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(54) A METHOD OF OPERATING A CENTRIFUGAL SEPARATOR

(57) The present invention provides a method (100) of operating a centrifugal separator (1). The centrifugal separator (1) comprises a centrifuge bowl (10) arranged to rotate around an axis of rotation (X) and in which the separation of a liquid mixture takes place and a drive member (4) configured to rotate the centrifuge bowl (10) around the axis of rotation (X) at a rotational speed. The centrifuge bowl (10) further comprises an inlet (11) for receiving the liquid mixture to be separated, at least one liquid outlet (12) for discharging a separated liquid phase and at least one sludge (14) outlet for discharging a separated sludge phase. The centrifugal separator (1) further comprises an intermittent discharge system (30) for intermittently opening and closing the at least one sludge outlet (14). The method (100) comprises the steps of a) rotating (101) the centrifuge bowl (10) at a first rotational speed S1; b) increasing (102) the rotational speed of the centrifuge bowl (10) to a second rotational speed S2 that is higher than said first rotational speed S1, and c) opening (103) the at least one sludge outlet (14) to discharge contents within the centrifuge bowl (10) during rotation at said second rotational speed S2.

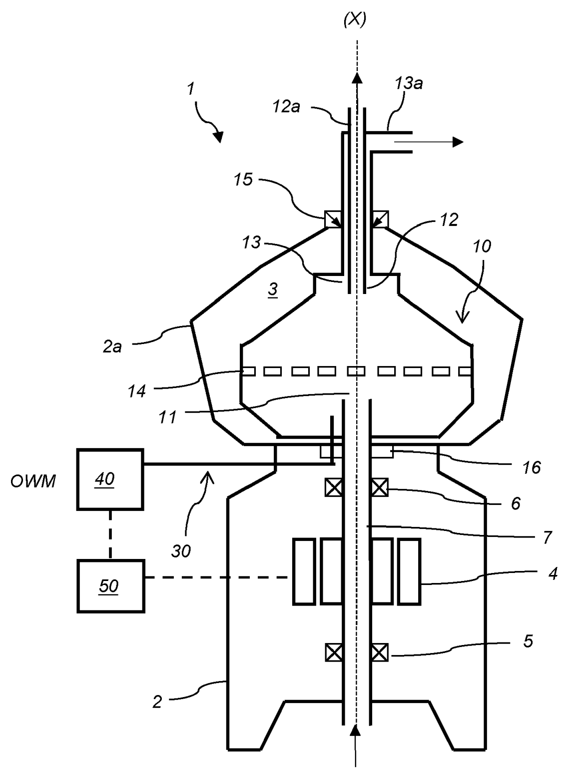

Fig. 1

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Description

Field of the Invention

[0001] The present invention relates to the field of centrifugal separators, and more specifically to a method of operating a centrifugal separator for separating a liquid mixture into at sludge phase and at least one liquid phase.

Background of the Invention

[0002] Centrifugal separators are generally used for separation of liquids and/or for separation of solids from a liquid. During operation, liquid mixture to be separated is introduced into a rotating bowl and heavy particles or denser liquid, usually water, accumulates at the periphery of the rotating bowl whereas less dense liquid accumulates closer to the central axis of rotation. This allows for collection of the separated fractions, e.g. by means of different outlets arranged at different radii from the rotational axis.

[0003] In certain types of centrifugal separators, separated sludge is discharged through a number of ports in the periphery of the separator bowl. Between discharges these ports are covered by e.g. an operating slide, which forms an internal bottom in the separating space of the bowl.

[0004] However, it may be difficult to control the volume of the discharge and to get effective discharges, such as discharges with a reduced amount of process liquid that is discharged together with the sludge as a waste. Such wasted volumes may be dependent on the properties of the liquid mixture that is separated.

[0005] Thus, there is a need in the art for improved methods of operating a centrifugal separator, such as during discharge of a separated sludge component.

Summary of the Invention

[0006] It is an object of the invention to at least partly overcome one or more limitations of the prior art. In particular, it is an object to provide a method of operating a centrifugal separator that leads to a better discharge of sludge from the centrifuge bowl.

[0007] As a first aspect of the invention, there is provided a method of operating a centrifugal separator. The centrifugal separator comprises

a centrifuge bowl arranged to rotate around an axis of rotation (X) and in which the separation of a liquid mixture takes place,
a drive member configured to rotate the centrifuge bowl around the axis of rotation (X) at a rotational speed, wherein
the centrifuge bowl further comprises an inlet for receiving the liquid mixture to be separated, at least one liquid outlet for discharging a separated liquid phase and at least one sludge outlet for discharging a separated sludge phase,
wherein the centrifugal separator further comprises an intermittent discharge system for intermittently opening and closing the at least one sludge outlet.

[0008] The method of the first aspect comprises the steps of

a) rotating the centrifuge bowl at a first rotational speed;
b) increasing the rotational speed of the centrifuge bowl to a second rotational speed that is higher than said first rotational speed,
c) opening the at least one sludge outlet to discharge contents within the centrifuge bowl during rotation at said second rotational speed.

[0009] The centrifugal separator may be a disc-stack centrifugal separator, e.g. as disclosed in US20210107014. The centrifuge bowl may be arranged to rotate relative a stationary frame of the centrifugal separator. Such frame may comprise a hood that encloses the centrifuge bowl, and the separator may be arranged such that separated sludge is discharged to a space between the hood and the bowl. Also the drive member may be arranged within the frame.

[0010] The centrifugal separator is arranged for discharging a sludge phase, i.e. a separated sludge phase that may also contain some liquid, to a surrounding space outside of the centrifuge bowl. This is performed by the intermittent discharge system.

[0011] The at least one sludge outlet may be in several different forms.

[0012] In embodiments of the first aspect, the at least one sludge outlet comprises a plurality of radial ports arranged at the periphery of the centrifuge bowl. The intermittent discharge system may then comprise an operating slide arranged for opening and closing the plurality of radial ports. Such operating slide may form an inner bowl bottom in the centrifuge bowl. Thus, the at least one sludge outlet may be in the form of a set of ports arranged to be opened intermittently during operation. The intermittent discharge system may be arranged for emptying a partial content of the bowl during such an intermittent discharge (partial discharge) or arranged for emptying the whole content of the centrifuge bowl during intermittent discharge (full discharge).

[0013] The intermittent discharge system thus controls the opening of the sludge outlets. For this purpose, the intermittent discharge system may comprise a
an operating slide that is movable between a closed position, in which the at least one sludge outlet is closed, and an open position, in which the at least one sludge outlet is open. The operating slide may form part of the inner wall of the centrifuge bowl, such as part of the wall of the separation space within the bowl. Keeping the operating slide in a closed position may be effected by supply-

ing hydraulic fluid to a closing chamber within the bowl in order to hold the operating slide in the closed position. The intermittent discharge system may further comprise an opening chamber, to which hydraulic fluid is supplied when to shift the operating slide to its open position.

[0014] In embodiments of the first aspect, the at least one sludge outlet comprises a plurality of axial ports, and wherein the intermittent discharge system is arranged for opening and closing the plurality of axial ports.

