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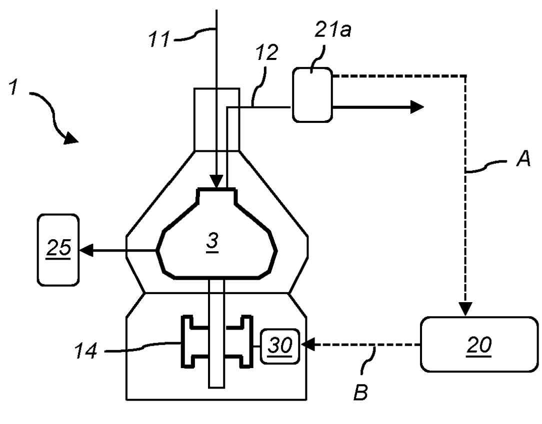
(54) METHOD FOR OPERATING A CENTRIFUGAL SEPARATOR

(57) The present invention provides a method (100) for operating a centrifugal separator (1) for separating at least one liquid phase from a liquid feed mixture. The centrifugal separator (1) is comprising a rotatable centrifuge bowl (3) in which the separation takes place. The method is comprising the steps of a) rotating (101) the centrifugal bowl (3) at first rotational speed (S1); b) supplying (102) a liquid feed mixture to the centrifuge bowl (3); c) separating (103) said liquid feed mixture in the centrifuge bowl (3) into at least one liquid phase at said first rotational speed (S1); d) measuring (104) a parameter (Ax) related to the separation performance of the centrifugal separator (1) and/or a parameter (Bx) of the liquid feed mixture supplied to the centrifuge bowl (3); e) changing (105) the rotational speed of the centrifuge bowl (3) from the first rotational speed (S1) to a second rotational speed (S2) based on the measured parameter of step d); and f) separating (106) said liquid feed mixture in the centrifuge bowl (3) into at least one liquid phase at said second rotational speed (S2). The present invention further provides a centrifugal separator (1) for separating at least one liquid phase from a liquid feed mixture.

Fig. 2



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Description

Field of the Invention

[0001] The present invention relates to the field of high-speed centrifugal separators, and more specifically to methods for operating high speed centrifugal separators.

Background of the Invention

[0002] High speed 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 centrifuge 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 the periphery and close to the rotational axis, respectively. Separation members, such as a stack of frustoconical separation discs, are usually used within the rotating bowl in order to enhance the separation performance. An example of a high-speed centrifugal separator is described in patent application EP 3315205.

[0003] The rotational movement of the separator bowl may be generated by an electrical motor, which is provided with a rotor and a stator. However, the centrifuge bowl that is rotated in a high-speed centrifugal separator may be very heavy and e.g. weigh from hundreds of kilograms to over 1000 kilograms. Thus, the energy required to rotate the centrifuge bowls is large. Also friction losses may be large with such heavy centrifuge bowls. There is thus a need in the art to find more energy efficient ways of separating liquid feed mixtures with high-speed centrifugal separators.

Summary of the Invention

[0004] A main object of the present invention is to provide a method for operating a centrifugal separator that leads to a decreased energy consumption during separation of a liquid feed mixture.

[0005] As a first aspect of the invention, there is provided a method for operating a centrifugal separator for separating at least one liquid phase from a liquid feed mixture; said centrifugal separator comprising a rotatable centrifuge bowl in which the separation takes place; the method comprising the steps of

a) rotating the centrifugal bowl at first rotational speed;
b) supplying a liquid feed mixture to the centrifuge bowl;
c) separating said liquid feed mixture in the centrifuge bowl into at least one liquid phase at said first rotational speed;
d) measuring a parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture supplied to the centrifuge bowl;
e) changing the rotational speed of the centrifuge bowl from the first rotational speed to a second rotational speed based on the measured parameter of step d); and
f) separating said liquid feed mixture in the centrifuge bowl into at least one liquid phase at said second rotational speed.

[0006] The method of the first aspect is a method of centrifugal separator, such as a high-speed centrifugal separator, for separating a liquid mixture. This liquid mixture may comprise one or two liquid phases and also solids, which may be separated as a sludge phase. The separation takes place in the rotatable centrifuge bowl. Such bowl may comprise surface enlarging inserts, such as a stack of separation discs, for enhancing the separation efficiency. The method and the centrifugal separator may be adapted for liquid-liquid or liquid-solid separation. Tus, in embodiments, the liquid feed mixture does not comprise a gas phase that is separated as a separate phase or within a liquid phase. However, small amounts of gas may of course be present in the liquid feed mixture, such as dissolved in the liquid feed mixture.

[0007] Step a) of the method comprises rotating the centrifuge bowl at a first rotational speed. This may be an operating speed under which separation is taking place. The first rotational speed may for example be in the range of 3000- 10000 rpm.

[0008] Step b) comprises introducing the liquid feed mixture into the separator bowl. This is performed while the bowl rotates at the first rotational speed. The liquid feed mixture may be supplied continuously to the centrifuge bowl.

[0009] Step c) of separating the liquid feed mixture is thus also performed at the first rotational speed. The liquid feed mixture is separated into at least a liquid phase. Depending on the contents of the liquid feed mixture, more than one liquid phase may be separated from the liquid mixture. As an example, the liquid feed mixture may be separated into one liquid phase and a sludge phase, into two liquid phases or into two liquid phases and a sludge phase.

[0010] Steps b) and c) may be performed at the same time, i.e. the liquid feed mixture may undergo separation as it is continuously fed into the centrifuge bowl.

[0011] Step d) comprises measuring a parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture supplied to the centrifuge bowl. This parameter or parameters may be measured and repeatedly continuously or at several discrete time points. Step d) may thus be performed during step c), such as during both steps b) and c).

[0012] Based on the measured parameter in step d), the rotational speed of the centrifuge bowl is changed, up or down, to a second rotational speed in step e). The second rotational speed may thus be higher or lower than the first rotational speed. The method may thus comprise feedback control back to a drive system of the centrifugal separator, so that the rotational speed may be adapted to the separation performance and/or a parameter of the liquid feed mixture.

[0013] Step f) involves continuing the separation process at the second rotational speed.

[0014] Consequently, each of steps c) and f) are performed during a time period that involves an actual separation process at the first and second rotational speeds, respectively. As an example, each of steps c) and f) may be performed during a time period that is longer than 1 min.

[0015] The first aspect of the invention is based on the insight that adjusting the rotational speed of the centrifugal separator to the actually needed separation performance and/or to properties of the feed that is to be separated is a very energy efficient way of operating the separator. Thus, instead of as in prior art centrifugal separators, in which a separator is run at a fixed rotational speed independent of operating conditions, the rotational speed is adapted and changed during the separation process to e.g. optimize energy consumption. As an example, if a liquid feed mixture is easily separated and this is measured by e.g. turbidity or capacitance or other suitable method, then the rotational speed may be lowered until a change in separation performance is detected. The new operating speed may then be just before the separation performance decreased. In analogy, if a liquid feed mixture is hard to separate, the rotational speed may be increased until the detected separation performance (e.g. turbidity/ capacitance) has reached its target. In this way, the risk of operating a centrifugal separator at a rotational speed that is higher than necessary may be decreased or avoided and will thus decrease energy consumption.

[0016] In addition, running the centrifugal separator at an adapted rotational speed will also lead to a decreased wear on the centrifugal separator.

[0017] The method involves measuring either one or several parameters related to the separation performance and/or one or several parameters of the liquid feed mixture and using them as feedback for setting the rotational speed. Thus, in embodiments of the first aspect, step d) comprises measuring a parameter related to the separation performance of the centrifugal separator and a parameter of the liquid feed mixture supplied to the centrifuge bowl. Thus, both a parameter that is related to the separation performance and a parameter of the liquid feed mixture may be used in order to determine how the rotational speed is adjusted. This may thus give an enhanced and more detailed feedback for setting the second rotational speed.

[0018] The changing of the rotational speed is performed during the separation process. Consequently, in embodiments of the first aspect, each of steps c) and f) comprises discharging the at least one liquid phase from the centrifuge bowl.

[0019] As an example, the liquid feed mixture may comprise two liquid phases, and each of steps c) and f) may comprise separating the liquid feed mixture into two liquid phases and discharging both of those phases from the centrifuge bowl.

[0020] The liquid feed mixture may thus be separated into a liquid heavy phase and a liquid light phase, in which the liquid heavy phase has a density that is higher than the liquid light phase.

[0021] The method may also comprise a step of discharging a sludge phase that has been separated from the liquid feed mixture. Such sludge phase may be discharge continuously from the centrifuge bowl or intermittently from the centrifuge bowl, as known in the art. Intermittently discharging the sludge phase may be performed during steps c) and f), or as a separate step at a separate rotational speed that is not the first or second rotational speed. During intermittent sludge discharge, the supply of liquid feed mixture to the centrifuge bowl is often stopped. Thus, during a sludge discharge, step b) may not be performed.

