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# (54) A NOZZLE FOR A CENTRIFUGAL SEPARATOR AND A CENTRIFUGAL SEPARATOR

(57) The present invention provides nozzle (30) for a sludge outlet (17) of centrifuge bowl (10) of a centrifugal separator (1). The nozzle (30) is comprising a nozzle body (31) adapted to be engaged and releasably positioned in a sludge outlet (17) of said centrifuge bowl (10). The nozzle body (31) comprises an inlet (32) for sludge that is to be ejected from the centrifuge bowl (10), an outlet (33) for ejecting the sludge to the outside of the centrifuge bowl (10) and a fluid channel (34) extending between said inlet (32) and outlet (33). Further, the fluid channel (34) comprises an elbow portion (35) in which the fluid channel (34) changes direction, wherein the elbow portion (35) forms an expanded chamber having a larger inner cross-sectional area (A1) than the inner cross-sectional area (A2, A3) of the portions of the fluid channel (34) adjacent to said elbow portion (35). The present invention also provides a centrifugal separator comprising a nozzle in at least one sludge outlet.

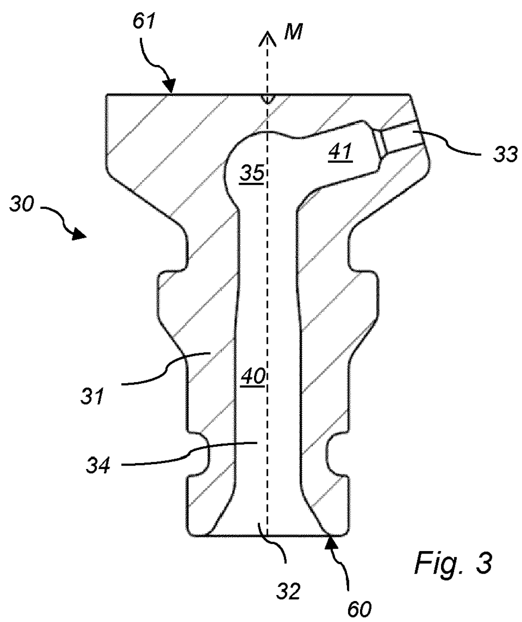


Fig. 3

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## Description

### Field of the Invention

**[0001]** The present invention relates to the field of centrifugal separators, and more precisely to nozzles used in centrifugal separators arranged for continuous discharge of a solids 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 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 one or two liquid outlets arranged at different radii and a sludge outlet arranged at the periphery of the centrifuge bowl. The sludge outlet may take the form of a plurality of permanently open nozzles that allow for continuous discharge of a separated sludge phase.

**[0003]** Nozzle centrifuges are often used when the solids content of the liquid mixture to be separated is high. One such application is the de-sanding bitumen froth recovered from oil sands. During the separation in the centrifugal separator, bitumen accumulate near the center of the rotating bowl, where it can be removed as a liquid light phase. Water and the solids may instead be continuously discharged from the bowl through the plurality of nozzles, which are arranged into outlets formed in the periphery of the centrifuge bowl.

**[0004]** However, the nozzles of the centrifuge are subjected to high wear and abrasion due to the high amount of solids being discharged. Erosion may occur in the channel leading through the nozzle, but also in the nozzle bushing and the centrifuge bowl body.

**[0005]** An example of a nozzle for a centrifugal separator is shown in WO2006029200, which discloses a nozzle having a nozzle body adapted to be releasably positioned in an aperture defined by a centrifuge bowl assembly.

**[0006]** However, there is a need in the art for improved nozzles for centrifugal separators that are more resistant to abrasive wear

### Summary of the Invention

**[0007]** 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 nozzle with improved abrasive wear resistance.

**[0008]** As a first aspect of the invention, there is provided a nozzle for a sludge outlet of centrifuge bowl of a centrifugal separator, said nozzle comprising

a nozzle body adapted to be engaged and releasably positioned in a sludge outlet of said centrifuge bowl, wherein the nozzle body comprises
an inlet for sludge that is to be ejected from the centrifuge bowl;
an outlet for ejecting the sludge to the outside of the centrifuge bowl,
a fluid channel extending between said inlet and outlet,
wherein the fluid channel comprises an elbow portion in which the fluid channel changes direction,
wherein the elbow portion forms an expanded chamber having a larger inner cross-sectional area than the inner cross-sectional area of the portions of the fluid channel adjacent to said elbow portion.

**[0009]** The nozzle is adapted to be arranged in a sludge outlet of a centrifuge bowl, such as in a bushing in a sludge outlet. The centrifuge bowl is a part of a centrifugal separator, such as a separator for separating at least a sludge phase and at least one liquid phase from a liquid feed mixture. The centrifugal separator may be a disc stack centrifugal separator, i.e. comprising a stack of separation discs for increasing the surface area within the centrifuge bowl.

**[0010]** The nozzle body is usually substantially cylindrical along a longitudinal axis. The nozzle body may be mounted and released from the sludge outlet e.g. by means of a mounting tool. The nozzle body also defines an inlet and outlet, and the fluid channel extending therebetween. Thus, sludge that is discharge enters the fluid channel via the inlet and exits the nozzle, and thus the centrifuge bowl, via the outlet. The nozzle body may be made of any suitable material, such as a carbide. As an example, the nozzle body may comprise, or be formed by, tungsten carbide.