[0015] The axial ports may be arranged for discharging sludge axially downwards. The intermittent discharge system may for example comprise valves or a slide for opening and closing the axial ports. Such slide may be arranged so that it does not form part of an inner wall of the centrifuge bowl.

[0016] However, the at least one sludge outlet may be a combination of constantly open sludge outlets and intermittently openable sludge outlets.

[0017] Step a) of the method comprises rotating the centrifuge bowl at a first rotational speed. This may be the operating speed of the centrifuge bowl, i.e. a speed used during operation after which the drive member has increased the rotational speed up to its operating speed.

[0018] Step b) then comprises increasing that rotational speed to a second rotational speed that is higher than the first rotational speed, and step c) comprises opening the sludge outlets to eject contents from within the centrifuge bowl while running at the higher speed. Step c) may thus also comprise closing the at least one sludge outlet.

[0019] The first aspect of the invention is based on the insight that it may be an advantage to increase the rotational speed and perform a sludge discharge at an increased speed. This may lead to a more complete emptying of the contents within the centrifuge bowl. Further, it may facilitate compacting of the sludge content within the centrifuge bowl such that the occupies a smaller volume within the centrifuge bowl, which may facilitate the discharge of the sludge. This may be important if the liquid mixture to be separated comprises e.g. pulp that is separated in a juice. Further, increasing the rotational speed before discharge may lead to a faster discharge of the sludge. Furthermore, the first aspect allows for a continuous operation, such as a separation or cleaning operation, at a low speed with the intermittent increase in rotational speed when a sludge discharge is needed. This may be more gentle to the liquid mixture that is processed in the centrifugal separator while at the same time allow for a thorough discharge of solids when needed. Discharging at a higher speed may also avoid clogging within the separator, such as clogging between separation discs.

[0020] In embodiments of the first aspect, the method is further comprising a step d) of

d) decreasing the rotational speed of the centrifuge bowl after step c) is performed.

[0021] Thus, after discharge, the rotational speed of the bowl may be decreased. As an example, step d) may comprise decreasing the rotational speed to the first rotational speed.

[0022] This thus means that after discharge, the rotational speed may be decreased back to an operational speed at which the bowl was rotating before initiating the discharge.

[0023] The method of the first aspect may be performed during normal separation of a liquid mixture that is fed to the separator. Thus, in embodiments of the first aspect, step a) further comprises supplying a liquid mixture to be separated to the inlet of the centrifuge bowl and separating said liquid feed mixture into at least one separated liquid phase and a separated sludge phase while rotating said centrifuge bowl at said first rotational speed, and further wherein a sludge phase that has been separated from said liquid feed mixture is discharged in step c).

[0024] The liquid mixture is a feed mixture that is fed to the centrifugal separator, e.g. by means of pumping. The centrifugal separator may thus be arranged for continuously separating the liquid mixture as it is being fed to the separator.

[0025] Supplying the liquid feed mixture via a stationary inlet pipe extending into the centrifuge bowl from the top, or via a rotating, hollow spindle onto which the centrifuge bowl is attached, such as via a hollow spindle attached to the bottom of the centrifuge bowl. Supplying a liquid feed mixture to be separated may thus performed while the centrifuge bowl is rotating. Separating the liquid feed mixture takes place within the centrifuge bowl, such as in a stack of separation discs arranged in the centrifuge bowl.

[0026] Consequently, normal separation of the liquid mixture may be performed at the first rotational speed, and before performing a discharge of a separated sludge phase, the speed may be increased to the second rotational speed. The, the rotational speed may again be decreased to the first rotational speed.

[0027] As an example, the liquid feed mixture may be a shear sensitive liquid, such as a cell culture mixture, a vegetable oil or a dairy product. The dairy product may be milk. As an example, the liquid mixture may comprise a cell fraction. Thus, the method of the first aspect allows for performing the separation at a lower rotational speed (the first rotational speed) than usual, but then increasing the rotational speed to a higher speed (the second rotational speed) before discharge. This may be an advantage when separating a shear sensitive liquid, since it may decrease the overall shear forces experienced by the liquid during the separation process. This may for example lead to a higher survival rate if the liquid mixture comprises shear sensitive cells, such as yeast.

[0028] As a further example, the liquid mixture to be separated is a fruit juice comprising pulp, such as a citrus fruit juice. Step b) of the method may then lead to a compacting of the pulp within the bowl.

[0029] During separation of a liquid mixture, step a) of rotating at the first rotational speed may be performed for a longer time than the time during which the centrifuge bowl is rotated at the second rotational speed. As an example, step a) may be performed for a time period of at least 10 minutes, such as from 10 minutes to one hour, such as from 10 minutes to several hours. Thus, the separation at lower rotational speed (step a)) may be performed for a first long time period and the increase in rotational speed and the sludge discharge (steps b) and c)) may be performed during a second time period that is much smaller than the first time period.

[0030] The method of the first aspect may also be performed during a cleaning operation of the centrifuge bowl, such as during a CIP (cleaning-in-place, cleaning-in-process) operation. Consequently, in embodiments of the first aspect, the step a) further comprises supplying a cleaning liquid to the inlet of the centrifuge bowl for removing contaminants within the centrifuge bowl, and further wherein at least a portion of said cleaning liquid is discharged in step c).

[0031] A cleaning liquid may thus be supplied with the purpose of keeping the centrifuge bowl clean and thereby preventing heavy displacement, clogging of a disc stack and to avoid micro-biological infection. The cleaning liquid may thus be supplied at the first lower rotational speed. Using a cleaning liquid together with opening and closing of the at least one sludge outlet during a higher rotational speed may lead to an increased sediment discharge and thus a better cleaning. This may in turn prolong the intervals between manual cleaning of the centrifuge bowl.

[0032] As an example, the cleaning liquid may comprise water and NaOH, or water with an acid, such as nitric acid. Step a) may comprise supplying more than one type of cleaning liquid to the separator, such that several types of cleaning liquids in sequence.

[0033] A centrifuge bowl of a centrifugal separator is configured to be driven within an upper nominal rotational speed interval SN. This is the upper rotational speed interval to which the centrifuge bowl has been designed to be driven for safety reason. This upper nominal rotational speed interval is dependent on the mechanics and material of the centrifuge bowl.

[0034] When increasing the rotational speed of the centrifuge bowl from standstill up to the upper nominal rotational speed interval, a critical speed interval is most often passed. The critical speed interval is an interval in which there are peaks in the vibrational behaviour of the centrifuge bowl. Thus, during conventional use of a centrifuge bowl, the bowl is driven at a rotational speed that is above the critical speed interval in order to avoid such vibrational peaks.

[0035] In embodiments of the first aspect, the centrifuge bowl is configured for rotation within an upper nominal rotational speed interval SN, wherein SN is above the critical speed interval SC of said centrifuge bowl, and wherein said second rotational speed S2 is above said critical speed interval SC.

[0036] Consequently, sludge discharge may be performed at a rotational speed that is above the critical speed interval SC.

[0037] As an example, the second rotational speed S2 may be within said upper nominal rotational speed interval SN.

[0038] As an example, the second rotational speed S2 may be within said upper nominal rotational speed interval SN and the first rotational speed S1 may be below said upper nominal rotational speed interval SN.