[0022] In embodiments of the first aspect, the method comprises repeatedly measuring the parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture and repeatedly changing the rotational speed of the centrifuge bowl during separation of the liquid feed mixture based on the repeatedly measured parameter.

[0023] Consequently, the method may comprise using the measured parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture supplied to the centrifuge bowl in a feedback loop to repeatedly adjust the rotational speed based on the measured parameter or parameters. The rotational speed may then be adjusted to a variety of rotational speeds, i.e. not just the first and second rotational speeds. In other words, the method allows for an adaptive rotational speed, i.e. a rotational speed that is adapted to the actual separation performance needed or the contents or properties of the liquid feed mixture that is to be separated.

[0024] As an example, the rotational speed may be adjusted, such as in step e), to any rotational speed within an operative speed interval. The operative sped interval may for example form a range extending more than 500 rpm, such as more than 1000 rpm, such as more than 2000 rpm, such as more than 3000 rpm, such as more than 5000 rpm.

[0025] Thus, the method may comprise dynamically adjusting the rotational speed of the centrifuge bowl based on the measured parameter or parameters. In other words, the method may comprise changing the rotational speed from the first rotational speed to any number of different rotational speeds, such as to a second, third, fourth rotational speed etc. during separation of the liquid feed mixtures based on the measured parameter or parameters.

[0026] As an example, the method may further comprise the steps of

g) repeating measuring a parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture supplied to the centrifuge bowl;

h) changing the rotational speed of the centrifuge bowl from the second rotational speed to a third rotational speed based on the measured parameter of step g); and

f) separating said liquid feed mixture in the centrifuge bowl into at least one liquid phase at said third rotational speed.

[0027] The method of the first aspect may be used to keep the separation performance at a certain level or within a certain interval during the separation process, i.e. only rotating the centrifuge bowl at a rotational speed that is necessary for a certain degree of separation, i.e. not rotating the centrifuge bowl at a rotational speed that is higher than necessary in order to achieve the desired separation performance. Consequently, in embodiments of the first aspect, step d) comprises measuring a parameter related to the separation performance of the centrifugal separator, and wherein step e) comprises the sub steps of increasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the separation performance is below a first setpoint value and decreasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the separation performance is above a second setpoint value.

[0028] Step d) may comprise measuring only one or several parameters related to the separation performance of the centrifugal separator and use that information to determine how the rotational speed is adjusted.

[0029] The first and second setpoint values may thus form an interval in which there is a desired degree of separation, and the method may be used to adjust the rotational speed so that the separation performance is within this interval.

[0030] As an alternative, the first and second setpoint value may be the same, which thus means that the steps of measuring the parameter and function as feedback for adjusting the speed to keep the separation performance at a certain fixed setpoint value, at least during a certain period of the separation process.

[0031] Hence, if the step e) comprises increasing the rotational speed, then the second rotational speed is higher than the first rotational speed, and if step e) comprises decreasing the rotational speed, then the second rotational speed is lower than the first rotational speed.

[0032] The method thus allows for an optimized energy usage, since the rotational speed may for example be lowered just until an undesired separation performance is measured and then be adjusted repeatedly in order to still have a desired separation performance with as low rotational speed as possible.

[0033] As an example, the parameter related to the separation performance may be measured on at least one separated liquid phase.

[0034] The liquid feed mixture may be measured the separated liquid phase if the liquid feed mixture is separated into a single liquid phase, or on one or several of the separated liquid phases if the liquid feed mixture is separated into a several liquid phases. The separation performance may for example be measured on a first and/or second liquid phase if the liquid feed mixture is separated into two liquid phases.

[0035] The parameter related to the separation performance measured on a separated liquid phase may relate to the concentration of a first liquid phase in the separated second phase, or vice versa. Thus, if the liquid feed mixture is separated into two liquid phases having different densities, i.e. a liquid light phase and a liquid heavy phase, the parameter related to the separation performance measured on a separated liquid phase may relate to the concentration of a liquid heavy phase in the separated liquid light phase and/or relate to the concentration of a liquid light phase in the separated liquid heavy phase.

[0036] As an example, the parameter related to the separation performance may be selected from the turbidity, the conductance, the capacitance, and the solids content of the at least one separated liquid phase.

[0037] In addition to separating the liquid feed mixture into at least one separated liquid phase, the method may comprise separating a solids phase, or a sludge phase, from the liquid feed mixture. In embodiments of the first aspect, step c) comprises separating the liquid feed mixture in the centrifuge bowl into a sludge phase and at last one liquid phase and intermittently discharging said sludge phase from the centrifuge bowl, and further wherein said parameter related to the separation performance is related to the frequency of sludge discharges.

[0038] Intermittent discharge of a solids phase may be performed through openable nozzles at or close to the periphery of the centrifuge bowl, as known in the art. The frequency of such discharges may relate to the separation performance.

[0039] As a further example, the method may comprise repeatedly measuring the parameter related to the separation performance of the centrifugal separator and repeatedly increasing and/or decreasing the rotational speed of the centrifuge bowl to keep the measured parameter related to the separation performance within a setpoint interval.

[0040] As mentioned above, the method may comprise using a measured parameter that is related to the separation performance of the centrifugal separator in a feedback loop to repeatedly adjust the rotational speed based on the measured parameter. This may be used to keep the separation performance at a desired level.

[0041] In embodiments of the first aspect, step d) comprises measuring a parameter of the liquid feed mixture.

[0042] The parameter of the liquid feed mixture may for example be related to an amount or concentration of one of the liquid phases in said liquid feed mixture, the amount or concentration of solids within said liquid feed mixture and/or the temperature of the liquid feed mixture, as explained below.

[0043] Step d) may comprise measuring only one or several parameters of the liquid feed mixture and use that information to determine how the rotational speed is adjusted.

[0044] As an example, the liquid feed mixture may comprise at least two liquid phases and said measured parameter of the liquid feed mixture is related to an amount or concentration of one of the liquid phases in said liquid feed mixture.

[0045] How the rotational speed is adjusted depends on which phases are present and what is to be separated from the other phase. Thus, the liquid feed mixture may comprise a first and a second liquid phase, and the second rotational speed of step e) may be lower than the first rotational speed if said measured parameter indicates that the amount or concentration of the first liquid phase is below a setpoint value; and wherein the second rotational speed of step e) is higher than the first rotational speed if said measured parameter indicates that the amount the amount or concentration of the first liquid phase is above a setpoint value, or vice versa.

[0046] As further example, the parameter of the liquid feed mixture may be related to an amount or concentration of solids within said liquid feed mixture. In such case, step e) may comprise decreasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the amount of solids is below a third setpoint value and increasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the amount of solids is above a fourth setpoint value.

[0047] Thus, an increase solids content of the liquid feed mixture may require an increased rotational speed in order to get a desired separation of the solids from the liquid feed mixture.

[0048] As further example, the parameter of the liquid feed mixture may be the temperature of the liquid feed mixture. In such case, step e) may comprise increasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the temperature of the liquid feed mixture is below a fifth setpoint value and decreasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the temperature of the liquid feed mixture is above a sixth setpoint value.

[0049] Measuring the temperature of the liquid feed mixture may be important when the viscosity of the feed mixture depends on temperature, such as for an oil, such as for fuel oil or vegetable oil. If the temperature is lower, the viscosity of the oil is usually higher, which means that a higher rotational speed may be required.

[0050] Furthermore, the method may comprise repeatedly measuring the parameter of the liquid feed mixture and repeatedly increasing and/or decreasing the rotational speed of the centrifuge bowl based on the measured parameter of the liquid feed mixture. Thus, as also discussed above, the parameter or parameters of the liquid feed mixture may be used as feedback to adapt the rotational speed of the centrifugal separator to changes in the liquid feed mixture that is to be separated.

[0051] As a second aspect of the invention, there is provided a centrifugal separator for separating at least one liquid phase from a liquid feed mixture. The centrifugal separator is comprising

- a rotatable centrifuge bowl in which the separation takes place;
- a drive motor for rotation the centrifuge bowl; and
- a separator control unit configured for
  - receiving information about a parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture;
  - sending operational requests to said drive motor for changing the rotational speed of the centrifuge bowl from a first rotational speed to a second rotational speed based on the received information.

[0052] This 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 of the invention.

[0053] The centrifugal separator of the second aspect may thus be used when performing the method of the first aspect discussed above. The centrifugal separator may be arranged for separating a at least one liquid phase and a solids phase from the liquid feed mixture.

[0054] The centrifugal separator may further comprise a stationary frame and a hood covering the centrifuge bowl.

[0055] The drive motor may be configured to rotate a centrifuge bowl within the hood. The axis of rotation for the centrifuge bowl may be a vertical axis of rotation. The centrifuge bowl may be enclosing a separation space in which the separation takes place. The separation space may comprise a stack of separation discs arranged centrally around the axis of rotation. Such separation discs form surface enlarging inserts in the separation space. The separation discs may have the form of a truncated cone, i.e. the stack may be a stack of frustoconical separation discs.