**[0011]** The nozzle body may comprise an inner end which faces the inside of the centrifuge bowl when mounted and an outer end facing the outside of the centrifuge bowl when mounted. The fluid channel may thus extend from the inner end to the outlet arranged at or near the outer end. The normal of the outer surface of the outer end may be substantially parallel to the direction of the inlet channel. Further, the Inlet may extend into the outer surface of the inner end.

**[0012]** There is an elbow portion in the fluid channel that forms a bend, or junction, in the fluid channel, i.e. a portion in which the direction of the fluid channel changes.

**[0013]** The nozzle body may comprise a single elbow portion.

**[0014]** Due to the larger inner cross-sectional area of the elbow portion compared to the inner cross-sectional area of the fluid channel that is adjacent to the elbow portion, the elbow portion forms a chamber in the fluid channel. The elbow portion thus forms an expanded portion of the fluid channel.

**[0015]** The inner cross-sectional area may thus be the area of a plane in the flow channel that is perpendicular to the general direction of the fluid flow through the fluid channel.

**[0016]** The first aspect of the invention is based on the insight that having an elbow portion that forms a chamber alters the flow of sludge within the nozzle, which increases the durability and wear resistance of the fluid channel. This may be due to the elbow portion formed as a chamber aids in keeping the particles of the sludge away from the inner walls of the nozzle, thereby decreasing the abrasive erosion of the inner walls.

**[0017]** The elbow portion may thus form a vortex chamber. The vortex chamber may be on the convex side of the bend formed by the elbow portion.

**[0018]** The elbow portion may be designed so as to form a seamless flow path without any sharp turns within the elbow portion. In embodiments, the inner surface of the fluid channel forms bends that are less than 90 degrees. Thus, the elbow portion and fluid channel may be arranged with a smooth inner surface forming no bends that are larger than 90 degrees.

**[0019]** In embodiments of the first aspect, the fluid channel has an inlet passage extending from the inlet to an entrance of the elbow portion and an outlet passage extending from an exit of the elbow portion to the outlet. The inlet passage may extend in a first direction and the outlet passage may extend in a second direction which is different from the first direction.

**[0020]** The elbow portion is connected to the inlet passage via the entrance, and the inlet channel may have a generally circular cross section that then expands into e. g. a non-circular cross-section having an outer side width dimension that is greater than the diameter of the entrance. Thus, the elbow portion may comprise a radially outward side that expands in depth and a radially inward side that maintains a linear relationship with respect to the inlet passage. At the exit, the inner diameter, or inner cross-sectional area, is reduced again to e.g. a generally circular cross-section of the outlet passage.

**[0021]** The inlet passage may have a dovetail cross section, i.e. having a larger cross-section just at the very entrance to the fluid channel. A major portion of the inlet passage may otherwise have a substantially uniform cross-section.

**[0022]** Further, the first direction may be substantially parallel to the longitudinal direction of the nozzle body, and the second direction may thus form an angle with the longitudinal direction of the nozzle body. The inlet and the outlet directions may thus form an angle with each other. The actual outlet of the outlet passage may have a reduced cross-section. Thus, in embodiments, the outlet has the smallest inner cross-sectional area of the fluid channel.

**[0023]** As an example, the angle (a) between the first and second direction may be between 20 and 90 degrees, such as between 40 and 80 degrees. This angle ($\alpha$) is thus the outer angle of the bend formed by the elbow portion, i.e. the complementary angle to the angle enclosed by the inlet and outlet passages. complementary. In other words, an angle ($\alpha$) of zero thus corresponds to no change in direction between the first and second direction

**[0024]** In embodiments of the first aspect, the inlet passage is longer than the outlet passage.

**[0025]** In embodiments of the first aspect, the elbow portion has an inner cross-sectional area that is at least 10 %, such as at least 20 %, such as at least 30%, larger than the inner cross-sectional area of the portions of the fluid channel adjacent to the elbow portion.

**[0026]** In embodiments of the first aspect, the elbow portion forms a rounded chamber. As an example, a major portion of the inner surface of the elbow portion may be rounded. Thus, in embodiments of the first aspect, a major portion of the inner surface of the elbow portion is concave.

**[0027]** The inlet passage and the outlet passage may thus bend at the concave portion. The concave portion may form an extension of the fluid channel and be formed in the direction of the apex between the inlet passage and the outlet passage. In other words, the concave portion may be at the extrados of the bend formed between the inlet passage and the outlet passage.

**[0028]** As an example, the rounded or concave portion may have a spherical form.

**[0029]** Moreover, the inner radius of curvature of the concave portion may be less than two times the inner diameter of the exit or the entrance to the elbow portion.

**[0030]** As an example, the concave portion may be large enough to form at least one quarter sphere on the inner surface of the elbow portion.

**[0031]** In embodiments of the first aspect, the nozzle body has been manufactured by an additive manufacturing method.

**[0032]** In an additive manufacturing method, the material is applied layer by layer to produce a three-dimensional structure. However, also physical or chemical flattening or melting processes may be performed as the nozzle body is being built up.

**[0033]** The additive manufacturing method may for example be a 3D-printing method. The nozzle body may thus be in the form of a single piece.

**[0034]** The inventor has found that it is advantageous to use an additive manufacturing method for manufacturing the nozzle of the first aspect, since it allows for producing a nozzle body with an elbow portion having a smooth and large inner surface, which is very difficult to achieve with conventional production methods. Moreover, the outer geometry of the nozzle may be formed with more degrees of freedom when using an additive manufacturing process as compared to conventional methods when using tools to form the nozzle. Thus, the outer geometry may made be tailor-made to better fit the function and the environment in which the nozzle is to function.