[0039] Furthermore, as an example, the first rotational speed may be at least 20 % lower than the upper nominal rotational speed interval SN, such as at least 30 % lower.

[0040] In embodiments of the first aspect, the centrifuge bowl is configured for rotation within an upper nominal rotational speed interval SN, wherein SN is above the critical speed interval SC of said centrifuge bowl, and wherein said first rotational speed S1 is within said critical speed interval SC.

[0041] Consequently, the first rotational speed may be a speed that is between to vibrational peaks within the critical speed interval, i.e. between two critical speeds. The method of the first aspect thus allows for separation at a very low speed, but with an increase in speed during discharge in order to get an increased emptying of the centrifuge bowl. This may be beneficial when separating a liquid mixture that is easy to separate but still requires a strong discharge of separated sludge. For example, a separation phase (step a) at low speed may be more gentle to the liquid mixture that is separated, and the discharge phase (step c) at a higher speed may make sure that all sludge is emptied and also may lead to at least a partial cleaning of the separation discs.

[0042] In embodiments of the first aspect, the first rotational speed is at least 20 % lower than the second rotational speed, such as at least 30 % lower than the second rotational speed.

[0043] In embodiments of the first aspect, the first rotational speed is within the critical speed interval SC and the second rotational speed is within the upper nominal rotational speed interval SN.

[0044] As an example, the second rotational speed may correspond to a peripheral velocity of the bowl that is 170-210 m/s.

[0045] Also, the upper nominal rotational speed interval SN may correspond to a velocity interval that is an interval found between 170-210 m/s.

[0046] The first rotational speed may correspond to a peripheral velocity of 150 m/s or less.

[0047] As a second aspect of the invention, there is provided a centrifugal separator for separating at least one liquid phase and a sludge phase from a liquid feed mixture. The centrifugal separator is comprising a centrifuge bowl arranged to rotate around an axis of rotation (X) and in which the separation of the liquid mixture takes place,

a drive member configured to rotate the centrifuge bowl around the axis of rotation (X) at a rotational speed.

[0048] The centrifuge bowl further comprises an inlet for receiving the liquid mixture to be separated, at least one liquid outlet for discharging a separated liquid phase and at least one sludge outlet for discharging a separated sludge phase. The centrifugal separator further comprises an intermittent discharge system for intermittently opening and closing the at least one sludge outlet. The centrifugal separator further comprises a control unit operable to control the rotational speed of the centrifuge bowl and when to perform an intermittent discharge. The control unit is further configured to perform as defined in the method of the first aspect as discussed above.

[0049] Consequently, the control unit is configured to perform the steps of a) rotating the centrifuge bowl at a first rotational speed, b) increasing the rotational speed of the centrifuge bowl to a second rotational speed that is higher than said first rotational speed, and c) opening the at least one sludge outlet to discharge contents within the centrifuge bowl during rotation at said second rotational speed.

[0050] The control unit may thus be operable to control the drive member and the intermittent discharge system.

[0051] This second aspect may generally present the same or corresponding advantages as the former aspect. Effects and features of this second aspect are largely analogous to those described above in connection with the first aspect. Embodiments mentioned in relation to the first aspect are largely compatible with the second aspect.

[0052] The centrifugal separator may be operated according to the method of the first aspect. The centrifugal separator is for separation of a liquid feed mixture. The liquid feed mixture may be an aqueous liquid or an oily liquid. As an example, the centrifugal separator may be for separating solids and one or two liquids from the liquid feed mixture.

[0053] The centrifuge bowl encloses by rotor walls a separation space. The separation space, in which the separation of the liquid feed mixture takes place, may comprise separation members, such as a stack of separation discs. The separation discs may e.g. be of metal. Further, the separation discs may be frustoconical separation discs, i.e. having separation surfaces forming frustoconical portions of the separation discs. The separation discs may be arranged coaxially around the axis of rotation (X) at a distance from each other such that to form passages between each two adjacent separation discs.

[0054] As used herein, the term "axially" denotes a direction which is parallel to the rotational axis (X). Accordingly, relative terms such as "above", "upper", "top", "below", "lower", and "bottom" refer to relative positions along the rotational axis (X). Correspondingly, the term "radially" denotes a direction extending radially from the rotational axis (X). A "radially inner position" thus refers to a position closer to the rotational axis (X) compared to "a radially outer position".

[0055] The centrifuge bowl is further arranged to be rotated around an axis of rotation (X) in relation to a stationary frame. The stationary frame may comprise a n upper hood that covers the centrifuge bowl. The centrifuge bowl of the separator may be arranged to be rotated around vertical axis of rotation, i.e. the axis of rotation (X) may extend vertically. The centrifuge bowl is usually supported by a spindle, i.e. a rotating shaft, and may thus be mounted to rotate with the spindle. Consequently, the centrifugal separator may comprise a spindle that is rotatable around the axis of rotation (X). The centrifugal separator may be arranged such that the centrifuge bowl is supported by the spindle at one of its ends, such at the bottom end or the top end of the spindle.

[0056] The drive member may comprise an electrical motor having a rotor and a stator. The rotor may be fixedly connected to a rotating part, such as to a spindle. Advantageously, the rotor of the electrical motor may be provided on or fixed to the spindle of the rotating part. Alternatively, the drive member may be provided beside the spindle and rotate the rotating part by a suitable transmission, such as a belt or a gear transmission.

[0057] The centrifugal separator also comprises an inlet for liquid mixture to be separated (the liquid feed mixture). This inlet may be arranged for receiving the liquid feed mixture and be arranged centrally in the centrifuge bowl, thus at rotational axis (X). The centrifuge bowl may be arranged to be fed from the bottom, such as through a spindle, so that the liquid feed mixture is delivered to the inlet from the bottom of the separator. However, the centrifuge bowl may also be arranged to be fed from the top, such as through a stationary inlet pipe extending into the bowl.

[0058] Further, also one or two liquid outlets may be arranged at the top or the bottom of the centrifugal separator.

[0059] The centrifuge bowl further comprises at least one sludge outlet. As discussed in relation to the first aspect above, the at least one sludge outlet may for example take the form of radial ports or axial ports that are arranged to be opened intermittently during operation.

[0060] The centrifugal separator is further arranged for discharging a sludge phase, i.e. a separated sludge phase that may also contain some liquid, to the outside of the centrifuge bowl via the at least one sludge outlet. The centrifugal separator may be arranged for emptying a partial content of the bowl during such an intermittent discharge (partial discharge) or arranged for emptying the whole content of the centrifuge bowl during intermittent discharge (full discharge).

[0061] Discharging sludge is performed by the intermittent discharge system of the centrifugal separator. The intermittent discharge system thus controls the opening of the sludge outlets. For this purpose, the intermittent discharge system may comprise an operating slide arranged within the centrifuge bowl and movable between a closed position, in which the sludge outlets are closed, and an open position, in which the sludge outlets are open. Keeping the operating slide in a closed position may be effected by supplying hydraulic fluid, such as water, via a channel to a closing chamber between the operating slide and the bowl wall in order to hold the operating slide in the closed position. The intermittent discharge system may further comprise an opening chamber, to which hydraulic fluid is supplied when to change the operating slide to its open position. The intermittent discharge system may thus comprise sludge outlets and an operating slide arranged within the centrifuge bowl to open and close the sludge outlets. The intermittent discharge system may also comprise an operating water module (OWM) for supplying water to the closing and opening chambers. This OWM is arranged outside of the centrifuge bowl.

