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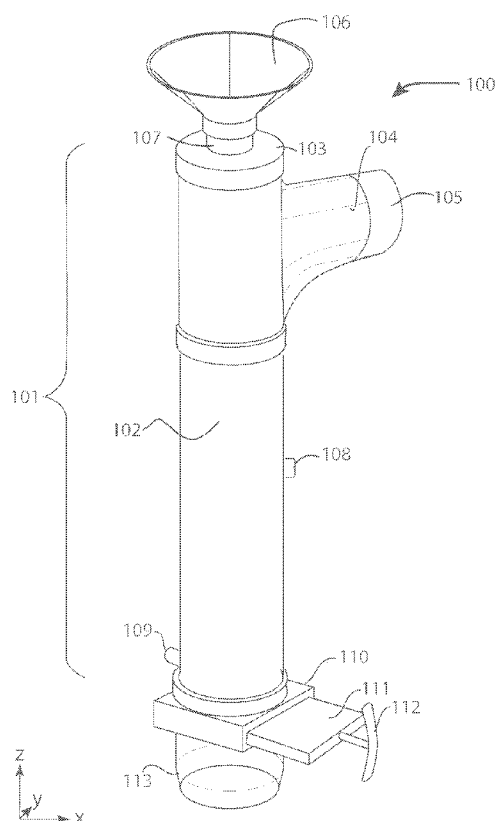


Fig. 1

(57) **Abrégé/Abstract:**

A compact hydraulic particle separator apparatus is disclosed. The disclosed apparatus comprises an upper chamber and a lower chamber separated by a partition. A liquid fluid flow upwelling through the partition from the lower chamber is caused to mix with



(57) **Abrégé(suite)/Abstract(continued):**

tangential jet of fluid flowing introduced above the partition in the upper chamber produces an upwardly-flowing cyclonic flow within the upper chamber. Particle mixtures containing low- and high-density particles and other solids are introduced into the upper chamber through a feed tube having a mouth that is offset from the center of the upper chamber. Low-density particles are immediately entrained in the cyclonic flow and swept upward and exit the apparatus.

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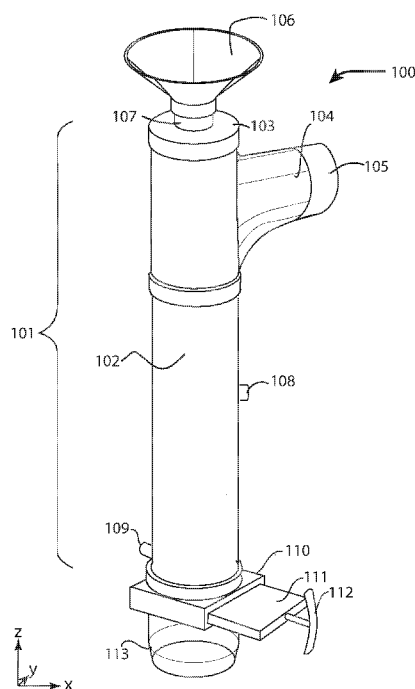


Fig. 1

(57) Abstract: A compact hydraulic particle separator apparatus is disclosed. The disclosed apparatus comprises an upper chamber and a lower chamber separated by a partition. A liquid fluid flow upwelling through the partition from the lower chamber is caused to mix with tangential jet of fluid flowing introduced above the partition in the upper chamber produces an upwardly-flowing cyclonic flow within the upper chamber. Particle mixtures containing low- and high-density particles and other solids are introduced into the upper chamber through a feed tube having a mouth that is offset from the center of the upper chamber. Low-density particles are immediately entrained in the cyclonic flow and swept upward and exit the apparatus.

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PARTICLE SEPARATION APPARATUS

BACKGROUND

[0001] Alluvial or placer gold prospecting and mining conventional methods include panning, sluice box and more recently, suction dredging of placer deposits found in stream beds, creek beds and riverbeds. The latter method has become popular among recreational as well as professional placer gold mining and prospecting enthusiasts. The method involves suction to pull silt material from the benthic zones of streams, creeks and river bottoms into a suction hose via a pumping means, and onto a sluice box for separation of silt components by specific gravity or density. As an example, a typical suction dredging apparatus used for placer gold mining comprises a pump, which is often disposed on floating platform or raft. The bottom material comprises a fine silt composed primarily of silica sand and other finely divided minerals. Stones and pebbles of various sizes are also present. A suction hose is used to aspirate, or “vacuum” the bottom silt and small pebbles to a gold recovery system, such as a portable sluice box, may also be mounted on the same floating platform. In some configurations, the sluice box is assembled on the bank of the river, creek or stream, and is built as a permanent or semi-permanent structure on the shore.

[0002] In portable suction dredging operations, the sluice box has a short run, and may not be efficient. Siltification takes place as the silt effluent of the sluice box drops back into the water. This, in addition to the disruption of benthic and riparian habitat, current suction dredging practice creates serious environmental destruction for fish and other aquatic wildlife. Siltification causes increased turbidity, as well as release of toxic metals such as mercury into the water column. The state of California has already banned suction dredging in most streams and creeks to protect endangered aquatic species as well as cultural resources. While current suction dredging practices are damaging to the environment, improvements can be made by introduction of equipment of improved design and function to avoid many of the issues that threaten the continuation of the practice. In particular, significant reduction of siltification and bottom disruption is needed.

[0003] Panning is an ancient and popular form of batch prospecting of placer deposits for gold and precious stones and minerals. In contrast to suction dredging, it requires only a pan

designed for the purpose. As an entirely manual prospecting technique, it is a slow and low yield process.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] **Fig. 1** illustrates an oblique exterior view of a particle separator apparatus, according to some embodiments of the disclosure.

[0005] **Fig. 2** illustrates an oblique cutaway view of the separation apparatus shown in **Fig. 1**, showing details of the interior chambers, according to some embodiments of the disclosure.

[0006] **Fig. 3** illustrates an oblique cutaway view of a separator apparatus, showing interior details, according to some embodiments of the disclosure.

[0007] **Fig. 4** illustrates an oblique magnified cutaway view in the x-z plane of the separator apparatus shown in **Fig. 2**, showing interior details, according to some embodiments of the disclosure.

[0008] **Fig. 5** illustrates a cross-sectional view in the x-y plane of an upper chamber of the separation apparatus shown in **Fig. 1** or **Fig. 2**, according to some embodiments of the disclosure.

[0009] **Fig. 6** illustrates an oblique cutaway view of the separator apparatus shown in **Fig. 1**, showing interior details of upper chamber 201, according to some embodiments of the disclosure.

[0010] **Fig. 7** illustrates an oblique exploded view of a bottom portion of the separation apparatus shown in **Fig. 1** or **Fig. 2**, according to some embodiments of the disclosure.

[0011] **Figs. 8a** and **8b** illustrate a profile view in the x-z plane of a collection vessel, according to some embodiments of the disclosure.

[0012] **Fig. 9** illustrates a first exemplary system comprising the particle separation apparatus shown in **Fig. 1** or **Fig. 2**, according to some embodiments of the disclosure.

[0013] **Fig. 10** illustrates a second exemplary system comprising particle separation apparatus shown in **Fig. 1** or **Fig. 2**, according to some embodiments of the disclosure.

DETAILED DESCRIPTION

[0014] Described herein is a hydraulic gravity particle separation apparatus for highly efficient hydraulic force field separations of high-density particulates from lower density particulates in solids-liquid suspensions, to enhance placer deposit mining or general separation of particles by specific gravity differences. Placer deposit particulates that have high specific gravity, henceforth referred to as high-density particles, may comprise precious metals such as gold, lead, silver, copper brass, hafnium and mercury. Lower density particulates may comprise silica, gravel, magnetite sand, clays, organic matter, and other mineral particles that are found in placer deposits, riparian stream beds and ocean sediments.

[0015] By way of example, the density of gold is 19 g/cm^3 , comprise the highest density (specific gravity) particulates; lead, 11 g/cm^3 , silver, 10.4 g/cm^3 , copper, 10 g/cm^3 , mercury 13.5 g/cm^3 , and hafnium 13.3 g/cm^3 , comprise medium-density particulates. The density of silica may range from $2.2\text{-}2.7 \text{ g/cm}^3$, being a component of the lowest-density particulates. Alumina has a density of approximately 4 g/cm^3 . Riverbottom silt, for example, has a composition made up primarily of quartz and feldspar (source of alumina and aluminosilicate AlSi_3O_8) as the main mineral composition of the silt particulate matter. Clays and organic matter are also included in more minor abundances. Both main minerals have a density between 2.2 and 2.7 g/cm^3 . Silica derived from quartz is the most abundant mineral found in riverbottom silt composition. In traditional methods of placer deposit prospecting, such as sluice box classifying and panning, gold particles are commonly mixed with black sand, comprising primarily magnetite. This mineral has a density of approximately 5 g/cm^3 .

[0016] The apparatus described in this disclosure affords high-efficiency particulate separations in a compact volume. By high efficiency, it is meant that the separation occurs within seconds with minimal use of resources. Some embodiments include a substantially upright tubular body, having a substantially circular cross section and tubular wall surrounding an interior chamber. In alternate embodiments, the cross section of the body may be non-circular. In other embodiments, the apparatus body cross section may have other suitable shapes. A partition within the body separates the interior chamber into an upper chamber and a lower chamber. In some embodiments, the partition comprises a funnel-shaped surface having at least one orifice, from which a downspout extends into the lower chamber. In some embodiments, a raw material feed tube extends through the upper chamber to the level of the partition from a slurry inlet at or near the top of the upper chamber.

[0017] In some embodiments, the raw material feed tube, (henceforth referred to as the feed tube), descends diagonally from a slurry inlet positioned substantially at the center of the top of the upper chamber, terminating near the wall just above the partition. The feed tube may extend from a raw material feed inlet at the top of the apparatus. In some embodiments, the raw material feed inlet is an opening at the top of the apparatus body that is symmetric about the central axis of the apparatus body. In some embodiments, the raw material feed inlet is an opening in the top of the apparatus body that is coupled to any one of an externally-mounted hopper, a pan or an auger, to name a few apparatuses to facilitate the introduction of raw material into the apparatus.

[0018] In some embodiments, the feed tube comprises two or more vertical portions that are laterally offset from one another. Adjacent offset vertical portions are interconnected by a bend, where a bend being defined as a diagonally extending portion in the feed tube interconnecting two offset vertical portions. In some embodiments, the feed tube comprises a first portion of the feed tube extends substantially vertically (e.g., parallel to the chamber wall) through the center of the upper chamber, whereby the feed tube central axis and the upper chamber central axis are substantially coincident. The feed tube then bends toward the chamber wall, deviating off-axis to a second portion of the feed tube is laterally offset from the first portion. The second portion is proximal to the wall. The second portion extends substantially vertically, terminating above the partition. In some embodiments, the entirety of the feed tube extends substantially vertically and off center (e.g., the axis of the feed tube is offset from the central axis of the upper chamber).

[0019] During an exemplary operation of the apparatus, at least two streams of water or other suitable separation fluids may be introduced the apparatus, one fluid stream introduced into the upper chamber above the partition, and one fluid stream introduced into the lower chamber below the partition. Both fluids may be introduced through inlets above and below the partition, respectively. In some embodiments, a tangential flow is introduced in a region of the upper chamber close to the partition through a first inlet, and a non-tangential flow may be introduced into the lower chamber through a second inlet.

[0020] Continuing with the example, a clean separation fluid (e.g., water) is introduced in both chambers of the apparatus as described above, filling both chambers with flowing liquid that exits the apparatus through an outlet near the top of the upper chamber. Within the upper

chamber, the first inlet is oriented tangentially to the wall of the chamber. Separation fluid (e.g., water) introduced tangentially into the upper chamber may initially flow in a circular path following the contour of the wall of the chamber. The tangential stream may spiral inwardly, causing a circular flow pattern of the fluid occupying the upper chamber to be established. A second flow of fluid may be introduced tangentially or non-tangentially into the lower chamber through a second inlet. The second flow may initially fill the lower chamber, then rise upwards through the downspout into the upper chamber. The flow entering the upper chamber from the lower chamber may be laminar. Upward-flowing clean fluid from the lower chamber may encounter and mix with the clean tangential flow in the upper chamber, establishing an upwardly-spiraling flow toward the top of the upper chamber, exiting the apparatus through an outlet.

