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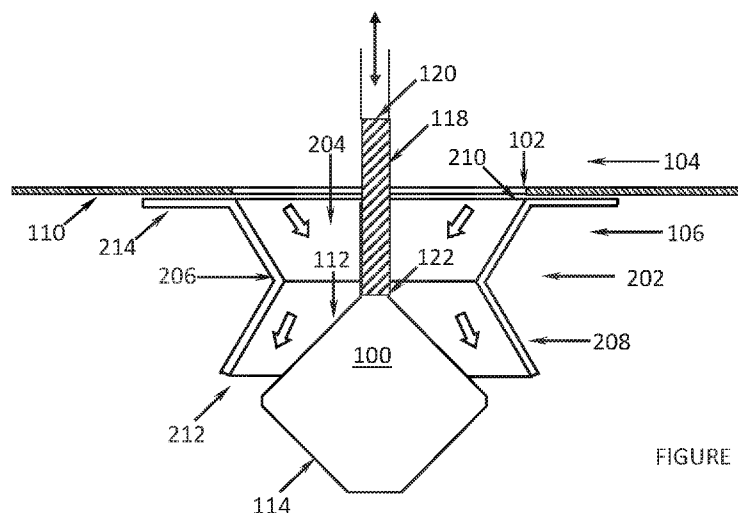


FIGURE 3

(57) Abstract: Disclosed, is a valve apparatus for use with flotation cells. The valve apparatus is characterized in that it comprises a nozzle tube (202) for attaching to the wall (110) adjacent the orifice (102). The nozzle tube (202) is provided between the orifice (102) and the dart (100) and configured such that while in use, the dart (100) does not come into direct contact with the orifice (102) provided to the wall (100). The nozzle tube (202) further comprises an inwardly-tapered inlet (204) which extends from a wider open end to a throat (206) of smaller diameter. By virtue of the shape of the upstream-facing surface (112) of the dart (100) and the inwardly-tapered inlet (204), a nozzle structure is formed as the dart (100) moves upstream or closer to the throat (206) of the nozzle tube (202). This nozzle structure is particularly adapted for reducing head losses.



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VALVE APPARATUS FOR FLOTATION CELLS

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FIELD OF THE INVENTION

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This invention relates to flotation cells used for industrial froth flotation processes, and more particularly to dart valve apparatus used to transfer slurry or pulp from one flotation cell tank to another flotation cell tank. Embodiments of valve apparatus disclosed herein may be applicable for use within mineral processing (e.g.,

15 beneficiation), paper recycling, and waste-water treatment industries.

BACKGROUND OF THE INVENTION

Flotation cells are typically arranged in banks. Valve apparatus may be placed

20 inside or between flotation cells to control the flow of pulp/slurry between adjacent flotation cells. Conventional dart valves can be linearly actuated, or actuated by a hinge. See, for example, US Patent No. 5,965,857.

FIG. 1 depicts a conventional linear valve arrangement which has, to date, been

25 used in conjunction with flotation apparatus. Such an assembly is generally provided to a floor of a flotation cell and is vertically-arranged and oriented. As depicted, a vertically-arranged dart 100 is located on an upstream side 104 of a horizontally-extending wall 110 of a flotation cell, rather than on a downstream side 106. The vertically-arranged dart 100 is provided adjacent and upstream of an orifice 102 in

30 the wall 110. The orifice 102 comprises a conventional sealing grommet 101. An inside diameter of the conventional sealing grommet 101 has chamfers that have no effect (or negligible effect) to the flow through the orifice 102. Linear actuation (e.g.,

vertical motion up and down motion of a shaft) moves the dart 100 closer to or further away from the upstream side 104 of the conventional sealing grommet 101 and wall 110, thereby controlling the amount of flow between the downstream-facing surface 114 of the dart 100 and the upstream side 104 of the conventional sealing grommet 101. The dart 100 may come into contact with the conventional sealing grommet 101 provided to the orifice 102, in order to completely restrict flow between adjacent flotation cells.

FIG. 2 depicts a conventional hinged valve arrangement which has, to date, been used in conjunction with flotation apparatus. Such an assembly is generally provided to a sidewall portion of a flotation cell and used to control flow between adjacent flotation cell tanks. As depicted, a hinged dart 100 is located on a downstream side 106 of a vertically-extending wall 110 of a flotation cell and is configured to articulate in an arcuate path, via a hinge. The dart 100 is provided adjacent and downstream of an orifice 102 of the wall 110, and the orifice 102 is provided with a conventional sealing grommet 101 having chamfers with no effect (or negligible effect) to the flow through the orifice 102. Arcuate actuation (e.g., hinged motion) moves the dart 100 closer or further away from the orifice 102, downstream of the wall 110, thereby controlling the amount of flow between the upstream-facing surface 112 of the dart 100 and the downstream side 106 of orifice 102. The dart 100 may come into contact with the conventional sealing grommet 101 provided to the orifice 102, in order to completely restrict flow between adjacent flotation cells.

One problem with existing dart valve designs and/or standard configurations is that they tend to contribute to excessive head losses, as evidenced by the data shown in FIGS. 14-17.

Another problem with existing dart valve designs is low levels of controllability. For example, as a linear (FIG. 1) or hinged dart 100 (FIG. 2) moves away from a conventional sealing grommet 101 and orifice 102, flow rate does not change linearly with regard to changes in distance between the dart 100 and conventional sealing

grommet 101. This leads to significant changes in sensitivity of the dart valve at certain opening distances.

Traditionally, in order to increase flow capacity with a conventional grommet, a larger
5 hole (i.e., orifice) needs to be cut through a wall of a flotation cell, and larger
grommet or plug supplied thereto. Often, this increased projected area of the orifice
means a larger actuator is required to handle the increased capacity. Other
mechanical parts (e.g., connecting rods or support frames, for example) which are
associated with the dart valve will generally also need to be increased in size or
10 upgraded to match the larger actuator capacity.

OBJECTS OF THE INVENTION

Accordingly, it is an object of embodiments of the present invention to provide
15 improved flotation cell valve apparatus which are configured to improve hydraulic
performance and control characteristics, as well as reduce head losses between
adjacent flotation cells, without limitation.

It is a further object of embodiments of the present invention to provide a retrofit kit
20 and method of retrofitting a flotation cell (or flotation cells), which reduces head
losses, increases throughput without altering or enlarging an existing orifice 102,
and/or improves controllability of flow through a dart valve, without limitation.

It is a further object of embodiments of the present invention to provide a method for
25 reducing head losses, increasing throughput, and improving controllability of a dart
valve without requiring substantial cutting or drilling.

It is yet a further object of embodiments of the present invention to enable a larger
capacity nozzle tube to be installed in place of an existing conventional
30 grommet adjacent an orifice without the need for additional actuator capacity and/or

without requiring changing of other major mechanical components (e.g., connecting rods or support frames), without limitation.

5 These and other objects of the invention will be apparent from the drawings and description herein. Although every object of the invention is believed to be attained by at least one embodiment of the invention, there is not necessarily any one embodiment of the invention that achieves all of the objects of the invention.

SUMMARY OF THE INVENTION

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A valve apparatus for use with a flotation cell or flotation cells (e.g., within a bank or circuit) is disclosed. The entire valve apparatus, or one or more components thereof, may be retrofittable into an existing device (e.g., a flotation cell, a flotation cell bank/circuit, or an external flotation cell valve apparatus provided externally between 15 two flotation cells), without limitation. In some embodiments, the valve apparatus may be configured to control flow rate to or from a flotation cell. The valve apparatus may be provided to a wall 110, and the wall 110 may be provided with an orifice 102. The wall 110 may extend horizontally or horizontally as shown, although it is envisaged that in some embodiments, the wall 110 may extend obliquely, without 20 limitation.

The valve apparatus may further comprise a dart 100 which may be configured to be actuated and moved linearly with respect to the orifice 102, or non-linearly with respect to the orifice 102 (via a hinge). In use, the dart 100 may change its proximity 25 with respect to the orifice 102; for example, in order to control flow rate therebetween. The dart 100 may comprise an upstream-facing surface 112 and a downstream-facing surface 114.