**[0035]** In embodiments of the first aspect, the outlet comprises a reinforcement portion for increasing the hardness of the material of the nozzle at the outlet.

[0036] Thus, the nozzle body may be formed as a single piece with the exception of the reinforcement portion at the outlet. The reinforcement portion may give rise to a smaller inner cross-sectional area at the outlet.

[0037] As an example, the reinforcement portion may comprise aluminium oxide ($AlO_3$).

[0038] The reinforcement portion may be sleeve shaped.

[0039] Further, the reinforcement portion may be attached to the outlet by a method comprising sintering the material, such as $AlO_3$, into the outlet of the nozzle body.

[0040] Sintering may comprise compacting and forming a solid mass of the reinforcement material by heat or pressure without melting it to the point of the material being liquid. The reinforcement portion may be added to the nozzle body by sintering to the "green body" of the nozzle body, so that the nozzle body then shrinks and secures the position of the reinforcement portion during sintering.

[0041] The reinforcement portion may comprise tungsten carbide. As an example, the tungsten carbide of the reinforcement portion may be of a higher degree of purity and may be harder than tungsten carbide used for the nozzle body.

[0042] However, the reinforcement portion may also be attached to the outlet by means of welding or soldering.

[0043] In embodiments of the first aspect, the nozzle body comprises an inner end facing the inside of the centrifuge bowl when mounted and an outer end facing the outside of the centrifuge bowl when mounted, and wherein the outer surface of the outer end comprises a receiving portion for an insertion and extraction tool, wherein said receiving portion extends into the outer surface of the outer end.

[0044] The receiving portion is thus a tool grip portion and may comprise one or several, such as two, cavities into the outer surface of the outer end adapted for receiving a tool used for mounting or dismounting the nozzle from a nozzle bushing in the centrifuge bowl. The tool may be a hand-held tool, such as a hand-held tool having a grip that fits the tool-grip portion.

[0045] The normal to the outer surface of the outer end may be substantially parallel to the direction of the inlet passage of the fluid channel.

[0046] As an example, the receiving portion may be defined solely by cavities into the outer surface of the outer end.

[0047] Thus, with such an arrangement, the tool-grip is completely within the bowl outer diameter. This may will generate less erosion on the centrifuge bowl body and nozzle bushing used for holding the nozzle in the sludge outlet of the centrifuge bowl.

[0048] As a second aspect of the invention, there is provided a centrifugal separator for separating a sludge phase and at least one liquid phase from a liquid feed mixture, said centrifugal separator comprising

a centrifuge bowl arranged for rotation around an axis of rotation (X) and in which said separation takes place, and

a plurality of sludge outlets arranged in the periphery of said centrifuge bowl for continuous discharge of a sludge phase during operation of said separator, and

a nozzle according to the first aspect arranged in at least one of said plurality of sludge outlets.

[0049] The nozzle or nozzles may be arranged in nozzle bushings arranged within the sludge outlet or outlets. As an example, all sludge outlets may comprise a nozzle according to the first aspect.

[0050] 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 potentially also another liquid, from the liquid feed mixture. The centrifugal separator may be used for de-sanding bitumen froth recovered from oil sands.

[0051] The centrifuge rotor forms part of a rotatable part of the separator and encloses a separation space comprising surface enlarging inserts, such as a stack of separation discs, for increasing the separation performance of the centrifugal separator.

[0052] 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) and thus perpendicular to 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". A "radial plane" is a plane extending in the radial direction and having a normal extending in the axial direction. In analogy, an "axial plane" is a plane extending in the axial direction and having a normal extending in the radial direction.

[0053] The centrifugal separator usually comprises a frame, i.e. a non-rotatable part and the rotatable part may be supported by the frame by at least one bearing device. The rotatable part may also comprise a rotatable shaft, i.e. a spindle, and the centrifuge bowl is usually supported by and mounted to rotate with the spindle. The frame may also enclose the centrifuge bowl, thus forming a space in which the centrifuge bowl is arranged.

[0054] The axis of rotation (X) may extend vertically. Consequently, the centrifuge bowl may be arranged such that the centrifuge bowl is supported by the spindle at one of its ends, such at the top end of the spindle.

[0055] The centrifugal separator further comprises a drive member for rotating the rotatable part. The drive member may comprise an electrical motor or be provided beside the spindle and rotate the spindle and centrifuge bowl by a suitable transmission, such as a belt or a gear transmission.

[0056] The separation space within the centrifuge bowl is where the separation between the phases takes place during operation. Surface enlarging inserts are usually arranged in that separation space. Such surface enlarging insert may be a stack of separation discs. The separation discs may 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 to form passages between adjacent separation discs. The interspaces or passages between the discs are provided by distance arranged on the surface of the separation discs. In the formed interspaces, separation takes place during operation.

**[0057]** The centrifugal separator also comprises an inlet for liquid feed mixture to be separated. The liquid feed mixture may be supplied to the inlet via stationary inlet pipe extending into the centrifuge bowl, such as from the top of the centrifuge bowl. Alternatively, the liquid feed mixture may be supplied via a duct in the rotating spindle.

**[0058]** The centrifuge bowl comprises at least one liquid outlet for a separated liquid phase. The plurality of sludge outlets may be equidistantly spaced around the axis of rotation (X).

**[0059]** The centrifugal separator may also be arranged for separating more than one liquid phase from the liquid feed mixture. Therefore, the centrifuge bowl may be provided with a first liquid outlet for a liquid light phase and a second liquid outlet for a liquid heavy phase. The liquid heavy phase has thus a density that is higher than the density of the liquid light phase. The second liquid outlet may therefore be arranged at a larger radial distance then the first liquid outlet.