[0021] Once a steady state flow may be established within the apparatus, a raw slurry comprising placer silt may be introduced into upper chamber through the raw material feed tube. In some embodiments, the outlet (e.g., mouth) of the feed tube is laterally offset from the central axis of the upper chamber. In some embodiments, the vertical position of the mouth of the feed tube is proximal to the partition. Tangential flow introduced by the first fluid flow inlet may intersect the mouth of the feed tube. During operation of the disclosed particle separation apparatus, a stream of raw silt slurry may enter the upper chamber near the wall of the chamber, encountering the upward spiral flow near the wall. Initially, all silt particles may be entrained in a three-dimensional flow comprising radial flow toward the center of the upper chamber, tangential flow along a spiral path, and vertical flow toward the top of the upper chamber.

[0022] Centrifugal force may drive all particles entrained in the spiral flow toward the wall of the upper chamber. Low density and light weight particles may be swept inwardly and upwardly by the entrainment, flowing out of the apparatus with the exiting flow. Heavier particles entrained near the wall may sink toward the partition by gravity into the partition.

[0023] The higher-density and heavy particles may separate from the lower density particles by gravity. Higher-density and heavy particles may encounter the partition as they sink. In some embodiments, the partition is conical with an apex extending into the lower chamber. In some embodiments, the conical partition may have a tapered or sloping bottom portion with an apex opening to a central orifice. In some embodiments, a tubular downspout extends downward from the central orifice and into the lower chamber. In some embodiments, the downspout

extends coaxially within the lower chamber. By the term “coaxial”, it is understood that the axis extending through the apex of the conical partition is coincident with the central axis of the upper chamber. In alternate embodiments, the downspout does not extend coaxially within the upper chamber of the separator, and may extend diagonally in some embodiments, or have laterally offset sections that deviate toward the sidewall of the upper chamber. The diameter of the downspout may be significantly smaller than the diameter of the upper and lower chambers. High-density and heavy particles may continue to gravitationally separate from the lower-density and lighter particles by falling through the partition into the lower chamber through the downspout.

[0024] In alternate embodiments, the partition may be substantially flat or have a slope, either symmetrically arranged about the central axis, or arranged asymmetrically with respect to the central axis. In some embodiments, the partition is a flat disc that separates the upper and lower chambers. A flat partition may be a plate or mesh tilted in one direction so that collected high-density particles may slide towards an orifice. In some embodiments, the orifice is at the bottom of the slope adjacent to the sidewall of the upper chamber.

[0025] Cyclonic flow patterns may be established within the upper chamber by the introduction of flow streams as described above. Adjacent to the sidewall, flow velocities may be low relative to flow velocities further from the sidewall. Particles flowing out of the feed tube outlet into the upper chamber adjacent to the sidewall (e.g., the outlet of the feed tube is adjacent to the sidewall) may be entrained by the slower-moving spiral flow along the sidewall. High-density and heavy particles comprising small gold nuggets, gold flakes, mercury, lead, etc., may be entrained in the slower moving flow along the sidewall. The heaviest particles may fall more readily into the partition than lighter particles entrained in faster moving flow further toward the central axis of the upper chamber.

[0026] High density particles entrained in faster cyclonic flow further from the sidewall may be projected to the sidewall by centrifugal force. The high-density particles entering the slower cyclonic flow may also drop out by gravity. These particles may also fall into the partition and continue to fall into the lower chamber through the downspout. During operation of the separation apparatus, a secondary flow of separation fluid (e.g., water) is introduced into the lower chamber through a second inlet opening into the lower chamber. The rate of the secondary flow may be regulated to enable flow from the lower chamber to the upper chamber through the

partition. As an example, the flow rate of the secondary flow may be regulated to carry upwards any lower-density particles that may have escaped the cyclonic flow in the upper chamber and fall into the downspout. Such particles may be reintroduced into the upward spiraling cyclonic flow to carry away these particles towards the outlet of the separation apparatus.

[0027] In some embodiments, a collection vessel is coupled to the separator apparatus below the lower chamber at the bottom of the separator main body for collecting the newly separated high-density particulates. In some embodiments, the collection vessel is coupled to the sidewall of the separator main body. The collection vessel may be detached from the separator apparatus and emptied by decantation or suction through an attached hose or tube.

[0028] In some embodiments, a hopper is attached to a coupling opening into the upper chamber through a top wall over the upper chamber. During operation of the apparatus, the hopper may receive untreated silt either dug, dredged or otherwise gathered from a placer deposit. The raw silt may be dry silt or naturally wet or mixed with water to form a slurry. The raw placer silt may then be fed into the hopper manually or by automated mechanism, such as, but not limited to, an auger or dredge. In some embodiments, the hopper is a pan having a tapered or sloping bottom that converges at an orifice from which an extension tube opens into the upper chamber. In some embodiments, the feed tube is coupled to the hopper through the extension tube. For example, the hopper may comprise a simple conical pan that is manually fed or fed by conveyer from a dredging apparatus. In other embodiments, the hopper may comprise mechanical fittings such as an auger to facilitate dislodgement of the charged material into the upper chamber. In other embodiments, the hopper may comprise a flat pan or box. In some embodiments, the hopper may include a water flow pipe or tubing for adding to slurry formation of relatively dry silt.

[0029] In this disclosure, the vertical orientation is in the z-direction and it is understood that recitations of "top", "bottom", "above" and "below" refer to relative positions in the z-dimension with the usual meaning. However, it is understood that embodiments are not necessarily limited to the orientations or configurations illustrated in the figure.

[0030] The terms "substantially," "close," "approximately," "near," and "about," generally refer to being within +/- 10% of a target value (unless specifically specified). Unless otherwise specified, the use of the ordinal adjectives "first," "second," and "third," etc., to describe a common object, merely indicate that different instances of like objects are being

referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking or in any other manner.

[0031] For the purposes of the present disclosure, phrases “A and/or B” and “A or B” mean (A), (B), or (A and B). For the purposes of the present disclosure, the phrase “A, B, and/or C” means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C).

[0032] Views labeled “cross-sectional”, “profile”, “plan”, “oblique” and “isometric” correspond to orthogonal planes within a cartesian coordinate system. Thus, cross-sectional and profile views are taken in the x-z plane, plan views are taken in the x-y plane, oblique and isometric views are taken in a 3-dimensional cartesian coordinate system (x-y-z). Where appropriate, drawings are labeled with axes to indicate the orientation of the figure.

[0033] **Fig. 1** illustrates an exterior oblique view of particle separator apparatus 100, according to some embodiments of the disclosure. In the illustrated embodiment, separator body 101 comprises a substantially tubular body, comprising sidewall 102 extending vertically downward (e.g., in the negative z-direction) from top wall 103. Sidewall 102 and top wall 103 comprise one or more metal or nonmetal structural materials, such as, but not limited to, steel alloys, aluminum and alloys of aluminum, brass, copper, titanium, or alloys of the aforementioned metals. Non-metal materials include, but are not limited to, organic polymers such as polymethyl methacrylate (PMMA, Plexiglas), polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polyimides (e.g., polyetherimide, Ultem), and inorganic materials such as silicate glasses.

[0034] The diameter of separator body 101 may range between approximately 10 cm (approximately 4 inches) to over 30 cm (approximately 12 inches or more), depending on the volume of silt to be processed. Separator body 101 may have a length ranging from approximately 60 cm (approximately 24 inches) to over 180 cm (approximately 72 inches or more).

[0035] In some embodiments, top wall 103 is part of an endcap that is integrally bonded to sidewall 102. As an example, top wall 103 is part of a metal endcap that is welded to sidewall 102. In some embodiments, top wall 103 is bonded by an adhesive to sidewall 102. In some embodiments, top wall 103 is removable from sidewall 102. For example, top wall 103 may be an endcap comprising threads that mate with complementary threads on sidewall 102, allowing removal of top wall 103. While separator body 101 is substantially tubular (e.g., cylindrical) as

shown in the illustrated embodiment, other suitable cross-sectional shapes are possible. In the illustrated embodiment, sidewall 102 is a tubular shell enclosing interior chambers, described below (**Fig. 2**). While separator body 101 is shown in the illustrated embodiment as having a tubular shape, other suitable longitudinal and cross-sectional shapes are also possible. As an example, separator body 101 may have a non-tubular form factor, such as, but not limited to, a conical form factor or an hourglass form factor (e.g., having a conical upper chamber and a conical lower chamber meet at a constriction near the middle). Separator body 101 may have an elliptical or ovoid cross section.

[0036] Flow outlet 104 extends laterally from sidewall 102 near the top of separator body 101 (e.g., near top wall 103). Flow outlet 104 may have a mouth 105 for connection of a threaded hose or tubing coupling. Mouth 105 may comprise threads to screw on fittings, or may comprise a slip-on receptacle to receive a quick-disconnect fitting, for example. Hopper pan 106 is connected to separator body 101 by conduit 107 extending in the vertically (in the z-direction) over top wall 103. Conduit 107 penetrates through top wall 103 into the interior chamber enclosed by sidewall 102 and top wall 103. Upper and lower flow inlet ports 108 and 109 extend from sidewall 102 in middle and bottom portions of separator body 101, respectively. In some embodiments, upper flow inlet port 108 has is a tangential flow inlet (e.g., having a central axis tangential to sidewall 103). In the illustrated example, upper flow inlet port 108 is approximately at the middle of separator body 101. In alternate embodiments, upper flow inlet port 108 may be at another suitable position along sidewall 102.

[0037] Lower flow inlet port 109 extends from sidewall 103 below upper flow inlet 108. Both upper and lower flow inlet ports 108 and 109 may be threaded to receive a threaded hose or tubing coupling. In alternate embodiments, upper and lower flow inlet ports 108 and 109 may have non-threaded receiving ends to accept quick-disconnect fittings, for example. Upper and lower flow inlet ports 108 and 109 may be sized to any suitable diameter. In the illustrated embodiment, lower flow inlet port 109 is near the bottom of separator body 101. Lower flow inlet port 109 may open into the interior of separator body 101 at a tangential or a non-tangential angle.

[0038] In some embodiments, upper flow inlet port 108 introduces a jet tangentially that evolves into a circulating flow around the wall. Lower flow inlet port 109 may introduce a

secondary flow into particle separator apparatus 100. The secondary flow may be non-tangential, where the flow is directed towards the center of the interior chamber (described below).

[0039] Valve body 110 is below flow inlet port 109. In the illustrated embodiment, valve body 110 is a housing for a sluice valve (gate valve) comprising gate 111. Handle 112 extends from gate 111. Handle 112 may facilitate manual control of gate 111, whereby gate 111 is a movable partition between separator body 101 and collection vessel 113. While the illustrated embodiment shows a sluice valve to represent valve body 110, any suitable type of valve, such as a ball valve.

[0040] **Fig. 2** illustrates an oblique cutaway view of separation apparatus 100, showing details of the interior chambers, according to some embodiments of the disclosure. Separator body 101 comprises upper chamber 201 and lower chamber 202 separated by partition 203. In the illustrated embodiment, partition 203 has a conical form. As noted above, partition 203 may have other suitable forms. The means of attachment of partition 203 to wall 103 of main body 102 are various, and may range from casting techniques, welding or gluing the partition to an internal receiving structure such as a flange, or force fitting. A seam may be formed about the perimeter of partition 203 where it abuts sidewall 102.

[0041] Downspout 204 extends vertically downward (in the figure) from an orifice (not shown) at the apex of partition 203. Downspout 204 may have a length d that is less than height h of lower chamber 202. Mouth 205 of downspout 204 may be adjacent to bottom 206 of lower chamber 202. Bottom 206 may be coplanar with gate 111 of sluice valve 110. During operation of particle separator apparatus 100, secondary flow introduced by lower flow inlet port 109 may engender an upward vertical flow through the one or more orifices of partition 203 into upper chamber 201 once the lower chamber is filled with separation fluid. During continuous operation, an upward vertical flow emanating from lower chamber 202 mixes with tangential flow introduced by upper flow inlet 108 to create an upwardly-spiraling cyclonic flow pattern in upper chamber 201. In some embodiments, the velocity of the vertical flow from lower chamber 202 (e.g., introduced through lower flow inlet port 109) to upper chamber 201 through partition 203 may be lower than the flow velocity than the tangential flow introduced into upper chamber 201 through upper flow inlet port 108.

[0042] Feed tube 207 extends obliquely through upper chamber 201 from approximately the center of top wall 103 and terminates at feed tube mouth 208. In the illustrated embodiment,

the feed tube 207 is not parallel to sidewall 102, descending diagonally from top wall 103 with respect to central axis 250 (indicated by the alternate dashed line) of separator body 101. Feed tube mouth 208 is offset from the center of upper chamber 201 by a distance x as shown in the figure. Feed tube mouth 208 may occupy a position adjacent to sidewall 102 and may be immediately above partition 203.

