surfaces of each channel are small, phases and particles of small size are capable of being separated: e.g. solid and liquid particles entrained in gases with sizes of the order of 0.5 μm; hydrocarboneous phases in water with sizes of the order of 10 μm. In case of solid particles in gases the larger sized fraction of such particles will stay at the collecting surface as a result of dry or Coulomb friction apparent under the action of centrifugal forces. The smaller particles (<1 μm) adhere at the wall because of Van Der Waals’ forces. Under partially humid conditions surface tension causes particles to stick to the
walls. It prevents separated material from re-entrainment in the gas. Separated material collected at the walls can be removed periodically, if necessary, by blowing or flushing fluids through the channels. In case of mists or liquid phases entrained in gases or liquids, the separated material forms films along the collecting surfaces. The liquid films are squeezed out of the channels in the form of droplets being centrifuged in the chambers up- and downstream of the rotating separation element. Under typical conditions pressure drops over the channels of the separation element are limited to some hundred Pascals for gases as carrier fluid and to some thousands of Pascals for liquids as carrier fluid.

3. Elementary separation

Consider a situation where a fluid rotates as a rigid body and flows axially parallel to the rotation axis in a laminar fashion. By design such a situation prevails in the channels of the separation element of the rotational particle separator. As particles and phases are assumed to be very small in size, inertia forces acting on them are small. Particle or phase concentrations are small so that mutual interactions can be disregarded. Particles and phases follow the streamlines of the fluid except for the radial direction where as a result of centrifugal and buoyancy forces they move relative to the fluid. The

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Working range ( d_p &gt; \mu \mu )</th>
<th>Fixed costs</th>
<th>Variable costs</th>
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<tbody>
<tr>
<td>Gravitation chamber</td>
<td>Gravitational force</td>
<td>100</td>
<td>Low</td>
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<tr>
<td>Cyclone</td>
<td>Centrifugal force</td>
<td>5</td>
<td>Low</td>
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<td>Rotational particle separator</td>
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<td>Venturi scrubber</td>
<td>Inertia, interception, diffusion</td>
<td>0.2</td>
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<td>Fabric filter</td>
<td>Inertia, interception, diffusion</td>
<td>0.01</td>
<td>High</td>
</tr>
<tr>
<td>Electrostatic precipitator</td>
<td>Coulomb force</td>
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<td>High</td>
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</tbody>
</table>
radial velocity of the particle or phase follows from a balance between centrifugal and buoyancy forces and the drag force exerted by the fluid in case of relative motion

\[ F_c = F_d + F_b \]  \hspace{1cm} (1)

where centrifugal and buoyancy forces are given by, respectively

\[ F_c = \frac{\pi}{6} \rho_p d_p^3 \Omega^2 r, \quad F_b = \frac{\pi}{6} \rho_f d_p^3 \Omega^2 r \]  \hspace{1cm} (2)

\( \rho_p \) being particle or dispersed phase density, \( \rho_f \) fluid density, \( d_p \) particle or dispersed phase diameter or equivalent diameter, \( \Omega \) angular velocity and \( r \) radial position. For small-sized particle and phases subject to slow relative motion, the drag force can be described according to Stokes [5]:

\[ F_d = 3 \pi \mu_f d_p u_p \]  \hspace{1cm} (3)

where \( \mu_f \) is dynamic viscosity of the fluid. From Eq. (1) then follows for the radial velocity of particles or phases the expression

\[ u_p = \frac{\left( \rho_p - \rho_f \right) d_p^2 \Omega^2 r}{18 \mu_f} \]  \hspace{1cm} (4)

Whether particles or phases reach a collecting wall depends on the residence time, their radial velocity and the position they have at entrance. The smallest particle or phase which with 100% probability reaches the wall is the particle or phase which during the available time moves over the entire cross-sectional distance \( d_c \) between radially placed walls. Assuming a uniform axial velocity profile \( w_f \), the radial velocity of such particles or phases is given by

\[ u_{p,100\%} = \frac{d_c}{t_r} \]  \hspace{1cm} (5)

where the residence time \( t_r = L_c/w_f \), \( L_c \) being axial length of the collecting walls. Equating Eqs. (4) and (5) yields for the diameter of the particle or phase which is collected with 100% probability, the equation

\[ d_{p,100\%} = \sqrt{\frac{18 \mu_f w_f d_c}{\left( \rho_p - \rho_f \right) \Omega^2 r L_c}} \]  \hspace{1cm} (6)