[0062] If the centrifuge bowl comprises axial ports, the axial ports may be arranged for discharging sludge axially downwards from the centrifuge bowl. The opening and closing of such ports may be performed by a slide that is arranged so as not form a part of an inner wall of the centrifuge bowl.

[0063] The control unit may thus be configured for controlling the supply of water from the OWM to the centrifuge bowl for opening and closing the sludge outlets. In order to do this, the control unit may comprise any suitable type of programmable logical circuit, processor circuit, or microcomputer, e.g. a circuit for digital signal processing (digital signal processor, DSP), a Central Processing Unit (CPU), a processing unit, a processing circuit, a processor, an Application Specific Integrated Circuit (ASIC), a microprocessor, or other processing logic that may interpret and execute instructions.

Brief description of the Drawings

[0064] The above, as well as additional objects, features and advantages of the present inventive concept, will be better understood through the following illustrative and non-limiting detailed description, with reference to the appended drawings. In the drawings like reference numerals will be used for like elements unless stated otherwise.

Figure 1 shows a schematic drawing of a centrifugal separator according to an embodiment of the present invention.

Figure 2 shows a schematic drawing of a centrifuge bowl according to an embodiment of the present invention.

Figure 3 shows a flow chart of an embodiment of the method of operating a centrifugal separator.

Figure 4 shows a flow chart of a further embodiment of the method of operating a centrifugal separator.

Detailed Description

[0065] The method and the centrifugal separator according to the present disclosure will be further illustrated by the following description with reference to the accompanying drawings.

[0066] Fig. 1 show a cross-section of an embodiment of a centrifugal separator 1 arranged to separate a sludge phase, a liquid heavy phase and a liquid light phase from a liquid feed mixture.

[0067] The centrifugal separator 1 comprises a centrifuge bowl 10 which is arranged to rotate around an axis of rotation (X) by means of a spindle 7. The spindle 7 is supported in a stationary frame 2 in a bottom bearing 5 and a top bearing 6. The centrifuge bowl 10 is attached the upper portion of the spindle 7 and forms within itself a separation chamber in which centrifugal separation of the liquid feed mixture takes place during operation. The centrifuge bowl 10 is covered by stationary hood 2a.

[0068] The spindle 7 is in this example a hollow spindle for introducing the liquid feed mixture to the inlet 11 of the centrifuge bowl 10. The centrifuge bowl 10 further comprises a liquid outlet 12 for discharging a separated liquid light phase and a liquid outlet 13 for discharging a liquid heavy phase. The liquid light phase outlet 12 is arranged at a smaller radius than the liquid heavy phase outlet 13. There is further a stationary outlet pipe 12a connected to the liquid light phase outlet 12 for receiving the separated liquid light phase, and a stationary outlet pipe 13a connected to the liquid heavy phase outlet 13 for receiving the separated liquid heavy phase.

[0069] The centrifuge bowl 10 further comprises a set of sludge outlets 14 for discharging a separated sludge phase to the surrounding space 3, which is in this example sealed relative the surroundings of the hood 2a and in which the centrifuge bowl 10 is arranged. The sludge outlet 14 takes in this example the form of a set of intermittently openable sludge outlets arranged as radial ports at the outer periphery of the centrifuge bowl 10, for discharge of sludge from a radially outer portion of the separation space to the surrounding space 3. The sludge outlets may form part of or be connected to an intermittent discharge system 30, which also comprises an axially movable operating slide 21 - further shown in Fig. 2- arranged in the centrifuge bowl 10.

[0070] The centrifugal separator 1 further comprises a drive motor 4 configured to rotate the centrifuge bowl 10 in relation to the frame 2 around the axis of rotation (X). The drive motor 4 is connected directly to the spindle 7. However, the drive motor may also be connected to the spindle 7 via a transmission means in the form of a worm gear which comprises a pinion and an element connected to the spindle in order to receive driving torque. The transmission means may alternatively take the form of a propeller shaft, drive belts or the like.

[0071] The surrounding space 3 is sealed relative the surroundings of the frame by means of an upper seal 15 and a lower seal 16. The upper seal 15 may be an outlet seal that seals the liquid outlets from the surroundings. If the centrifugal separator 1 is arranged with a stationery inlet pie extending into the centrifuge bowl from the top, the upper seal 15 could also be the seal that seals such an inlet from the surroundings.

[0072] The upper seal 15 could for example be a mechanical seal or a liquid seal. Further, the upper seal 15 may be a gas seal, a liquid seal, a labyrinth seal or combinations thereof. Also the lower seal 16 could be a mechanical seal or a liquid seal. Further, the lower seal 16 may be a gas seal, a liquid seal, a labyrinth seal or combinations thereof. One or both of the upper 15 and lower seal 16 could be a hermetic seal.

[0073] The centrifugal separator 1 further comprises a control unit 50 which is operable to control the rotational speed of the motor 4 and thus the centrifuge bowl 10. Moreover, the control unit 50 is arranged to initiate a discharge by sending operational instructions that affects an operating water module (OWM) 40. The OWM is part of the intermittent discharge system and is arranged for supplying water to the centrifuge bowl 10 for opening and closing the sludge outlets 14, as explained further in relation to Fig. 2 below.

[0074] Fig. 2 further shows the interior of the centrifuge bowl 10. The separation space 21 within the centrifuge bowl 10 is provided with a stack 22 of frustoconical separation discs in order to achieve effective separation of the liquid feed mixture. The stack 22 is arranged on distributor 23 which guides the liquid feed mixture from the central inlet 11 to the separation space 21.

[0075] The closing of the sludge outlets 14 by the intermittent discharge system 30 is controlled by means of an operating slide 24 that is actuated by operating water supplied to the volume 25 under the operating slide, as known in the art. In its position shown in the drawing, the operating slide 24, also called a sliding bowl bottom, abuts sealingly at its periphery against the upper part of the centrifuge bowl 10, thereby closing the separation space 21 from connection with outlets 14, which are extending through the centrifuge bowl 10.

[0076] The operating slide 24 forms the lower part of the inner wall of the centrifuge bowl 10 and is movable between a closed position, shown in Fig 2, in which the sludge outlets 14 are closed, and an open position, in which sludge outlets 14 are open. A closing chamber (not shown) is provided below the operating slide 24. During operation, the closing chamber contains water supplied by the OWM. This water is acting on the operating slide 24 to close the outlets 14.

[0077] In order to initiate a sludge discharge, the water pressure from underneath the operating slide is reduced so that the lifting force acting to press the operating slide 24 upwards is decreased, which in turn initiates a motion of the operating slide 24 so that the sludge outlets 14 are opened.

[0078] To reduce the pressure from underneath the operating slide 24, water may for example be introduced water from the OWM 40 to an opening chamber (not shown) via a line 31, as well-known in the art. When the water has been drained from such an opening chamber, the operating slide 24 is again moved to an upper position to close the sludge outlets 14.