[0043] In some embodiments, upper flow inlet port 108 penetrates sidewall 102 tangentially, forming a substantially elliptical orifice (e.g., orifice 209). While flow inlet port 108 is shown immediately above rim 210 of partition 203, flow inlet port 108 may be further above partition 203 within upper chamber 201. During operation of particle separation apparatus 100, upper flow inlet port 108 directs a tangential flow as a stream or jet into upper chamber 201, where the tangential flow of clean separation fluid (e.g., water) introduced through orifice 209 may be directed substantially along a substantially tangent chord to the inner surface of sidewall 102. The tangential flow may follow a spiral path around rim 210 of partition 203.

[0044] In the exemplary embodiment shown in **Fig. 2**, partition 203 is shown to be substantially conical-shaped. Not shown in the figure is a central orifice at the apex of partition 203 from which downspout 204 descends into lower chamber 202. While lower flow inlet port 109 is shown below the level of mouth 205 of downspout 204, other configurations are possible. For example, lower flow inlet 109 may be above the level of downspout mouth 205 without consequence to the function of separator apparatus 100. In some embodiments, a tube may extend from exit 204 into the cavity.

[0045] In some embodiments, lower flow inlet port 109 is below partition 203, opening through orifice 211 into lower chamber 202. While lower flow inlet port 109 is shown to be below mouth 205 of downspout 204 in the illustrated embodiment, lower flow inlet port 109 may be positioned at any suitable level within lower chamber 202. During operation of separation apparatus 100, lower flow inlet port 109 may introduce a non-tangential flow of clean separation fluid (e.g., water) into lower chamber 202. The separation fluid may flow into upper chamber 201 through downspout 204 when lower chamber 202 fills with the introduced fluid. In some embodiments, the upward vertical flow within downspout 204 may be substantially laminar.

[0046] Upon entering upper chamber 201, upward flow emanating from downspout 204 encounters the tangential flow introduced by upper flow inlet port 108, causing an upwardly spiraling cyclonic flow within upper chamber 201. The upward cyclonic flow in upper chamber

201 imposes a centrifugal force on the particles introduced into the upper chamber by feed tube 207, causing lower-density particulates to spin laterally as well as being carried upward by vertical fluid forces. As a result of the acentric position of mouth 208 of feed tube 207, high-density particles as well as lower-density particles of the raw placer silt may be introduced peripherally within upper chamber 201, close to sidewall 102, where the angular velocity of the cyclonic flow of separation fluid, as well as the vertical flow component of the cyclonic flow, may be the lowest. In the peripheral region of upper chamber 201, the majority of the high-density particles may not be entrained in the vertical flow. Weak hydraulic forces of impinging vertical flow and angular flow may be overcome by gravitational forces, causing the higher-density particles to sink. The high-density particles may then accumulate against the inner surface of sidewall 102 and slide into partition 203 under the influence of gravity.

[0047] The flow rate of separation fluid introduced in lower chamber 202 by lower flow inlet port 109 may be regulated by an external valve to reduce the hydraulic forces of the upward flow through partition 203. The flow rate of the fluid introduced by lower flow inlet port 109 be regulated so that vertical flow into upper chamber 201 may not significantly impede or overcome gravitational forces causing the high-density particulates to drop downwardly through the partition 203 (and extension duct or tube extending below the partition, e.g., downspout 204, if one is so equipped). By adjusting the flow rates of the fluid streams entering upper and lower chambers 201 and 202, respectively, the fluid forces may be regulated to obtain a desired gravitational separation of particulates having disparate specific gravities (e.g., densities), such as the separation of gold particles, nuggets and flakes from silt components, mostly clays and silicates, mixed with small gravel. The vertical proximity of feed tube mouth 208 to partition 203 may reduce chances of high-density particles being entrained in faster cyclonic flow occurring closer to the center of upper chamber 201 and potentially carried to exit port 105.

[0048] At the bottom of lower chamber 202 is collection vessel 113. In some embodiments, collection vessel 113 is attached to separator body 101 by a threaded receiving portion (not shown). In some embodiments, a flange may be used (described below).

[0049] **Fig. 3** illustrates an oblique cutaway view of separator apparatus 200, showing interior details, according to some embodiments of the disclosure. In the embodiment illustrated in **Fig. 3**, separator apparatus 300 comprises feed tube extending into upper chamber 201. Lower chamber 202 is separated from upper chamber 202 by partition 203. As described above,

partition 203 may be substantially conical in shape. In alternate embodiments, partition 203 may have other suitable shapes.

[0050] Feed tube 301 extends into upper chamber 201 from port 107. In the illustrated embodiment, feed tube 301 comprises three non-coaxial segments. Segment 302 is coaxial with central axis 250. Segment 303 extends diagonally from segment 302, and segment 304 extends from segment 303, terminating at mouth 305. In some embodiments, segments 303, 304 and 305 have the substantially same diameter. In some embodiments, segment 304 extends substantially vertically from segment 303, offset from central axis 250 by a distance y as shown, where y is the distance between the center of segment 304 and central axis 250. In some embodiments, offset distance y is adjusted so that segment 304 is adjacent to sidewall 102. In some embodiments, distance y is 25% to 80% of the inner radius of upper chamber (see **Fig. 5**). The magnitude of distance y may depend at least in part on the diameter of segment 304. As an example, an intervening gap (not shown; see **Figs. 4 and 5**) is between sidewall 102 and the rim of feed tube mouth 305.

[0051] **Fig. 4** illustrates a magnified oblique cutaway view of separator apparatus 200, showing interior details in proximal to partition 203, according to some embodiments of the disclosure. In the illustrated embodiment, feed tube 301 comprises segments 302, 303 and 304 as described above and shown in **Fig. 3**. Segment 302 is coaxial with central axis 250. Segment 304 is offset from segment 302, therefore from central axis 250, by offset distance y . Offset y may be defined as the difference between center lines of segments 302 and 304, indicated in the figure by the dashed lines (referenced to central axis 250) where segment 302 is shown to be coaxial with central axis 250. In some embodiments, segment 302 itself is offset from central axis 250. Segments 302-304 are shown to have diameter ϕ . In some embodiments, segments 302 -304 have different diameters. Gap g is a distance between wall 305 of segment 304 and sidewall 102, and results from the difference between offset y and diameter $\phi/2$. Gap g may range between zero and up to 50% of the radius of upper chamber 201 (see **Fig. 5**). By way of example, gap g may range between 1 cm and 3 cm (approximately 0.5 inch to over one inch).

[0052] Segment 304 terminates at mouth 205. In some embodiments, segment 304 extends from segment 304 and terminates at feed tube mouth 305. In the illustrated embodiment, mouth 305 is a distance z_1 below rim 210 of partition 203. In some embodiments, mouth 205 is above rim 210. Orifice 209 may be a distance z_2 above rim 210. By way of example, z_2 may

range up to 5 cm (approximately 2 inches). During operation of separation apparatus 200, high-density particles may be entrained in tangential flow introduced by orifice 209. The close placement of mouth 205 and orifice 209 to partition 203 may enable rapid trapping of high density particles by partition 203.

[0053] **Fig. 5** illustrates a cross-sectional view in the x-y plane of upper chamber 201 of separation apparatus 100 or 200, showing partition 203 in plan view, according to some embodiments of the disclosure. In **Fig. 5**, the view is taken along x-y plane A-A' in **Fig. 4**. the lateral position of feed tube mouth 205 relative to sidewall 102 and the center of partition 203 (e.g., downspout 204) is shown. The center of feed tube mouth 205 (305) is offset by distance y from center axis 250, leaving gap g between sidewall 102 and an edge of mouth 205 (305). Offset y may be a portion of inner radius r of upper chamber 201 ranging between 25% and 80% of r . Offset y and gap g may be adjusted to place feed tube mouth 205 (305) within slower cyclonic flow to disperse raw silt exiting feed tube mouth 205 (305) to enable efficient capture of high-density and heavy particles in partition 203 during operation of separator apparatus 100 or 200.

[0054] Flow inlet port 105 opens into upper chamber 201 through orifice 209. Flow inlet port 105 may be substantially aligned tangential to sidewall 102, where axis 501 of flow inlet port 105 is coincident with chord 502 of upper chamber 201 as shown. Chord 502 may be any chord that extends substantially tangential to sidewall 102 within an x-y plane (e.g., plane A-A') that cuts upper chamber 201. While mouth 205 (305) of feed tube 207 or 301 is shown in the figure to be diametrically opposite (e.g., 180°) from orifice 209, mouth 205 (305) may be at any angular position relative to orifice 209. The relative position of mouth 205 with respect to flow inlet port 105 may be at least in part determined from local hydrodynamic behavior of the complex flow pattern set up by the tangential flow introduced by upper flow inlet port 108 mixing with fluid upwelling from lower chamber 202 through downspout 204 by fluid introduced through lower fluid inlet port 109.

[0055] **Fig. 6** illustrates an oblique cutaway view of separator apparatus 100, showing interior details of upper chamber 201, according to some embodiments of the disclosure. Flow outlet port 104 opens into upper chamber 201 through orifice 601. In the illustrated embodiment (e.g., separator apparatus 100), feed tube 207 extends downward through upper chamber 201, where feed tube 207 is oblique to central axis 250 of separator body 101, and to sidewall 102.

While the illustrated embodiment shows feed tube 207 extending obliquely within upper chamber 201, it is understood that feed tube 301 of particle separator apparatus 200 may be equally represented (e.g., shown) without changing any of the other described details of the internal structure of upper chamber 201.

[0056] Hopper 106 is coupled to feed tube 207 that extends into conduit 107. In some embodiments, hopper 106 is fastened to body 101 by a permanent weld or adhesive bond to conduit 107. In some embodiments, conduit 107 comprises external or internal threads. Hopper collar 602 may comprise mating threads (not shown), enabling fastening and removal of hopper 106 by turning hopper 106 about conduit 107. In some embodiments, hopper 106 is bolted to conduit 107 or to a flange (not shown).

[0057] In some embodiments, conduit 107 may comprise a receiving portion for interchangeable coupling to hopper 106 and other structures, such as, but not limited to, an auger, dredge or slurry pipe. As an example, an auger, dredge or slurry pipe may introduce raw placer silt into the disclosed separator apparatus continuously or semi-continuously.

[0058] Flow outlet port 104 comprises mouth 105 as a coupling to flexible hose, tubing or rigid conduit. Mouth may be threaded for coupling to threaded hose coupling or a conduit or may receive a quick-connect hose coupling. The diameter of orifice 601 and flow outlet port 104 may have a size to accommodate exiting flow without causing a significant backpressure. As an example, exit flow combines both tangential flow introduced into upper chamber 201 by flow inlet 105 and fluid flow into the lower chamber (e.g., lower chamber 202) flow inlet 109. The combined fluid flow exits through flow outlet port 104.

[0059] **Fig. 7** illustrates an oblique exploded view of a bottom portion of separation apparatus 100 (200), showing a cutaway view of lower chamber 202, according to some embodiments of the disclosure. Downspout 204 extends in the z-direction, downward from the partition (e.g., partition 203, not shown), terminating at mouth 205. Lower flow inlet 209 may introduce a non-tangential (e.g., toward the center of lower chamber 202) flow of clean separation fluid (e.g., water) into lower chamber 202. As an example, during operation of separation apparatus 100 or 200, the separation fluid (e.g., water) fills lower chamber 202, and flows into the upper chamber through downspout 204. In some embodiments, the volumetric flow rate of clean separation fluid through orifice 211 is lower than the volumetric flow rate into the upper chamber (e.g., through orifice 209 in upper chamber 201), and may produce

substantially laminar flow through downspout 204. In some embodiments, the volumetric flow rate through orifice 211 is the same or greater than the volumetric flow rate into the upper chamber. While mouth 205 is shown to be below flow inlet port orifice 211 in the illustrated embodiment, mouth 205 may be positioned to any suitable vertical distance relative to inlet port orifice 211 as development of flow in downspout 204 is not sensitive to the relative position of orifice 211 relative to mouth 205.

[0060] A valve such as, but not limited to, valve 110 may separate lower chamber 202 from collection vessel 113. While in the illustrated embodiment valve 110 is a sluice valve, any suitable valve may be employed. For example, valve 110 may be a ball valve or a butterfly valve. As shown, collection vessel 113 is a transparent container. Collection vessel 113 may comprise silicate glass or an organic polymeric material, such as, but not limited to, polycarbonates, polyesters (e.g., polyethylene terephthalate, PETE), polypropylene, polyethylene, polyimides, polyamides (e.g., nylon) or polyarylsulfones (PAS). Collection vessel 113 may comprise a non-transparent material at least in part, such as a metal (e.g., stainless steel, aluminum), ceramic materials (e.g., aluminum oxide).