This result applies to a separation unit formed by two adjoining radially placed walls, i.e. a single channel of the rotational particle separator. In case of an assembly of radially placed walls, i.e. a complete filter element consisting of a multitude of channels, for fixed values of \( d_c, w_f \) and \( L_c \) the value of \( d_{p,100\%} \) increases with decreasing \( r \). This can be avoided by designing an axial velocity which is proportional with \( r \). In that case the smaller centrifugal or buoyancy force at smaller radii is compensated by a larger residence time. In case of the rotational particle separator the appropriate axial velocity profile can be achieved by proper fluid mechanical design of inlet and outlet chambers up- and downstream of the filter element. For \( w_f \propto r \), Eq. (6) can be written as

\[ d_{p,100\%} = \sqrt{\frac{27 \mu_f Q d_c}{\left( \rho_p - \rho_f \right) \Omega^2 L_c (1 - \varepsilon) \pi (R_o^3 - R_i^3)}} \]  \hspace{1cm} (7)

where \( Q \) is volume flow through the entire assembly of separation channels, \( R_o \) outer radius, \( R_i \) inter radius and \( \varepsilon \) reduction of cross-sectional area because of finite wall-thickness of the channels.
In Table 2 two example cases are presented for the dimensioning of the rotating element of the rotational particle separator, one for solid particles in air and the other for oil phase in water. It is seen that all particles or phases with diameters larger than 0.7 and 17 μm, respectively, are separated.

For illustrative purposes, consider the conventional technique of cyclones having swirling velocities, through flow and external dimensions which are comparable in magnitude to those of the rotating configurations considered in Table 2. For such cyclones one can show that the particle cut-off diameter will be much larger, by roughly a factor 5–10 than $d_{p,100%}$ of the corresponding rotating configurations. The underlying reason is the large radial distance over which particles must travel to reach the collecting wall. This distance amounts to $R_0$ in the cyclone. In the rotating element of the rotational particle separator the effective separation distance amounts to the radial gap $d_c$ formed by the walls of the separation channels which is much less than $R_0$. Despite the smallness of this gap the axial pressure losses the fluid is subjected to while flowing in between these walls is limited. Its value can be estimated considering Hagen–Poiseuille flow in a pipe of diameter $d_c$ [6]

$$\Delta p = 32 \mu L_c \frac{w_l}{d_c^2}$$  \hspace{1cm} (8)

It yields pressure drops of 509 and 2096 Pa for examples 1 and 2 of Table 2 respectively. More important are the energy losses which occur by bringing the fluid in rotation prior to entry to the rotating configuration and transferring rotation back to static pressure while leaving the rotating configuration. The same losses occur in the cyclone. These losses typically amount to $\rho_c \Omega^2 R_0^4$ expressed in Pascals or Watts per unit volume flow. For examples 1 and 2 it yields values of 2025 and 43659 Pa or W/(m³/s) respectively. In general it can be concluded that for equal external dimensions, throughput and energy consumption, the rotational particle separator enables the separation of particles or phases which are about a factor 5–10 smaller than the corresponding cyclone. This advantage should outweigh the efforts involved with the additional component of a rotating element.

4. Separation efficiency as a function of phase or particle diameter

From Eqs. (6) and (7) the diameter of the phase or particle can be determined which is collected with 100% efficiency. Albeit being less than 100% also smaller phases or particles have a probability of being collected. They are at shorter distance from the collecting surface when entering a separation channel and therefore do not need to cross the entire width of the channel during residence. To assess the separation probability or efficiency of phases or particles smaller than $d_{p,100%}$, three types of channel geometries are considered: annuli, circles and triangles: Fig. 3. The axial velocity is uniform over the cross-section. The height of the channel is small in comparison with the radius and phases and particles are uniformly distributed over the cross-section at channel entry. Considering phases and particles of the same diameter, they all move with the same radial velocity. While being axially transported through the channel, they all have moved over the same radial distance at channel exit: Fig. 3. The shape of the cross-sectional area formed by the moving phases or particles is equal to the shape of the channel. The separation efficiency $\eta$ or the ratio of the number of phases or particles of a specific diameter which reaches the wall to the number of phases or particles entering the channel is equal to the ratio of the shaded area in Fig. 3 to the cross-sectional area of the channel. Furthermore,