[0056] The drive motor may be an electrical motor comprising a stator and a rotor. As an example, the rotor may be directly connected to a shaft for rotating the centrifuge bowl.

[0057] Further, the centrifugal separator may comprise a variable frequency drive, VFD, configured to control torque and speed of the drive motor.

[0058] The VFD may vary frequency and amplitude of the voltage being supplied by the VFD to the drive motor of the separator to increase/decrease the speed and torque of the motor, which in its turn increases/decreases the rotational speed and torque with which the centrifuge bowl is rotated.

[0059] The drive motor may also be an induction motor without a VFD.

[0060] The separator 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. Thus, the control unit may comprise a processor and an input/output interface for communicating with the drive motor, such as to a VFD configured to control torque and speed of the drive motor, for adjusting the rotational speed of the drive motor and for receiving the information about a parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture.

[0061] Thus, the control unit may be operable to perform the step e) of changing the rotational speed of the centrifuge bowl from the first rotational speed to a second rotational speed based on the measured parameter of step d).

[0062] The centrifugal separator may further comprise at least one sensor for measuring the parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture supplied to the centrifuge bowl.

[0063] The centrifugal separator may further comprise an inlet for receiving the liquid feed mixture and at least one liquid outlet for a separated liquid phase.

[0064] The at least one sensor may be arranged downstream any liquid outlet of the centrifugal separator for measuring a parameter related to the separation performance on a separated liquid phase. The sensor arranged downstream a liquid outlet may thus be selected from a turbidity sensor, a sensor for measuring the conductance, a sensor for measuring the capacitance and a sensor for measuring the solids content of a separated liquid phase.

[0065] The at least one sensor may be arranged upstream of an inlet for supplying liquid feed mixture to the centrifugal separator for measuring a parameter of the liquid feed mixture supplied to the centrifuge bowl. Such sensor may for example be a temperature sensor, a sensor for measuring an amount or concentration of one of the liquid phases of the liquid feed mixture, or a sensor for measuring an amount or concentration of solids within the liquid feed mixture.

[0066] The control unit may further be configured for receiving information about a parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture from any of the sensors described above.

[0067] The centrifugal separator may be arranged for separating the liquid feed mixture in the centrifuge bowl into a sludge phase and at last one liquid phase and further arranged for intermittently discharging the sludge phase from the centrifuge bowl. In embodiments, the centrifugal separator further comprises a sludge outlet arranged at the periphery of the centrifuge bowl. As an example, the sludge outlet may be in the form of a set of intermittently openable outlets.

[0068] The control unit may then further be configured for receiving information about the frequency of sludge discharges.

[0069] The control unit may further be configured for repeatedly receiving information about the parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture and further configured for repeatedly sending operational requests to the drive motor for repeatedly changing the rotational speed of the centrifuge bowl during separation of the liquid feed mixture based on the repeatedly received information.

[0070] The control unit may be configured for receiving information about a parameter related to the separation performance of the centrifugal separator, and configured for increasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the separation performance is below a first setpoint value and decreasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the separation performance is above a second setpoint value.

[0071] Thus, the control unit may be configured to repeatedly increase and/or decrease the rotational speed of the centrifuge bowl to keep the measured parameter related to the separation performance within a setpoint interval.

[0072] The control unit may be configured for receiving information related to an amount or concentration of solids within said liquid feed mixture, and further configured for decreasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the amount of solids is below a third setpoint value and increasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the amount of solids is above a fourth setpoint value.

[0073] The control unit may be configured for receiving information related to the temperature of the liquid feed mixture, and further configured for increasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the temperature of the liquid feed mixture is below a sixth setpoint value and decreasing the rotational speed of the centrifuge bowl if said measured parameter indicates that the temperature of the liquid feed mixture is above a fifth setpoint value.

[0074] The method and centrifugal separator of the first and second aspect of the invention thus allows for dynamically adjusting the rotational speed of the centrifugal separator for e.g. optimizing energy efficiency. Traditionally, centrifugal separators have fixed alarm triggering levels (e.g. low inlet pressure "x bar" or low speed "y rpm"). However, for the inventive method and separator of the present disclosure, also these alarm triggering level may be dynamically adjusted. As an example, the low-speed alarm could always be triggered at a certain level below the speed setpoint. As another example, a mathematical model may be used to adapt the alarm triggering levels to the actual operating conditions.

Brief description of the Drawings

[0075] The above, as well as additional objects, features and advantages of the present inventive concept, will be better understood through the following illustrative and nonlimiting 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 schematically shows the process steps of the general method of the present disclosure.
Figure 2 shows a schematic drawing of an embodiment of a centrifugal separation in which the method may be implemented.
Figure 3 shows a schematic drawing of a further embodiment of a centrifugal separator in which the method may be implemented.
Figure 4 shows a schematic drawing of a further embodiment of a centrifugal separator in which the method may be implemented.
Figure 5 shows a schematic drawing of a further embodiment of a centrifugal separator in which the method may be implemented.
Figure 6 shows a schematic drawing of a further embodiment of a centrifugal separator in which the method may be implemented.
Figure 7 shows a schematic drawing of some further features of an embodiment of a centrifugal separator.
Figure 8 schematically shows the process steps that may be executed by a control unit of the centrifugal separator.
Figure 9 schematically shows the process steps an embodiment of the method of the present disclosure.
Figure 10 schematically shows the process steps an embodiment of the method of the present disclosure.
Figure 11 schematically shows the process steps an embodiment of the method of the present disclosure.

Detailed Description

[0076] The method and the system according to the present disclosure will be further illustrated by the following description with reference to the accompanying drawings.

[0077] Fig. 1 shows the process steps of the overall method for operating a centrifugal separator 1. The centrifugal separator 1, further discussed in relation to Figs 2-7 below, is a centrifugal separator arranged for liquid separation, such as for separating at least one liquid phase, e.g. one or two liquid phases, from a liquid feed mixture. The liquid feed mixture may further comprise a solids fraction, or solids phase, which may be separated into a sludge phase. In general, the centrifugal separator 1 comprises a rotatable centrifuge bowl 3 in which the separation takes place, and the method comprises a step a) of rotating 101 the centrifugal bowl 3 at first rotational speed S1. The bowl thus rotates around an axis of rotation (x) that may be vertical. The first rotational speed S1 may be an operating speed of the centrifugal separator 1, i.e. a speed that is above the critical rotational speed of the centrifuge bowl 3. The first rotational speed S1 may for example be between 3000 -11000 rpm. The method 100 further comprises step b) of supplying 102 the liquid feed mixture to the centrifuge bowl 3 and a step c) of separating 103 the liquid feed mixture in the centrifuge bowl 3 into at least one liquid phase during rotation at the first rotational speed S1. Thus, the first rotational speed is a speed at which separation takes place. Step c) may also comprise discharging 110 the separated liquid phase or phases, such as continuously discharging these phase or phases. During rotation at the first rotational speed S1, step d) of measuring 104 at least one parameter takes place. This parameter or parameter may include

- a parameter Ax that is related to the separation performance of the centrifugal separator 1, or
- a parameter Bx of the liquid feed mixture that is supplied to the centrifuge bowl 3, or
- both a parameter Ax that is related to the separation performance of the centrifugal separator 1 and a parameter Bx of the liquid feed mixture that is supplied to the centrifuge bowl 3.

[0078] The method 100 then comprises a step e) of changing 105 the rotational speed of the centrifuge bowl 3 from the first rotational speed S1 to a second rotational speed S2 based on the measured parameter or parameters of step d). Depending on the value of the measured parameter, the second rotational speed S2 may be higher or lower than the first rotational speed S1.

[0079] The separation process is then continued at the adjusted speed, i.e. the method comprises a step f) of separating 106 the liquid feed mixture in the centrifuge bowl 3 into at least one liquid phase at said second rotational speed S2. Also during step f) may at least one separated liquid phase be discharged, i.e. step f) may include discharging 110 the separated liquid phase or phases from the centrifuge bowl 3.

[0080] The method 100 allows for using the measured parameter or parameters as feedback to dynamically adjust the rotational speed of the centrifuge bowl. The method may thus comprise repeatedly measuring 111 the parameter Ax that is related to the separation performance of the centrifugal separator 1 and/or repeatedly measuring 111 a parameter Bx of the liquid feed mixture and thus also repeatedly changing the rotational speed of the centrifuge bowl 3 during separation of the liquid feed mixture based on the repeatedly measured parameter or parameters.

[0081] The rotational speed of the centrifuge bowl may be adjusted to a variety of rotational speed levels, not only the first and second rotational speeds S1, S2.

[0082] Figs. 2-7 show different embodiments of a centrifugal separator 1 in which the method 100 may be implemented.

[0083] The centrifugal separator 1 is arranged for separating at least one liquid phase from a liquid feed mixture and comprises a rotatable centrifuge bowl 3 in which the separation takes place as well as a drive motor 14 for rotating the centrifuge bowl 3 at different rotational speeds.