The valve apparatus can be characterized in that rather than a conventional sealing 30 grommet 101, as depicted in FIGS. 1 and 2, it may instead comprise an elongated nozzle tube 202 for attaching to the wall 110, adjacent the orifice 102. The nozzle

tube 202 may be provided between the orifice 102 and the dart 100. The nozzle tube 202 may be configured such that during use, the dart 100 does not come into direct contact with the orifice 102 provided to the wall 100, without limitation. The nozzle tube 202 is preferably much longer, in an axial direction along an axis of the orifice 102, than the traditional grommet shown in FIGS. 1 and 2. As shown, the dart 100 may be relatively positioned much further from the orifice 102 using the inventive nozzle tube 202 than with a conventional sealing grommet 101.

The orifice 102 may be defined by a portion of the nozzle tube 202, without limitation. The nozzle tube 202 may be provided as an extension of the wall 110, without limitation. The nozzle tube 202 may be provided as an extension of the orifice 102, without limitation. The wall 110, orifice 102, and nozzle tube 202 may be formed as one homogenous, integral, monolithic structure; or, the wall 110, orifice 102, and nozzle tube 202 may be formed by a collection of permanently-joined or separably-joined modular units, without limitation. The nozzle tube 202 or portions thereof may comprise a different material than the wall 110 or orifice 102, without limitation. The nozzle tube 202 may be provided in the form of a separate insert which may be attached to a wall 110 adjacent the orifice 102.

The nozzle tube 202 may be attached to the upstream side 104 of the wall 110, or to a downstream side 106 of the wall 110, for example, via a mount 214. The mount 214 may comprise, as shown, a radially-extending flange provided to the upstream wide end 210 of the nozzle tube 202. The radially-extending flange may be bolted, welded, fastened, and/or adhered to the wall using any means known in the art. For example, one or more holes or cutouts for bolts may be provided to the mount 214, without limitation.

If the nozzle tube 202 is affixed to the wall 110 by mounting the radially-outwardly extending flange against the upstream side 104 of the wall 110 (as shown in FIGS. 4 and 6), and the radially-outwardly extending flange is integral with and not detachable from nozzle tube 202, then it is important in such embodiments that the

orifice 102 be large enough to allow the nozzle tube 202 to pass through the orifice 102. If mounting a radially-outwardly extending flange against the downstream side 106 of the wall 110, the orifice 102 need not necessarily be large enough to allow the nozzle tube 202 to pass through the orifice 102.

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It should be understood that a radially-inwardly extending flange may be alternatively employed when mounting a nozzle tube 202 to a downstream side 106 of the wall 110. Moreover, it should be understood that no flange may be needed to secure the nozzle tube 202 to the wall 110. For example, in some embodiments, a nozzle tube 10 202 may be secured to a wall 110 adjacent an orifice 102 by welding an edge or rim of the nozzle tube 202 at the upstream wide end 210 thereto, without limitation.

A nozzle tube 202 as described herein may be secured to a wall 110 at its upstream wide end 210 as depicted in FIGS. 3-6 and 9, without limitation. Alternatively, in 15 some embodiments, a nozzle tube 202 as described herein may be secured to a wall 110 at its downstream wide end 212, without limitation.

The nozzle tube 202 may comprise an inwardly-tapered inlet 204 which narrows from an upstream wide end 210 to a throat 206 of smaller diameter, the throat 206 20 being provided downstream of the upstream wide end 210. The interior of the inwardly-tapered inlet 204 is preferably wider at adjacent the upstream wide end 210. The interior of the inwardly tapered inlet 204 is preferably narrower at the throat 206. The upstream wide end 210 of the inwardly-tapered inlet 204 is preferably located proximate an upstream side 104 of the nozzle tube 202. The narrower throat 25 206 is preferably located more proximate to a downstream side 106 of the nozzle tube 202; wherein the downstream side 106 of the nozzle tube 202 is preferably closer to the upstream-facing surface 112 of the dart 100 than the upstream wide end 210.

30 The dart 100 is preferably located downstream of the nozzle tube 202; wherein both the upstream-facing surface 112 of the dart 100 and the downstream-facing surface

114 of the dart 100 may be substantially situated downstream of the throat 206 of the nozzle tube 202. The upstream-facing surface 112 of the dart 100 may be defined at least partially by a cone, a sphere, a paraboloid, an ellipsoid, a bullet nose shape, a curved cone, or a combination thereof. By virtue of the shape of the upstream-facing surface 112 of the dart 100 and the inwardly-tapered inlet 204, a nozzle structure may be formed as the dart 100 moves upstream and closer to the throat 206; wherein the nozzle structure is preferably adapted for reducing head losses and/or preferably adapted for improving flow rate control sensitivity by increasing control resolution in one or more flow regions around the dart 100.

In some embodiments, the nozzle tube 202 may further comprise a skirt 208 downstream of the throat 206. In some embodiments, the skirt 208 may be straight, short, or missing, as depicted in FIGS. 3-7, 9, 10, and 12, without limitation. In some embodiments, the skirt 208 may be flared with an outwardly-tapered section which is opposite of the inwardly-tapered inlet 204, without limitation. Flaring of the skirt 208, if present, may be linear/frustoconical as depicted in the figures, and/or non-linear (e.g., curved/parabolic in cross-section), without limitation. It should be noted that only linear/frustoconical flaring is depicted for skirt 208 and inwardly-tapered inlet 204; however, curved/parabolic cross-sectional shapes are anticipated.

A method of retrofitting a flotation machine is also disclosed. In some embodiments, the method may comprise the steps of: providing a flotation machine; removing a dart 100 from an upstream side 104 of a wall 110 in the flotation machine; and removing a conventional sealing grommet 101 from an orifice extending through a wall 110 in the flotation machine; wherein the sealing grommet 101 may initially abut an upstream side 104 and a downstream side 106 of the wall 110 adjacent the orifice 102. The method of retrofitting may further include the step of providing a nozzle tube 202 having an inwardly-tapered inlet 204, a skirt 208, and a throat 206 therebetween; and joining the nozzle tube 220 to the wall 110 proximate the orifice 102, wherein a shaft extender 118 may optionally be employed to move a dart 100 further downstream of the orifice 102, without limitation. For example, the shaft extender 118 may be provided and attached between the dart 100 and a shaft

supporting the dart 100, without limitation. An upstream-facing surface 112 of a dart 100 may be positioned downstream of the outwardly-tapered skirt 208, without limitation. The nozzle tube 202 may further comprise an upstream wide end 210 which may be suitable for facilitating the mounting of the nozzle tube 102 to an
5 upstream side 104 or a downstream side 106 of the wall 110.

According to some embodiments, the method may further comprise the step of providing and attaching a shaft extender 118 to move the dart 100 downstream of the orifice 102. In some embodiments, a dart 100 and a nozzle tube (202)
10 configuration may be provided as shown in FIG. 7, such that it possesses the dimensions shown in Table 1.

A method of flotation is also disclosed. In some embodiments, the method may comprise the step of providing the aforementioned valve apparatus. The method
15 may further comprise the step of moving the dart 100 towards or away from the throat 206 of the nozzle tube 202 to adjust flow rate between the nozzle tube 202 and the dart 100. The method may further comprise the step of setting a relative position of the dart 100 with respect to the throat 206 of the nozzle tube 202 (e.g., to control flow rate). In this regard, flow between inner surfaces of the nozzle tube 202
20 and an upstream-facing surface 112 of the dart 100 can be both adjusted and fixed according to process operation needs. By virtue of the two preceding steps, the method may further comprise the step of controlling flow rate from the upstream side 104 of the wall 110 to the downstream side 106 of the wall 110 whilst reducing head losses. By virtue of its design, the nozzle structure of the dart valve apparatus
25 described herein may be advantageously adapted for improving flow rate control sensitivity, for example, by increasing control resolution in one or more flow regions around the dart 100.