$$\frac{s}{d_c} = \frac{u_p}{u_{p,100%}}$$  \hspace{1cm} (9)

and because the radial velocity $u_p$ is proportional to $d_p^2$, cf. Eq. (4), one has

$$\frac{s}{d_c} = \frac{d_p^2}{d_{p,100%}^2}$$  \hspace{1cm} (10)

Eq. (10) can be combined with the geometrical relationships: which can be derived for the shaded areas of Fig. 4 expressed as a function of $s$. In this way analytical descriptions are obtained [7] for the efficiency by which

![Fig. 3. Centrifugation of equally sized particles in annulus, circle and triangle.](image)
phases and particles are collected as a function of the dimensionless diameter
\[ x = \frac{d_p}{d_{p,100\%}} \]  
(11)
i.e., for the annulus,
\[ \eta = \begin{cases} x^2 & x < 1 \\ 1 & x \geq 1 \end{cases} \]  
(12)
for the circle,
\[ \eta = \left( 2x^2 \sqrt{1-x^2} + \frac{y}{x} \sin x^2 \right) \frac{1}{x} \]  
(13)
and for the triangle,
\[ \eta = \begin{cases} 2x^2 - x^4 & x < 1 \\ 1 & x \geq 1 \end{cases} \]  
(14)
Efficiencies according to these formulae have been plotted in Fig. 4. The shape of the curves depends on the geometry of the channel. The absolute value of the diameter of the phases or particles which are separated depends on the value of \( d_{p,100\%} \) as specified by Eq. (6).

The above expressions for separation efficiency apply to a single channel. To assess the efficiency of an assembly of channels, i.e. a complete filter element of the rotational particle separator it is necessary to know the distribution of the axial velocity over the filter element. This velocity namely determines the value of \( d_{p,100\%} \): cf. Eq. (6). Moreover the number of particles which enters any particular channel can be taken to be proportional to \( w_f \). The filter efficiency \( \eta_{\text{filter}} \) can then be assessed by weighing the efficiency of every separate channel with the fluid velocity \( w_f \) and integrating this over the total surface:
\[ \eta_{\text{filter}} = \frac{1}{2} \int_{0}^{2\pi} \int_{r_0}^{R_0} \eta(r) w_f(r) r dr d\theta \]  
(15)
For the case that \( w_f \propto r \) the separation efficiency \( \eta \) is the same for every channel: i.e. \( \eta \) does not depend on \( r \). The dimensionless efficiency distributions given by Eqs. (12)–(14) and shown in Fig. 3 then hold for the assembly as well. The value of \( d_{p,100\%} \) is the same for every channel

and can be calculated from either Eqs. (6) or (7). But for other distributions of \( w_f \) the efficiency distributions will become different as \( \eta \) will vary with \( r \) through its dependency on \( d_{p,100\%} \). In this connection it is interesting to consider the case where \( w_f \) is constant over the entire cross-section: Fig. 5. Such a situation will occur when the pressure drop over the channels is very large. In that case there will be a tendency for the flow to become more uniformly distributed over the assembly. The implications using Eq. (15) have been assessed for the case of annuli and triangles implementing Eqs. (12) and (14) respectively:

**Annuli:**
\[ \eta_{\text{filter}} = \begin{cases} x^2 & x \leq \beta_i^{1/2} \\ \left( \beta_0^2 - \beta_i^{2-1} \right) \left( \beta_i^2 - \frac{1}{3x^4} \beta_i^2 x^2 \right) & \beta_i^{1/2} \leq x \leq \beta_i^{-1/2} \\ 1 & x \geq \beta_i^{-1} \end{cases} \]  
(16)