[0061] **Figs. 8a** and **8b** illustrate a profile view in the x-z plane of collection vessel 113, according to some embodiments of the disclosure. In **Fig. 8a**, receiving member 801 is an extension of separator body 101, extending below valve 110. Collection vessel 113 is attached to receiving member 801 by threaded interface 802 at the base of receiving member 801. In **Fig. 8b**, collection vessel 113 is attached to receiving member 801 via flange 803. In the embodiment depicted in **Fig. 8b**, flange member 804 is integral with collection vessel 113, and may be fastened to flange 803 with bolts 805.

[0062] **Fig. 9** illustrates an exemplary system 900 comprising particle separation apparatus 100 or 200, according to some embodiments of the disclosure. In the illustrated embodiment, system 900 comprises sluice box 901 for pre-classifying raw placer silt. In alternate embodiments, sluice box may be omitted. Sluice box 901 may be lined with matting mesh 902, adapted to allow fine material and water to fall through the mesh into settling vessel 903. A partial crude separation of liquid and solids may take place within settling vessel 903, where a substantial portion of solids may settle to the bottom, falling through throat 904 into auger screw casing 905. Partially clarified water filling hopper 903 may exit via conduit 906 into a first

settling vessel 907. Auger 908 may carry a slurry of placer silt to the top of separator apparatus 100.

[0063] System 900 further comprises one or more pumps (e.g., pumps 909 and 910) to circulate water between a plurality of settling vessels and the innovative separator itself. In the illustrated embodiment, system 900 is self-contained, whereby all of the water required for operation of separation apparatus 100 is recirculated, requiring only small amounts of makeup water from an external source. In the embodiment depicted in Fig. 9, water is supplied to separation apparatus 100 via pumps 909 and 910 and conduits 911 and 912. In the illustrated example, conduit 911 supplies pumped filtered water to lower chamber inlet 109 treated through a fine filter (described below). Conduit 912 may supply pumped partially clarified water to flow inlet 105.

[0064] As shown in **Fig. 9**, flow or pressure meters 913 and 914 may be used to monitor water flow rates into both chambers. External valves (not shown) may be mounted in line with conduits 913 and 914 to regulate flow rates. Meters 913 and 914 monitor flow rates or pressure with conduits 911 and 912, respectively. Return water may exit separation apparatus 100 through flow outlet port 104. Exit water flow is shown to be directed to flow through flow splitter 915, where water and fine particulates are separated from coarser material, such as stones, by a mesh or other filter medium fitted at the junction of the bifurcation of flow splitter 915 and conduit 916. Water and fines exiting separation apparatus 100 may then flow into conduit 917, leading into settling vessel 918. Partially clarified overflow from vessel 918 may then flow out through conduit 919 to a fourth settling vessel (e.g., settling vessel 920).

[0065] Within settling vessel 920, separation tube 921 may house a fine filter medium, indicated by the hidden outlines within settling vessel 920. Separation tube 921 may aid in separation of remaining coarse particulates from the water, permitting water to flow into the lumen of separation tube 921 while particulates may settle outside of separation tube 921. Water within settling vessel 920 may be caused to infiltrate a fine filter cartridge (e.g., 2 micron) by suction created by pump 910. Filtered water may circulate through pump 910 via conduits 922 and 911, where conduit 911 connects with lower flow inlet 109 and supplies filtered and clarified water to the lower chamber (e.g. lower chamber 202) of separation apparatus 100.

[0066] In the illustrated embodiment, portable sluice box 901 comprises a water spray system for washing placer dirt fines that are small enough to fall through mat 902 and collect in

hopper 903. Water spray may wash larger rocks and nuggets to the edge of sluice box 901. Clean or clarified water from settling vessel 929 may be supplied to the spray system comprising conduit 923, carrying water pressurized by pump 909, into perforated conduit 924. The latter may extend around the perimeter of sluice box 901, as shown. Larger materials that are too large to fall through matting mesh 902 may then be washed to the bottom edge of portable sluice box 901, where discharge chute 925 is attached to receive rocks and guide their removal into bucket 926. Smaller nuggets may fall into slot 927, potentially rolling out onto chute 928 for collection and/or disposal.

[0067] The exemplary deployment of separation apparatus 100 in silt processing system 900 provides for recirculation of water (or other suitable separation fluid) employed for the separation process. Other suitable methods of employment of separation apparatus 100 are equally possible. By attaching hoses or conduit (e.g., conduits 911 and 912) to upper and lower flow inlet ports 105 and 109, respectively, whereby the hoses may be coupled to pumps (e.g., pumps 909 and 910), water, or another suitable separation fluid, may be delivered into upper and lower chambers 201 and 202, respectively. In the exemplary embodiment shown in Fig. 9, conduits 911 and 912 may be rigid pipes or a flexible hoses.

[0068] By adjustment of the pressures and/or flow rates of the separation fluid by use of valves (not shown), impingement forces of vertical and tangential flows may be likewise regulated. During operation of separation apparatus 100, a static pressure in the lower chamber may be maintained to be greater than the static pressure in the upper chamber, forcing a continuous upward flow of separation fluid from the lower chamber (e.g., lower chamber 202) to the upper chamber (e.g., upper chamber 201).

[0069] According to some embodiments, water pressure in the lower chamber may be regulated to force an upward flow into the upper chamber, whereby the vertical flow impinging on high-density and heavy particles does not entrain at least a majority of the high-density and heavy particles that fall through the downspout (e.g., downspout 204). During operation of separation apparatus 100, tangential flow may be introduced through flow inlet 105 above the partition (e.g., partition 203) mixes with the upward flow emerging from the lower chamber, creating an upwardly spiraling cyclonic flow.

[0070]

[0071] Still referring to **Fig. 9**, high-density particle-bearing silt, for example, silt from a placer deposit bearing gold particles, may be introduced batch-wise into separation apparatus 100, for example, in a semi-continuous manner through sluice box 901 and auger 908. Sluice box 901 may be employed to classify the raw silt from coarser components, which may include pebbles, gravel, and/or organic debris. In some embodiments, silt may be dredged and conveyed (e.g., by a dredging machine or conveyer belt) continuously to sluice box 901 or an equivalent receiving structure. The dredged silt may require pre-mixing with water to liquefy the silt enough so that it may easily enter the innovative apparatus. Wash water may be added by perforated conduit 924 to aid in separation of silt from coarse components.

[0072] The silt entering into the upper chamber begin to separate into low-density and high-density particles upon contact with the cyclonic flow. The internal cyclonic flow within separation apparatus 100 may be balanced by adjustment of the flow rates and/or pressures of separation fluid through flow inlet ports 105 and 109 so that it readily carries low-density particulates (e.g., silica sand and clay particulates) upward and out of flow outlet port 104. At the same time, the cyclonic flow does not carry away high-density particulates, but allows them to fall by gravity into the lower chamber to gather in collection vessel 113.

[0073] In the embodiments described above, partition 203 may comprise a conical shape, or a sloped surface, such that high-density particulates impinging on the upper surface of partition 203 may slide toward central orifice 212 in the featured embodiment, into downspout 206. From there, high-density particles fall against upward fluid flow, where the impinging upward flow through downspout 206 does not entrain the high-density particles.

[0074] As noted above, the offset of the feed tube (e.g., feed tube 207) may place high-density particles in proximity of the sidewall (e.g., sidewall 102) and of the partition (e.g., partition 203), separating them from strong tangential fluid forces that may exist near the center of the upper chamber. The disclosed internal geometry of separation apparatus 100 may enable a high-efficiency particle separation.

[0075] A waste stream may flow from flow outlet 104. The waste stream may carry out lower-density particulates and silt material, such as sand, clays and minerals, including small stones, through conduit 915. In the illustrated embodiment, conduit 915 splits into branched pipe 916, through which the coarser components may drop into a collection bucket or other vessel (not shown), while the exit water stream mostly drops into conduit 916, which may carrying with

it fine low-density silt that has been separated from high-density components into settling vessel 918 via interconnecting conduit 917.

[0076] Coarse or partial clarification may take place within vessel 918 by settling of particulate matter. This partially clarified water may be cascaded from vessel 918 to vessel 920 via interconnecting conduit 919, where vessel 920 serves as a second stage settling tank or vat. A filter element may be immersed in the partially clarified water within settling vessel 920, which filters water that is actively pumped out of this vessel by pump 910, supplying clean water to the flow inlet 109. Overflow water from settling vessel 918 is also transferred to settling vessel 929, which receives overflow from settling vessel 907, also serving as a second settling stage. In turn, partially clarified water from settling vessel 929 is pumped via pump 909 to the upper chamber via conduit 912.

[0077] **Fig. 10** illustrates exemplary system 1000 comprising particle separation apparatus 100 or 200, according to some embodiments of the disclosure. In the illustrated embodiment, system 1000 is a semi-continuous or continuous flow system. Arrows in the diagram of **Fig. 10** indicate direction of flow. Separation fluid (e.g., water) is recycled by passage of burdened separation fluid, carrying lighter-density silt particles out of particle separation apparatus 100 (200) through outlet port 104 for continuous processing. System 1000 comprises settling vessels 1001 and 1002 for clarifying used separation fluid to remove coarse and fine silt particles from separation fluid before return to particle separation apparatus 100. In the illustrated example, filter 1003 receives exiting separation fluid exiting through conduit 1004 containing separated silt particles. Sand and other coarser particles may be captured by filter 1003, permitting finer particles to flow into settling vessel 1001.

[0078] Conduit 1005 may transfer partially clarified separation fluid from settling vessel 1001 to settling vessel 1002. Separation fluid may be transferred actively by a submerged pump (not shown) or by siphon action through conduit 1005. Settling vessel 1002 may be a second settling stage, permitting finer particles to settle out before returning the separation fluid to particle separation apparatus 100 (200). A pump (shown in hidden lines in the example) within settling vessel 1002 may actively transfer pressurized clarified separation fluid to particle separation apparatus 100 (200) through conduit 1006. The pump is shown as a submersible pump in the illustrated example, but the pump may be external to settling vessel 1002.

[0079] Manifold 1007 may divide arriving clarified separation fluid into three streams, each flowing in separate conduits 1008, 1009 and 1010. Gauges 1011 and 1012 may measure pressure or flow rate. While gauges 1011 and 1012 are shown as dial gauges, gauges 1011 and 1012 may be digital gauges mounted peripherally or in-line. Flow rates of at least two streams may be monitored by gauges 1011 and 1012. In the illustrated example, gauges 1011 and 1012 are proximal to upper and lower flow inlet ports 108 and 109, respectively, fed by conduits 1008 and 1009, respectively. Flow rates and/or pressure of fluid entering the two inlets may be regulated by valves (not shown) to produce internal cyclonic flow in the interior chambers of particle separation apparatus described above.

[0080] Conduit 1010 may intermittently direct flow of separation fluid to hopper 106. Hopper 106 may receive intermittently, semi-continuously or continuously charged batches of raw placer silt. Conduit 1010 may direct flow of water (clarified separation fluid) into hopper 106 to form a slurry with the raw placer silt.

[0081] Reference in the specification to "an embodiment," "one embodiment," "some embodiments," or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some embodiments, but not necessarily all embodiments. The various appearances of "an embodiment," "one embodiment," or "some embodiments" are not necessarily all referring to the same embodiments. If the specification states a component, feature, structure, or characteristic "may," "might," or "could" be included, that particular component, feature, structure, or characteristic is not required to be included. If the specification or claim refers to "a" or "an" element, that does not mean there is only one of the elements. If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

[0082] Furthermore, the particular features, structures, functions, or characteristics may be combined in any suitable manner in one or more embodiments. For example, a first embodiment may be combined with a second embodiment anywhere the particular features, structures, functions, or characteristics associated with the two embodiments are not mutually exclusive.

[0083] It will be appreciated by persons skilled in the art that the embodiments disclosed herein are exemplary and are by no means to be construed as limiting. Other variations of the

described embodiments may be considered without deviating from the scope and spirit of the innovation, as claimed in the claims below.