**[0060]** In embodiments of the second aspect, the nozzle is arranged in the sludge outlet such that it does not protrude from the outer surface of the centrifuge bowl.

**[0061]** As an example, all nozzles of the centrifuge bowl may be arranged such that the do not protrude from the outer surface of the centrifuge bowl.

**[0062]** Thus, the nozzle or nozzles may all be arranged within the bowl outer diameter. By eliminating protruding features of the nozzles, erosion on the nozzle itself and centrifuge bowl body may be reduced.

## Brief description of the Drawings

**[0063]** 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.

Figure 2 shows a schematic drawing of an example of a centrifuge bowl which forms part of a centrifugal separator according to an embodiment of the present invention.

Figure 3 shows a schematic drawing of a cross-section of a nozzle according to an embodiment of the present invention.

Figure 4 shows a cross-section of the elbow portion of a nozzle according to an embodiment of the present invention.

Figure 5 also shows a cross-section of the elbow portion of a nozzle according to an embodiment of the present invention.

Figure 6 shows a schematic drawing of a nozzle with a reinforcement at the outlet according to an embodiment of the present invention.

Figure 7 shows a perspective view of a nozzle according to an embodiment of the present invention.

Figure 8 shows a schematic drawing of a nozzle inserted in the sludge outlet of a centrifuge bowl.

## Detailed Description

**[0064]** The nozzle and the centrifugal separator according to the present disclosure will be further illustrated by the following description with reference to the accompanying drawings.

**[0065]** Figs. 1 and 2 schematically show a centrifugal separator and the centrifuge bowl of the centrifugal separator in which the nozzle according to the present disclosure may be used.

**[0066]** Fig. 1 shows a cross-section of an embodiment of a centrifugal separator 1 configured to separate a sludge phase and a liquid phase from a liquid feed mixture. The centrifugal separator 1 has a rotatable part 8 comprising the centrifuge bowl 10 and drive spindle 4.

**[0067]** The centrifugal separator 1 is further provided with a drive motor 5. This motor 5 may for example comprise a stationary element and a rotatable element, which rotatable element surrounds and is connected to the spindle 4 such that it transmits driving torque to the spindle 4 and hence to the centrifuge bowl 10 during operation. The drive motor 5 may be an electric motor. Alternatively, the drive motor 5 may be connected to the spindle 4 by transmission means such as a drive belt.

**[0068]** The centrifuge bowl 10, shown in more detail in Fig. 2, is supported by the spindle 4, which is rotatably arranged in a stationary frame 2 around a vertical axis of rotation (X) in a bottom bearing 7 and a top bearing 6. The stationary frame 2 surrounds centrifuge bowl 10. Liquid feed mixture to be separated is fed from the top to the centrifuge bowl 10 via a stationary inlet pipe 20 extending into the centrifuge bowl 10.

**[0069]** After separation has taken place within the centrifuge bowl 10, separated liquid phase is discharged through a first liquid outlet 16 to stationary outlet pipe 25 at the top. Separated sludge are continuously discharged via open nozzles 30 arranged in the sludge outlets 17 at the periphery of the centrifuge bowl 10.

**[0070]** Fig. 2. shows a more detailed view of the centrifuge bowl 10 of the centrifugal separator 1.

**[0071]** The stationary inlet pipe 20 extends into the centrifuge bowl 10 axially from the top to a central inlet chamber 11 within the bowl 10. The stationary inlet pipe 20 is thus arranged for supplying the liquid feed mixture to the central inlet chamber 11, which is arranged within the distributor 12. This distributor 12 is designed to accelerate and guide the liquid feed mixture from the central inlet chamber 11, via channels 18 to the separation space 13, in which a stack 15 of separation discs is arranged.

**[0072]** The separation discs of stack 15 is arranged coaxially around the axis of rotation (X) and thus arranged to rotate together with the centrifuge bowl 10. The stack 15 is supported at its axially lowermost portion by the distributor 12. The separation discs of the disc stack 15 are frustoconical and extend outwardly and downwardly from the distributor 12. It should be noted that the separation discs also could extend outwardly and upwardly, or be formed as axial sheets, such as axial sheets having a curved cross-section in a radial plane.

**[0073]** The separation discs of the stack 20 are provided at a distance from each other by means of distance members (not disclosed) in order to form interspaces between adjacent separation discs, i.e. an interspace between each pair of adjacent separation discs. The stack 15 of separation discs therefore provide for an efficient separation of the liquid mixture into at least a liquid phase and a solids phase. Depending on the feed mixture, also a liquid heavy phase may be separated between the separation discs in the disc stack 15. For clarity, only a few separation discs are shown in Fig. 2. The disc stack could comprise at least 50, such as at least 100, separation discs.

**[0074]** A first liquid outlet 16 in the form of a paring disc is arranged at the top of the centrifuge bowl 10. Separated liquid phase that has passed radially inwards through the disc stack is thus guide out via paring disc 16 to the stationary outlet pipe 25 .

**[0075]** The centrifugal separator 1 further comprises a plurality of sludge outlets 17 arranged in the periphery of said centrifuge bowl 10 for continuous discharge of a sludge phase during operation. A nozzle 30 of the present disclosure is arranged in each of the plurality of sludge outlets 17. The nozzles 30 are evenly distributed around the rotational axis (X) and each nozzle 30 has a fluid channel via which liquid and finely divided solids accumulated in the sludge space 14 are continuously ejected from the separating space 13 during operation. The nozzles will be further explained in relation to Figs. 3-8 below.