[0084] In the centrifugal separator 1 of Fig. 2, the liquid feed mixture is introduced to the centrifuge bowl 3 via inlet pipe 11 from the top of the separator. The liquid feed mixture is separated in a single liquid phase that is discharged via outlet pipe 12 and a sludge phase that is intermittently ejected to a sludge tank 25, as known in the art, see for example US11027290.

[0085] The drive motor 14 is in this case an electrical motor comprising a stator and rotor for rotating a shaft upon which the centrifuge bowl 3 is mounted.

[0086] The centrifugal separator 1 also comprises a separator control unit 20 that is configured for controlling the drive motor 14 to rotate at different rotational speeds, such as at the first S1 and second rotational speeds S2. This may be performed by controlling, e.g. sending operational requests to, a variable frequency drive, VFD 30, that is configured to control torque and speed of the drive motor 14.

[0087] Also, the centrifugal separator comprises a sensor 21a arranged for measuring a parameter Ax that related to the separation performance of the centrifugal separator. This sensor 21a is arranged for measuring a parameter of the separated liquid phase that is discharged in stationary outlet pipe 12, i.e. arranged downstream of a liquid outlet of the centrifugal separator 1. The sensor 21a could be a turbidity sensor for measuring the turbidity of the separated liquid phase, a sensor for measuring the conductance of the separated liquid phase, a sensor for measuring the capacitance of the separated liquid phase or a sensor for measuring the solids content of the separated liquid phase. These measurements by sensor 21a may thus give information about how clarified the separated liquid phase is and thereby gives information about a parameter Ax related to the separation performance of the centrifugal separator 1. This information is sent to the control unit 20, as indicated by arrow A in Fig. 2, and the control unit is configured to control the drive motor 14 based on these measurements to dynamically adjust the rotational speed of the centrifuge bowl 13 during separation of the liquid feed mixture, as indicated by arrow B in Fig. 2.

[0088] The centrifugal separator 1 of Fig. 2 could be used to perform the embodiment of the method 100 as illustrated in Fig. 9, which comprises the steps of rotating 101 the centrifuge bowl 3 at the first rotational speed S1, supplying 102 liquid feed mixture via inlet pipe 11 to the centrifuge bowl 3 during rotation of the centrifuge bowl 3 at speed S1, measuring 104 a parameter Ax that is related to the separation performance using sensor 21a arranged downstream the liquid outlet. As discussed above, the parameter Ax may be selected from the turbidity, the conductance, the capacitance and the solids content of the separated liquid phase

[0089] For adjusting the rotational speed S1 to another rotational speed S2, the sub steps 107 could be performed, i.e. as a step e) changing 105 the rotational speed of the centrifuge bowl 3. The subsets 107 comprises increasing the rotational speed of the centrifuge bowl 3 if said measured parameter Ax indicates that the separation performance is below a first setpoint value X1 and decreasing the rotational speed of the centrifuge bowl 3 if said measured parameter Ax indicates that the separation performance is above a second setpoint value X2. Hence, the rotational speed could be adjusted so as to keep the separation performance between setpoints X1 and X2. This means that the method 100 could comprise repeatedly measuring 111 the parameter Ax related to the separation performance of the centrifugal separator 1 and repeatedly increasing and/or decreasing the rotational speed of the centrifuge bowl 3 to keep the measured parameter Ax related to the separation performance within a setpoint interval.

[0090] The sub steps 107 could be performed using the separator control unit 20. In other words, the control unit 20 could be operable to perform the steps of increasing the rotational speed of the centrifuge bowl 3 if said measured parameter Ax indicates that the separation performance is below a first setpoint value X1 and decreasing the rotational speed of the centrifuge bowl 3 if said measured parameter Ax indicates that the separation performance is above a second setpoint value X2.

[0091] If the rotational speed is adjusted, then the separation process of course continues at the adjusted rotational speed.

[0092] The separator control unit 20 may in this example be configured to perform method 200 as illustrated in Fig. 8, i.e. configured for receiving 201 information about a parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture and sending 202 operational requests to the drive motor 14 for changing the rotational speed of the centrifuge bowl 3 from a first rotational speed S1 to a second rotational speed S2 based on the received information.

[0093] The information received may thus be received from sensor 21a. In order to perform these method steps, the control unit 20 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 20 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.

[0094] Fig. 3 and Fig. 4 show embodiments of a centrifugal separator 1 that may be used to perform the method 100 of the present disclosure. The centrifugal separator 1 with its control unit 20 mainly function as discussed above and the other features are the same as previously discussed, with only a few differences as discussed below.

[0095] In Fig. 3, the centrifugal separator is arranged for separating the liquid feed mixture into two liquid phases; a liquid heavy phase and a liquid light phase, in which the liquid heavy phase has a density that is higher than the density of the liquid light phase. The liquid light phase is discharged into liquid light phase outlet 12 and liquid heavy phase is discharged into liquid heavy phase outlet 17. The liquid feed mixture may thus be an oil containing an amount of water, and the oil would then be discharged as the liquid light phase and the water as the liquid heavy phase. The sensor 21b is arranged to measure the water content in the discharged oil phase, i.e. a parameter Ax that is related to the separation performance, and the control unit 20 could then repeatedly adjust the rotational speed of the centrifuge bowl 3 based on the received information from the sensor 21b.

[0096] In Fig. 4, the centrifugal separator 1 is also arranged for separating the liquid feed mixture into two liquid phases. The difference from the embodiment as shown in Fig. 3 is that the liquid feed mixture is supplied from the bottom of the centrifuge bowl 3, such as through a hollow spindle 4 connected to the drive motor 14. Also, the sensor 21c for measuring the parameter Ax related to the separation performance is arranged for measuring a parameter of the liquid heavy phase discharged to stationary outlet pipe 17.

[0097] The centrifugal separators as shown in the Figures of the present disclosure are further arranged to separate a solids phase, or a sludge phase, from the liquid feed mixture and eject such sludge phase from the centrifuge bowl. It is to be understood that this is not necessary, but the sludge phase could be instead collected within the bowl 3.

[0098] The separated sludge phase could be ejected continuously via open nozzles arranged at the outer portion of the centrifuge bowl 3 or intermittently via intermittently openable outlets arranged at the outer portion of the centrifuge bowl 3.

[0099] Consequently, step c) of the method 100 of the present disclosure may comprise separating the liquid feed mixture in the centrifuge bowl 3 into a sludge phase and at last one liquid phase and intermittently discharging 110 the sludge phase from the centrifuge bowl 3.

[0100] As an example, the control unit 20 could be operable to control the centrifugal separator to intermittently discharge the sludge phase and the parameter Ax that is related to the separation performance could as an alternative be related to the frequency of sludge discharges. Therefore, the frequency of sludge discharges could be used by the control unit 20 to adjust the rotational speed of the centrifuge bowl 3. A high frequency of sludge discharges may mean that there are higher amounts of solids within the liquid feed mixture and that the rotational speed needs to be increased in order to keep the separation performance within a desired interval or at a certain setpoint.

[0101] The centrifugal separator as shown in the embodiment of Fig. 5 may also be used to perform the method 100 of the present disclosure. The centrifugal separator 1 with its control unit 20 mainly function as discussed above and the other features are the same as previously discussed, with only a few differences as discussed below.

[0102] In the centrifugal separator 1 of Fig. 5, the sensor 21d is arranged to measure a parameter Bx of the liquid feed mixture that is supplied via inlet pipe 11. Information from this sensor 21d may then be used by the control unit 20 to adjust the rotational speed of the centrifuge bowl 3. Thus, the method 100 of the present disclosure may comprise repeatedly measuring 111 the parameter of the liquid feed mixture and repeatedly increasing and/or decreasing the rotational speed of the centrifuge bowl 2 based on the measured parameter.

[0103] As an example, the liquid feed mixture may comprise at least two liquid phases that are separated into a liquid light phase discharged to outlet pipe 12 and a liquid heavy phase discharged to outlet pipe 17, and the measured parameter Bx of the liquid feed mixture may be related to an amount or concentration of one of the liquid phases in the liquid feed mixture.

[0104] The centrifugal separator as shown in Fig. 5 could be used to perform the embodiment of the method 100 as illustrated in Fig. 10. This embodiment of the method 100 comprises the steps of

a) rotating 101 the centrifugal bowl 3 at first rotational speed S1;

b) supplying 102 a liquid feed mixture to the centrifuge bowl 3;

c) separating 103 said liquid feed mixture in the centrifuge bowl 3 into at least one liquid phase at said first rotational speed S1;

d) measuring 104 a parameter Bx of the liquid feed mixture that is supplied to the centrifuge bowl 3, wherein Bx is related to an amount or concentration of solids within said liquid feed mixture.

