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(54) Ejection of solid particles from a centrifugal separator

(57) The present invention relates to a method for separating solid particles from a liquid mixture in a centrifugal separator. The separator comprises a rotor body which is rotatable around an axis of rotation (R). The rotor body has a separation chamber for separating solid particles from the liquid mixture and an inlet for the liquid mixture and a screw conveyor adapted to rotate in the rotor body around the axis of rotation (R) for transporting the separated solid particles in the separation chamber (16) towards and out of a sludge outlet. The method comprises the steps of a) operating the separator in a separation phase, in which solid particles are separated from the liquid mixture, and b) operating the separator in an ejection phase, in which separated solid particles are transported towards the sludge outlet and further ejected out of the sludge outlet. An ejection liquid is introduced in the separation chamber during said ejection phase. The present invention further relates to a centrifugal separator for performing the method.

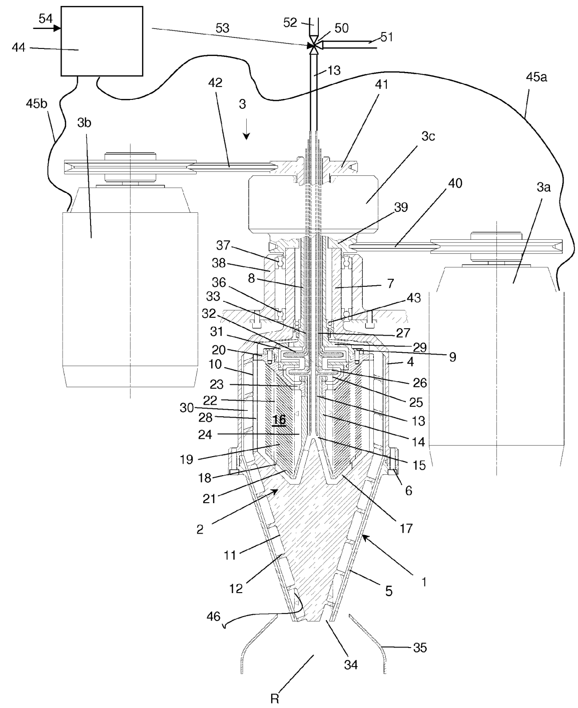

Fig. 1

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Description

Field of the Invention

[0001] The present invention relates to the field of centrifugal separators for separating solid particles from a liquid mixture, and especially to a method for ejecting solid particles from a centrifugal separator.

Background of the Invention

[0002] Centrifugal separators, such as decanter centrifuges, are used for separating solid particles from a liquid mixture.

[0003] WO 2008/140378 discloses a centrifugal separator initially defined for purifying a fluid from contaminating particles. The particles separated from the fluid deposit themselves on the inside of the rotor body in the form of a layer of sludge, wherein the screw conveyor is arranged for transporting the sludge towards and out of the outlet. However, this layer of sludge may be difficult to transport due to the viscosity of the sludge (the viscosity may be too high or low for good transportation characteristics). Furthermore, when rotating the rotor body at high speed the sludge transportation problem may be worsened. The resulting high centrifugal forces have a compressing effect on the sludge making it more difficult to transport out of the sludge outlet. Failure to discharge the sludge from the rotor body will cause a relatively solid sludge phase to grow radially inwards towards the axis of rotation, impairing the degree of separation and ultimately rendering continued separation impossible because of obstruction.

[0004] Consequently, there is a need in the art for improved methods of ejecting or discharging solid particles such as sludge from a centrifugal separator.

Summary of the Invention

[0005] A main object of the present invention is to provide a method and a centrifugal separator for effectively separating solid particles, such as sludge, from a liquid mixture and further transporting separated solid particles out of the separator.

[0006] As a first aspect of the invention, there is provided a method for separating solid particles from a liquid mixture in a centrifugal separator, wherein the separator comprises a rotor body which is rotatable around an axis of rotation (R), the rotor body having a separation chamber for separating solid particles from the liquid mixture and an inlet for the liquid mixture and a screw conveyor adapted to rotate in the rotor body around the axis of rotation (R) for transporting the separated solid particles in the separation chamber towards and out of a sludge outlet, the method comprising the steps of

a) operating the separator in a separation phase, in which solid particles are separated from the liquid mixture, and

b) operating the separator in an ejection phase, in which separated solid particles are transported towards the sludge outlet and further ejected out of the sludge outlet, wherein an ejection liquid is introduced in the separation chamber during the ejection phase.

[0007] The first aspect of the invention is based on the insight that introducing or injecting an ejection liquid during the period when solid particles are ejected or discharged from the separator has several advantages. The introduction of additional liquid during the period when solid particles are discharged leads to improved removal of solid particles.

[0008] The inventors have found that by introducing a liquid during discharge, the effect of the centrifugal forces on the solid particles is reduced during the discharge. The force required for discharging the solid particles may increase exponentially to the decrease in liquid level in the separator, and by introducing an ejection liquid the force for ejecting the solids may accordingly be decreased. As an example, if the sludge solids have a density of about 1.1 g/cm^3 and if the ejection liquid has a density of about 1 g/cm^3, then the force for discharging the solids may be about 1/10 of the force required if the ejection liquid was not present.

[0009] During the separation phase of the step a), the rotor body is usually rotating at high speed, whereby solid particles are effectively separated from the liquid mixture in the separation chamber of the rotor body. These separated particles are deposited on the inside of the rotor body. At such a high rotational speed the deposited particles, such as sludge, may be difficult to discharge from the separator, at least in a sufficient amount. Hence, with time the deposited particles will cause a sludge layer to grow radially inwards towards the axis of rotation. During the ejection phase of step b), an ejection liquid is introduced in the separation chamber as the screw conveyor may transport the sludge towards and out of the sludge outlet. Consequently, the ejection phase of step b) may be regarded as a particle discharge phase. By introducing an ejection liquid in the separation chamber during the ejection phase, the liquid level in the decanter is prevented from decreasing, and as discussed above, this has been found to facilitate the removal of sludge.