It will be appreciated from this disclosure, and the drawings, that various
30 features/components and method steps described herein may be altered without significantly departing from the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

5 To complement the description which is being made, and for the purpose of aiding to better understand the features of the invention, a set of drawings illustrating preferred valve apparatus and methods of using the same is attached to the present specification as an integral part thereof, in which the following has been depicted with an illustrative and non-limiting character. It should be understood that like
10 reference numbers used in the drawings may identify like components. In the figures:

FIGS. 1 and 2 describe or illustrate dart valve apparatus of the prior art; in particular, a conventional linear dart valve apparatus and conventional hinged dart,
15 respectively;

FIGS. 3 and 4 describe or illustrate vertically-arranged linear dart valve apparatus according to some embodiments, comprising a linear-actuated dart having an upstream-facing surface; wherein the linear-actuated dart may comprise an
20 upstream-facing surface forming a portion of a truncated cone, cone, frustrocone, or curved cone, without limitation;

FIGS. 5 and 6 describe or illustrate rotationally-arranged hinged dart valve apparatus according to some embodiments, comprising a hinged dart having an upstream-
25 facing surface; wherein the hinged dart may comprise an upstream-facing surface forming a portion of a truncated cone, cone, frustrocone, or curved cone, without limitation;

FIG. 7 describes or illustrates a cross-section of a vertically-arranged linear dart
30 valve apparatus according to some embodiments; and further depicting certain

preferred, but non-limiting relative dimensions of technical features associated therewith;

FIG. 8 is an isometric representation of a bench-scale test flotation cell bank used to
5 procure the data found in FIGS. 14-21 and 24-26;

FIGS. 9-11 are representative of a hinged valve assembly according to some embodiments; wherein particularly shown are detailed views of the hinged dart apparatus embodiment depicted in FIG. 8;

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FIGS. 12 and 13 are representative of a linear valve assembly according to some embodiments; wherein particularly shown are detailed views of the linear dart apparatus depicted in FIG. 8;

15 FIGS. 14-21 and 24-26 are data comparing the performance of disclosed embodiments of the invention with conventional dart valve designs found in the prior art;

20 FIG. 22 shows a bank of two flotation cells comprising a linear dart valve apparatus according to some embodiments;

FIG. 23 is a close-up view of a portion of FIG. 22 showing more clearly, a non-limiting embodiment of linear dart valve apparatus used to control flow between

25 scaled commercial flotation cells;

FIG. 24 compares the product of flow coefficient and open area (i.e., $C_v \cdot A$, mm²) as a function of opening distance (inches) for both: i) a linear dart valve apparatus according to an embodiment of the present invention, and ii) a standard linear dart

30 valve apparatus of the prior art; and,

FIGS. 25 and 26 compare head loss as a function of flow rate; wherein FIG. 25 shows head loss as a function of flow rate for a linear dart valve apparatus according to some embodiments; and wherein FIG. 26 shows head loss as a function of flow rate for a linear dart valve apparatus according to the prior art;

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In the following, the invention will be described in more detail with reference to drawings in conjunction with exemplary embodiments.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

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FIGS. 1 and 2 describe or illustrate dart valve apparatus according to the prior art. Turning to prior art FIG. 1, a linear dart 100 is traditionally positioned upstream of a wall 110, adjacent an upstream side 104 of the wall 110, and is further positioned upstream of an orifice 102 provided to the wall 110. As shown, a conventional sealing grommet 101, which may have small angled chamfers or radiuses at its edges, may be provided within the orifice 102 to help with sealing and reduce wear to the linear dart 100 when coming into close proximity with the orifice 102.

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As the upstream-facing surface 112 of the dart 100 moves upstream and away from the orifice 102, flow increases between a downstream-facing surface 114 of the dart 100 and the sealing surfaces of the conventional sealing grommet 101 provided within the orifice 102. Flow proceeds around the downstream-facing surface 114 of the dart and through the inside opening of the conventional sealing grommet 101 in the orifice 102, and then to the downstream side 106 of the wall 110. Turbulence generally occurs adjacent the downstream side 106 of the wall 110 adjacent the conventional sealing grommet 101 surfaces surrounding the orifice 102. This turbulence may increase wear or hinder performance of the linear dart 100, and may contribute to hydraulic losses. While not shown, eddy currents and areas of low velocity may additionally form around the upstream-facing surface 112 of the dart

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100.

Turning to prior art FIG. 2, a hinged dart 100 is positioned downstream of a wall 110, adjacent a downstream side 106 of the wall 110, and is further positioned downstream of a conventional sealing grommet 101 provided within an orifice 102 extending through the wall 110. As the upstream-facing surface 112 of the dart 100 moves downstream and away from the orifice 102 and conventional sealing grommet 101 therein, flow increases between the upstream-facing surface 112 of the dart 100 and downstream sealing surfaces of the conventional sealing grommet 101 within the orifice 102. Flow proceeds from the upstream side 104 of the wall to the downstream side 106 of the wall 110 via the central opening (i.e., inner diameter aperture) which extends through the conventional sealing grommet. Turbulence generally occurs adjacent the downstream side 106 of the wall 110 adjacent the conventional sealing grommet 101 surfaces surrounding the orifice 102. This turbulence may increase wear or hinder performance of the hinged dart 100, and may contribute to hydraulic losses.

FIGS. 3, 4, and 7 describe or illustrate improved linear-actuated dart valve apparatus according to some embodiments. Embodiments of the apparatus may comprise a dart 100. As shown, the dart 100 may be provided with a curved upstream-facing surface 112. As shown, the curved upstream-facing surface 112 of the dart 100 may comprise a frustoconical surface; however, while not shown, it is envisaged that the upstream-facing surface 112 may alternatively comprise a portion of a hemisphere, sphere, ellipsoid, paraboloid, bullet nose shape, or a combination thereof, without limitation. In some less desired, but anticipated designs, a periphery of a nozzle tube 202 could comprise be a shape other than round. For example, a dart 100 may comprise a square pyramidal upstream-facing surface 112, and a nozzle tube 202 may be square in transverse cross sectional shape. Many other functional polygonal geometries for peripheries of nozzle tubes 202 and darts 110 are envisioned. Nozzle tubes 202 and darts 110 of different peripheral geometries may be coupled together, without limitation. Alternatively, nozzle tubes 202 and darts 110 of similar peripheral geometries may be coupled together, without limitation.

Turning to FIG. 3, a linear dart 100 is positioned adjacent a downstream side 106 of a wall 110 and also positioned downstream of an orifice 102 provided to the wall 110. The dart 100 is further positioned downstream of a nozzle tube 202 which is secured to the wall 110. The dart 100 is preferably concentrically aligned with the orifice 102 through the wall 110. As the upstream-facing surface 112 of the dart 100 moves downstream and away from the orifice 102 and nozzle tube 202, flow increases between an upstream-facing surface 112 of the dart 100 and inner surfaces of the nozzle tube 202 provided adjacent the orifice 102. Flow proceeds from the upstream side 104 of the wall 110 to the downstream side 106 of the wall 110, through the nozzle tube 202.

The nozzle tube 202 may be mounted to the downstream side 106 of the wall 110, via a mounting flange, as shown in FIG. 3; or, the nozzle tube 202 may be mounted to the upstream side 104 of the wall 110, via a mounting flange, as shown in FIG. 4. Either way, slurry within a flotation cell tank moves through an inwardly-tapered inlet 204 which slowly constricts in diameter, then through a narrower throat portion 206 of the nozzle tube 202, and then finally through a radially-outwardly tapered or flared skirt 208 of the nozzle 202, which slowly expands in diameter, before being discharged into an adjacent flotation cell tank adjacent the nozzle tube's downstream wide end 212.

Embodiments depicted herein may be configured and/or adapted to minimize or eliminate eddy currents and/or areas of low velocity (common with the conventional dart apparatus shown in FIGS. 1 and 2) around an upstream-facing surface 112 of the dart 100, without limitation.

Turbulence may be reduced adjacent a downstream side 106 of the wall 110, for example, adjacent a skirt 208 of the nozzle tube 202, so as to reduce wear and improve performance of a linear dart 100. The embodiment shown in FIG. 3 employs a nozzle tube 202 comprised of an inwardly-tapered inlet 204 having an upstream wide end 210 which constricts down to a narrower throat 206 at its

downstream end. The throat 206 is generally located at a central region of the nozzle tube 202, but it does not necessarily have to be located at a midpoint along the length of the nozzle tube 202. For example, dimension A and B (found in FIG. 7) may not be equal in all embodiments, and could be different. It should be understood that the throat 206 may comprise sharp corners, rounded corners, generally tubular or cylindrical surfaces, and may comprise geometrical variations from what is shown in the drawings.