[0105] The step of changing the rotational speed may then comprise the sub steps 108 as illustrated in Fig. 10, i.e. decreasing the rotational speed of the centrifuge bowl 3 if the measured parameter Bx indicates that the amount of solids is below a third setpoint value X3 and increasing the rotational speed of the centrifuge bowl 3 if the measured parameter indicates that the amount of solids is above a fourth setpoint value X4. The control unit 20 could be operable to perform the steps of changing the rotational speed.

[0106] If the rotational speed is adjusted, then the separation process of course continues at the adjusted rotational speed.

[0107] The centrifugal separator as shown in Fig. 5 could also be used to perform the embodiment of the method 100 as illustrated in Fig. 11. This embodiment of the method 100 comprises the steps of

a) rotating 101 the centrifugal bowl 3 at first rotational speed S1;

b) supplying 102 a liquid feed mixture to the centrifuge bowl 3;

c) separating 103 said liquid feed mixture in the centrifuge bowl 3 into at least one liquid phase at said first rotational speed S1;

d) measuring 104 a parameter Bx of the liquid feed mixture that is supplied to the centrifuge bowl 3, wherein Bx is the temperature of the liquid feed mixture.

[0108] The step of changing the rotational speed may then comprise the sub steps 109 as illustrated in Fig. 11, i.e. increasing the rotational speed of the centrifuge bowl 3 if said measured parameter indicates that the temperature of the liquid feed mixture is below a fifth setpoint value X5 and decreasing the rotational speed of the centrifuge bowl 3 if said measured parameter indicates that the temperature of the liquid feed mixture is above a sixth setpoint value X6. The control unit 20 could be operable to perform the steps of changing the rotational speed.

[0109] If the rotational speed is adjusted, then the separation process of course continues at the adjusted rotational speed.

[0110] In the centrifugal separator of the embodiment of Fig. 5, the control unit 20 is thus configured for receiving 201 information about a parameter of the liquid feed mixture and sending 202 operational requests to the drive motor 14 for changing the rotational speed of the centrifuge bowl 3 from a first rotational speed S1 to a second rotational speed S2 based on the received information.

[0111] The method 100 of the present disclosure may of course comprise measuring both a parameter Ax related to the separation performance of the centrifugal separator 1 and/or a parameter Bx of the liquid feed mixture supplied to the centrifuge bowl 3. Fig. 6 shows a centrifugal separator 1 in which such an embodiment of the method may be performed. This separator 1 with its control unit 20 mainly function as discussed above and the other features are the same as previously discussed. The liquid feed mixture supplied vi inlet line 11 is separated into two liquid phases. The centrifugal separator 1 has a first sensor 21b for measuring the parameter Ax related to the separation performance on the separated liquid light phase and a second sensor 21d arranged for measuring a parameter Bx of the liquid feed mixture in inlet line 11. Ax and Bx may be as discussed in relation to the previous examples above. Thus, in this example, the control unit 20 is configured to adjust the rotational speed based on information from both Ax and Bx, as indicated by arrows A, C and B. In other words, in the centrifugal separator 1 of the embodiment of Fig. 6, the control unit 20 is configured for receiving 201 information about parameter Ax related to the separation performance of the centrifugal separator 1 and a parameter Bx of the liquid feed mixture supplied to the centrifuge bowl 3, and sending 202 operational requests to the drive motor 14 for changing the rotational speed of the centrifuge bowl 3 from a first rotational speed S1 to a second rotational speed S2 based on the received information.

[0112] Fig. 7 illustrates and gives some further details of a centrifugal separator 1 that may be used to perform the method of the present disclosure.

[0113] The centrifugal separator 1 comprises a rotating part that is arranged for rotation about an axis of rotation (X) and comprises centrifuge bowl 3 and spindle 4. The spindle 4 is supported in the stationary frame 5 of the centrifugal separator in a bottom bearing 6 and a top bearing 7. The centrifuge bowl 3 is arranged under stationary hood 5a.

[0114] The centrifuge bowl 3 forms within itself a separation chamber 8 in which centrifugal separation of the liquid feed mixture takes place during operation.

[0115] The separation chamber 8 is provided with a stack of frusto-conical separation discs 9 in order to achieve effective separation of the liquid mixture. The stack of truncated conical separation discs 9 are examples of surface-enlarging inserts. These discs 9 are fitted centrally and coaxially with the centrifuge bowl 3 and comprise holes which form channels 10 for axial flow of liquid when the separation discs 9 are fitted in the centrifuge bowl 3.

[0116] Liquid mixture to be separated is fed from the top via stationary inlet pipe 11 extending down into the centrifuge bowl 3.

[0117] A liquid light phase outlet 12 for a clean liquid phase extends from the centrifuge bowl 3 through the hood 5a at the top of the separator 1. In this example, the centrifugal separator 1 has only a single liquid outlet 12, but the separator 1 could also comprise further liquid outlets for liquid phases of other densities than the density of the liquid discharged via outlet 12. This depends on constituents of the liquid feed mixture that is to be processed. In such cases, any liquid of higher density may instead be forced out through a further liquid outlet (not shown) that is at a radial distance that is larger than the radial level of outlet 12.

[0118] The centrifuge bowl 3 is further provided at its outer periphery with a set of radially sludge outlets 13 in the form of intermittently openable outlets for discharge of higher density component such as sludge or other solids in the liquid. Solids present in the liquid feed mixture may thus be discharged from a radially outer portion of the separation chamber 8 to the space round the centrifuge bowl 3.

[0119] The centrifugal separator 1 is further provided with a drive motor 14. This motor 14 may for example be an electric motor that is arranged to transmit driving torque to the spindle 4 and hence to the centrifuge bowl 3. As an alternative, the drive motor 14 may be connected to the spindle 4 by transmission means such as drive belts or the like.

[0120] Thus, during operation of the separator in Fig. 7, the centrifuge bowl 3 is caused to rotate by torque transmitted from the drive motor 14 to the spindle 4. Via the stationary inlet pipe 11, liquid feed mixture may continuously be brought into the separation space 8, e.g. when the rotor is already running at its operational speed. Solids within the liquid mixture move radially outwards between the separation discs, whereas the clarified liquid phase liquid moves radially inwards between the separation discs and is forced to be discharged via outlet 12. The solid phase is accumulated at the periphery of the separation chamber 8 and is emptied intermittently from the separation space by the sludge outlets 13 being opened, whereupon the solid phase is discharged from the separation space by means of centrifugal force.

[0121] The invention is not limited to the embodiments disclosed but may be varied and modified within the scope of the claims set out below. The invention is not limited to the type of separator as shown in the Figures. The term "centrifugal separator" also comprises centrifugal separators with a substantially horizontally oriented axis of rotation.

Claims

1. A method (100) for operating a centrifugal separator (1) for separating at least one liquid phase from a liquid feed mixture; said centrifugal separator (1) comprising a rotatable centrifuge bowl (3) in which the separation takes place; the method comprising the steps of

a) rotating (101) the centrifugal bowl (3) at first rotational speed (S1);

b) supplying (102) a liquid feed mixture to the centrifuge bowl (3);

c) separating (103) said liquid feed mixture in the centrifuge bowl (3) into at least one liquid phase at said first rotational speed (S1);

d) measuring (104) a parameter (Ax) related to the separation performance of the centrifugal separator (1) and/or a parameter (Bx) of the liquid feed mixture supplied to the centrifuge bowl (3);

e) changing (105) the rotational speed of the centrifuge bowl (3) from the first rotational speed (S1) to a second rotational speed (S2) based on the measured parameter of step d); and

f) separating (106) said liquid feed mixture in the centrifuge bowl (3) into at least one liquid phase at said second rotational speed (S2).

2. A method (100) according to claim 1, wherein step d) comprises measuring (104) a parameter (Ax) related to the separation performance of the centrifugal separator (1) and a parameter (Bx) of the liquid feed mixture supplied to the centrifuge bowl (3).

3. A method (100) according to claim 1 or 2, wherein each of steps c) and f) comprises discharging (110) said at least one liquid phase from the centrifuge bowl (3).

4. A method (100) according to any previous claim, further comprising repeatedly measuring (111) the parameter (Ax) related to the separation performance of the centrifugal separator (1) and/or a parameter (Bx) of the liquid feed mixture and repeatedly changing the rotational speed of the centrifuge bowl (3) during separation of the liquid feed mixture based on the repeatedly measured parameter.

5. A method (100) according to any previous claim, wherein step d) comprises measuring a parameter (Ax) related to the separation performance of the centrifugal separator (1), and wherein step e) comprises the sub steps (107) of increasing the rotational speed of the centrifuge bowl (3) if said measured parameter (Ax) indicates that the separation performance is below a first setpoint value (X1) and decreasing the rotational speed of the centrifuge bowl (3) if said measured parameter (Ax) indicates that the separation performance is above a second setpoint value (X2).

6. A method (100) according to claim 5, wherein said parameter (Ax) related to the separation performance is measured on at least one separated liquid phase.

7. A method (100) according to claim 6, wherein said parameter (Ax) related to the separation performance is selected from the turbidity, the conductance, the capacitance and the solids content of the at least one separated liquid phase.