**Triangles:**
\[ \eta_{\text{filter}} = \begin{cases} 2x^2 - \frac{1}{2} \left( \beta_i^1 + \beta_o^1 \right) x^4 & x \leq \beta_o^{1/2} \\ \left( \beta_0^1 - \beta_i^1 \right) \beta_i^2 & \beta_i^{1/2} \leq x \leq \beta_i^{-1/2} \\ 1 & x \geq \beta_i^{-1} \end{cases} \]  
(17)

here, \( \beta_i \) and \( \beta_o \) are defined as
\[ \beta_i = \frac{3(1+\delta)}{2(1+\delta+\delta^2)}, \quad \beta_o = \frac{3(1+\delta)}{2(1+\delta+\delta^2)}, \]  
(18)
where
\[ \delta = \frac{R_i}{R_o} \]  
(19)
while \( x \) is given by Eq. (10) with \( d_{p,100\%} \) defined by Eq. (7). Results have been shown in Fig. 6 for the case \( \beta_i = R_i = 0 \), i.e. channels up to the rotation axis. For comparison the efficiency distributions for the ideal velocity distribution \( w_f \propto r \) have been shown as well. It is seen that for uniform \( w_f \) the efficiency only approaches asymptotically the value of 100% for \( d_p/d_{p,100\%} \gg 1 \).
This is caused by leakage through less efficient channels at smaller radii. The effect can be reduced significantly by designing such that $R_o > 0$. For example, for $R_i = 1/2R_o$, $\beta_i = 9/14$ and according to Eqs. (16) and (17) efficiencies of 100% are obtained for $d_p$ equal or larger than $1.25d_{p,100\%}$. At the same time the value of $d_{p,100\%}$ only increases by 7% by blocking the interior of the filter element keeping the total flow the same $Q$: cf. Eq. (7).

5. Stability of rotating laminar channel flow

Although at first glance simple and straightforward the radial motion of phases and particles in a channel is a subtle and sensitive process. The smallest fractions aimed of being separated are those which move with a radial velocity which compares to the axial fluid velocity as the ratio of channel height to channel length: cf. Eq. (5). In practical applications of the rotational particle separator this ratio is very small, typically $10^{-2}$. So smallest separated fractions move with radial velocities which are only one percent of the axial fluid velocity. If now secondary fluid flows occur in planes perpendicular to the axial channel flows which are only one percent in magnitude of the axial fluid velocity, the process of radial migration of the smallest separated fraction is already disturbed. To avoid this from happening it is necessary to have laminar fluid flow. But it is known that such flow only occurs for limited value of the Reynolds number $Re_w$. For non-rotating channels [8–10],

$$Re_w \leqslant 2000$$

where

$$Re_w = \frac{\rho_i w_id_e}{\mu_t}$$

For $Re_w > 2000$, various sorts of secondary flows appear ultimately evolving into turbulence. The magnitude of these secondary flows amounts to typically 5–10% of the axial channel velocity.

The above observations regarding instability of laminar channel flow apply to non-rotating channels. Rotation is an additional factor for destabilization. For a cylindrical pipe rotating around its own symmetry axis condition (20) is sufficient as long as the Reynolds number based on rotation,

$$Re_Q = \frac{\rho_t \Omega (d_c/2)^2}{\mu_t}$$

is limited such that [11]

$$Re_Q \leqslant 30$$

If however, $Re_Q$ is larger than 30, $Re_w$ should become much less, in fact less than about 80 to ensure laminar flow [11].

The above results for instability of rotating laminar pipe flow were deduced from experiments carried out on a pipe rotating around its own symmetry axis. The question arises whether they are also valid for a pipe rotating around an axis which is parallel with its symmetry axis but not coinciding; this is the situation encountered in the rotational particle separator. To answer this question, the equations pertaining to conservation of fluid flow have to be considered, viz. the Navier–Stokes equations. Written in a frame that rotates around an axis and considering incompressible flow only, these equations are [12]:

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \nabla \mathbf{u} + \mathbf{\Omega} \times (\mathbf{u} \times \mathbf{r}) + 2\mathbf{\Omega} \times \mathbf{u}$$

$$= -\frac{1}{\rho_t} \nabla P - \frac{\mu_t}{\rho_t} \nabla \times \nabla \times \mathbf{u}$$