CLAIMS

We claim:

1. A particle separation apparatus, comprising:
 - a first chamber over a second chamber, the first chamber having a first sidewall and the second chamber having a second sidewall;
 - a partition between the first chamber and the second chamber; and
 - a feed tube extending through the first chamber, wherein the feed tube has a first end coupled to a feed inlet and a second end is proximal to the partition and is proximal to the first sidewall.
2. The particle separation apparatus of claim 1, wherein a first flow inlet port is on the first sidewall and opens into the first chamber above the partition, and a second flow inlet port is on the second sidewall and opens into the second chamber below the partition.
3. The particle separation apparatus of claim 2, wherein the second sidewall is substantially tubular, and wherein the second flow inlet port is tangentially oriented to the second sidewall.
4. The particle separation apparatus of claims 1 or 2, wherein first sidewall is substantially tubular, wherein the first end of the feed tube is substantially aligned to a central axis of the upper chamber, and wherein the second end is between the central axis and the first sidewall.
5. The particle separation apparatus of claim 4, wherein second end of the feed tube is at a first distance from the first sidewall, and wherein the first distance is less than 50% of a radius of the first chamber, wherein the radius extends between the central axis and the first sidewall.
6. The particle separation apparatus as in any one of claims 1 through 5, wherein substantially the entire feed tube is oblique to the sidewall of the first chamber.
7. The particle separation apparatus as in any one of claims 1 through 5, wherein a first portion of the feed tube is parallel to the sidewall of the upper chamber, and a second portion of the feed tube is oblique to the sidewall of the upper chamber, and wherein the first portion of the feed tube is adjacent to the second portion of the feed tube .

8. The particle separation apparatus as in any one of claims 1 through 7, wherein the partition comprises an orifice and a downspout extending into the second chamber from the orifice.
9. The particle separation apparatus as in any one of claims 1 through 8, wherein the partition has a substantially conical shape.
10. The particle separation apparatus as in any one of claims 1 through 9, wherein a top wall is over the first chamber, the top wall is coupled to the first sidewall, wherein a feed inlet is on the top wall and opens into the first chamber, wherein the feed tube extends through the feed inlet, and wherein a hopper is coupled to the feed inlet.
11. The particle separation apparatus of claim 10, wherein the hopper has a substantially conical shape.
12. The particle separation apparatus as in any one of claims 1 through 11, wherein a top wall is over the first chamber, the top wall is coupled to the first sidewall, wherein a feed inlet is on the top wall and opens into the first chamber, wherein the feed tube extends through the feed inlet, wherein an auger is coupled to the feed inlet.
13. The particle separation apparatus as in any one of claims 1 through 12, wherein a valve is coupled to a bottom wall of the second chamber.
14. The particle separation apparatus of claim 13, wherein the valve is a sluice gate valve.
15. The particle separation apparatus as in claims 13 or 14, wherein a collection vessel is below the valve.
16. The particle separation apparatus of claim 15, wherein the collection vessel comprises a threaded portion.
17. The particle separation apparatus of claim 15, wherein the collection vessel comprises a flange.
18. The particle separation apparatus as in any one of claims 1 through 17, wherein a flow outlet port is on the first sidewall, and wherein the flow outlet port opens into the first chamber.

19. The particle separation apparatus of claim 18, wherein the flow outlet port comprises a threaded end.

20. The particle separation apparatus as in any one of claims 1 through 19, wherein the second end of the feed tube is a second distance from a rim of the partition, wherein the second distance is less than one fifth of a length of the first chamber.

21. The particle separation apparatus as in any one of claims 1 through 20, wherein the first sidewall and the second sidewall comprise any of steel, aluminum, copper, brass, titanium, polymethyl methacrylate, polyethylene terephthalate, polypropylene, polyethylene, polyvinyl chloride, polyimides, or a silicate glass.

22. A system, comprising:

- a particle separation apparatus, comprising:

- a first chamber over a second chamber, the first chamber having a first sidewall and the second chamber having a second sidewall;

- a partition between the first chamber and the second chamber; and

- a feed tube extending through the first chamber, wherein the feed tube has a first end coupled to a feed inlet and a second end is proximal to the partition and is proximal to the first sidewall;

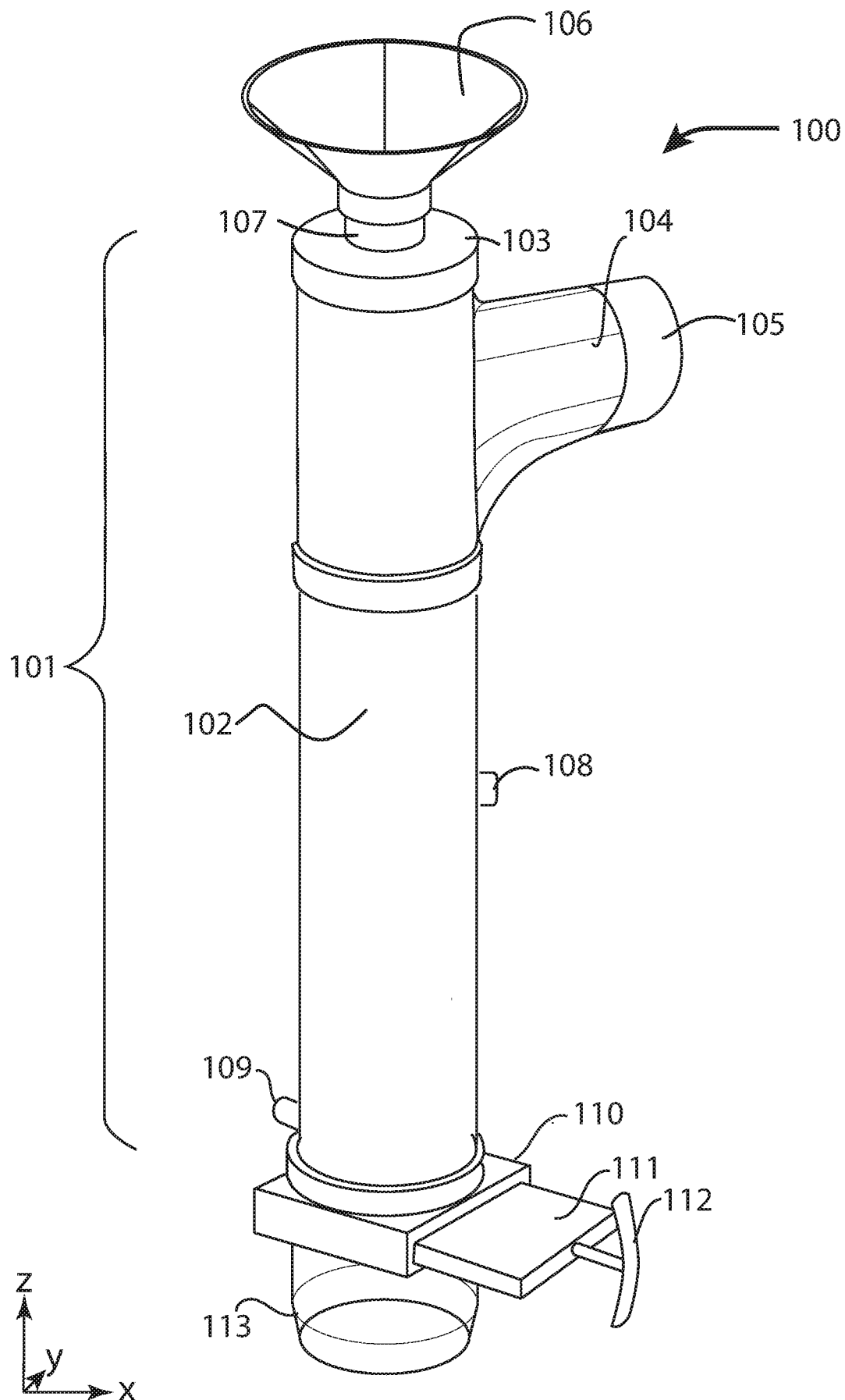
- a vessel; and

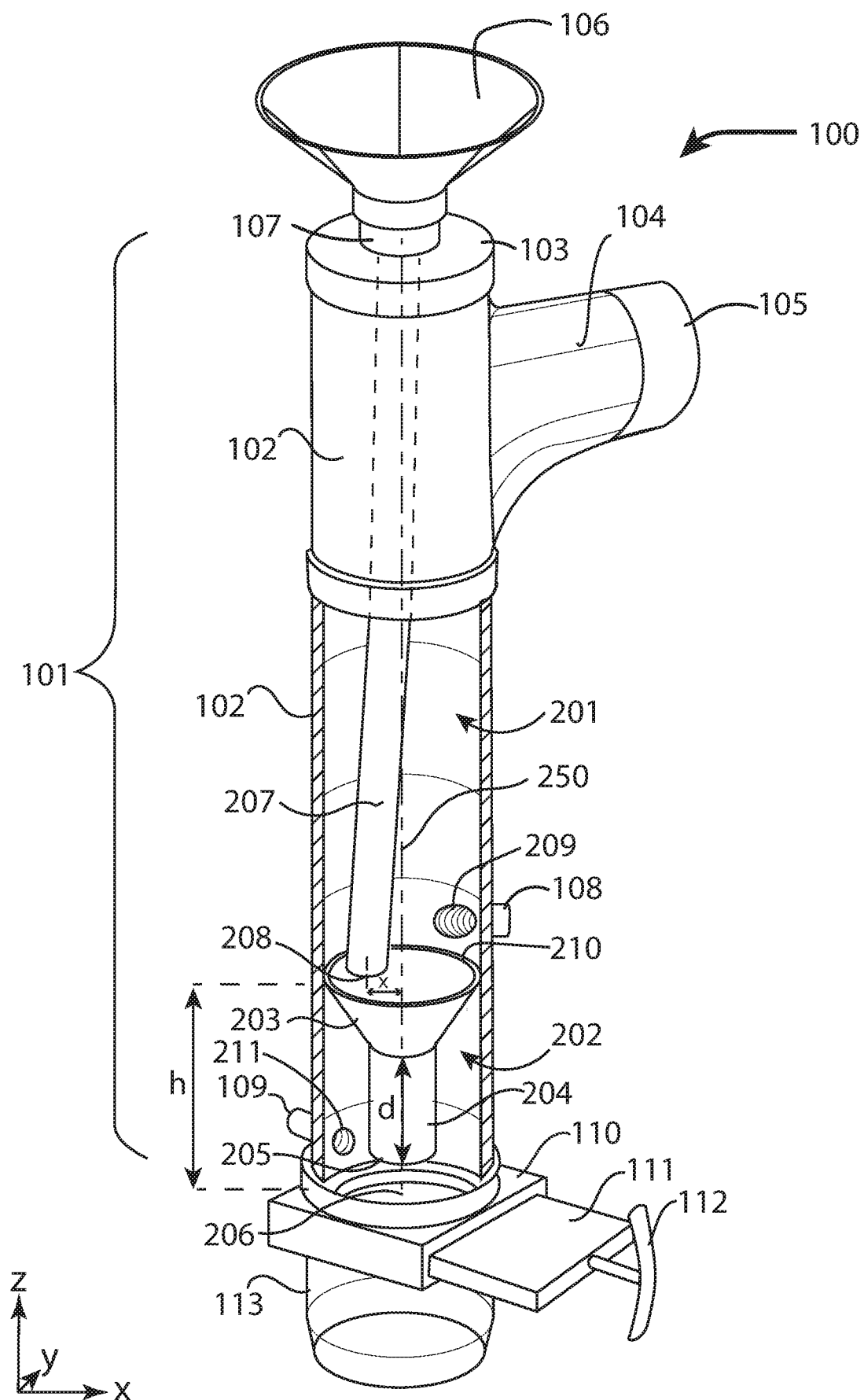
- a conduit extending from the vessel, wherein the conduit is coupled to a first flow inlet port on the first sidewall and a second flow inlet port on the second sidewall.

23. The system of claim 22, wherein the conduit is a first conduit, wherein the first conduit is coupled to a second conduit and a third conduit, wherein the second conduit is coupled to the first flow inlet port and the third conduit is coupled to the second flow inlet port.

24. The system of claim 23, wherein the first, second and third conduits are coupled to a manifold.

25. The system as in any one of claims 22 through 24, wherein a flow outlet port is coupled to the first chamber, and wherein the flow outlet port is coupled to the at least one settling vessel.