[0010] In other words, a larger amount of solid particles, such as sludge, may be removed and additionally, the risk of clogging the separator decreases. Thus, a higher efficiency of the separation process may be achieved.

[0011] The liquid mixture may comprise different liquid phases in addition to the solid particle. The liquid phases may have different density. As an example, the liquid mixture may comprise oil, an aqueous phase and solid particles. Consequently, step a) may further comprise separating the liquid mixture into a first liquid phase and a second liquid phase, wherein the density of the first liquid phase is higher than the density of the second liquid phase. Accordingly, the first liquid phase may be an aqueous phase and the second liquid phase may be oil.

[0012] The solid particles may for example be sludge.

[0013] In embodiments of the first aspect of the invention, the ejection liquid introduced in step b) is introduced via the inlet for the liquid mixture that is to be separated.

[0014] In embodiments of the first aspect of the invention, the method further comprises rotating the rotor body at a first speed during the separation phase and at a second speed, which is lower than the first speed, during the ejection phase.

[0015] This is advantageous in that lowering the rotational speed during the ejection phase further facilitates removal or ejection of solid particles from the separator. During the ejection phase, the rotor body may thus be brought to rotate at a slower speed. This means that the centrifugal forces are decreased so that the screw conveyor may transport the sludge towards and out of the sludge outlet more easily

[0016] In embodiments of the first aspect of the invention, the weight of the ejection liquid introduced in step b) is about the same or less than the maximum weight of the solid particles that is ejected in step b).

[0017] Consequently, the weight of the ejection liquid introduced does not have to be higher than the amount of solid particles that can possibly be removed during step b). Thus, this may optimize the amount of ejection liquid that is used in step b).

[0018] Furthermore, the density of the ejection liquid may be equal or less than the solid particles or sludge that is ejected during step b).

[0019] In embodiments of the first aspect of the invention, the feed of the liquid mixture into the separation chamber is lowered or interrupted during the ejection phase.

[0020] Consequently, the feed of feed through the inlet during the ejection phase may be interrupted or lowered during step b). Further, if the rotor rotates at a lower speed during the ejection phase compared to the separation phase, the separation performance of the centrifugal separator may be reduced, which means that the liquid mixture may be introduced into the separation chamber at a reduced rate during the ejection phase.

[0021] In embodiments of the first aspect of the invention, the method is further comprising rotating the screw conveyor at a different speed than the rotor body during both step a) and b).

[0022] Consequently, the screw conveyor may be rotated at a different speed than the rotor body during both the separation phase and the ejection phase, which facilitates discharge of solid particles. However, in embodiments, the differential speed between the screw conveyor and the rotor body is activated exclusively during the ejection phase of step b).

[0023] Through such a differential speed between the rotor body and the screw conveyor, some amount of the sludge may be discharged even during the separation phase in step a). Furthermore, by upholding a differential speed during the separation phase, the screw conveyor may distribute and work on the solid particles or sludge deposited on the inside of the rotor body to reduce some negative effects caused by the centrifugal forces. One of those negative effects is that compressing the solid particles or sludge may make it more difficult to discharge. Another negative effect is that compressed sludge may be unevenly distributed in the rotor body, causing an unbalance with harmful vibrations of the centrifugal separator during operation.

[0024] In embodiments of the first aspect of the invention, the method is further comprising increasing the differential speed between the screw conveyor and the rotor body in step b) compared to step a).

[0025] Through such a change the solid particles may be discharged at a relative high rate to make the ejection or discharge phase short in duration.

[0026] However, it is to be understood that the differential speed between the screw conveyor and the rotor body in step b) compared to step a) also may be decreased.

[0027] In embodiments of the first aspect of the invention, the method is further comprising repeating steps a) and b) for any number of cycles.

[0028] Consequently, the method of the first aspect of the invention may be a cyclic method, i.e. the repetition of cycles comprising the separation phase of step a) and the ejection phase of step b). The ejection phase may thus be initiated before the growing layer of solid particles or sludge becomes a problem. If the rotor body is rotating at a first speed during the separation phase and at a second speed, which is lower than the first speed, during the ejection phase, the rotor body may be accelerated back to high speed rotation for the separation phase of the next operating cycle when essentially all of the solid particles or at least a sufficient amount of solids has been discharged from the separator. Furthermore, if needed by the process, the feed may be stopped until full rotor speed is re-established. When the rotor body is rotating at full speed with the increased separation performance in the separation phase, the feed rate may be re-established.

[0029] As an example, the switch from step a) to step b) and/or from step b) to step a) may be performed after a predetermined period of time.

[0030] Consequently, step a) may be performed during a predetermined period of time, step b) may be performed during a predetermined period of time or both steps a) and b) may be performed during a predetermined period of time. Thus, after a predetermined time in the separation phase, the ejection phase may be initiated, whereby the sludge is discharged. Further, after a predetermined time in the ejection phase, the centrifugal separator may switch back to the separation phase. The predetermined times of the separation phase and/or the ejection phase could be manually set by an operator. However, predetermined times could also be calculated from operating parameters of the centrifugal separator measured by various sensors. As an example, the time of the separation phase may be calculated from sensors registering a feed rate and concentration of particles in the feed through the inlet. Moreover, the ejection phase may be calculated from parameters as the accumulated sludge amount, the differential speed between the screw conveyor and the rotor body, the type of sludge and viscosity of the sludge etc. However, both the ejection phase and separation phase may be controlled by combining the above described predetermined time and the threshold value of one or several operating parameters. The separation phase and ejection phase could for example have set default predetermined times combined with measured threshold values, whereby an ejection phase would be initiated in advance if the threshold value was reached before the default predetermined time had lapsed.