(24)

where $\mathbf{u}$ is fluid velocity, $t$ is time, $\nabla$ is nabla operator, $\mathbf{r}$ is distance from the rotation axis, $\mathbf{\Omega}$ is angular velocity of the rotating frame, $P$ is static fluid pressure. The terms on the left hand side are due to instationary and convective acceleration forces, centrifugal forces and Coriolis forces respectively, which are balanced by pressure and viscous forces. The centrifugal force can be eliminated by introducing the reduced pressure $P_r$ as

$$P = P_t + \frac{1}{\rho_t} (\mathbf{\Omega} \times \mathbf{r}) \cdot (\mathbf{\Omega} \times \mathbf{r})$$

(25)

by which Eq. (24) reduces to

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \nabla \mathbf{u} + 2\mathbf{\Omega} \times \mathbf{u} = -\frac{1}{\rho_t} \nabla P_t - \frac{\mu_t}{\rho_t} \nabla \times \nabla \times \mathbf{u}$$

(26)

The nabla operator in this equation can be based on local cylindrical co-ordinates coinciding with the pipe. From Eq. (26) it then follows that the impulse balance which governs incompressible fluid flow in a rotating frame does not depend on the distance from the rotation axis. The distance only occurs indirectly in the expression for the reduced pressure which acts as a vehicle to generate axial flow through the pipe. It leads to the conclusion...
that results for flow in a pipe that rotates around its own symmetry axis equally apply to pipes rotating around an axis parallel to its own axis, the situation encountered in the rotational particle separator. Speeds can be quite high but channel heights are small such that conditions (20) and (23) are satisfied. Stable laminar flow is likely to be ensured in triangular or square shaped channels as well provided conditions (20) and (23) are satisfied taking for \( d_c \) channel height. Quite a different situation occurs in case of channels formed by annuli. For practically realistic conditions of phase separation in centrifugal fields circumferential speeds are large in comparison with axial fluid velocities. Radial heights of channels, annuli or otherwise, are small in comparison with radii. Under these circumstances stability of laminar flow in annuli is observed [13] for,

\[
Re_a \leq 80,
\]

It is a much stronger condition than (26) and difficult to satisfy in practice. Apparently the freedom the fluid has to make an entire swirl around the rotation axis without meeting a wall as is the case in annuli makes the flow much more prone to instability under rotation. Placing radial walls inside the annulus stabilizes the flow in case of rotation. It indicates to use filter elements whose channels are enclosed by singly connected walls. One practical way to achieve this is to use corrugations, i.e. to wind up around a shaft layers of corrugated and uncorrugated sheet material being metal, paper or plastic: Fig. 7. It is a simple and cheap method for manufacturing filter elements which meet fluid mechanical constraints.

6. Secondary flows in tilted rotating pipes

Unwanted secondary flows can also occur in case the symmetry axis of a channel makes an angle with respect to the rotation axis: For example, by fabrication inaccuracy the channels can be twisted around the symmetry axis of the filter element, or they can diverge or converge as their distance from the axis of the filter element increases (or decreases) in axial direction. Coriolis forces will act on the fluid as soon as the fluid flow is non-parallel to the rotation axis. Such forces lead to circulatory secondary flows in planes, perpendicular to the axial channel axis [14–16] of a kind similar to the circulatory flows in bends [17,18]. For circular pipes it is possible to calculate these flows analytically as solutions of the Navier–Stokes obtained under certain limiting conditions which coincide with the conditions under which the rotational particle separator operates [16]. The streamlines of the particles are governed by the equation [16],

\[
\kappa = \frac{\rho f w_f \Omega a^2 \sin \alpha}{24 u_p \mu_f} \geq 80
\]

where \( \kappa \) is a constant and the dimensionless number \( \kappa \) is defined by

\[
\kappa = \frac{\rho f w_f \Omega a^2 \sin \alpha}{24 u_p \mu_f}
\]
The first term on the left hand side of Eq. (28) describes particle trajectories due to circulatory Coriolis-induced fluid motion, the second and third term describe straight particle trajectories due to centrifugation. The dimensionless number $\kappa$ weighs the disturbing effect of circulatory fluid motion on particle centrifugation. This has been illustrated in Fig. 9. Here, we have plotted particle trajectories according to Eq. (28) for increasing values of $\kappa$ considering $\gamma = 0^\circ$ and $\gamma = -90^\circ$. It is seen that particles become more and more trapped in circulatory motion with increasing $\kappa$. In practical design it implies that non-parallellity of channels must be limited to specific values, to angles of inclination of a few degrees in typical cases.