8. A method (100) according to claim 5, wherein step c) comprises separating the liquid feed mixture in the centrifuge bowl (3) into a sludge phase and at last one liquid phase and intermittently discharging (110) said sludge phase from the centrifuge bowl (3), and further wherein said parameter (Ax) related to the separation performance is related to the frequency of sludge discharges.

9. A method (100) according to any one of claims 5-8, further comprising repeatedly measuring (111) the parameter (Ax) related to the separation performance of the centrifugal separator (1) and repeatedly increasing and/or decreasing the rotational speed of the centrifuge bowl (3) to keep the measured parameter (Ax) related to the separation performance within a setpoint interval.

10. A method (100) according to any one of claims 1-4, wherein step d) comprises measuring (104) a parameter (Bx) of the liquid feed mixture.

11. A method (100) according to claim 10, wherein the liquid feed mixture comprises at least two liquid phases and said measured parameter (Bx) of the liquid feed mixture is related to an amount or concentration of one of the liquid phases in said liquid feed mixture.

12. A method according to claim 10, wherein said parameter (Bx) of the liquid feed mixture is related to an amount or concentration of solids within said liquid feed mixture, and wherein step e) comprises decreasing the rotational speed of the centrifuge bowl (3) if said measured parameter indicates that the amount of solids is below a third setpoint value (X3) and increasing the rotational speed of the centrifuge bowl (3) if said measured parameter indicates that the amount of solids is above a fourth setpoint value (X4).

13. A method according to claim 10, wherein said parameter (Bx) of the liquid feed mixture is the temperature of the liquid feed mixture, and wherein step e) comprises increasing the rotational speed of the centrifuge bowl (3) if said measured parameter indicates that the temperature of the liquid feed mixture is below a fifth setpoint value (X5) and decreasing the rotational speed of the centrifuge bowl (3) if said measured parameter indicates that the temperature of the liquid feed mixture is above a sixth setpoint value (X6).

14. A method (100) according to any one of claims 10-13, further comprising repeatedly measuring (111) the parameter of the liquid feed mixture and repeatedly increasing and/or decreasing the rotational speed based on the measured parameter.

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

a rotatable centrifuge bowl (3) in which the separation takes place;
a drive motor (14) for rotation the centrifuge bowl (3); and
a separator control unit (20) configured for

receiving (201) information about a parameter related to the separation performance of the centrifugal separator and/or a parameter of the liquid feed mixture;
sending (202) operational requests to said drive motor for changing the rotational speed of the centrifuge bowl (3) from a first rotational speed (S1) to a second rotational speed (S2) based on the received information.

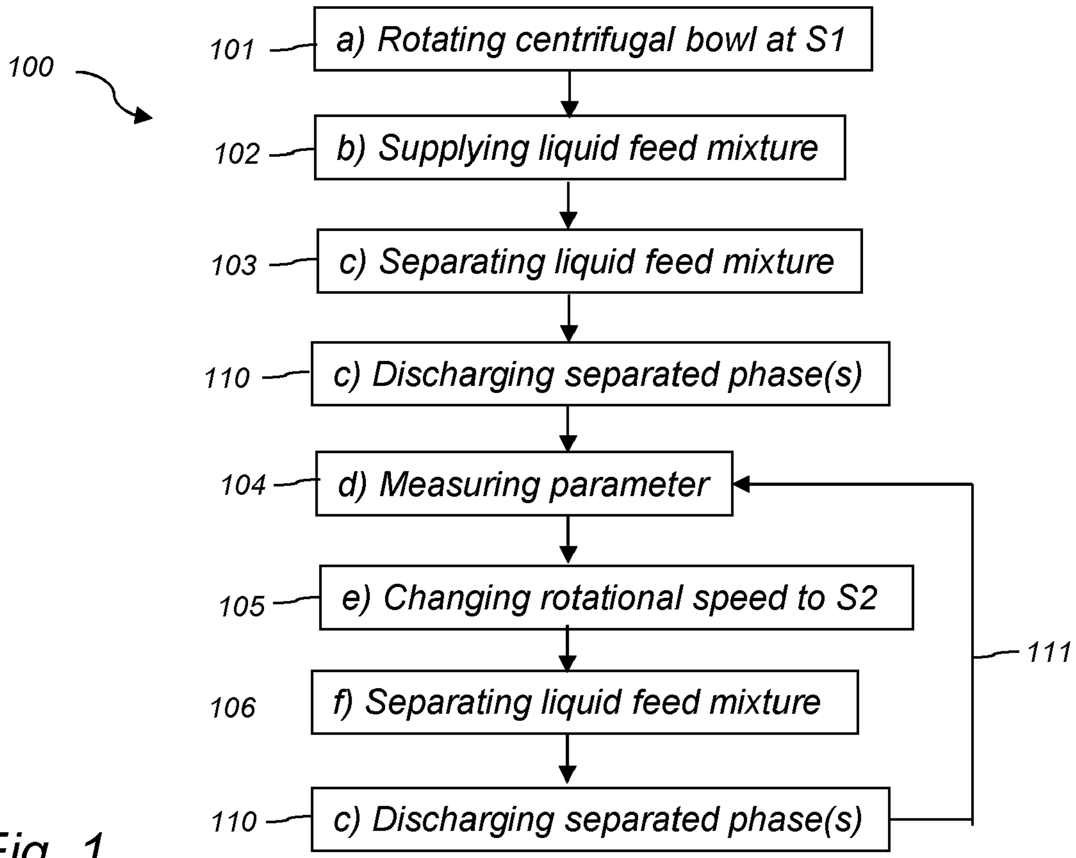

100
101
a) Rotating centrifugal bowl at S1
102
b) Supplying liquid feed mixture
103
c) Separating liquid feed mixture
110
c) Discharging separated phase(s)
104
d) Measuring parameter
105
e) Changing rotational speed to S2
106
f) Separating liquid feed mixture
110
c) Discharging separated phase(s)
111