**[0076]** During operation of the separator as shown in Fig. 1 and 2, the centrifuge bowl 10 is brought into rotation by the drive motor 5. Via the stationary inlet pipe 20, liquid feed mixture to be separated is brought into the central inlet chamber 11 and further guided in channels 18 the annular separation chamber 13. Depending on the density, different phases in the liquid feed mixture is separated between the separation discs of the stack 15. Heavier component, such as a sludge phase, move radially outwards between the separation discs to the radially outer sludge space 14. Separated liquid phase moves radially inwards between the separation discs and is forced through the liquid light phase outlet 16 to the stationary outlet pipe 25. Solids, or sludge, that accumulate at the periphery of the centrifuge bowl, i.e. in the sludge space 14, is continuously ejected from the nozzles 30 by means of centrifugal force.

**[0077]** Fig. 3 schematically shows the cross-section of a nozzle 30 used in the sludge outlets 17 of the centrifugal separator. The nozzle 30 comprises a nozzle body 31, which is elongated along axis M from an inner end 60 to an outer end 61. When mounted in the sludge outlet 17, the inner end 60 is facing the inside of the centrifuge bowl 10 whereas the outer end 61 is facing the outside of the centrifuge bowl 30, and the nozzle 30 is oriented so that the elongation direction M is in the radial direction of the centrifuge bowl 10.

**[0078]** The nozzle body further comprises an inlet 32 for sludge that is to be ejected from the centrifuge bowl 10, which is in fluid communication with an outlet 33 for ejecting the sludge to the outside of the centrifuge bowl 10. Thus, the nozzle body 30 further comprises a fluid channel 34 extending between the inlet 32 and the outlet 33. The fluid channel 34 forms an inlet passage 40 that extends substantially parallel to the elongation direction M of the nozzle body to an elbow portion 35 in which the fluid channel 34 changes direction to an outlet passage 41 extending from the elbow portion 35 to the outlet 33.

**[0079]** As seen in Fig. 3, the inlet passage 40 is longer than the outlet passage 41, and the outlet 33 at the end of the outlet passage 41 is arranged in a direction so that sludge exiting the outlet is directed with an angle to the radial direction of the centrifuge bowl. The outlet 33 has further the smallest inner cross-sectional area of the fluid channel 34.

**[0080]** The elbow portion 35 forms an expanded chamber having a larger inner cross-sectional area A1 than the inner cross-sectional area A2, A3 of the portions of the fluid channel 34 adjacent to said elbow portion 35. This is illustrated in more detail in Fig. 4. Thus, the inner cross-sectional area A1 within the elbow portion is larger than the inner cross-sectional area A2 at the entrance 51 to the elbow portion 35 and larger than the inner cross-sectional area A3 at the exit 52 of the elbow portion 35.

**[0081]** As seen in Fig. 4, the elbow portion 35 makes the fluid channel 34 expand in volume and has further a rounded inner surface that forms a concave portion 54 on the radially outer side. This concave portion 54 is large enough to form half a sphere on the inner surface of the elbow portion 35. Thus, the elbow portion 35 comprises a concave portion 54 on the radially outer side that expands in depth and a radially inward side 72 that maintains more or less a linear relationship with respect to the inlet passage 40 and the outlet passage 41.

**[0082]** Moreover, as illustrated in Fig. 5, the inlet passage 40 extends in a first direction Z1 and the outlet passage 41 extends in a second direction Z2 which is thus different from the first direction Z1 due to the bend of the elbow portion. The angle $\alpha$ of the change of direction may be between 45 and 80 degrees.

**[0083]** The nozzle body 31 may be formed by an additive manufacturing method, such as 3D-printing, of e. g. tungsten carbide (WC). The additive manufacturing method may be a binder jetting method, in which granules of tungsten carbide are formed together layer-by-layer.

**[0084]** Additive manufacturing makes it possible to form a large elbow portion with a smoothly rounded inner surface, which is not possible, or very difficult, to perform with previously used manufacturing techniques involving casting.

**[0085]** Fig. 6 shows an embodiment of a nozzle 30, such as the nozzle 30 of Figs 3-5, in which a reinforcement portion 55 has been added to the nozzle body just at the outlet. The reinforcement portion 55 increases the hardness of the nozzle body 31 at the outlet and thus increases the wear resistance at the outlet and the lifetime of the nozzle 30. This reinforcement portion 55 may be of aluminium oxide ($AlO_3$) and may be sintered into the outlet 33 after production of the nozzle body 31, such as after manufacturing the nozzle body 31 by means of additive manufacturing. As an alternative, the reinforcement portion may be glued into the outlet 33.

**[0086]** The reinforcement portion 55 has in this example the form of a sleeve. This sleeve could be pyramidical with its point directed against the outlet 33 to decrease the risk of the reinforcement portion being shifted in position during operation, i.e. when sludge is discharged through the nozzle 30.

**[0087]** The nozzle body 31, and thus the whole nozzle 30, is adapted to be engaged and releasably positioned in a sludge outlet 17 of the centrifuge bowl 10. This may be performed by using a tool that is fastened to the nozzle body 31. The means for doing this is illustrated in the perspective view of Fig. 7. As previously mentioned, the nozzle body 31 comprises an inner end 60 facing the inside of the centrifuge bowl 10 when mounted and an outer end 61 facing the outside of the centrifuge bowl 10 when mounted. The outer surface 62 of the outer end 61 comprises a receiving portion 70 for an insertion and extraction tool. This receiving portion 70 takes the form of two cavities that extend into the outer surface 62 of the outer side 61 of the nozzle body 31. Also seen in Fig. 7 are fastening means 71 in the form of protrusions that are used to engage with a nozzle bushing 80 in the sludge outlet 17 to secure the position of the nozzle 30 in the outlet 17.