[0031] As a further example, the switch from step a) to step b) and/or from step b) to step a) may be dependent on one or several operating parameters

[0032] As an example, any other parameter may be a torque of the centrifugal separator. The torque may be measured by a torque measuring arrangement for the screw conveyor, which torque may be measured directly through a torque sensor or by calculating the torque using the current consumed by the electric motor of the screw conveyor. Consequently, when the torque increases above a specific threshold value, the ejection phase may be initiated. Another operating parameter may be the turbidity, such as the turbidity measured by a turbidity sensor associated with at least one liquid outlet. Thus, the ejection phase may be initiated when the turbidity of the purified liquid increases above a specific threshold value. Another possible operating parameter is the capacity, such as the capacity measured by a capacity sensor arranged in a liquid outlet for a liquid having a relatively low density. As an example, the concentration of heavy liquid, e.g. water, may be measured by means of capacity in the outlet for a liquid having a relatively low density, such as oil, when separating two different liquid phases. Consequently, the ejection phase may be initiated when the measured concentration of heavy liquid reaches a certain threshold. Furthermore, the pressure in the liquid outlet may also be utilized to trigger the ejection phase. Thus, when the pressure in the liquid outlet drops below a specific threshold value, which may indicate that a sludge layer obstructs the heavy and/or light liquid flow passages, the ejection phase may be initiated. The pressure may for example be measured by sensors located in the liquid outlet.

[0033] In embodiments of the first aspect of the invention, the ejection liquid is an aqueous liquid. Thus, the ejection liquid may be a liquid of relatively high density that aids in maintaining a high pressure in the separation chamber. As an example, the ejection liquid may be water or comprise water.

[0034] As a further example, if the rotor body is rotating at a first speed during the separation phase and at a second speed, which is lower than the first speed, during the ejection phase, the ejection liquid may be the feed itself, i.e. the liquid mixture itself.

[0035] In embodiments of the first aspect of the invention, the separation chamber comprises a stack of separation discs. The separation discs may be truncated, conical separation discs. A stack of separation discs further facilitates separation of the liquid mixture.

[0036] As a second aspect of the invention, there is provided a centrifugal separator for separating solid particles from a liquid mixture, the centrifugal separator comprising

- a rotor body which is rotatable around an axis of rotation (R), the rotor body having a separation chamber with an inlet for the liquid mixture,
- at least one liquid outlet for a separated liquid from the liquid mixture,
- a sludge outlet for the separated solid particles,
- a screw conveyor adapted to rotate in the rotor body around the axis of rotation (R), at a speed differing from the rotational speed of the rotor body, for transporting the separated solid particles in the separation chamber towards and out of the sludge outlet,
- a drive arrangement adapted to rotate the rotor body and the screw conveyor at their respective speeds, and
- a control unit adapted to control the introduction of an ejection liquid to the separation chamber during an ejection phase, in which separated solid particles are transported towards the sludge outlet and further ejected out of the sludge outlet.

[0037] The centrifugal separator of the second aspect of the invention may thus be adapted to perform the separation method according to the first aspect discussed above. Accordingly, the centrifugal of the second aspect of the invention may facilitate improved removal of solid particles from the liquid mixture due to the introduction of additional liquid during the period when solid particles are discharged.

[0038] Terms and definitions used in relation to the second aspect of the invention may be as discussed in relation to the first aspect above.

[0039] The control unit may be adapted to regulate a valve such that ejection liquid is introduced into the separator during the ejection phase.

[0040] The drive arrangement may for example include one or several electrical motors for rotating the rotor body and the screw conveyor. The control unit may thus also include a device for driving such electrical motors.

[0041] In embodiments of the second aspect of the invention, the control unit is further adapted to control the drive arrangement to rotate the rotor body at a first speed during a separation phase and at a second speed, which is lower than the first speed, during an ejection phase.

[0042] As discussed in relation to the first aspect above, rotating at a lower speed during the ejection phase facilitates removal or ejection of solid particles from the separator. In other words, the control unit may cause the rotor body to rotate at a slower speed during ejection, whereby the centrifugal forces are decreased so that the screw conveyor may transport the sludge towards and out of the sludge outlet more easily.

[0043] A difference in speed between the screw conveyor and the rotor body may be activated by the control unit exclusively during the particle discharge phase. However, according to an embodiment of the second aspect of the invention, the control unit is adapted to control the drive arrangement to rotate the screw conveyor at a different speed than the rotor body during both the separation phase and the ejection phase. Through such a differential speed between the rotor body and the screw conveyor, some amount of the sludge may be discharged even during the separation phase. As an example, the control unit may be adapted to control the drive arrangement to change, preferably increase, the differential speed between the screw conveyor and the rotor body in the ejection phase compared to the separation phase. As discussed in relation to the first aspect above, by such a change, the sludge may be discharged at a rate that is suitable. Preferably, the sludge may be discharged at a relative high rate by increasing the differential speed to make the discharge phase short in duration.

[0044] According to yet another embodiment of the invention, the centrifugal separator is arranged to reduce or interrupt a feed of the mixture through the inlet during the ejection phase. Consequently, the liquid mixture may be introduced into the separation chamber at a reduced rate during the ejection phase. As discussed above, the control unit may decrease the rotational speed during ejection and if needed by the process, the feed may be stopped until full rotor speed is re-established. When the rotor body is rotating at full speed with the increased separation performance in the separation phase, the separator may re-establish the feed.

[0045] In embodiments of the second aspect of the invention, the control unit is adapted to control the drive arrangement to rotate the rotor body at the first speed during the separation phase for a predetermined time, wherein the first speed is higher than the second speed at which the rotor rotates during the ejection phase. Furthermore the control unit may be adapted to control the drive arrangement to rotate the rotor body at the second speed during the ejection phase for a predetermined time. The predetermined time may be as discussed in relation to the first aspect above.

[0046] Furthermore, in embodiments of the second aspect of the invention, the control unit is adapted to initiate an ejection phase when receiving a threshold value from an arrangement for measuring an operating parameter of the centrifugal separator. The operating parameter may be as discussed in relation to the first aspect above. Thus, an arrangement for measuring an operating parameter may for example be include a torque measuring arrangement for the screw conveyor, a turbidity sensor associated with at least one liquid outlet, a capacity sensor arranged in a liquid outlet, and/or pressure sensors measuring the pressure in a liquid outlet.