[0079] The intermittent discharge system 30 with the OWM 40 allows for opening and closing of the ports for only a fraction of a second and may result in partial or complete emptying of the content in the separation bowl.

[0080] During operation of the separator in Fig. 1 and 2, the centrifuge bowl 10 is caused to rotate by torque transmitted from the drive motor 4 to the spindle 7. Via the inlet 11, a liquid mixture to be separated is brought into the separation space 21 within the centrifuge bowl 10 and between the separation discs of the stack 22 fitted in the separation space 21.

[0081] A separated liquid light phase moves radially inwards between the separation discs and is discharged via the liquid light phase outlet 12 to the stationary outlet pipe 12a, whereas separated liquid heavy phase is discharged via the liquid heavy phase outlet 13 to the stationary outlet pipe 13a. Heavier components in the liquid mixture, e.g. sludge particles and/or heavy phase, move radially outwards between the separation discs and accumulate at the periphery of the separation space 21 at the sludge outlets 14.

[0082] Sludge is emptied intermittently from the sludge outlets 14 by supplying hydraulic fluid to the intermittent discharge system 30 from the OWM 40, whereupon sludge and a certain amount of fluid is discharged from the separation space by means of centrifugal force.

[0083] The method 100 of operating the centrifugal separator according to the present invention is further illustrated by the flow charts presented in Figs. 3a-c and Fig. 4.

[0084] As illustrated in Fig. 3, the overall method 100 of operating the centrifugal separator 1 comprises a first step a) of rotating 101 the centrifuge bowl 10 at a first rotational speed S1, followed by a step b) of increasing 102 the rotational speed of the centrifuge bowl 10 to a second rotational speed S2. This second rotational speed S2 is higher than the first rotational speed S1. As an example, S1 may still be above 1000 rpm, such as in the range of 1000-4000 rpm, and S2 may be above 4000 rpm. The method 100 further comprises a step of opening 103 the at least one sludge outlet 14 to discharge contents within the centrifuge bowl 10 during rotation at the second rotational speed S2.

[0085] The method 100 may also comprise performing steps a), b) and c) repeatedly. In other words, after opening the at least one sludge outlet in step c), the method may comprise repeating steps a), b) and c) for any number of times.

[0086] The method 100 may be performed during normal operation of the centrifugal separator, i.e. during separation of a liquid feed mixture into at least a liquid phase and a sludge phase. As an example, the method may comprise separating the liquid feed mixture into a single liquid phase and a sludge phase, or into a liquid light phase, a liquid heavy phase and a sludge phase.

[0087] In Fig. 3b, the method 100 is illustrated when separating a liquid feed mixture. In addition to rotating 101 the centrifuge bowl at the first rotational speed S1, step a) further comprises supplying 103 a liquid feed mixture to be separated to the inlet 11 of the centrifuge bowl 10 and separating 104 the liquid feed mixture into at least one separated liquid phase and a separated sludge phase while rotating said centrifuge bowl 10 at the first rotational speed S1. Liquid feed mixture may be introduced while the centrifuge bowl is running at the first rotational speed S1. Furthermore, a sludge phase that has been separated from the liquid feed mixture during step a) is discharged in step c), i.e. after the rotational speed of the centrifuge bowl 10 has been increased to the second rotational speed S2.

[0088] Also, as illustrated in Fig. 3b, the method 100 also comprises a step d) of decreasing 105 the rotational speed of the centrifuge bowl 10 after the sludge discharge of step c) has been performed. As an example, step d) may comprise decreasing 105 the rotational speed to the first rotational speed S1, i.e. step d) may comprise decreasing the rotational speed so that step a) is yet again performed.

[0089] The method 100 may of course also comprise a step of supplying hydraulic fluid, such as closing water, to the centrifugal bowl 10 for closing the sludge outlets again, as known in the art.

[0090] The liquid feed mixture to be separated may be a shear sensitive liquid, such as a cell culture mixture, a vegetable oil or a dairy product.

[0091] In Fig. 3c, the method 100 is illustrated when performing a cleaning procedure of the centrifuge bowl, such as a cleaning-in-place or cleaning-in-process (CIP). In such a procedure, step a) of the method 100 comprises supplying 106 a cleaning liquid to the inlet 11 of the centrifuge bowl 10 while running at the first rotational speed S1. Such a cleaning liquid is thus for removing, or at least decreasing the amount of, contaminants within the centrifuge bowl 10. Furthermore, when performing a CIP, at least a portion of the cleaning liquid is discharged in step c), i.e. at the second, higher rotational speed S2. Moreover, also during CIP, the method 100 may comprise a step d) of decreasing 105 the rotational speed of the centrifuge bowl 10 after step c) is performed, such as decreasing back to the first rotational speed S1.

[0092] The diagram of Fig 4 further illustrates the method of the present invention. The centrifuge bowl 10 may be dimensioned and have material properties to be rotated within an upper nominal rotational speed interval SN. SN is for a high-speed centrifugal separator above the critical speed interval SC of the centrifuge bowl 10, i.e. the interval at lower speeds where peaks in the vibrations of the centrifugal separator are found. As illustrated in Fig. 4, the second rotational speed S2 used during discharge of the sludge phase is within that upper nominal rotational speed interval SN.

[0093] Furthermore, the first rotational speed S1 is below the upper nominal rotational speed interval SN. In this example, the first rotational speed S1 is within the critical speed interval SC. S1 may for example be in a sub interval within SC in which no vibrational peak is found.

[0094] In this example, a separation process of a liquid mixture is performed at a lower rotational speed S1 during time period t1. Before discharging a sludge phase, the rotational speed is increased to rotational speed S2. After time period t2, the rotational speed is yet again lowered to the first rotational speed S1. Then, when an additional discharge is needed after time period t3, the rotational speed is again increased to S2. Time periods t2 and t3 may be much shorter than time period t1. As an example, t1 and or t3 may be performed for above 10 minutes up to several hours, such as for at least 2 hours, such as at least 5 hours, whereas t2, i.e. the increase in rotational speed, may be performed for shorter periods of time. If the motor for rotating the centrifuge bowl is controlled by a variable-frequency drive (VFD), the time period t2 may be defined by the time it takes for the VFD to increase the rotational speed of the centrifuge bowl to S2 and also the time it takes for the centrifuge bowl to decrease in rotational speed after the discharge has been performed during t2.

[0095] As an example, the first rotational speed S1 may be at least 10 %, such as at least 20 %, such as at least 30%, lower than the second rotational speed S2.

[0096] In order to perform the method 100 as discussed above, the centrifugal separator comprises a control unit 50 that is operable to control the rotational speed of the centrifuge bowl 10 and when to perform an intermittent discharge. The control unit 50 may thus be configured to control the intermittent discharge system and e.g. the VFD of the drive motor. The control unit 50 is thus configured to perform the steps of step a) of rotating 101 the centrifuge bowl 10 at the first rotational speed S1, step b) of increasing 102 the rotational speed of the centrifuge bowl 10 from S1 to the second rotational speed S2 and step c) of opening 103 the at least one sludge outlet 14 to discharge contents within the centrifuge bowl 10 during rotation at S2.