Fig. 1

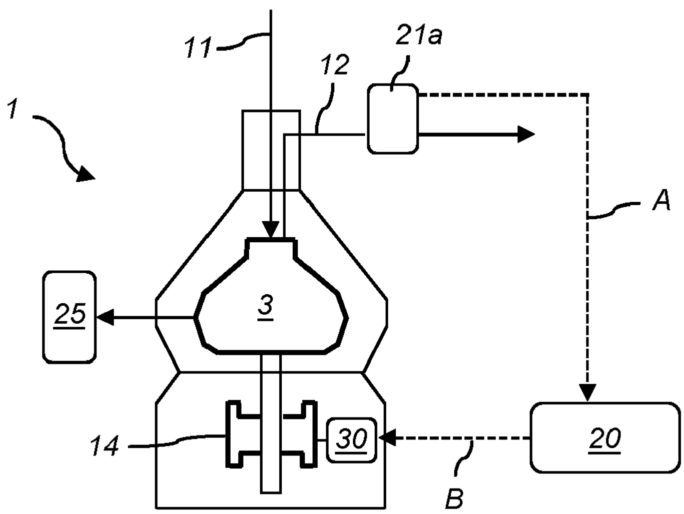

11
12
21a
1
A
25
3
14
30
20
B

Fig. 2

Fig. 3

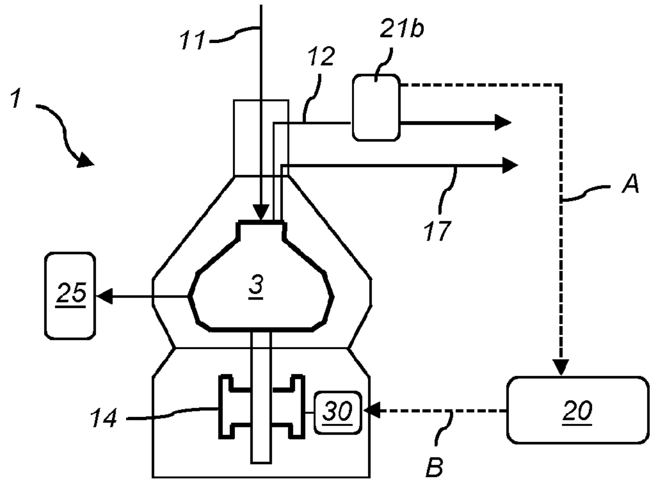


Fig. 4

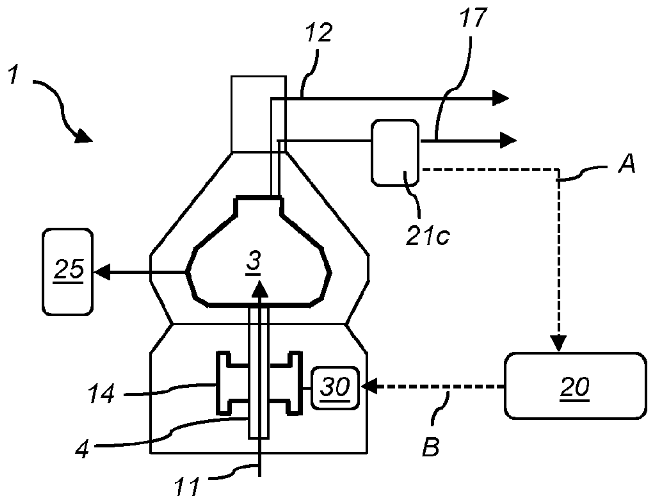


Fig. 5

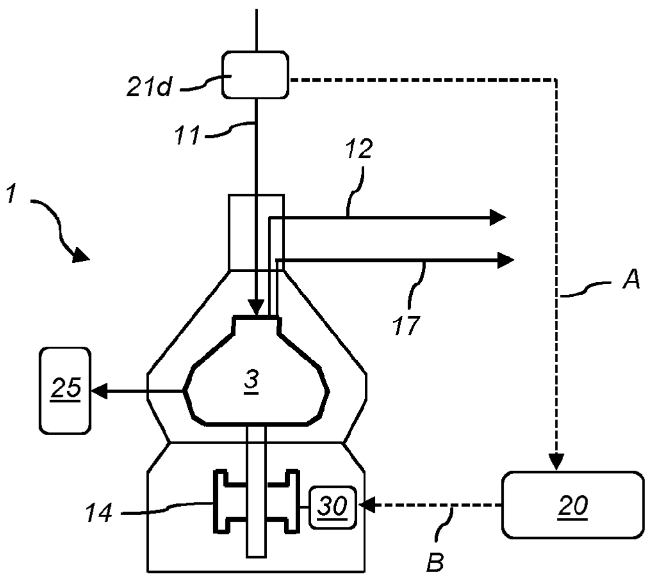


Fig. 6

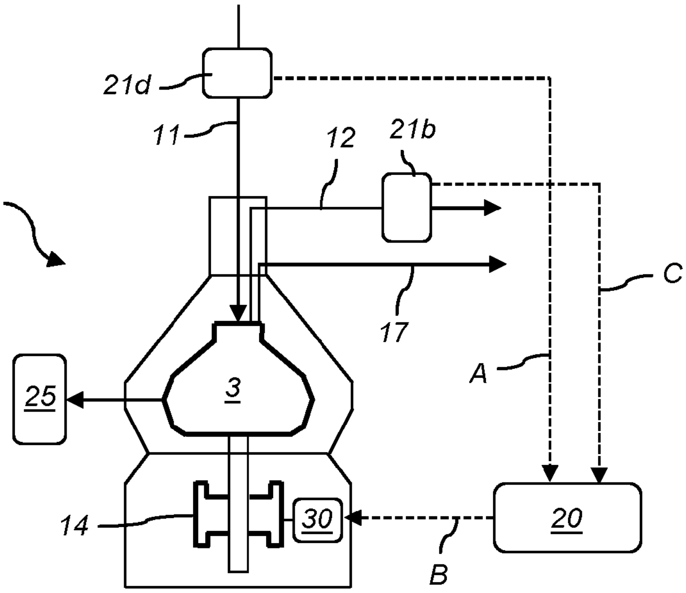
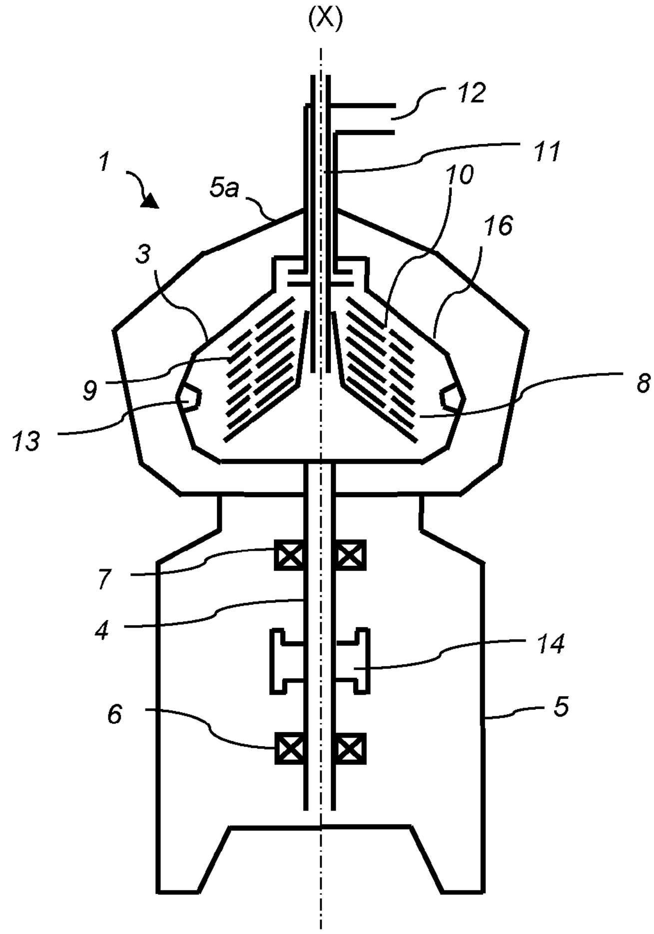


Fig. 7



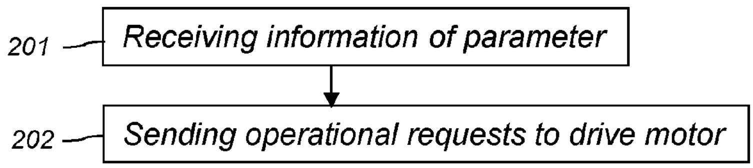

201
Receiving information of parameter
202
Sending operational requests to drive motor

Fig. 8

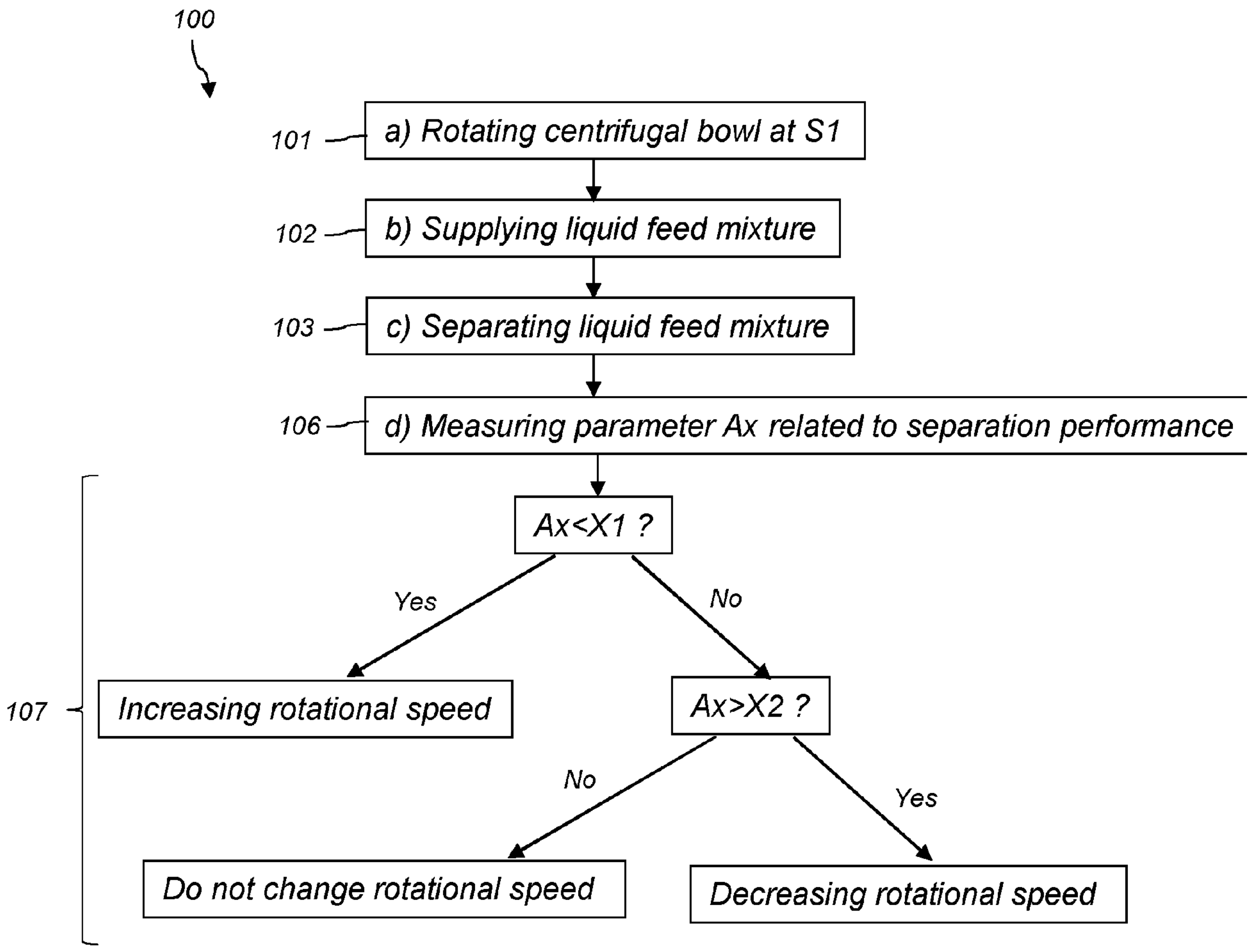

100
101
a) Rotating centrifugal bowl at S1
102
b) Supplying liquid feed mixture
103
c) Separating liquid feed mixture
106
d) Measuring parameter Ax related to separation performance
Ax<X1 ?
Yes
No
107
Increasing rotational speed
Ax>X2 ?
No
Yes
Do not change rotational speed
Decreasing rotational speed