[0047] According to embodiments of the invention, the rotor body is rotatably supported only at its one end through a rotor shaft, which is arranged so that the axis of rotation extends substantially vertically. This type of centrifugal separator is typically more light weight than for example a decanter centrifuge, which comprises a relatively heavy rotor body with a horizontal axis of rotation. The rotor body according to this embodiment is more suitable to accelerate back and forth between a separation phase and discharge phase. Such a separator will many times include a stack of truncated conical separation discs in the separation chamber, whereby the separation efficiency is improved. Furthermore, the inlet of such a separator would preferably include an inlet pipe, which extends into the rotor body at its one end, the liquid outlet for separated liquid including at least one outlet channel, which extends out of the rotor body at its one end, and the sludge outlet for separated solids situated at the opposite other end of the rotor body.

[0048] According to yet another embodiment of the invention the drive arrangement includes a so called Harmonic Drive gear device, also known as a strain wave gearing device, arranged between the rotor body and the screw conveyor

[0049] In embodiments of the invention, the screw conveyor comprises a conveyor shaft which extends axially through the rotor shaft, the rotor shaft and the conveyor shaft being coupled together through a gear device. The gear device may include three co-operating members, of which a first gear member is connected with the rotor shaft and a second gear member is connected with the conveyor shaft. The three gear members may be adapted for rotation relative to each other around a prolongation of the axis of rotation (R). The inlet pipe may extend centrally through the gear device.

[0050] Furthermore, the gear device may be a strain wave gear device including the first gear member in the form of a stiff cylindrical gear member, which is rotatable around the axis of rotation (R) and has a first number of cogs or teeth distributed around this centre axis, the second gear member in the form of a flexible gear member, which extends around the same axis of rotation (R) and has a different second number of cogs or teeth distributed around the centre axis, which are adapted successively to be brought into and out of engagement with the cogs or teeth of the cylindrical gear member, and the third gear member in the form of a wave generator which is adapted gradually to deform the flexible gear member and thereby accomplish the teeth engagement between the gear members.

[0051] In embodiments of the second aspect of the invention, the separation chamber comprises a stack of separation discs. The separation discs may be truncated, conical separation discs. A stack of separation discs further facilitates separation of the liquid mixture.

[0052] As a third aspect of the invention, there is provided a computer program product comprising computer-executable components for causing a device to perform any one or all of the method steps recited in relation to the first aspect of the invention when the computer-executable components are run on a processing unit included in the device

[0053] The device may for example be a control unit as discussed in relation to the second aspect above.

Brief description of the Drawings

[0054]

Figure 1 shows schematically a section view of a centrifugal separator according to an embodiment of the invention.

Figure 2 shows a section view of a schematically drawn separator and the level of solid particles before and after ejection.

Detailed Description

[0055] The method and centrifugal separator according to the present disclosure will be further illustrated by the following description of an embodiment with reference to the accompanying drawings

[0056] Fig. 1 discloses a centrifugal separator according to an embodiment of the invention. The centrifugal separator includes a rotor body 1, which is rotatable at a speed around a vertical rotational axis R, a screw conveyor 2 arranged in the rotor body 1 and rotatable around the same rotational axis R. In this example, the screw conveyor 2 is rotatable at a speed differing from the rotational speed of the rotor body 1. A drive arrangement 3 is adapted for rotation of the rotor body 1 and the screw conveyor 2 at their respective speeds. The drive arrangement 3 includes two electric motors 3a and 3b and a gear device 3c.

[0057] The rotor body 1 has a cylindrical upper rotor body portion 4 which is connected with a conical lower rotor body portion 5 by means of bolts 6. Alternative connection members can of course be used. The cylindrical rotor body portion 4 includes an extension axially upwards in the form of a hollow rotor shaft 7, which is connected to the electric motor 3a for rotating the rotor body 1 around the axis of rotation R.

[0058] A further hollow shaft, the conveyor shaft 8, extends into the rotor body 1 through the interior of the hollow rotor shaft 7. The shaft 8 supports the screw conveyor 2 by means of screws 9. The hollow shaft 8 drivingly connects electric motor 3b with the screw conveyor 2 via the gear device 3c. The screw conveyor 2 comprises an upper cylindrical part 10 which extends axially inside the cylindrical rotor body portion 4, a lower conical part 11 which extends axially inside the conical rotor body portion 5, and a conveying thread 12 which extends in a screw-like manner along the upper cylindrical part 10 and the lower conical part 11 of the screw conveyor 2. The screw conveyor 2 may of course have more than one conveying thread, such as two, three or four conveying threads, which may all extend in a screw-like manner along the inside of the rotor body 1.

[0059] An inlet pipe 13 for a liquid mixture to be treated in the rotor body 1 extends through the conveyor shaft 8 and leads on into a central sleeve 14 in the interior of the screw conveyor 2. The central sleeve 14 delimits an inlet chamber 15 for the liquid mixture, wherein the inlet chamber 15 communicates with a separation chamber 16 via radially extending distribution channels 17. A number of wings 18 are distributed around the axis of rotation R and extend into a lower part of the inlet chamber 15 and further define radially extending side walls of the distribution channels 17. The wings 18 are arranged to cause the liquid mixture in the inlet chamber 15 and the distribution channels 17 to rotate with the screw conveyor 2. Consequently, the distribution channels 17 are arranged between the wings 18.

[0060] The separation chamber 16 is an annular space that surrounds the inlet chamber 15 and comprises a stack of truncated conical separation discs 19. The stack is fitted radially inside the cylindrical part 10 of the screw conveyor 2 and arranged coaxially with the axis of rotation R. The conical separation discs 19 are held together axially between an upper conical support plate 20 and a lower conical support plate 21. As can be seen, the lower conical support plate 21 is formed in one piece with the central sleeve 14. The separation discs 19 comprise holes which form channels 22 for axial flow or distribution of liquid through the stack of separation discs 19 in the centrifugal separator. The lower support plate 21 comprises a corresponding hole, whereby the distribution channels 17 communicate with the channels 22 for axial flow of liquid in the stack of separation discs 19. The upper conical support plate 20 comprises a number of holes 23 which connect a radially inner annular space 24, within the stack of separation discs 19, with a relative lower density or light liquid outlet chamber 25. Such liquid of lower density, or light liquid, may for example be oil. A so called paring disc 26 for discharging purified light liquid is disposed within the outlet chamber 25. The paring disc 26 is stationary and firmly connected to the inlet pipe 13, wherein the paring disc 26 is communicating with an outlet channel 27 extending in an outlet pipe which surrounds the inlet pipe 13.