The nozzle tube 202 shown in FIG. 3 further comprises a skirt 208 extending downstream from the throat 206. The skirt 208, as shown, may flare or taper outwardly and oppositely of the inwardly-tapered inlet 204 to form an hourglass shape or a double-napped cone shape, without limitation.

A downstream-facing surface 114 of the dart 100 may be curved, flat, or disk shaped (as depicted in FIG. 7), or, it may mirror or substantially resemble the upstream-facing surface 112 of the dart 100 (as suggested in FIGS. 3 and 4), without limitation. In some embodiments, the downstream-facing surface 114 of the dart 100 may be planar, as shown, without limitation. While not shown, in some embodiments, the downstream-facing surface 114 of the dart 100 may be pointed, without limitation.

The dart 100 may be solid, hollow, or thin-walled, without limitation. While not shown, the downstream-facing surface 114 of the dart 100 may follow the contour of the upstream-facing surface 112 of the dart 100, forming a "cupped" dart 100 having a uniform thickness, without limitation.

In any of the embodiments described herein, the upstream-facing surface 112 of the dart 100 may have a shape that is complementary to a skirt 208 of a nozzle tube 202, without limitation. While not expressly shown, an upstream-facing surface 112 of a dart 100 may have a shape that substantially matches or is substantially complementary to: i) the shape of a skirt 208 of a nozzle tube 202 and/or ii) the shape of a throat 206 of a nozzle tube 202, without limitation. Where the term is used herein, "shape" may include any "outline," "form," "structure," "profile,"

"geometrical surface feature," or "line in cross-section" (whether taken transversely to a flow axis or taken from a side along a flow axis), without limitation.

For example, in some embodiments, an upstream-facing surface angle " α " may be equal to skirt angle " Φ ", without limitation (see FIG. 7). However, some preferred
5 embodiments may include an upstream-facing surface angle " α " which is different than skirt angle " Φ ". In the particular non-limiting exemplary embodiment shown in FIG. 7, the upstream-facing surface angle " α " is less than the skirt angle " Φ " by approximately 15 degrees (e.g., wherein " α " is approximately 45 degrees, and the
10 skirt angle " Φ " is approximately 55 degrees, without limitation.

Moreover, in any of the embodiments described herein, the orifice 102 may be defined by a portion of the nozzle tube 202, without limitation. The nozzle tube 202 may be provided as an extension of the wall 110, without limitation. The nozzle tube
15 202 may be provided as an extension of the orifice 102, without limitation. The wall 110, orifice 102, and nozzle tube 202 may be formed as one homogenous, monolithic structure; or, the wall 110, orifice 102, and nozzle tube 202 may be formed as a collection of permanently-joined or separably-joined modular units, without limitation. The nozzle tube 202 or portions thereof may comprise a different
20 material than the wall 110 or orifice 102, without limitation. The nozzle tube 202 may comprise an insert which is attached to a wall 110 adjacent the orifice 102. The nozzle tube 202 may be formed or extruded from one or more portions of the wall 110 or orifice 102, without limitation. For example, a nozzle tube 202 may be drawn from material in the wall 110, without limitation. Tools, presses, punches, dies, or
25 other fabrication machinery may be used to create a nozzle tube 202 which is monolithically integral with wall 110, without limitation.

Turning to FIG. 4, a linear dart 100 may be positioned adjacent a downstream side 104 of a wall 110 and also positioned downstream of an orifice 102 provided to the
30 wall 110. As the upstream-facing surface 112 of the dart 100 moves downstream and away from the orifice 102, flow may increase between an upstream-facing

surface 112 of the dart 100 and a nozzle tube 202 provided to the orifice 102. Flow proceeds from the upstream side 104 of the wall 110 to the downstream side 106 of the wall 110. A nozzle tube 202 may be secured to the wall 110 and be positioned between the wall 110 and the dart 100. The nozzle tube 202 may be further
5 positioned between the orifice 102 and the dart 100. As shown, the nozzle tube 202 may be secured to the wall 110 at its upstream wide end 210. As shown, the nozzle tube 202 may be secured to the upstream side 104 of the wall 110, without limitation.

Turbulence may be reduced adjacent the downstream side 106 of the wall 110, for
10 example, adjacent a throat 206 of the nozzle tube 202, so as to reduce wear and improve performance of the linear dart 100. The embodiment shown in FIG. 4 employs a nozzle tube 202 comprised of an inwardly-tapered inlet 204 having an upstream wide end 210 and a narrower throat 206. A downstream-facing surface 114 of the dart 100 may be curved, pointed, or may mirror the upstream-facing
15 surface 112 of the dart 100, without limitation. Alternatively, the downstream-facing surface 114 of the dart 100 may be planar, as shown, without limitation. The dart 100 may be solid, hollow, or thin-walled, without limitation. The downstream-facing surface 114 of the dart 100 may follow the contour of the upstream-facing surface 114 of the dart 100, forming a "cupped" dart, without limitation.

20 Turning to FIGS. 5 and 6, a hinged dart 100 may be positioned adjacent a downstream side 104 of a wall 110 and also positioned downstream of an orifice 102 provided to the wall 110. As the upstream-facing surface 112 of the dart 100 moves downstream and away from the orifice 102, flow increases between an upstream-
25 facing surface 112 of the dart 100 and a skirt 206 of a nozzle tube 202 which is provided adjacent to the orifice 102. Flow proceeds from the upstream side 104 of the wall 110 to the downstream side 106 of the wall 110 through a throat 206 via the nozzle tube 202.

30 Turbulence may be reduced adjacent the downstream side 106 of the wall 110, for example adjacent a skirt 208 of the nozzle tube 202, so as to reduce wear and

improve performance of the linear dart 100. The embodiment shown in FIG. 5 employs a nozzle tube 202 comprised of an inwardly-tapered inlet 204 having an upstream wide end 210 and a narrower throat 206 at the downstream side of the inwardly-tapered inlet 204. The nozzle tube 202 further comprises a skirt 208
5 extending downstream from the throat 206. The skirt 208, as shown, may flare or taper outwardly in relation to the throat 206.

As with the embodiments discussed heretofore, a downstream-facing surface 114 of the dart 100 may be curved, pointed, or may mirror the upstream-facing surface 112
10 of the dart 100; or, the downstream-facing surface 114 of the dart 100 may be planar, as shown, without limitation. The dart 100 may be solid, hollow, or thin-walled, without limitation. The downstream-facing surface 114 of the dart 100 may follow the contour of the upstream-facing surface 114 of the dart 100, forming a
"cupped" dart, without limitation. FIG. 6 depicts an embodiments very similar to the
15 one shown in FIG. 5, except for the nozzle tube 202 being affixed to the upstream side 104 of the wall 110, rather than to the downstream side 106 of the wall 110.

As will be hereinafter described in further detail, FIG. 7 shows several non-limiting exemplary relative dimensions which may be employed for nozzle tubes 202
20 according to embodiments of the invention.

It should be understood that in any of the disclosed embodiments discussed or depicted herein, the skirt 208 of a nozzle tube 202 may have a similar taper or a different taper to that of the upstream-facing surface 112 of the dart 100, without
25 limitation. A downstream-facing surface 114 of the dart 100 may be pointed, truncated, or may mirror the upstream-facing surface 112 of the dart 100; or, the downstream-facing surface 114 of the dart 100 may be planar, as shown, without limitation. The dart 100 may be solid, hollow, or thin-walled, without limitation. The downstream-facing surface 114 of the dart 100 may follow the contour of the
30 upstream-facing surface 114 of the dart 100, forming a cupped dart, without limitation. While not shown, any of the embodiments described herein may comprise

a dart 100 provided with a curved upstream-facing surface 112, which may comprise a portion of a hemisphere or sphere, a portion of an ellipsoid, a portion of a paraboloid, a portion of a bullet nose shape, or a combination thereof, without limitation.

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According to some embodiments, a downstream-facing surface 114 of the dart 100 may smoothly blend into a link or other portion of a hinge mechanism, without limitation. , without limitation.