**Fig. 1**

**Fig. 2**

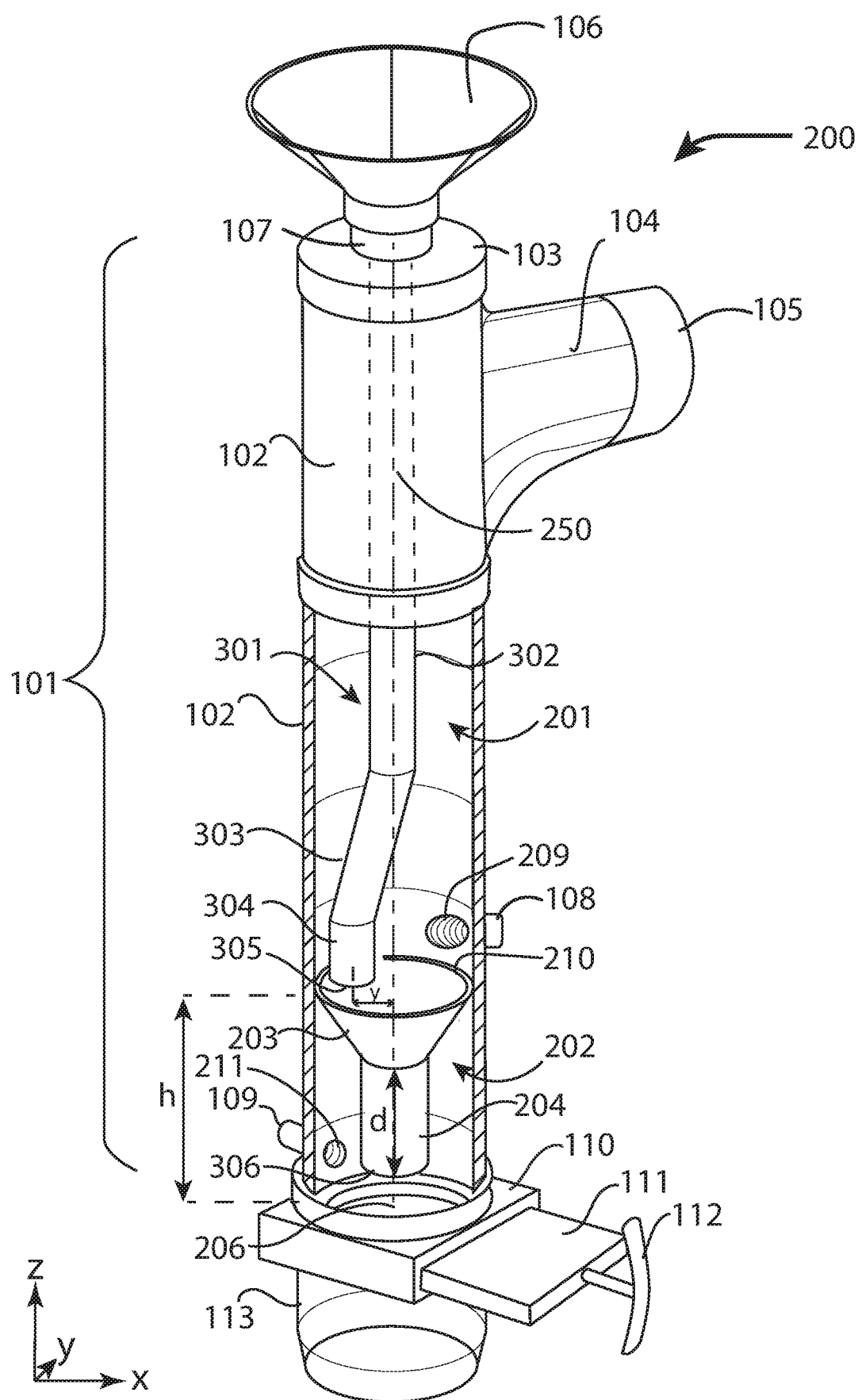
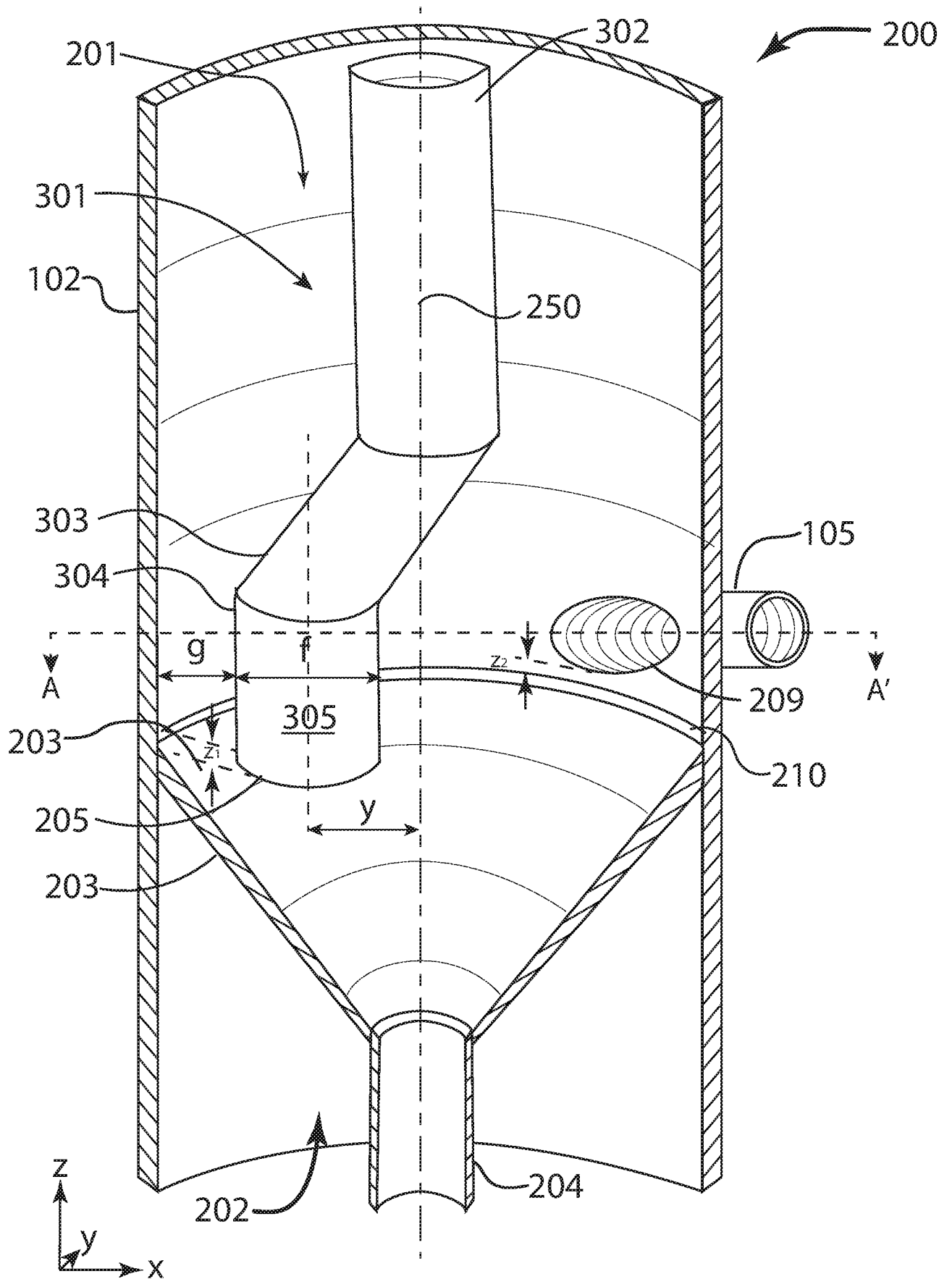
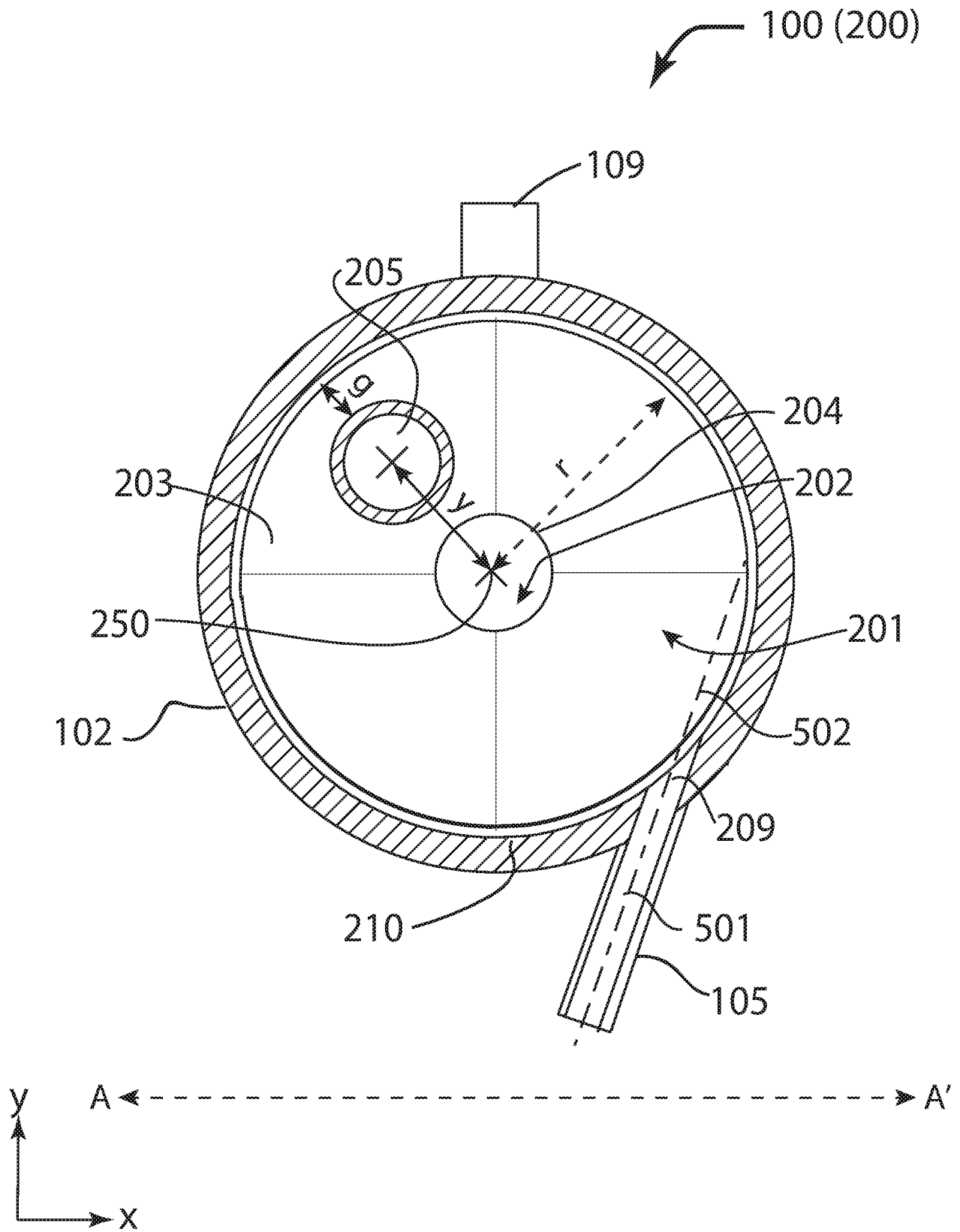
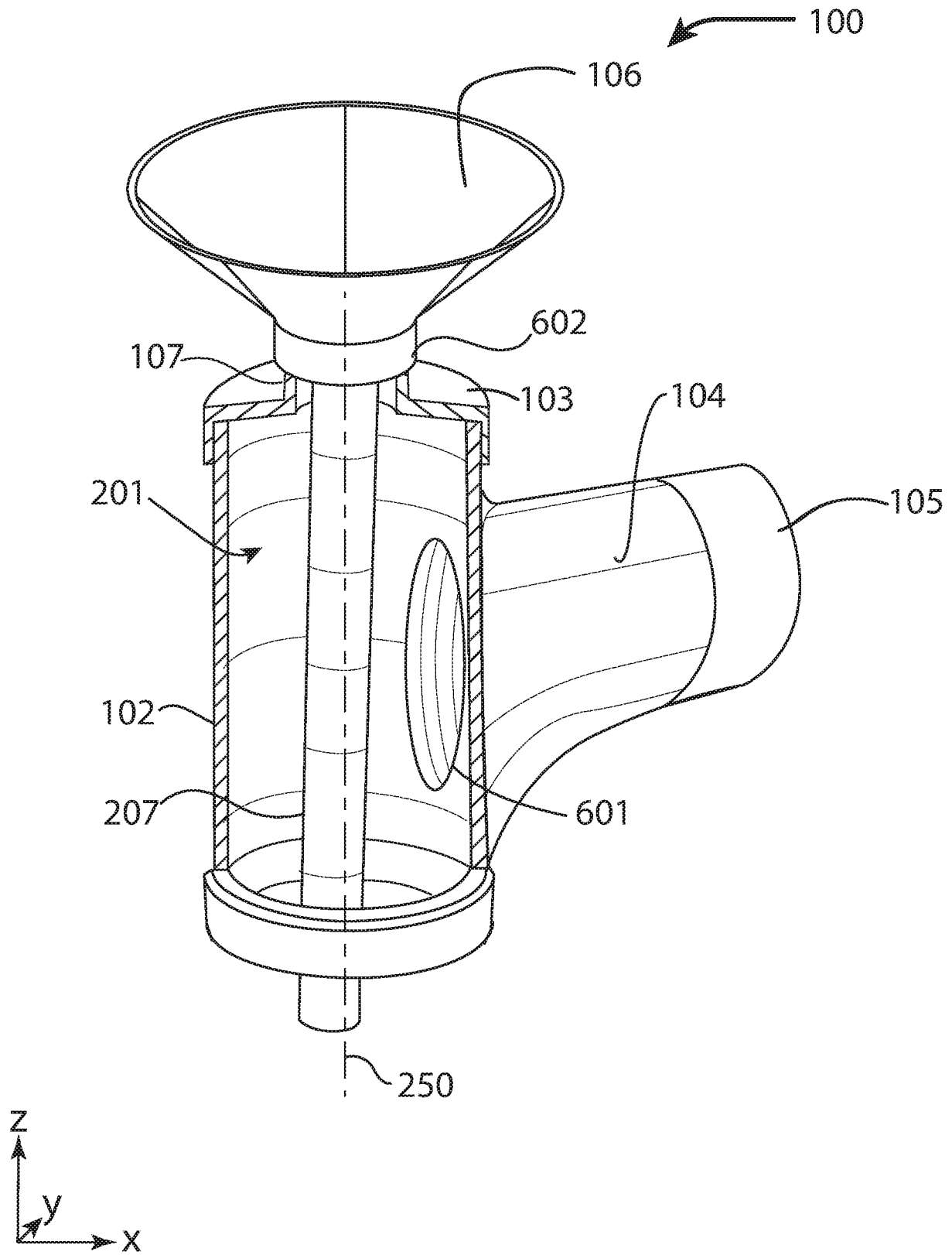
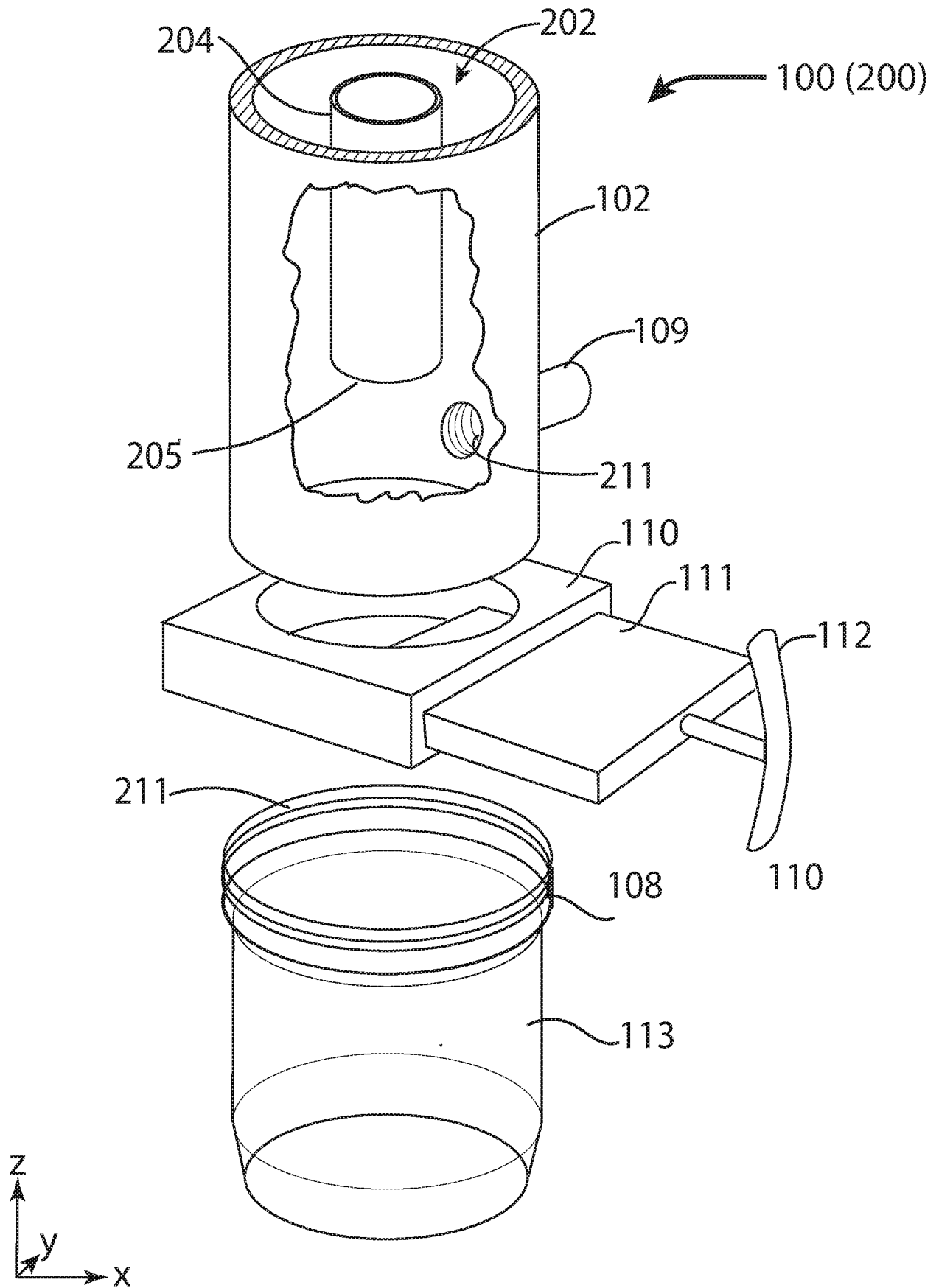