Fig. 9

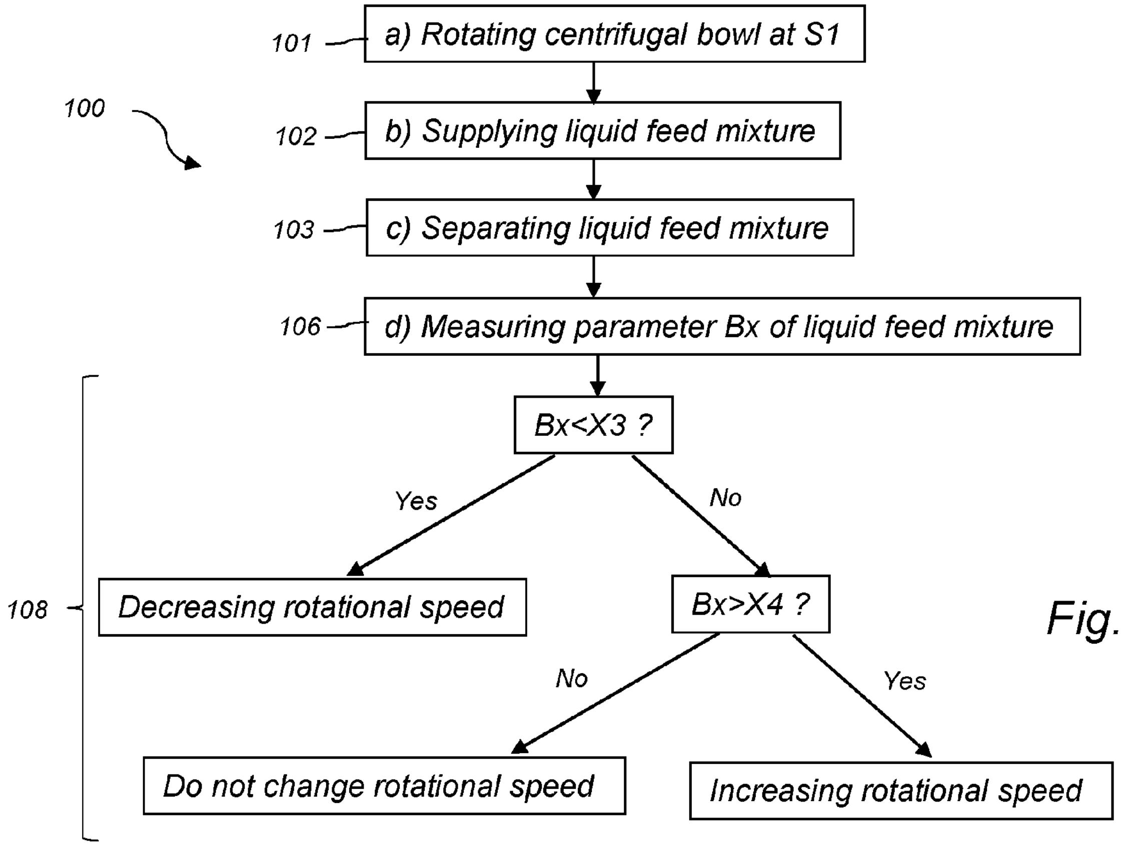

100
101
a) Rotating centrifugal bowl at S1
102
b) Supplying liquid feed mixture
103
c) Separating liquid feed mixture
106
d) Measuring parameter Bx of liquid feed mixture
108
Bx<X3 ?
Yes
No
Decreasing rotational speed
Bx>X4 ?
No
Yes
Do not change rotational speed
Increasing rotational speed

Fig. 10

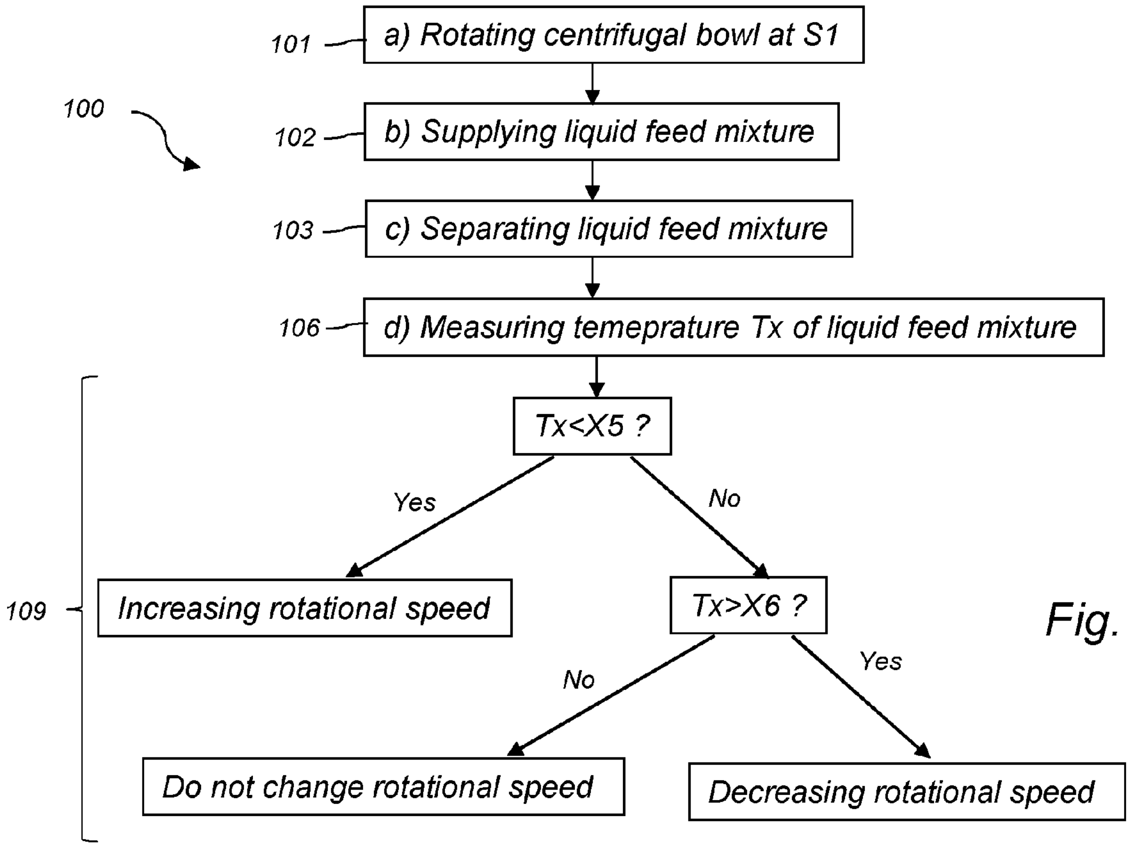

100
101
a) Rotating centrifugal bowl at S1
102
b) Supplying liquid feed mixture
103
c) Separating liquid feed mixture
106
d) Measuring temeprature Tx of liquid feed mixture
109
Tx<X5 ?
Yes
No
Increasing rotational speed
Tx>X6 ?
No
Yes
Do not change rotational speed
Decreasing rotational speed

Fig. 11

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EUROPEAN SEARCH REPORT

Application Number
EP 23 21 6294

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 3 698 877 A1 (ALFA LAVAL CORP AB [SE]) 26 August 2020 (2020-08-26) * paragraphs [0001] - [0008], [0029] - [0032], [0036] - [0082], [0105] - [0107]; figures 1,2 *	1-14	INV. B04B1/14 B04B1/20 B04B11/02 B04B11/04 B04B13/00
X	WO 2022/109612 A1 (LIFE TECHNOLOGIES CORP [US]) 27 May 2022 (2022-05-27) * paragraphs [0302] - [0305], [0335], [0369] - [0372], [0383], [0421] - [0428]; figures 24,26,38 *	7,11-13, 15	B04B1/08 B04B9/10

TECHNICAL FIELDS SEARCHED (IPC)

B04B

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	25 June 2024	Iuliano, Emanuela

CATEGORY OF CITED DOCUMENTS

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EP 23 21 6294

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25-06-2024

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		EP 3698877 A1	26-08-2020
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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- US 11027290 B **[0084]**