[0097] In order to perform these steps, the control unit 50 may for example comprise a calculation unit which may take the form of substantially any suitable type of programmable logical circuit, processor circuit, or microcomputer, e.g. a circuit for digital signal processing (digital signal processor, DSP), a Central Processing Unit (CPU), a processing unit, a processing circuit, a processor, an Application Specific Integrated Circuit (ASIC), a microprocessor, or other processing logic that may interpret and execute instructions. The calculation unit may represent a processing circuitry comprising a plurality of processing circuits, such as, e.g., any, some or all of the ones mentioned above. The control unit 50 may further comprise a memory unit which provides the calculation unit with, for example, stored program code and/or stored data which the calculation unit needs to enable it to do calculations. The calculation unit may also be adapted to storing partial or final results of calculations in the memory unit. The memory unit may comprise a physical device utilised to store data or programs, i.e., sequences of instructions, on a temporary or permanent basis.

[0098] 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 (X) disclosed in the figures. The term "centrifugal separator" also comprises centrifugal separators with a substantially horizontally oriented axis of rotation. In the above the inventive concept has mainly been described with reference to a limited number of examples. However, as is readily appreciated by a person skilled in the art, other examples than the ones disclosed above are equally possible within the scope of the inventive concept, as defined by the appended claims.

Claims

1. A method (100) of operating a centrifugal separator (1), wherein the centrifugal separator (1) comprises

a centrifuge bowl (10) arranged to rotate around an axis of rotation (X) and in which the separation of a liquid mixture takes place,
a drive member (4) configured to rotate the centrifuge bowl (10) around the axis of rotation (X) at a rotational speed, wherein
the centrifuge bowl (10) further comprises an inlet (11) for receiving the liquid mixture to be separated, at least one liquid outlet (12) for discharging a separated liquid phase and at least one sludge outlet (14) for discharging a separated sludge phase,
wherein the centrifugal separator (1) further comprises an intermittent discharge system (30) for intermittently opening and closing the at least one sludge outlet (14);
wherein the method (100) comprises the steps of

a) rotating (101) the centrifuge bowl (10) at a first rotational speed S1;
b) increasing (102) the rotational speed of the centrifuge bowl (10) to a second rotational speed S2 that is higher than said first rotational speed S1,
c) opening (103) the at least one sludge outlet (14) to discharge contents within the centrifuge bowl (10) during rotation at said second rotational speed S2.

2. A method (100) according to claim 1, further comprising a step d) of:
d) decreasing (105) the rotational speed of the centrifuge bowl (10) after step c) is performed.

3. A method (100) according to claim 2, wherein step d) comprises decreasing (105) the rotational speed to the first rotational speed S1.

4. A method (100) according to any previous claim, wherein step a) further comprises supplying (103) a liquid feed mixture to be separated to the inlet (11) of the centrifuge bowl (10) and separating (104) said liquid feed mixture into at least one separated liquid phase and a separated sludge phase while rotating said centrifuge bowl (10) at said first rotational speed S1, and further wherein a sludge phase that has been separated from said liquid feed mixture is discharged in step c).

5. A method (100) according to claim 4, wherein said liquid feed mixture is a shear sensitive liquid, such as a cell culture mixture, a vegetable oil or a dairy product.

6. A method (100) according to any one of claims 4 or 5, wherein step a) is performed for a time period of at least 10 min.

7. A method (100) according to any one of claims 1-4, wherein step a) further comprises supplying (106) a cleaning liquid to the inlet (11) of the centrifuge bowl (10) for removing contaminants within the centrifuge bowl (10), and further wherein at least a portion of said cleaning liquid is discharged in step c).

8. A method (100) according to any previous claim, wherein said centrifuge bowl (10) is configured for rotation within an upper nominal rotational speed interval SN, wherein SN is above the critical speed interval SC of said centrifuge bowl (10), and wherein said second rotational speed S2 is above said critical speed interval SC.

9. A method (100) according to claim 8, wherein said second rotational speed S2 is within said upper nominal rotational speed interval SN.

10. A method (100) according to claim 9, wherein said first rotational speed S1 is below said upper nominal rotational speed interval SN.

11. A method (100) according to any previous claim, wherein said centrifuge bowl (10) is configured for rotation within an upper nominal rotational speed interval SN, wherein SN is above the critical speed interval SC of said centrifuge bowl (10), and wherein said first rotational speed S1 is within said critical speed interval SC.

12. A method (100) according to any previous claim, wherein the first rotational speed S1 is at least 20 % lower than said second rotational speed S2.

13. A method (100) according to any previous claim, wherein the at least one sludge outlet comprises a plurality of radial ports (14) arranged at the periphery of the centrifuge bowl (10), and wherein the intermittent discharge system (30) comprises an operating slide (24) arranged for opening and closing the plurality of radial ports (14).

14. A method according to any one of claims 1-11, wherein the at least one sludge outlet comprises a plurality of axial ports, and wherein the intermittent discharge system (30) is arranged for opening and closing the plurality of axial ports.

15. A centrifugal separator (1) for separating at least one liquid phase and a sludge phase from a liquid feed mixture, comprising

a centrifuge bowl (10) arranged to rotate around an axis of rotation (X) and in which the separation of the liquid mixture takes place,
a drive member (4) configured to rotate the centrifuge bowl (10) around the axis of rotation (X) at a rotational speed,
wherein the centrifuge bowl (10) further comprises an inlet (11) for receiving the liquid mixture to be separated, at least one liquid outlet (12) for discharging a separated liquid phase and at least one sludge outlet (14) for discharging a separated sludge phase,
wherein the centrifugal separator (1) further comprises an intermittent discharge system (30) for intermittently opening and closing the at least one sludge outlet (14),
wherein the centrifugal separator (1) further comprises a control unit (50) operable to control the rotational speed of the centrifuge bowl (10) and when to perform an intermittent discharge, the control unit (50) being configured to perform the steps of

a) rotating (101) the centrifuge bowl (10) at a first rotational speed S1;
b) increasing (102) the rotational speed of the centrifuge bowl (10) to a second rotational speed S2 that is higher than said first rotational speed S1,
c) opening (103) the at least one sludge outlet (14) to discharge contents within the centrifuge bowl (10) during rotation at said second rotational speed S2.