[0061] The cylindrical part 10 of the screw conveyor 2 radially surrounds the stack of separation discs 19, wherein the cylindrical part 10 comprises a number of axially extending apertures 28 which are distributed round the axis of rotation R. The axially extending apertures 28 are provided to allow for separated solid particles or sludge from the liquid mixture to pass through and deposit on the inside of the cylindrical wall of the rotor body 1. Liquid may of course also be able to pass through the apertures 28 in the cylindrical part 10. The conveyor shaft 8 comprises a number of holes 29 which connect an annular space 30 situated radially outside the cylindrical part 10 with a heavy liquid outlet chamber 31 for liquid of relative higher density. Such heavy liquid may for example be water. A paring disc 32 for discharging heavy liquid is disposed within this outlet chamber 31, wherein the paring disc 32 communicates with an outlet channel 33 for the heavy liquid. The heavy liquid outlet channel 33 extends in an outlet pipe which surrounds the outlet pipe and channel 27 for the light liquid.

[0062] The rotor body 1 has at its lower end a central and axially directed outlet 34 for separated solids particles, such has sludge. This sludge outlet 34 defines the initially mentioned sludge outlet for solid particles. In connection with this sludge outlet 34, the rotor body is surrounded by device 35 for intercepting sludge which leaves the sludge outlet 34. The sludge is disclosed in the drawing in the form of accumulations at the radially outer portion of the conveying thread 12, on the latter's side which faces toward the sludge outlet 34. The screw conveyor 2 may be made in one piece of plastic material, and may further be fibre-reinforced. The conical part 11 may have a hollow interior or cavity, which is either sealed or open to the surrounding. If desired, the cavity being possibly filled with some material having a relatively low density, such as cellular plastic or the like.

[0063] The rotor body 1 is supported through the rotor shaft 7 by two axially separated bearings 36 and 37, respectively. These bearings are supported in turn by a sleeve 38, which is resiliently connected to a frame (not shown). The rotor shaft 7 supports a belt pulley 39, around which a driving belt 40 extends. The driving belt 40 is connected to the electric motor 3a for rotating the rotor body 1.

[0064] The gear device 3c may for example be a Harmonic Drive gear device, which is also known as a strain wave gearing device. Gear device 3c comprises a stiff cylindrical first gear member (not shown), which is firmly connected with the pulley 39 and, thereby, is also firmly connected with the rotor shaft 7. The cylindrical first gear member has internal cogs or teeth, which are formed on the inside of a ring, which constitutes a part of the cylindrical first gear member. A second gear member (not shown) is situated radially inside of the cylindrical first gear member and includes a thin flexible sleeve. The second gear member is supported through a supporting member by the conveyor shaft 8 and has on the flexible sleeve external cogs or teeth situated opposite to the internal cogs or teeth on the ring of the surrounding cylindrical first gear member. In an unloaded state the teeth-provided flexible sleeve is circular-cylindrical and it has a smaller pitch diameter than the teeth-provided ring. Thus, the flexible sleeve has a smaller number of teeth than the ring. The gear device also includes a third gear member in the form of a so-called wave generator, which surrounds the rotational axis R and supports a belt pulley 41. A belt 42 extends around the belt pulley 41 and is connected to the electric motor 3b for rotating the screw conveyor 2.

[0065] The wave generator has an elliptically formed surrounding portion provided with two end portions or protuberances placed diametrically each on one side of the rotational axis R, the protuberances being dimensioned such that they locally deform the flexible sleeve, i.e. the second gear member, so that the external teeth of the sleeve are kept locally in engagement with the internal teeth of the surrounding stiff first gear member, i.e. the ring. Other parts of the gear members are situated radially spaced from each other in the areas of their respective teeth and, thus, are not in engagement with each other more than in the areas of the protuberances.

[0066] Between the respective protuberances of the wave generator and the flexible sleeve there are balls included in a ball bearing, which surrounds the wave generator and, thus, is also ellipse-formed. Upon rotation of the wave generator relative to the flexible sleeve, or vice versa, the protuberances will successively press, through the balls in the ball bearing, the external teeth of the sleeve into engagement with the internal teeth of the stiff cylindrical first gear member. Due to the fact that the number of external teeth on the flexible sleeve is smaller than the number of internal teeth on the surrounding stiff ring, the sleeve - upon rotation of the wave generator relative to the ring in a certain direction around the rotational axis R - will move in the opposite direction around the rotational axis R relative to the ring. In other words, if the rotor body 1 is rotated by means of the drive pulley 39 around the rotational axis R and the screw conveyor 2 is entrained in this rotation by teeth engagement between the ring and the sleeve, a relative movement, i.e. a difference in rotational speed, between the rotor body 1 and the screw conveyor 2 may be accomplished by rotating the wave generator with the electric motor 3b and belt 42 around the rotational axis R at a speed differing from that by which the wave generator is entrained by the rotor body.

[0067] As can be seen from figure 1, a bearing 43 is arranged between the conveyor shaft 8 and the surrounding rotor shaft 7. There is another bearing inside the gear device 3c, whereby this bearing and bearing 43 constitute the two bearings by means of which the screw conveyor 2 is supported in the rotor body 1.

[0068] As discussed above, the drive arrangement 3, in this case comprising the two electrical motors 3a and 3b as well as gear device 3c, is arranged for driving the rotor body 1 and the screw conveyor 2, respectively. In connection to the drive arrangement 3 there is arranged a control unit 44 that is adapted to drive the electrical motors 3a and 3b, respectively. As an example, the control unit may be adapted to drive the electrical motors 3a and 3b at varying speeds. The electrical motors 3a and 3b in the disclosed embodiment have a common control unit 44. It is however evident that each one of the two motors 3a and 3b may be controlled by an individual control unit. The control unit 44 is in this example connected through signal cables 45a and 45b to the motors 3a and 3b. The motors 3a and 3b may be a direct-current motor or an alternating-current motor; either a synchronous motor or an asynchronous motor. Depending upon the type of the electrical motor the control unit 44 may be designed in many different ways self-evident for a person skilled in the art of electrical motors.