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FIG. 8 is an isometric representation of a bench-scale test unit used to gather the data shown in FIGS. 14-20. As shown, one or more hinged dart valve apparatus employing the novel and inventive concepts and features discussed herein may be advantageously provided to a vertically-extending wall 110 separating two tanks of neighboring flotation cells 300, without limitation. Moreover, one or more linear dart valve apparatus employing the novel and inventive concepts and features discussed herein may be advantageously provided to a horizontally-arranged wall 110 separating flotation cell tanks, without limitation.

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20 FIGS. 9-11 represent a hinged valve assembly according to some embodiments. In particular, FIGS. 9-11 show detailed views of the hinged dart valve apparatus depicted in FIG. 8. FIG. 9 shows a dart 100 in operable communication with a nozzle tube 202. Due to the clearances and geometries between the dart 100 and inner surfaces of the nozzle tube 202, smooth nozzle flow and/or lower head losses
25 may be achieved. FIG. 10 shows another view of the nozzle tube 202 shown in FIG. 9; however, the optional mounting plate 216 has been removed from FIG. 10 for clarity. As shown, the nozzle tube 202 may incorporate an inwardly tapered inlet 204 comprising an upstream wide end 210, a narrower throat 206, and an optional skirt 208, which may be flared outwardly and opposite of the inwardly-tapered section
30 204. While the downstream-facing surface 114 shown in FIGS. 9 and 11 is generally planar; it is envisaged that many other shapes for downstream-facing surfaces 114

may be employed, without limitation. The inventors believe that the upstream-facing surface 112 of a dart 100 may be more critical to obtaining smooth nozzle flow and minimizing turbulence than the downstream-facing surface 114 of a dart 100. FIG. 11 shows a detailed view of the test dart 100 shown in FIGS. 8 and 9.

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FIGS. 12 and 13 represent a linear valve assembly according to some embodiments. In particular, FIGS. 12 and 13 show detailed views of the linear dart valve apparatus depicted in FIG. 8. The figures show respective upper and lower views a dart 100 in operable communication with a nozzle tube 202. Due to the clearance between the upstream-facing surface 112 of the dart 100 and inner surfaces of the nozzle tube 202, smooth nozzle flow and/or lower head losses may be achieved. As shown, the nozzle tube 202 may incorporate an inwardly tapered inlet 204 comprising an upstream wide end 210, a narrower throat 206, and an optional skirt 208, which may be flared outwardly and opposite of the inwardly-tapered inlet 204. While the downstream-facing surface 114 shown in FIG. 13 is generally planar; it is envisaged that many other shapes for downstream-facing surfaces 114 may be employed, without limitation. The inventors believe that the upstream-facing surface 112 of the dart 100 may be more critical to obtaining smooth nozzle flow and minimizing turbulence than the downstream-facing surface 114 of the dart 100.

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FIGS. 14-21 are data comparing the performance of newly disclosed embodiments of dart valve apparatus incorporating certain inventive features and concepts disclosed herein with those conventional devices found in the prior art (e.g., prior art FIGS. 1 and 2). Clearly, as demonstrated by FIG. 14 a smaller pressure drop may be exhibited by embodiments of the claimed invention for a given stroke length of movement. Moreover, as demonstrated by FIG. 15 a higher velocity of flow can be achieved (e.g., via embodiments of the claimed invention which employ darts 100 having an upstream-facing surface 112 that comprises a portion of a sphere), for a given stroke length of movement. The inventors believe that similar effects may be achieved using ellipsoid, paraboloid, bullet nose, and curved cone shapes as well. Additionally, as evidenced by FIG. 16, loss coefficients may be drastically reduced

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for a given stroke length of movement with the embodiments discussed and claimed herein.

FIG. 17 is a table describing head loss and head loss change (%) as a function of different flow rates. As shown, head losses may be reduced (at varying flow rates) through the provision of dart valve apparatus embodiments described herein, rather than dart valve apparatus of the prior art.

FIG. 18 is a table describing head loss and head loss change (%) as a function of different opening distance (measured in inches). As can be inferred from the table, head loss may be reduced (at varying opening distances) by employing embodiments discussed herein, rather than dart valve apparatus of the prior art.

FIG. 19 graphically illustrates head loss as a function of flow rate for various linear dart valve apparatus embodiments of the present invention. FIG. 26 also compares the results with prior art conventional linear dart valve apparatus. Clearly, head losses exhibited from embodiments of the present invention may be less than that which may be exhibited from prior art dart designs.

FIG. 20, when compared to FIG. 21, graphically suggests that head losses may not only be lower with hinged dart apparatus embodiments of the present invention (over prior art conventional designs), but that embodiments described herein may also exhibit more predictable or more uniform head losses across many different opening distances.

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FIG. 22 illustrates an embodiment wherein two flotation cells 300 may be placed in series, to form a flotation cell bank or circuit. An upstream flotation cell 300 may comprise the inventive linear dart valve apparatus disclosed herein, in order to control a flow of slurry or pulp therebetween. A horizontally-extending wall 110 of the upstream flotation cell 300 forms a bottom of the tank of the upstream flotation

cell 300. The wall 110 comprises two linear dart valve apparatus in accordance with the invention. Each linear dart valve apparatus shown in the exemplary figure comprises a nozzle tube 202 adjacent an orifice provided to the wall 110. In the particular embodiment shown, each nozzle tube 202 comprises an upstream
5 inwardly-tapered section, a throat, and a downstream skirt which is flared outwardly and opposite of the inwardly-tapered section.

The embodiment shown in FIG. 22 further comprises conical darts 100 which are each moved vertically, towards or away from its respective nozzle tube 202 via an
10 actuating mechanism 116 provided to the flotation cell 300. FIG. 23 is a close-up view of the linear dart valve apparatus shown in FIG. 22. Downstream flotation cells 300 may comprise similar linear dart valve apparatus, without limitation.

FIG. 24 shows the product of flow coefficient and open area ($C_v \cdot A$, mm^2), as a
15 function of opening distance (inches) for two different linear dart valve apparatus. The figure compares a vertically-arranged and oriented linear dart valve apparatus according to an embodiment of the invention, with a standard vertically-arranged and oriented linear dart valve apparatus of the prior art. As can be inferred from the drawing, that with embodiments of the present invention, the product of flow
20 coefficient and open area ($C_v \cdot A$, mm^2) can be made more consistent/constant over a range of various opening distances than with conventional linear dart valve apparatus.

Turning now to FIGS. 25 and 26, it can be inferred that linear valve apparatus
25 according to embodiments the invention may exhibit lower head losses than conventional prior art dart valves at similar flow rates. Moreover, FIGS. 25 and 26 suggest that higher flow rates may be possible with linear valve apparatus embodiments – particularly for small opening distances.

Conventional linear dart valve apparatus provided to an upstream portion of an
30 orifice can generate areas of low velocity and eddies upstream of the orifice. These hydrodynamic anomalies may lead to increased head losses or flow rate limitations

at small opening distances. Furthermore, hot spots of very high velocity may occur downstream of an orifice provided to a wall, when using a conventional dart valve apparatus. These very high velocity hot spots may increase the chances of wear to surrounding flotation components, or may negatively affect flotation operations. Dart valve apparatus according to embodiments of the present invention may comprise a
5 dart provided to a downstream portion of an orifice, and this can reduce or eliminate areas of low velocity or eddies upstream of the orifice. By smoothing out flows upstream of the orifice, head losses may be reduced, and greater flow rates may be achievable at smaller opening distances. Hot spots having very high flow velocities
10 may be mitigated or eliminated – in particular, mitigated or eliminated downstream of orifice when provided with a dart arrangement as taught herein. Rather than hot spots of very high velocity flow, small areas of moderate velocity flows may occur between a throat 206 or skirt 208 area of a nozzle tube 202 and an upstream-facing surface 112 of a dart 100. By reducing or eliminating hot spots via the employment
15 of a dart valve apparatus according to various embodiments of the invention, wear to surrounding flotation components due to abrasive/erosive slurries may be reduced.

The disclosure of every patent, patent application, and publication cited herein is hereby incorporated herein by reference in its entirety.