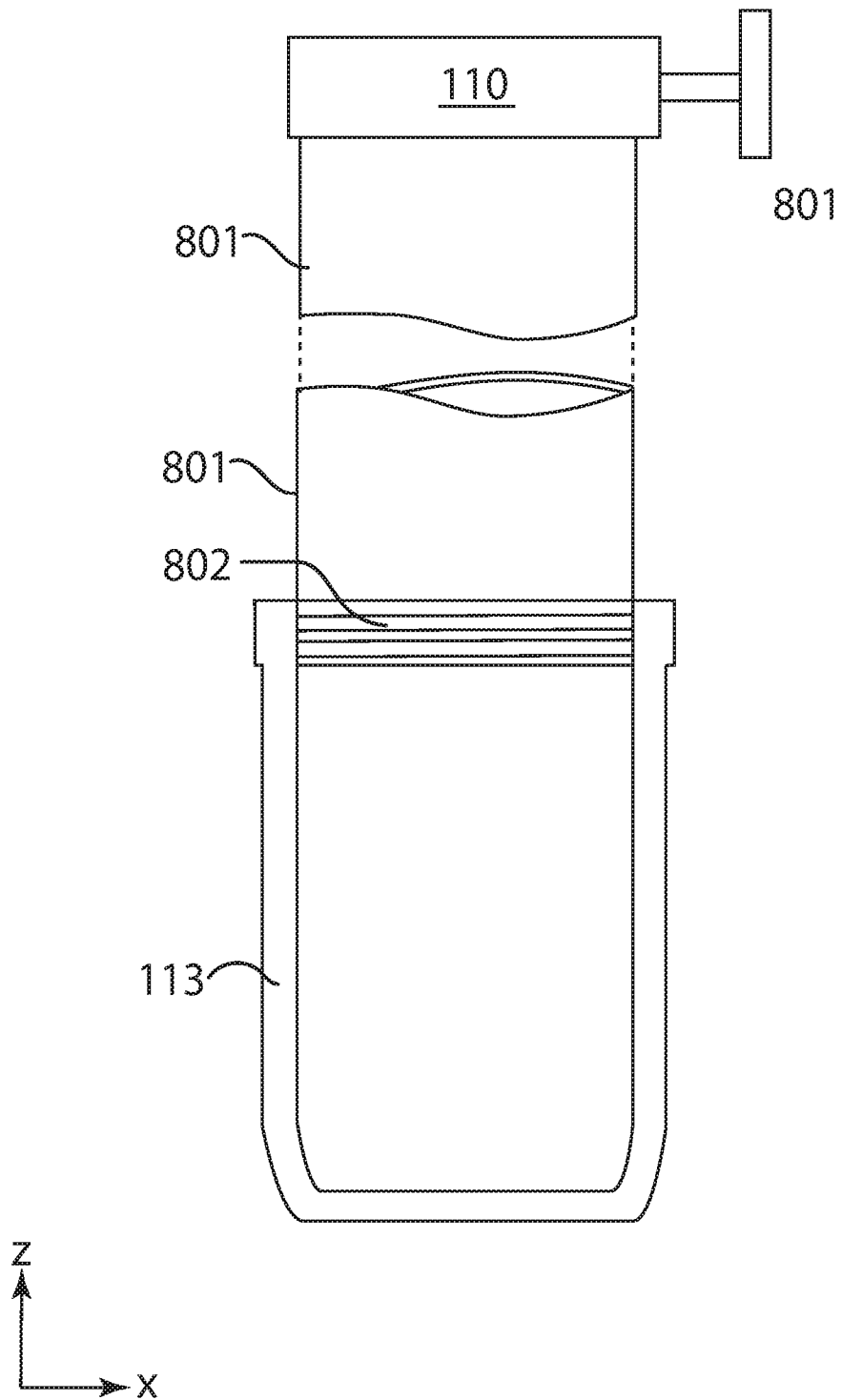
Fig. 3

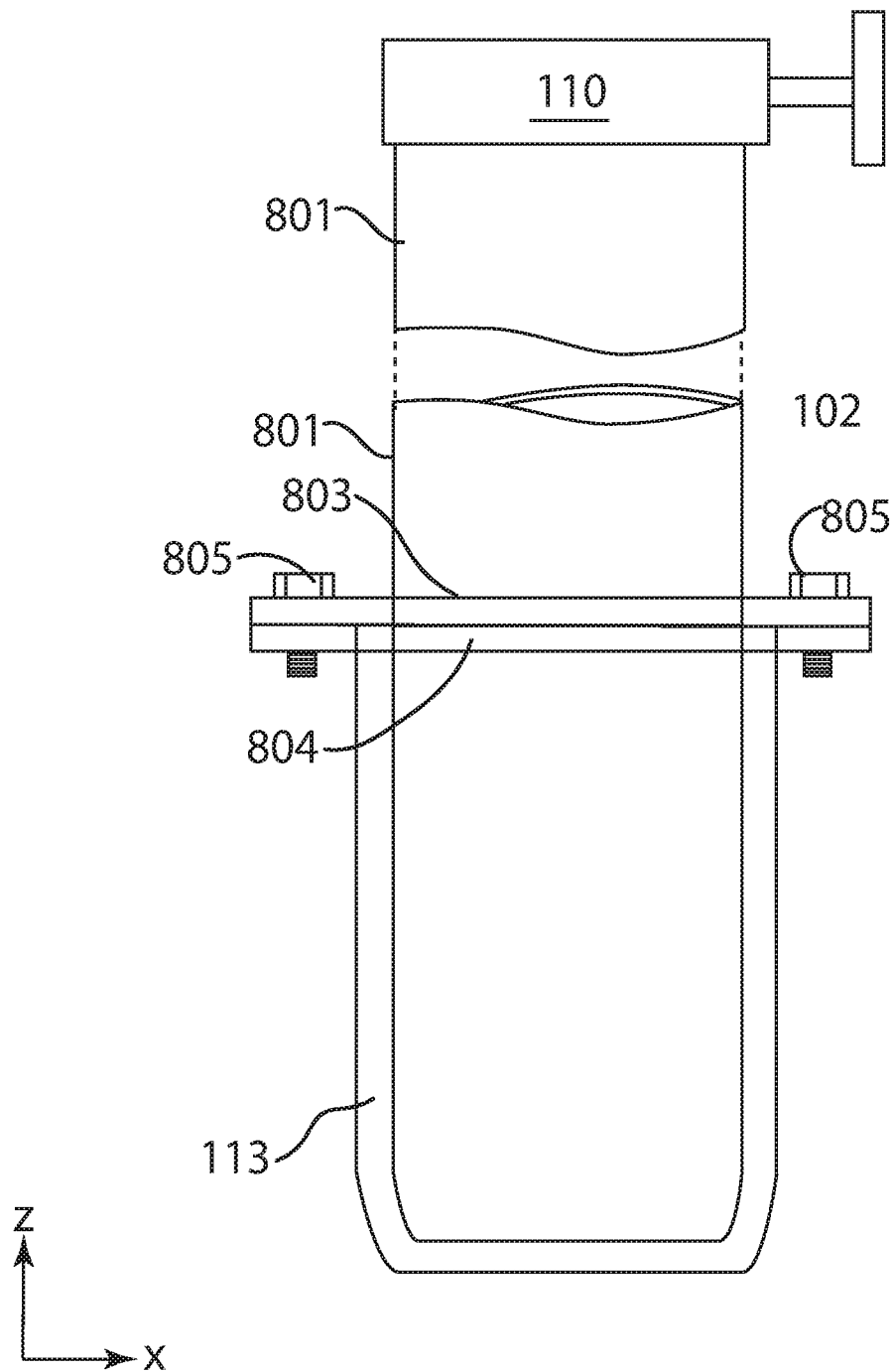
**Fig. 4**

**Fig. 5**

**Fig. 6**

**Fig. 7**

**Fig. 8a**

**Fig. 