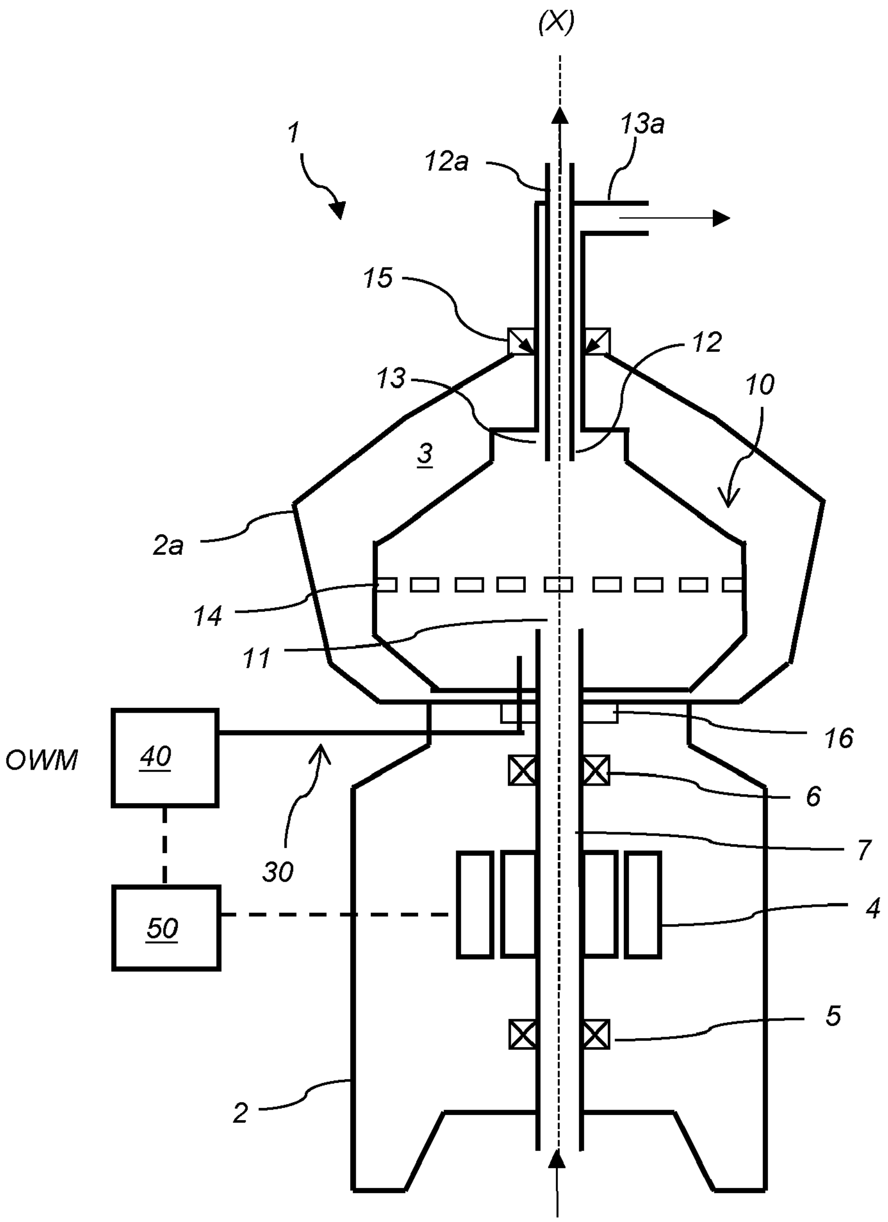

Fig. 1

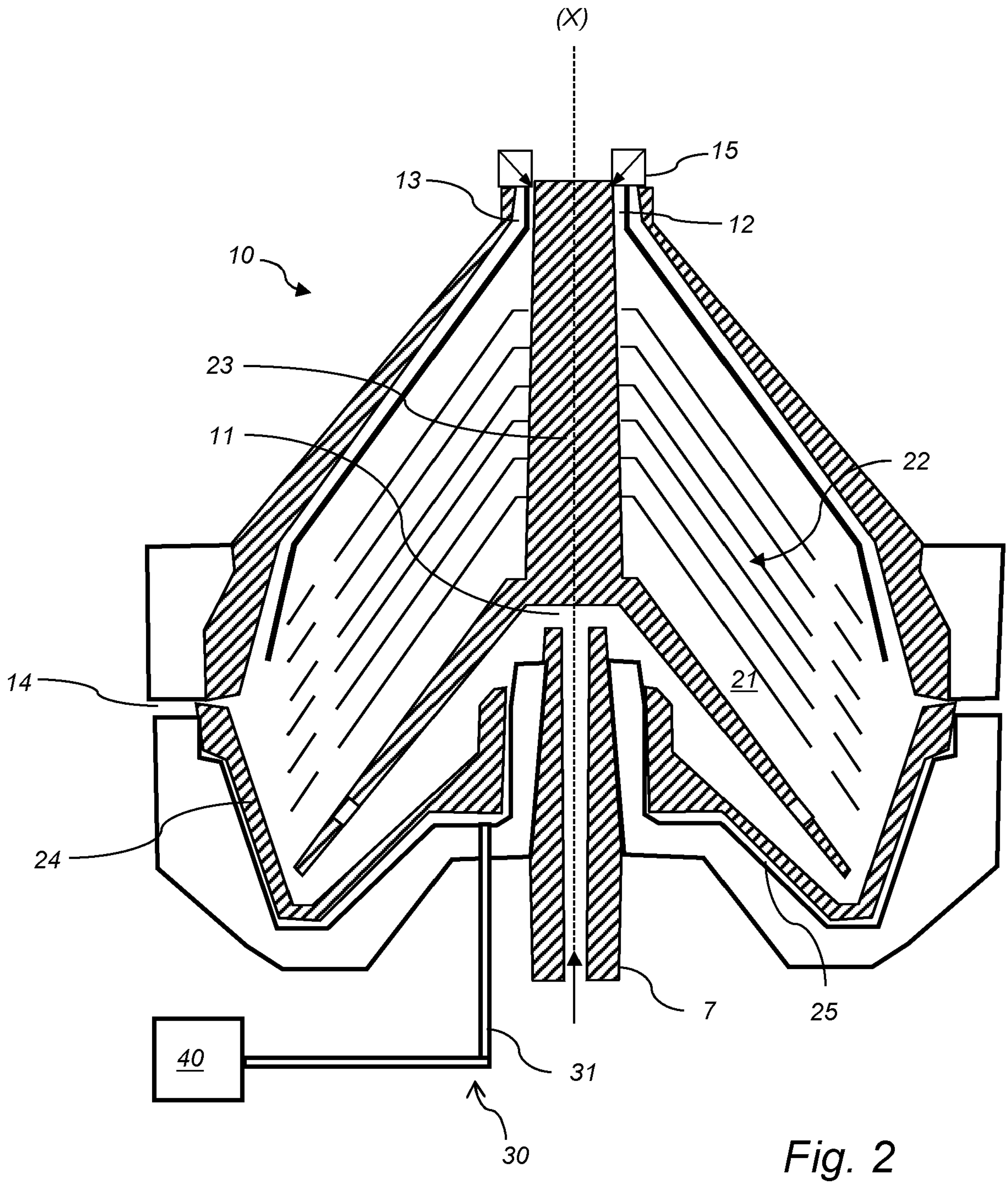

Fig. 2

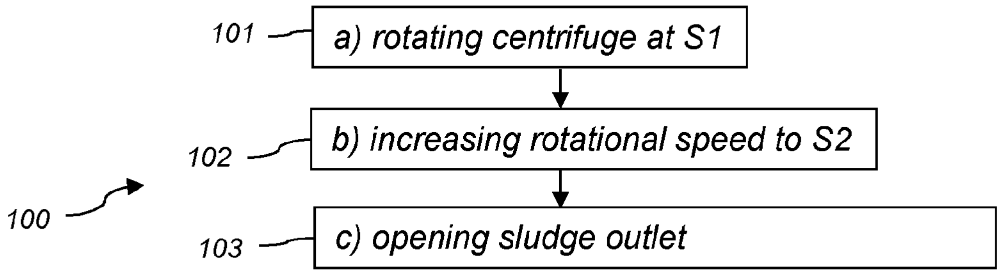

Fig. 3a

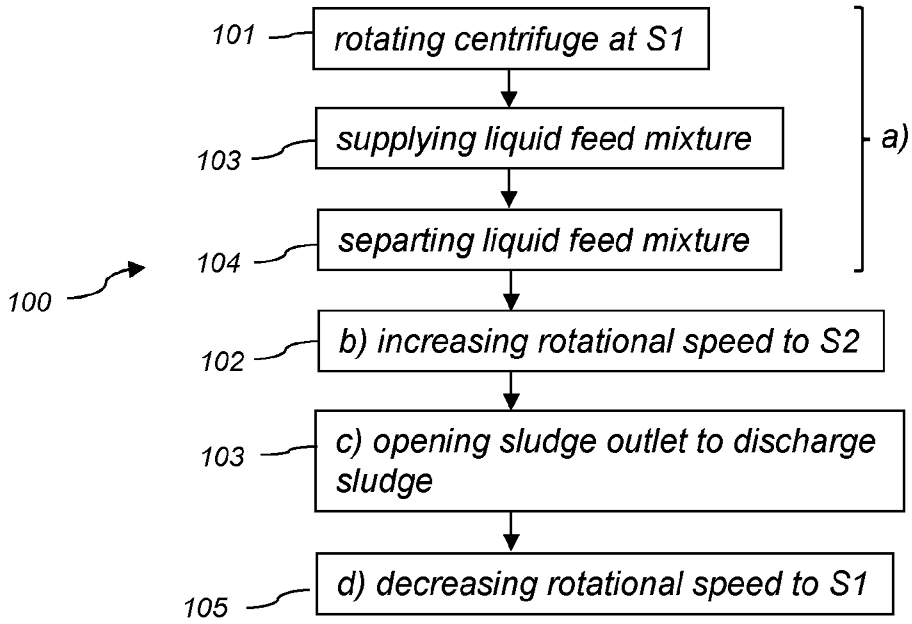

Fig. 3b

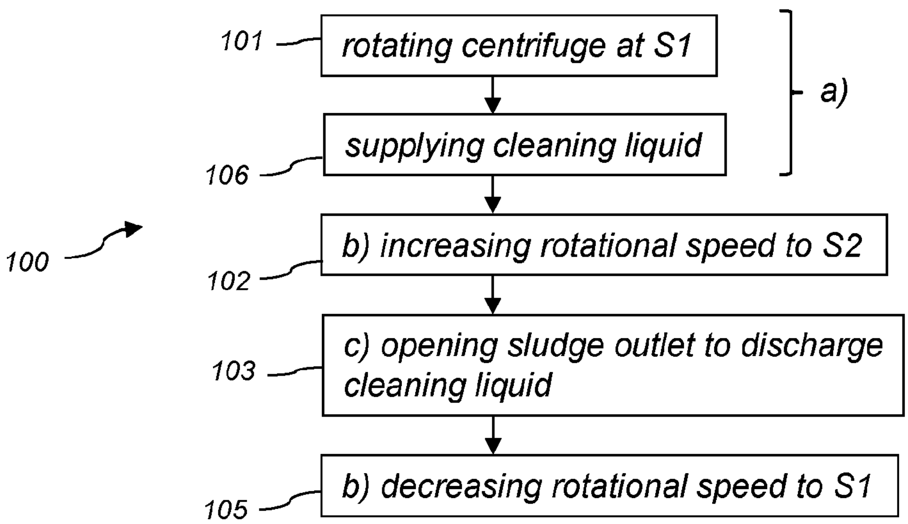

Fig. 3c

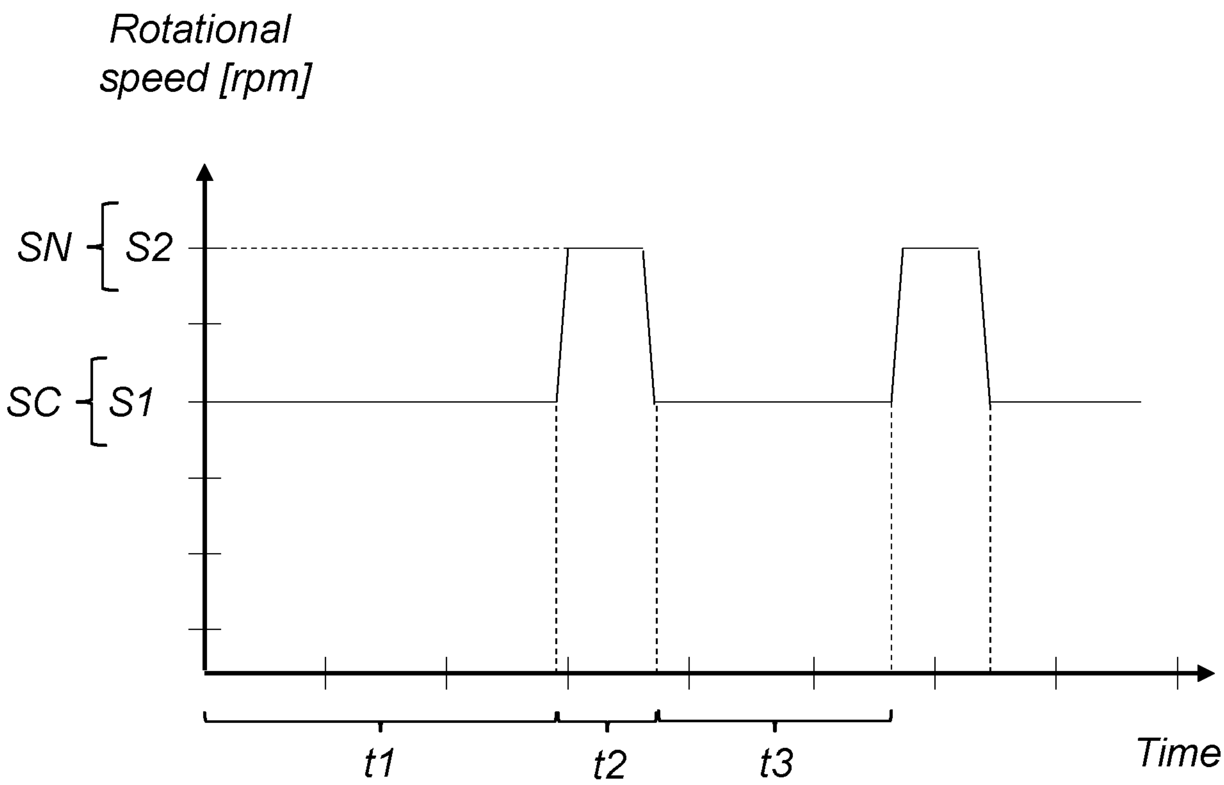

Fig. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 23 20 2682

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B04B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	4 April 2024	Iuliano, Emanuela

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