20 While this subject matter has been disclosed with reference to specific embodiments, it is apparent that other embodiments and variations can be devised by others skilled in the art without departing from the true spirit and scope of the subject matter described herein. The appended claims include all such embodiments and
25 equivalent variations.

For example, nozzle tube 202, while shown as comprising two generally frustoconical shells, portions of the nozzle tube 202 could comprise portions of a convergent-divergent nozzle. For example, embodiments may include a nozzle tube
30 202 which resembles a De Laval nozzle structure, without limitation.

While not expressly shown, in some embodiments, portions of a nozzle tube 202 may be curved, rather than straight or angled in cross-section. For example, some embodiments of a nozzle tube 202 may be provided with a smooth tubular hourglass shape. Other embodiments of a nozzle tube 202 may comprise a double-napped cone, without limitation. In some embodiments, the nozzle tube 202 may function as a nozzle and/or venturi tube, without limitation.

In some embodiments, the inlet 204 of the nozzle tube 202 may comprise a different peripheral shape than the peripheral shape of the skirt 208, without limitation.

In some embodiments, the nozzle tube 202 may be asymmetric in shape, along its direction of fluid flow, about the throat 206 of the nozzle tube 202 – wherein the inwardly-tapered inlet 204 may be geometrically profiled differently from the outwardly-tapered skirt 208. In some embodiments, the nozzle tube 202 may be symmetric in shape, about the throat 206, wherein the inwardly-tapered inlet 204 may be identical to and/or perfectly mirror the outwardly-tapered skirt 208, without limitation.

Referring to the labeled dimensions shown in FIG. 7, the below table represents various exemplary, non-limiting embodiments:

Table 1.

Dimension	As shown (FIG. 7)	Anticipated non-limiting exemplary embodiments
A	0.3175D	(0.25-0.375)D
B	0.3663D	(0.16-0.6)D
C	1.025D	(1.0-1.2)D
D	D	D
E	1.5D	(0.5-2.5)D
F	1.358D	(0.3-2.4)D
α	45 deg.	20-70 deg.
Φ	55 deg.	30-80 deg.
Θ	60 deg.	35-85 deg.

Values listed in the table above are not fully inclusive and/or exhaustive.

- 5 Accordingly, not all possible embodiments are adequately captured in the table, and other possible variants than what are shown may be anticipated or expected in light of this disclosure.

Per the above table, Dimension "A" in FIG. 7 may be approximately 0.25 to
 10 approximately 0.375 times dimension "D", without limitation; for example, 0.3175D as shown. Per the above table, Dimension "B" in FIG. 7 may be approximately 0.16 to approximately 0.6 times dimension "D", without limitation; for example, 0.3663D as shown. Per the above table, Dimension "C" in FIG. 7 may be approximately 1.0 to approximately 1.2 times dimension "D", without limitation; for example, 1.025D as
 15 shown. Per the above table, Dimension "E" in FIG. 7 may be approximately 0.5 to approximately 2.5 times dimension "D", without limitation; for example, 1.5D as shown. Per the above table, Dimension "F" in FIG. 7 may be approximately 0.3 to approximately 2.4 times dimension "D", without limitation; for example, 1.358D as shown.

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Per the above table, upstream-facing surface angle " α " in FIG. 7 may be between approximately 20 degrees and approximately 70 degrees, without limitation; for example, approximately 45 degrees as shown. Per the above table, skirt angle " Φ " in FIG. 7 may be between approximately 30 degrees and approximately 80 degrees, without limitation; for example, approximately 55 degrees as shown. Per the above table, inlet angle " Θ " in FIG. 7 may be between approximately 35 degrees and approximately 85 degrees, without limitation; for example, approximately 60 degrees as shown.

10 The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated and governed only by the appended claims, rather than by the foregoing description. All embodiments which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

15 A contractor or other entity may provide a flotation valve apparatus or operate a flotation valve apparatus in whole, or in part, as shown and described. For instance, the contractor may receive a bid request for a project related to designing, fabricating, installing, or operating a flotation valve apparatus substantially shown and described herein. Or, the contractor may offer or propose a project related to designing, fabricating, installing, or operating a flotation valve apparatus as substantially shown and described herein.

A contractor, fabricator, or end user may also design or offer to design valve apparatus described herein, one or more components thereof, and/or a process for a client involving one or more of the inventive features or concepts shown and described herein. The contractor may provide, for example, any one or more of the devices or inventive features thereof which are shown and described or inherently taught herein. The contractor may provide such devices or inventive features by selling those devices/inventive features or by offering to sell those devices/inventive features.

The contractor may provide various embodiments of flotation valve apparatus that may be sized, shaped, and/or otherwise uniquely configured or adapted to meet the design criteria of a particular client or customer, without departing from the scope of the invention. The contractor may subcontract the fabrication, delivery, sale, installation, or operation of a component of any of the devices disclosed, or of other devices used to provide said component and/or devices. The contractor may also survey a site and design or designate one or more storage areas for storing the material used to manufacture the components and/or the devices, or for storing the components and/or the devices.

The contractor may also maintain, modify, or upgrade the provided components and/or devices. The contractor may provide such maintenance, modifications, or upgrades by subcontracting such services or by directly providing those services or components needed for said maintenance, modifications, or upgrades; and, in some cases, the contractor may modify a preexisting flotation apparatus or existing valve apparatus of a flotation circuit, subassemblies thereof, components thereof, and/or parts thereof, with one or more "retrofit kits" to arrive at a modified valve apparatus or a method of operating or refurbishing a valve apparatus comprising one or more of the method steps, devices, components, or features of the systems and processes discussed herein.

Although the invention has been described in terms of particular embodiments and applications, one of ordinary skill in the art, in light of this teaching, can generate additional embodiments and modifications without departing from the spirit of or exceeding the scope of the claimed. Accordingly, it is to be understood that the drawings and descriptions herein are proffered by way of example to facilitate comprehension of the invention and should not be construed to limit the scope thereof.

30

REFERENCE NUMERAL IDENTIFIERS

	100	dart
	101	conventional sealing grommet
5	102	orifice
	104	upstream side
	106	downstream side
	110	wall (vertical or horizontal)
	112	upstream-facing surface
10	114	downstream-facing surface
	116	actuating mechanism
	118	shaft extender
	120	first coupling end
	122	second coupling end
15	202	nozzle tube
	204	inwardly-tapered inlet
	206	throat (e.g., nozzle venturi)
	208	outwardly-tapered skirt
	210	upstream wide end
20	212	downstream wide end
	214	mount (e.g., radially-extending flange; radially-outwardly- or radially-inwardly- extending flange)
	216	mounting plate
	300	flotation cell
25	A	first height
	B	second height
	C	dart diameter
	D	throat diameter
	E	downstream exit diameter
30	F	upstream inlet diameter
	α	upstream-facing surface angle
	Φ	skirt angle
	Θ	inlet angle (between 40 and 80 degrees, e.g., as 60 degrees as shown)

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CLAIMS

1. A valve apparatus for use with flotation cells and configured to control flow rate to or from a flotation cell, the valve apparatus being provided to a wall (110), the wall (110) being provided with an orifice (102), the valve apparatus further comprising a dart (100) which is configured to be actuated and moved linearly with respect to the orifice (102) or non-linearly with respect to the orifice (102) via a hinge; such that in use, the dart (100) may change its proximity with respect to the orifice (102) in order to control flow rate therebetween; the dart (100) comprising an upstream-facing surface (112) and a downstream-facing surface (114),

CHARACTERISED IN THAT:

the valve apparatus comprises a nozzle tube (202) for attaching to the wall (110) adjacent the orifice (102), the nozzle tube (202) being provided between the orifice (102) and the dart (100); the nozzle tube (202) being configured such that during use, the dart (100) does not come into direct contact with the orifice (102) provided to the wall (100); the nozzle tube (202) comprising an inwardly-tapered inlet (204) which narrows from an upstream wide end (210) to a throat (206) of smaller diameter, the throat (206) being provided downstream of the upstream wide end (210);

wherein the interior of the inwardly-tapered inlet (204) is wider adjacent the upstream wide end (210); and wherein the interior of the inwardly tapered inlet (204) is narrower at the throat (206), the upstream wide end (210) of the inwardly-tapered inlet (204) being located proximate an upstream side (104) of the nozzle tube (202); the narrower throat (206) being located proximate a downstream side (106) of the nozzle tube (202) which is closer to the upstream-facing surface (112) of the dart (100) than the upstream wide end (210); the dart (100) being located downstream of the nozzle tube (202);

wherein both the upstream-facing surface (112) of the dart (100) and the downstream-facing surface (114) of the dart (100) are downstream of the throat (206) of the nozzle tube (202); the upstream-facing surface (112) of the dart (100)

being defined at least partially by a cone, a sphere, a paraboloid, an ellipsoid, a bullet nose shape, a curved cone, or a combination thereof;

wherein by virtue of the shape of the upstream-facing surface of the dart (100) and the inwardly-tapered inlet (204), a nozzle structure is formed as the dart (100) moves upstream or closer to the throat (206); the nozzle structure being adapted for reducing head losses and/or adapted for improving flow rate control sensitivity by increasing control resolution in one or more flow regions around the dart (100).