8b**

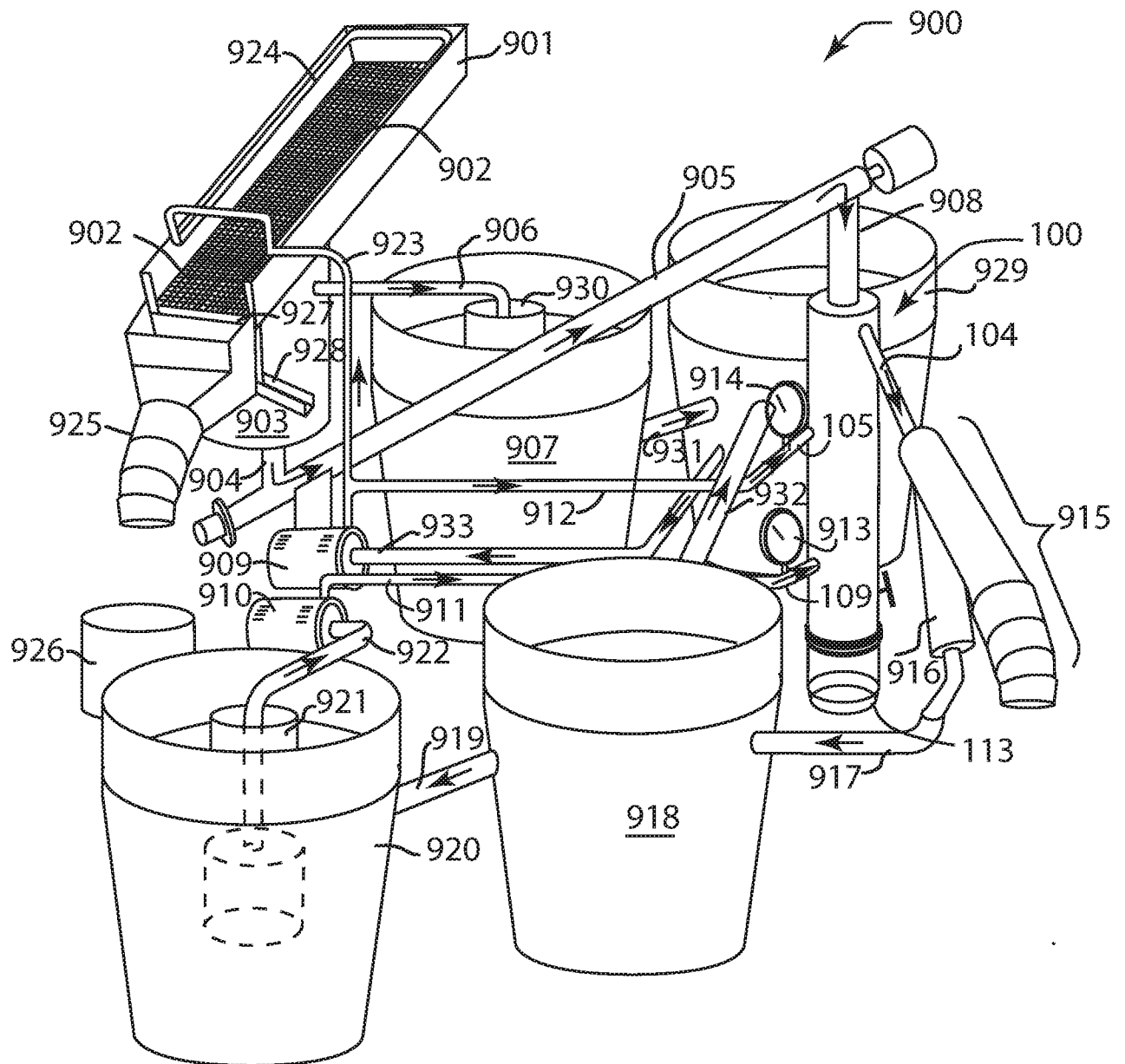
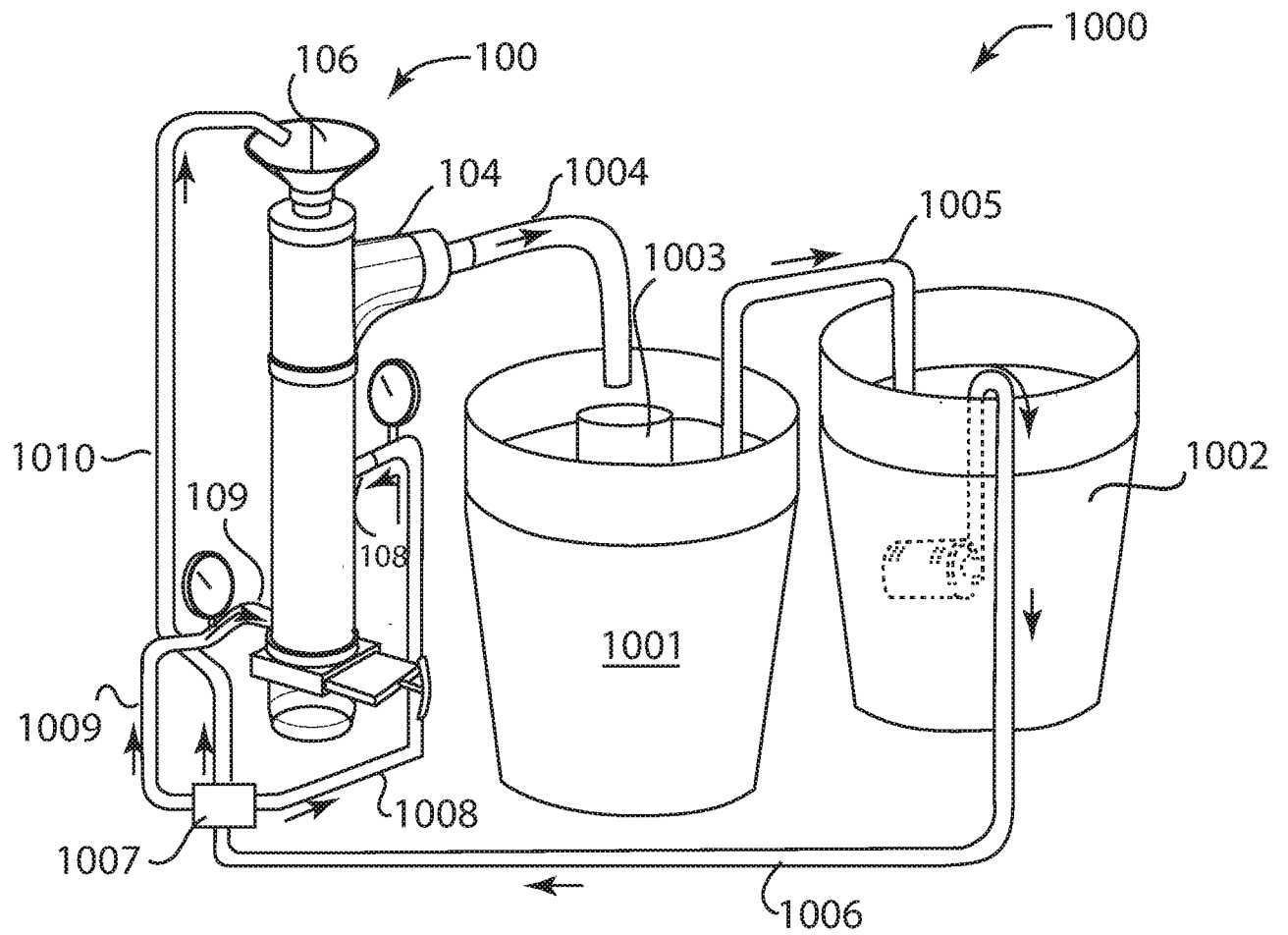


Fig. 9

**Fig. 10**

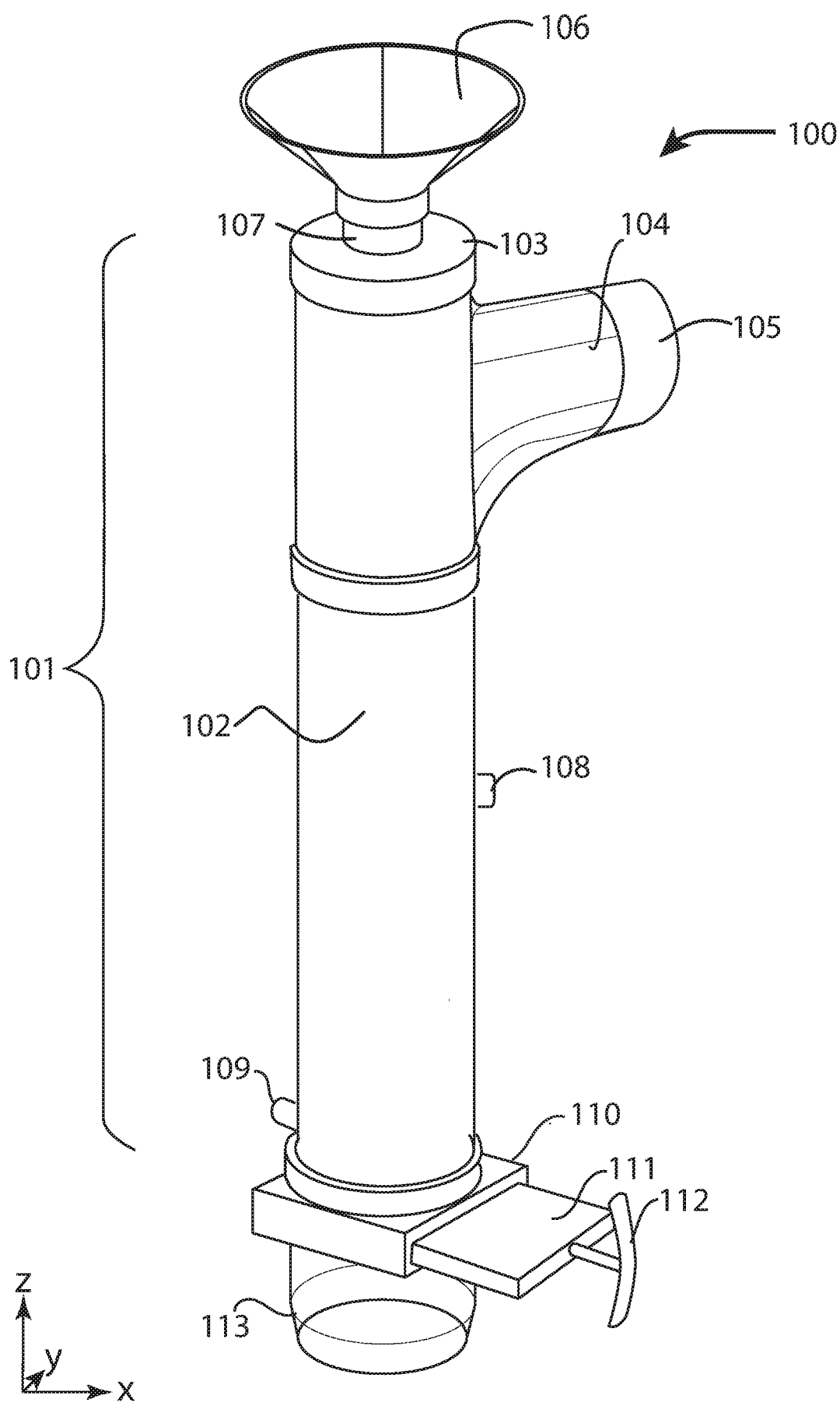


Fig. 1