[0069] The control unit 44 includes a device for driving its electrical motors 3a and 3b at different speeds; either so that a limited number of speeds can be obtained or so that a continuous change of the motor speed can be performed. Different kinds of devices for speed regulation of motors (both direct-current and alternate-current motors) are well known and need no closer description here. For a direct-current motor a simple device for voltage control may be used. For an alternate-current motor various kinds of frequency control equipment may be used.

[0070] The control units 44 is connected to one or several different sensors on the centrifugal separator and adapted to treat the signal(s) coming from the sensor(s). The incoming signal(s) is depicted in Fig. 1 with an arrow 54 pointing at the control unit 44. Consequently, the control unit 44 will treat the signal(s) and produce a control signal in signal cables 45a and 45b for the driving of the electrical motor 3a and 3b. The signal(s) from the sensor(s) may be used in an automatic control of the centrifugal separator in order to initiate the separation phase and the ejection phase, respectively. Thus, both the separation phase and the ejection phase may be initiated on the basis of a sensed value. The signal(s) may also be used to control optimize rotor body speed and screw conveyor speed in both the separation phase and the ejection phase.

[0071] A software, or computer program product, may be used for e.g. causing the control device 44 to switch between separation phase and ejection phase and to drive the rotor 1 and the screw conveyor 2 at different speed. Thus, the control device may comprise a processing unit on which the computer-executable components of the software are run.

[0072] However, in the simplest case the control unit 44 may include a manual operation, wherein an operator programs the control unit 44 for operation of the electrical motors 3a and 3b by means of manually programmed control signals. Hereby, the operator may set parameters such as separation phase time (duration in minutes or hours), ejection phase time (duration in seconds or minutes), rotor body speed (rpm) during the separation phase, rotor body speed (rpm) during ejection phase, and differential speed (rpm) between rotor body and screw conveyor during separation phase and ejection phase, respectively.

[0073] The signals, by means of which for example the speed of the electrical motors 3a and 3b should be controlled or adjusted, may be a function of many different variable factors.

[0074] Thus, one or more of the following factors may be included, for instance:

- the turbidity of the liquid in the light and/or the heavy liquid outlet, which may indicate a growing layer of sludge being accumulated in the rotor body
- the concentration of liquid of high density, such as water, in the outlet for the liquid of lower density, such as oil, or vice versa. This may indicate a decrease in separation performance due to growing layer of sludge
- the torque being applied on the screw conveyor by the motor, which may indicate a growing layer of sludge being accumulated in the rotor body
- the pressure in the light and/or the heavy liquid outlet of the separator, which may indicate that a sludge layer is obstructing the liquid flow in the rotor body
- the flow rate and particle concentration of the feed of liquid mixture to the separator, which may be used for estimating the amount of accumulated sludge in the rotor body
- the vibration amplitude of the rotor body, which may relate to an unbalance in the separator
- the time duration of each separation phase and/or ejection phase to control and monitor phase-time in manual and automatic operation
- the total operational time in the separation phase and/or ejection phase of the centrifugal separator, i.e. summarized over all cycles of separation and ejection phases. This may indicate a service or repair need.

[0075] The control unit is further adapted to control three-way valve 50, as depicted by arrow 53 in Fig. 1. For this purpose, a signal cable similar to cables 45b and 45a may be used. In the separation phase, the control unit sets three-way valve 50 so as to let feed of liquid mixture from pipe 52 enter the separator via inlet pipe 13. When switching to ejection phase, the control unit may switch three-way valve 50 so as to interrupt the feed from pipe 42 and instead let ejection liquid, such as water, from pipe 50 enter the separator via inlet pipe 13.

[0076] The centrifugal separator operates in the following manner:

> The pulleys 39 and 41 are kept in rotation, by means of the motors 3a and 3b with belts 40 and 42, around the rotational axis R in the same rotational direction but with somewhat different angular velocities. Thereby, the rotor body 1 and the screw conveyor 2 are kept in rotation at somewhat different rotational speeds.

[0077] It is assumed that the rotor body 1 initially doesn't contain any sludge and so the separation phase of the operating cycle is initiated, whereby the rotor body 1 is accelerated by its motor 3a to high speed rotation at a predetermined speed (e.g. at 7500 rpm) through a control signal from the control unit 44. The screw conveyor 2 being rotated at a somewhat different speed (e.g. a differential speed of 1 - 2 rpm) by means of the motor 3b and the gear device 3c, whereby the differential speed is set through a control signal in the signal cable 45b from the control unit 44. The control unit 44 further adjusts the three-way valve 50 such that the mixture of liquid and particles is introduced into the rotor body 1 from above through the inlet pipe 13. The mixture flows into the inlet chamber 15 and further through the distribution channels 17, in which it is brought into rotation by the wings 18, thereby subjecting the mixture to a centrifugal force. A free liquid surface is formed after a while in the rotor body 1 at the radial level 46, the position of which is determined by the radial position of the holes 23 in the upper support plate 20 at the light liquid outlet chamber 25. The liquid(s) and particles are separated in the separation chamber 16 comprising the stack of separation discs 19. The separated heavy liquid, i.e. the liquid with high density, flows through the radially outer annular space 30, through the holes 29 in the conveyor shaft 8 and out of the centrifugal separator through the heavy liquid outlet chamber 31 by means of the paring disc 32. The separated light liquid flows through the radially inner annular space 24, through the holes 23 in the upper support plate 20 and out of the centrifugal separator through the light liquid outlet chamber 25 by means of the paring disc 26.