**[0088]** Fig. 8 schematically shows the nozzle 30 of Fig. 7 mounted in a sludge outlet 17 of a centrifuge bowl 10. Since the receiving portion 70 for the insertion and extraction tool is defined solely by cavities into the outer surface 62 of the outer end 61, the nozzle 30 has no portions extending outside of the outer radius R of the centrifuge bowl 10 when mounted. Thus, the nozzle 30 is arranged in the sludge outlet 17 such that it does not protrude from the outer surface of the centrifuge bowl 10, i.e. the outer surface 62 of the outer end 61 is substantially in line with the outer radius R of the centrifuge bowl 10. This further reduces the erosion of the centrifuge bowl 10 during separation and discharge of the sludge phase through the nozzle 30.

**[0089]** As seen in Fig. 8, the nozzle 30 is oriented in the centrifuge bowl 10 so that the outlet 33 directs the flow of sludge at an angle with the radial direction. Therefore, also a recess 81 is provided in the outer surface of the centrifuge bowl 10 adjacent to each of the sludge outlets 17.

**[0090]** 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 nozzle (30) for a sludge outlet (17) of centrifuge bowl (10) of a centrifugal separator (1), said nozzle (30) comprising

   a nozzle body (31) adapted to be engaged and releasably positioned in a sludge outlet (17) of said centrifuge bowl (10), wherein the nozzle body (31) comprises
   an inlet (32) for sludge that is to be ejected from the centrifuge bowl (10)
   an outlet (33) for ejecting the sludge to the outside of the centrifuge bowl (10),
   a fluid channel (34) extending between said inlet (32) and outlet (33),
   wherein the fluid channel (34) comprises an elbow portion (35) in which the fluid channel (34) changes direction,
   wherein the elbow portion (35) forms an expanded chamber having a larger inner cross-sectional area (A1) than the inner cross-sectional area (A2, A3) of the portions of the fluid channel (34) adjacent to said elbow portion (35).

2. A nozzle (30) according to claim 1, wherein the fluid channel (34) has an inlet passage (40) extending from the inlet (32) to an entrance (51) of the elbow portion (35) and an outlet passage (41) extending from an exit (52) of the elbow portion (35) to the outlet (33), and wherein the inlet passage (40) extends in a first direction (Z1) and the outlet passage (41) ex-

tends in a second direction (Z2), different from said first direction (Z1).

3. A nozzle (30) according to claim 2, wherein the angle ($\alpha$) between the first (Z1) and second direction (Z2) is between 20 and 90 degrees.

4. A nozzle (30) according to claim 2 or 3, wherein the inlet passage (40) is longer than the outlet passage (41)

5. A nozzle (30) according to any previous claim, wherein the outlet (33) has the smallest inner cross-sectional area of the fluid channel (34).

6. A nozzle (30) according to any previous claim, wherein the elbow portion (35) has an inner cross-sectional area (A1) that is at least 10 %, such as at least 20 %, larger than the inner cross-sectional area (A2, A3) of the portions of the fluid channel (34) adjacent to said elbow portion (35).

7. A nozzle (30) according to any previous claim, wherein a major portion (54) of the inner surface of the elbow portion (35) is concave.

8. A nozzle (30) according to claim 7, wherein the concave portion (54) is large enough to form at least one quarter sphere on the inner surface of the elbow portion (35).

9. A nozzle (30) according to any previous claim, wherein the nozzle body (31) has been manufactured by an additive manufacturing method.

10. A nozzle (30) according to any previous claim, wherein the outlet (33) comprises a reinforcement portion (55) for increasing the hardness of the material of the nozzle (30) at the outlet.

11. A nozzle (30) according to claim 10, wherein the reinforcement portion (55) comprise aluminium oxide ($AlO_3$).

12. A nozzle (30) according to any previous claim, wherein the nozzle body (31) comprises an inner end (60) facing the inside of the centrifuge bowl (10) when mounted and an outer end (61) facing the outside of the centrifuge bowl (10) when mounted, and wherein the outer surface (62) of the outer end (61) comprises a receiving portion (70) for an insertion and extraction tool, wherein said receiving portion (70) extends into the outer surface (62) of the outer end (61).

13. A nozzle (30) according to claim 12, wherein the receiving portion (70) is defined solely by cavities into the outer surface (62) of the outer end (61).

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

a centrifuge bowl (10) arranged for rotation around an axis of rotation (X) and in which said separation takes place, and
a plurality of sludge outlets (17) arranged in the periphery of said centrifuge bowl (10) for continuous discharge of a sludge phase during operation of said separator, and
a nozzle (30) according to any one of claims 1-13 arranged in at least one of said plurality of sludge outlets (17).

15. A centrifugal separator (1) according to claim 14, wherein the nozzle (30) is arranged in the sludge outlet (17) such that it does not protrude from the outer surface of the centrifuge bowl (10).