7. Experimental results

Separation efficiencies have been assessed for a number of separation elements of different size (length, radius, channel, height, etc.) subject to different conditions (angular speed, flow rate, particulate matter, etc.). Particle collection efficiencies were determined by measuring distributions at inlet and outlet using cascade impactors and laser particle counter techniques. For each of the cases the value of $d_{p,100\%}$ according to Eq. (7) was calculated. These were subsequently used to generate efficiency distributions as a function of dimensionless particle diameter $d_p/d_{p,100\%}$. Results have been shown in Fig. 10. For reasons of comparison the theoretical curve according to Eq. (17) with $R_i = 0$ has been shown as well. It is seen that results of measurements are consistent with each other and compare well with theory.

8. Applications

Phase separation in centrifugal fields using the rotational particle separator has found its way to the market in various areas of application. A multinational electronic consumer goods company has adopted the principle in an air cleaner. The device, which is sold world-wide, serves to remove air-borne particles which can cause respiratory allergic reactions to men in houses and offices. Another application concerns the collection of powders and particles from gases in food and pharmaceutical processes. A specific advantage in this area is the possibility to fabricate the entire apparatus of stainless steel. It enables to meet strongest conditions on hygiene and cleaning. A design has been shown in Fig. 11. The rotating element has been integrated in a cyclone. The cyclone acts as a pre-separator in which the gas is filtered from course particles material prior to entrance in the separation element. The cyclone also serves as a pre-swirler within which the gas is brought in rotation before entering the rotating separation element. An impeller is fitted on the downstream side of the filter element. Here, the gas is brought to the desired pressure.
It avoids the necessity of installing a separate fan. This to compensate for the pressure loss incurred in the separation device. Moreover, the over-pressure in the exit chamber ensures that only clean air flows through the gap between rotating filter element and housing from exit chamber to inlet chamber/cyclone, instead of unfiltered air moving vice versa. On top of the device air nozzles are placed by which periodically material collected in the channels is blown towards the cyclone where it is collected in the cyclone outlet. Blowing occurs during normal operation of the filtering process, without stopping flow and rotation.

The device of the rotational particle separator can be made heat-resistant allowing temperatures up to 500 °C. It has induced application of filtering hot gases of small and medium sized coal and wood combustion and gasification installations [19,20]. Another feature is the capability to separate solid and liquid particles material simultaneously. It has led to the development of units suited for the filtering of polluted and misty intake air of land-based gas turbines for power generation [21,22]. A more recent development concerns the separation of oil droplets from water. A design suited for this application is shown in Fig. 12. The filter element is freely mounted in a pipe. Instead of externally driven by a motor, rotation of the element is induced naturally, like a turbine, by giving the water prior to entry a swirling motion through static vanes upstream of the filter element. Static diffuser vanes installed downstream of the element serve to convert swirling motion into static pressure thus bringing total pressure drop to a minimum. The design is particularly suited for operation under high pressure. The rotating element is fully contained within a cylindrical pipe allowing high pressures; there is no shaft pinning through an external wall requiring sealing. Lighter oil droplets immersed in the water will move to the inner walls of the separation channels. Here they form a film which is squeezed out of the channels. At the channel exit, the film will break up in droplets. For sufficiently large surface tension, the droplets will be relatively large, about 100 μm in diameter. The result is that due to the swirling motion in the chamber behind the filter element, the lighter droplets move to the interior in rather short time. Here, the oil fraction can be sucked off. With a similar device and in a similar manner tiny air bubbles can be separated from water.

References