[0078] The separated solids deposit on the inside of the surrounding wall of the rotor body 1. Even if the screw conveyor 2 doesn't discharge any sludge during the separation phase, the screw conveyor 2 through the differential speed may at least distribute and work on the sludge inside the rotor body 1 to reduce some negative effects caused by compressed and uneven distributed sludge. With time the deposited particles will cause the sludge layer to grow radially inwards towards the axis of rotation R. Before the growing layer of sludge becomes a problem, the control unit 44 will initiate the ejection phase, or particle discharge phase, of the present invention. This may be initiated after a predetermined time or after a sensed operating parameter of the centrifugal separator has reached a threshold value.

[0079] During the particle discharge phase of the operating cycle, the rotor body 1 is brought to rotate at a slower speed, e.g. 1500 rpm, by its motor 3a, whereby the centrifugal forces are decreased so that the screw conveyor 2 may transport the sludge towards and out of the outlet 34 more easily. In addition, control unit 44 switches three-way valve 50 such that ejection liquid, in this case water, from pipe 51 is directed into the separator via inlet pipe 13. In other words, the feed of liquid mixture is replaced during the ejection phase by a feed of ejection liquid. The pressure from the introduced ejection liquid aids in discharging sludge from the separator.

[0080] Hence, in the ejection phase, the separated particles are transported in the form of sludge along the surrounding wall downwardly and out through the outlet 34, which is also referred to as the initially mentioned sludge outlet 34 for solid particles. Furthermore, during the ejection phase the control unit 44 may control the screw conveyor motor 3b to increase the differential speed, e.g. to a differential speed of 3 - 6 rpm, whereby the sludge will be discharged at an increased rate. When essentially all of the sludge or at least a sufficient amount of sludge has been discharged from the rotor body 1 via the sludge outlet 34 for solid particles, the control unit 44 will switch back to separation phase by instructing the motors 3a and 3b to accelerate the rotor body 1 and the screw conveyor 2 back to high speed rotation with the differential speed and further switch valve 50 so that feed of liquid mixture again is introduced into the separator. Thus, at the end of the ejection phase, the separator may contain ejection liquid. This further facilitates turning the separator off after an ejection phase since problem with clogging etc. of the separator, such as clogging due to solid particles left in the separator when the separator is not operating, may be avoided.

[0081] Figure 2 further schematically shows radial levels of solid particles in a section of the rotor body 1. The radial level of solid particles, measured from rotational axis X, at the end of the separation phase is denoted by A. After the ejection phase, when solid particles have been discharged from the separator, the radial level of solid particles has increased to level C. The ejected amount of solid particles is thus represented by amount B. In other words, the amount of ejection liquid that is introduced into the separator may be less or about equal to amount B in terms of volume or weight.

[0082] The invention is not limited to the embodiment disclosed but may be varied and modified within the scope of the claims set out below. The invention is not limited to the orientation of the axis of rotation R disclosed in the figures. The term "centrifugal separator" also comprises centrifugal separators with a substantially horizontally oriented axis of rotation. The invention is not limited to the drive arrangement including the specific gear device 3c. Other known gear devices such as planetary gear dives may also be used. The drive arrangement may also comprise a direct drive adapted to rotate the screw conveyor, wherein direct drive includes a motor stator connected to the rotor body and a motor rotor connected to the screw conveyor shaft.

Claims

1. A method for separating solid particles from a liquid mixture in a centrifugal separator, wherein said separator comprises a rotor body (1) which is rotatable around an axis of rotation (R), the rotor body (1) having a separation chamber (16) for separating solid particles from the liquid mixture and an inlet (13, 15) for the liquid mixture and a screw conveyor (2) adapted to rotate in the rotor body (1) around the axis of rotation (R) for transporting the separated solid particles in the separation chamber (16) towards and out of a sludge outlet (34), said method comprising the steps of

   a) operating said separator in a separation phase, in which solid particles are separated

from said liquid mixture, and
b) operating said separator in an ejection phase, in which separated solid particles are transported towards said sludge outlet and further ejected out of said sludge outlet, wherein an ejection liquid is introduced in said separation chamber during said ejection phase.

2. A method according to claim 1, further comprising rotating the rotor body (1) at a first speed during said separation phase and at a second speed, which is lower than the first speed, during said ejection phase.

3. A method according to claim 1 or 2, wherein the weight of the ejection liquid introduced in step b) is about the same or less than the maximum weight of the solid particles that is ejected in step b).

4. A method according to any previous claim, in which the feed of said liquid mixture into said separation chamber is lowered or interrupted during said ejection phase.

5. A method according to any previous claim, further comprising rotating the screw conveyor (2) at a different speed than the rotor body (1) during both step a) and b).

6. A method according to claim 5, further comprising increasing the differential speed between the screw conveyor (2) and the rotor body (1) in step b) compared to step a).

7. A method according to any previous claim, further comprising repeating steps a) and b) for any number of cycles.

8. A method according to claim 7, wherein the switch from step a) to step b) and/or from step b) to step a) is performed after a predetermined period of time.

9. A method according to any previous claim, wherein the ejection liquid is an aqueous liquid.

10. A method according to any previous claim, wherein the separation chamber comprises a stack of separation discs.

11. A centrifugal separator for separating solid particles from a liquid mixture, said centrifugal separator comprising

- a rotor body (1) which is rotatable around an axis of rotation (R), the rotor body (1) having a separation chamber (16) with an inlet (13, 15) for the liquid mixture,
- at least one liquid outlet (25, 26, 31, 32) for a separated liquid from the liquid mixture,
- a sludge outlet (34) for the separated solid particles,
- a screw conveyor (2) adapted to rotate in the rotor body (1) around the axis of rotation (R), at a speed differing from the rotational speed of the rotor body (1), for transporting the separated solid particles in the separation chamber (16) towards and out of the sludge outlet (34),
- a drive arrangement (3, 3a, 3b, 3c) adapted to rotate the rotor body (1) and the screw conveyor (2) at their respective speeds, and
- a control unit (44) adapted to control the introduction of an ejection liquid to said separation chamber during an ejection phase, in which separated solid particles are transported towards said sludge outlet and further ejected out of said sludge outlet (34).