2. The valve apparatus according to claim 1, wherein the nozzle tube (202) further comprises a skirt (208) downstream of the throat (206).

3. The valve apparatus according to claim 2, wherein the skirt (208) is straight.

4. The valve apparatus according to claim 2, wherein the skirt (208) is flared with an outwardly-tapered section which is opposite of the inwardly-tapered inlet (204).

5. A method of reducing head losses from flows to or from a flotation cell, the method comprising:

providing a valve apparatus for use with flotation cells and configured to control flow rate to or from a flotation cell, the valve apparatus being provided to a wall (110), the wall (110) being provided with an orifice (102), the valve apparatus further comprising a dart (100) which is configured to be actuated and moved linearly with respect to the orifice (102) or non-linearly with respect to the orifice (102) via a hinge; such that in use, the dart (100) may change its proximity with respect to the orifice (102) in order to control flow rate therebetween; the dart (100) comprising an upstream-facing surface (112) and a downstream-facing surface (114),

CHARACTERISED IN THAT:

the valve apparatus comprises a nozzle tube (202) for attaching to the wall (110) adjacent the orifice (102), the nozzle tube (202) being provided between the orifice (102) and the dart (100); the nozzle tube (202) being configured such that during use, the dart (100) does not come into direct contact with the orifice (102)

provided to the wall (100); the nozzle tube (202) comprising an inwardly-tapered inlet (204) which narrows from an upstream wide end (210) to a throat (206) of smaller diameter, the throat (206) being provided downstream of the upstream wide end (210);

5 wherein the interior of the inwardly-tapered inlet (204) is wider adjacent the upstream wide end (210); and wherein the interior of the inwardly tapered inlet (204) is narrower at the throat (206), the upstream wide end (210) of the inwardly-tapered inlet (204) being located proximate an upstream side (104) of the nozzle tube (202); the narrower throat (206) being located proximate a downstream side (106) of the
10 nozzle tube (202) which is closer to the upstream-facing surface (112) of the dart (100) than the upstream wide end (210); the dart (100) being located downstream of the nozzle tube (202);

 wherein both the upstream-facing surface (112) of the dart (100) and the downstream-facing surface (114) of the dart (100) are downstream of the throat
15 (206) of the nozzle tube (202); the upstream-facing surface (112) of the dart (100) being defined at least partially by a cone, a sphere, a paraboloid, an ellipsoid, a bullet nose shape, a curved cone, or a combination thereof;

 wherein by virtue of the shape of the upstream-facing surface (112) of the dart (100) and the inwardly-tapered inlet (204), a nozzle structure is formed as the dart
20 (100) moves upstream or closer to the throat (206); the nozzle structure being adapted for reducing head losses;

 the method further comprising:

 moving the dart (100) towards or away from the throat (206) of the nozzle tube (202) to adjust flow rate;

25 setting the relative position of the dart (100) with respect to the throat (206) of the nozzle tube (202); and,

 by virtue of the two preceding steps, controlling flow rate from the upstream side (104) of the wall (110) to the downstream side (106) of the wall (110) whilst reducing head losses.

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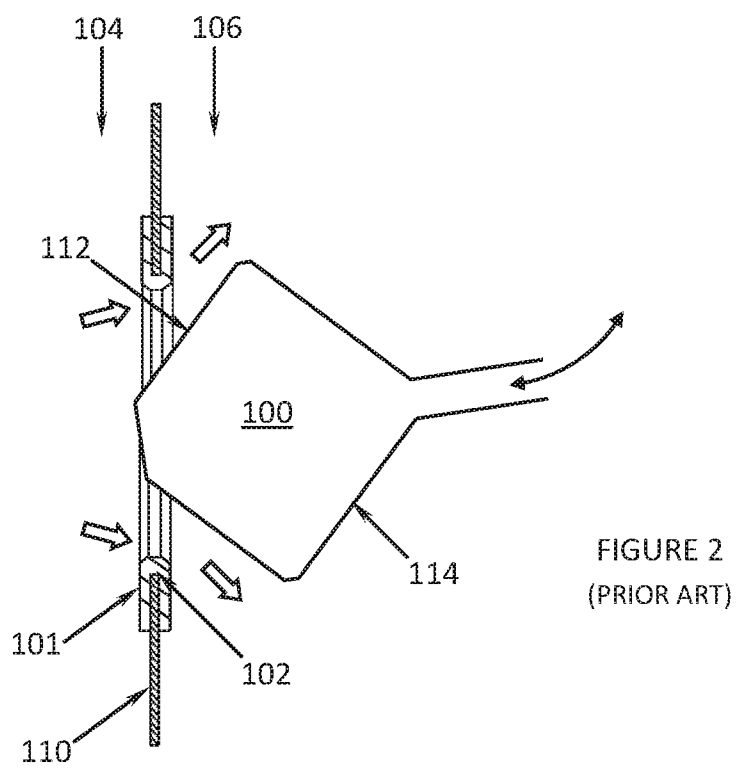
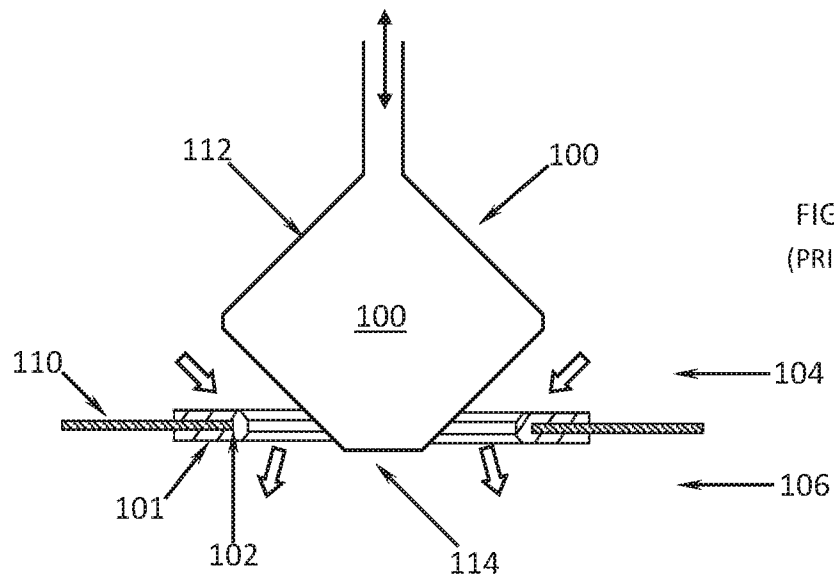
6. The method according to claim 5, wherein by virtue of its design, the nozzle structure is further adapted for improving flow rate control sensitivity by increasing control resolution in one or more flow regions around the dart (100).