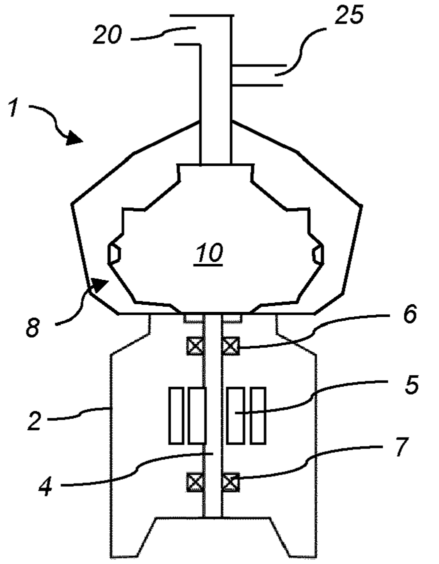


Fig. 1

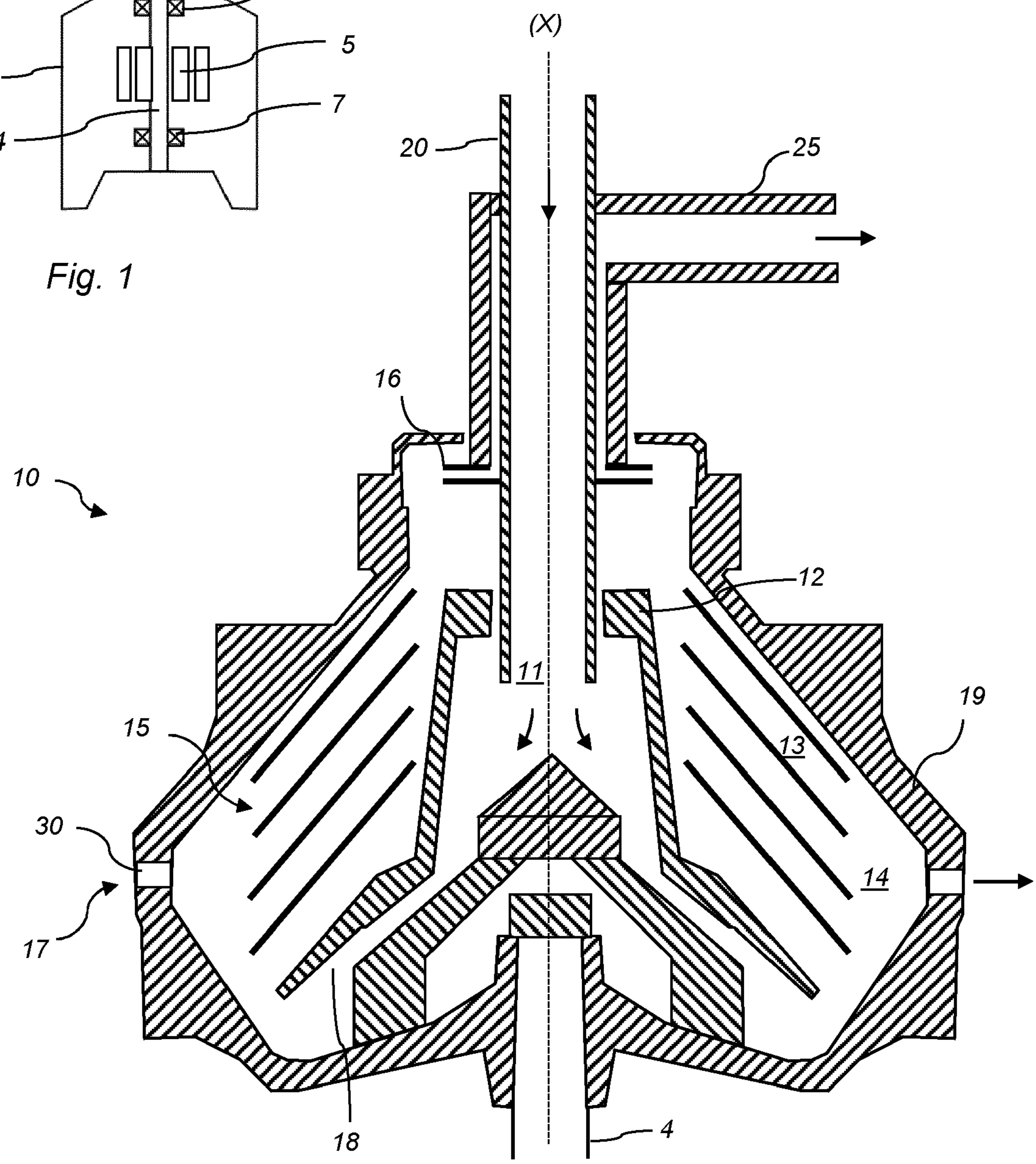


Fig. 2

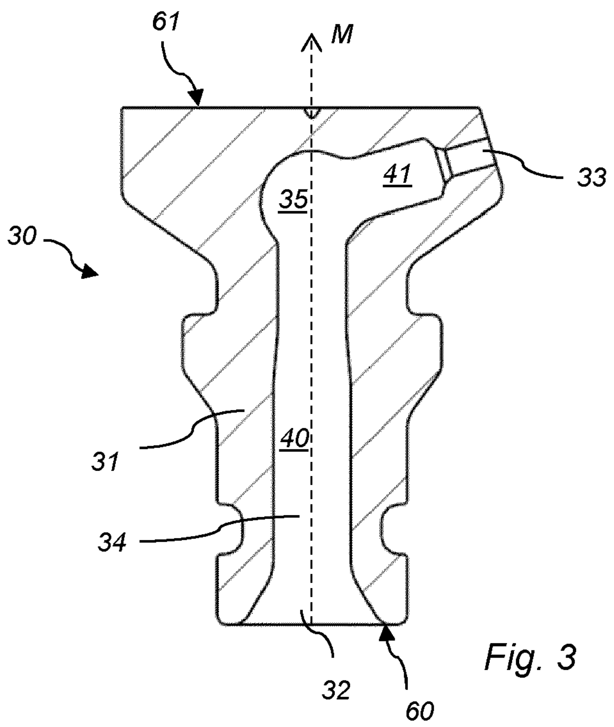


Fig. 3

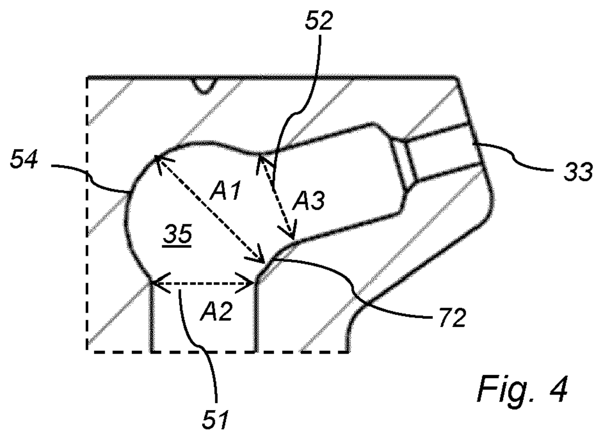


Fig. 4

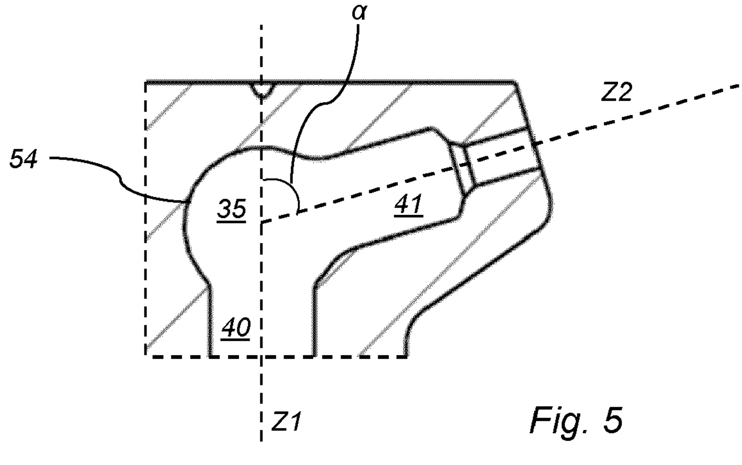


Fig. 5