12. A centrifugal separator according to claim 11, wherein the control unit (44) is further adapted to control the drive arrangement (3, 3a, 3b, 3c) to rotate the rotor body (1) at a first speed during a separation phase and at a second speed, which is lower than the first speed, during an ejection phase.

13. A centrifugal separator according to claim 11 or 12, wherein said control unit (44) is further adapted to control the drive arrangement (3, 3a, 3b, 3c) to rotate the screw conveyor (2) at a different speed than the rotor body (1) during both the separation phase and the ejection phase.

14. A centrifugal separator according to claim 13, wherein said control unit (44) is adapted to control the drive arrangement (3, 3a, 3b, 3c) to change, preferably increase, the differential speed between the screw conveyor (2) and the rotor body (1) in the ejection phase compared to the separation phase.

15. A centrifugal separator according to any one of claims 11-14, wherein the centrifugal separator is arranged to reduce or interrupt a feed of the mixture through the inlet (15) during the ejection phase.

16. A centrifugal separator according to any one of claims 11-15, wherein the separation chamber comprises a stack of separation discs.

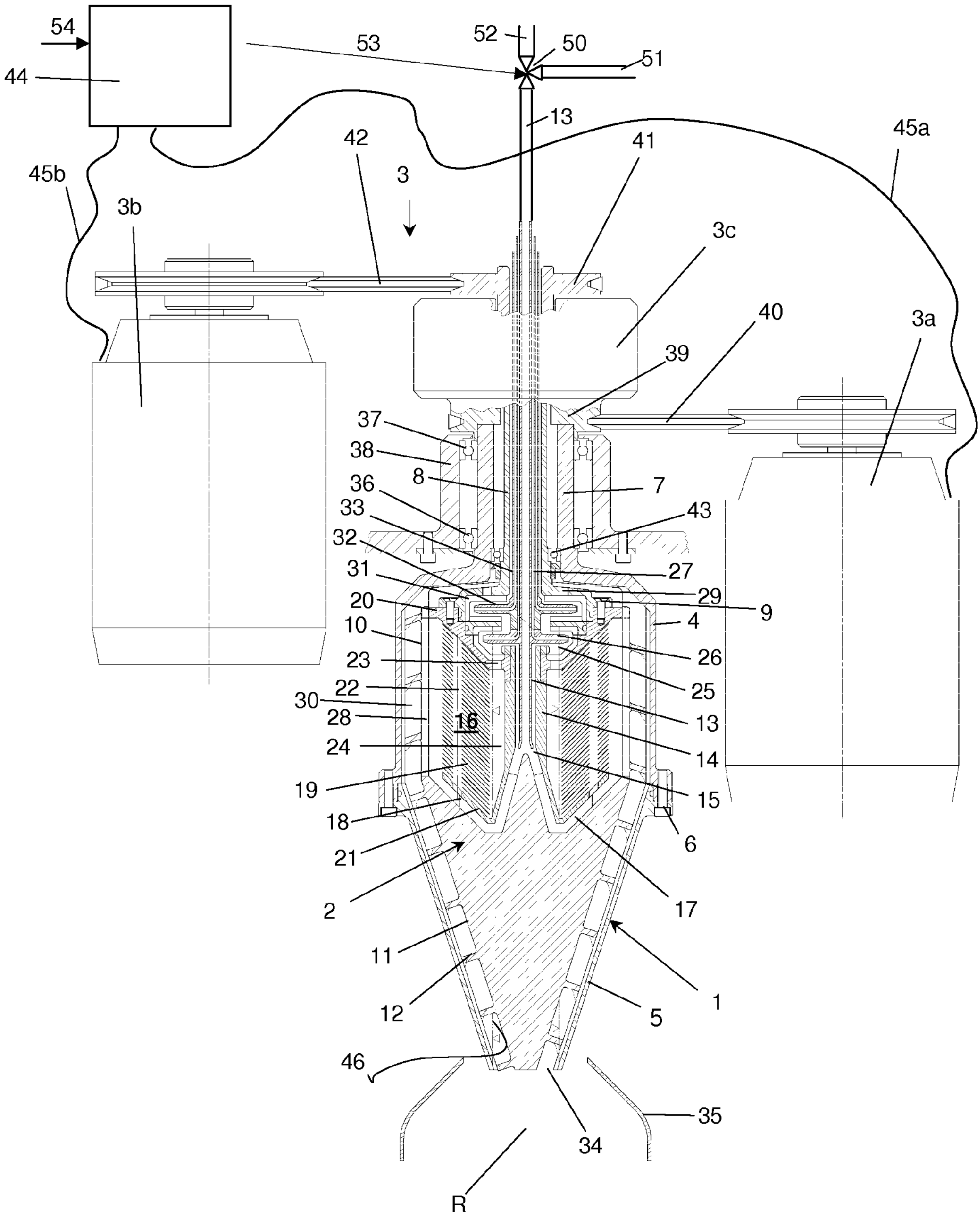
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Fig. 1

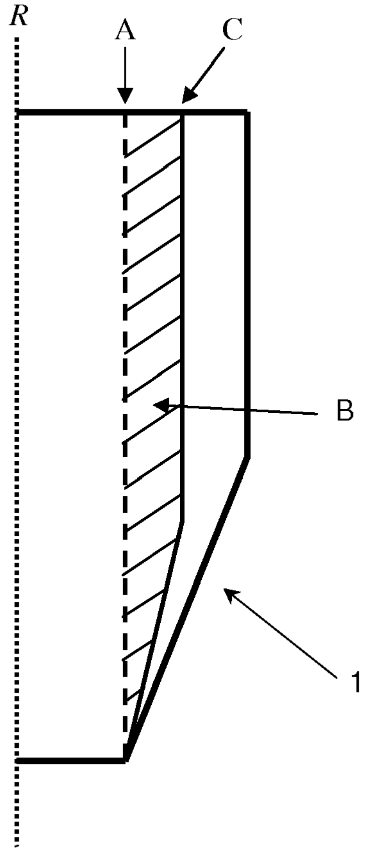

Fig. 2

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Application Number
EP 13 16 6245

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The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	27 November 2013	Desittere, Michiel

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