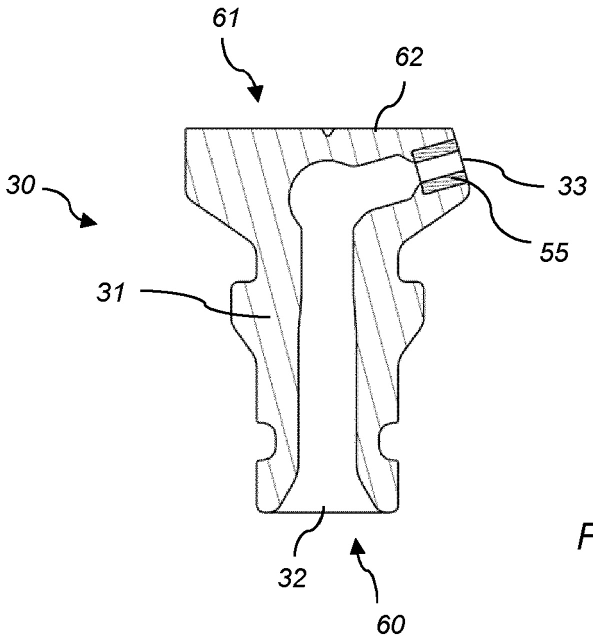


Fig. 6

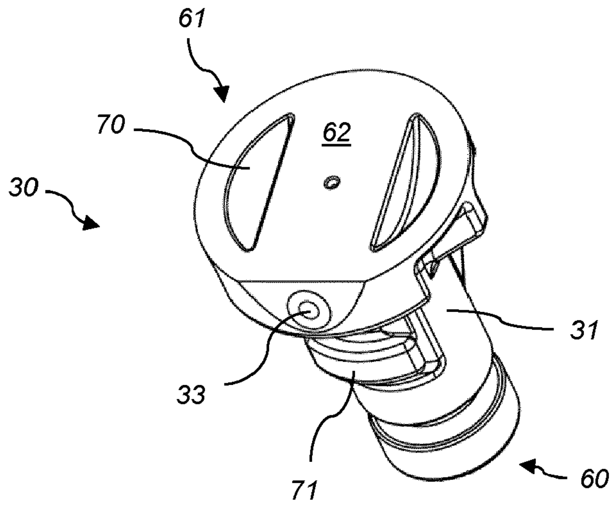


Fig. 7

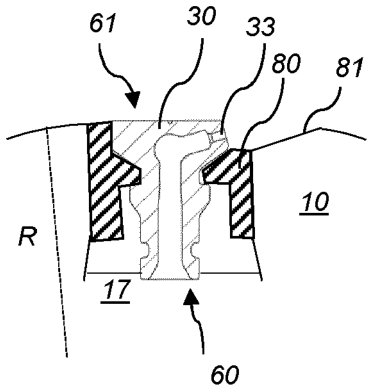


Fig. 8

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Application Number
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