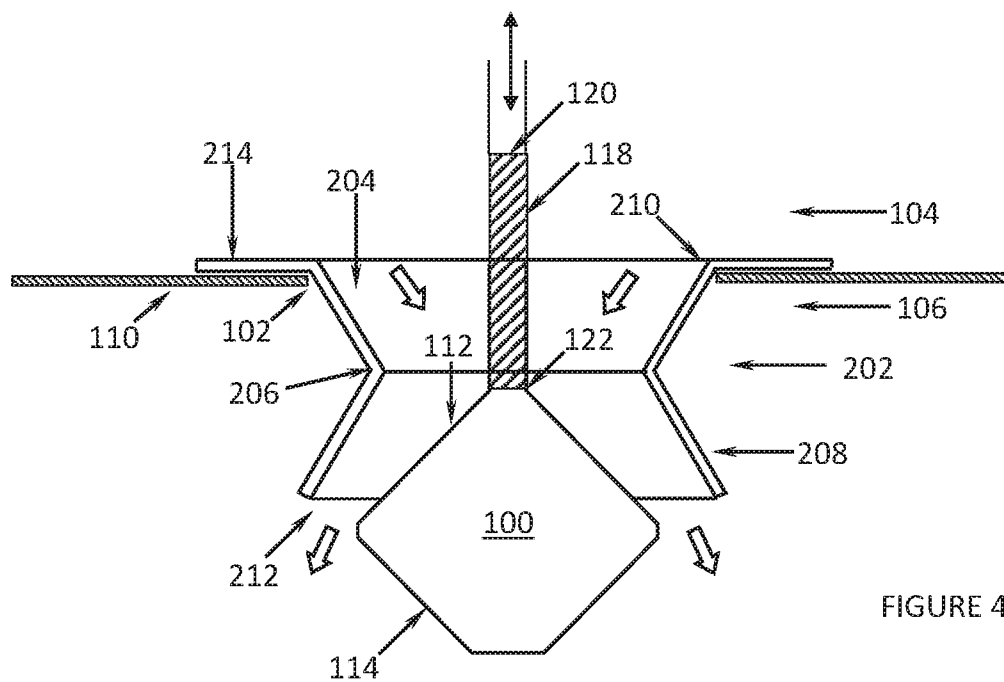
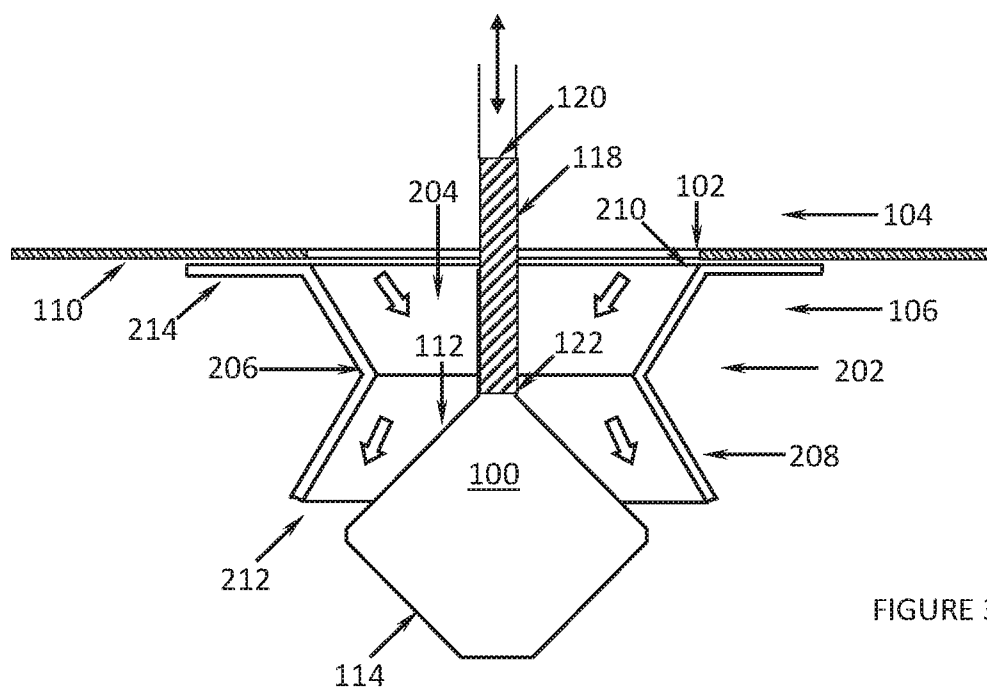
- 5 7. A method of retrofitting a flotation machine comprising:
providing a flotation machine; CHARACTERISED IN THAT the method
comprises the following steps:
removing a dart (100) from an upstream side (104) of a wall (110) in the
flotation machine; removing a conventional sealing grommet (101) from an orifice
10 (102), the orifice (101) extending through the wall (110) in the flotation machine, the
sealing grommet (101) abutting an upstream side (104) and a downstream side
(106) of the wall (110) adjacent the orifice (102);
providing a nozzle tube (202) having an inwardly-tapered inlet (204), an
outwardly-tapered skirt (208), and a throat (206) therebetween;
15 joining the nozzle tube (202) to the wall (110) and proximate the orifice (102);
and,
positioning an upstream-facing surface (112) of a dart (100) downstream of
the outwardly-tapered skirt (208).

- 20 8. The method according to claim 7, wherein the nozzle tube (202) further
comprises an upstream wide end (210) having a mount (214) which is suitable for
facilitating the mounting of the nozzle tube (102) to an upstream side (104) and/or a
downstream side (106) of the wall (110).

- 25 9. The method according to claim 7 or 8, further comprising the step of providing
and attaching a shaft extender (118) to move the dart (100) downstream of the
orifice (102).

10. A dart (100) and nozzle tube (202) configuration as shown in FIG. 7 or FIG.
30 10, and having the dimensions shown in column 3 of Table 1.





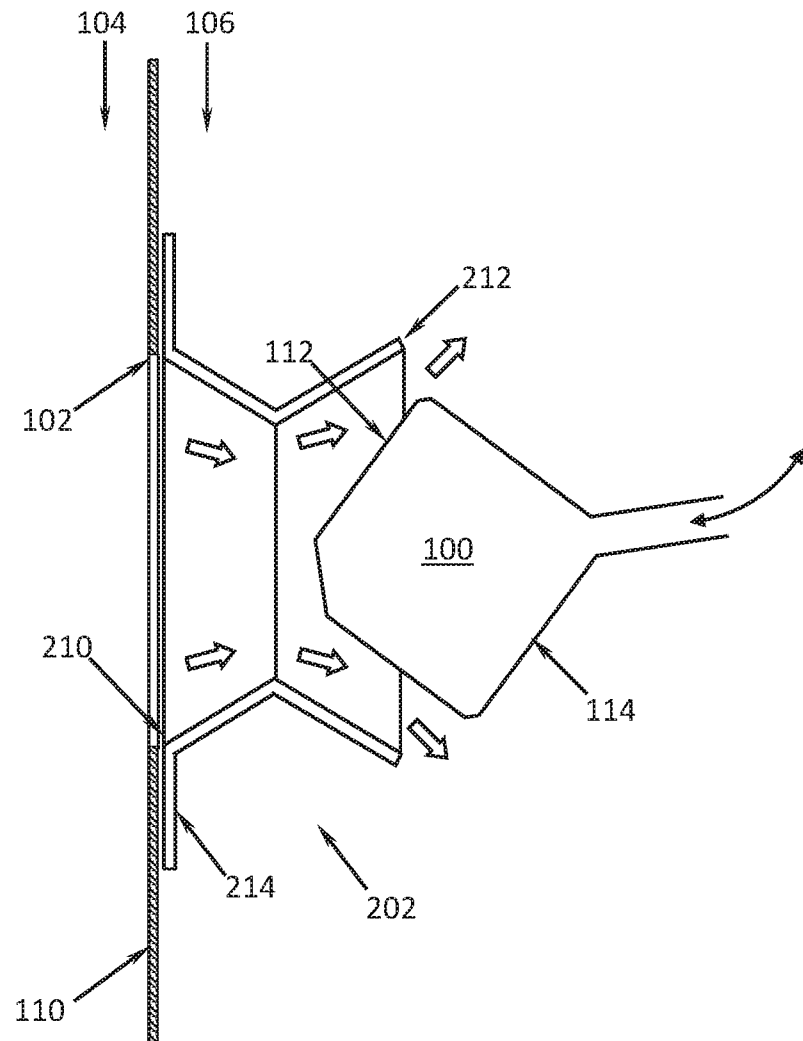


FIGURE 5

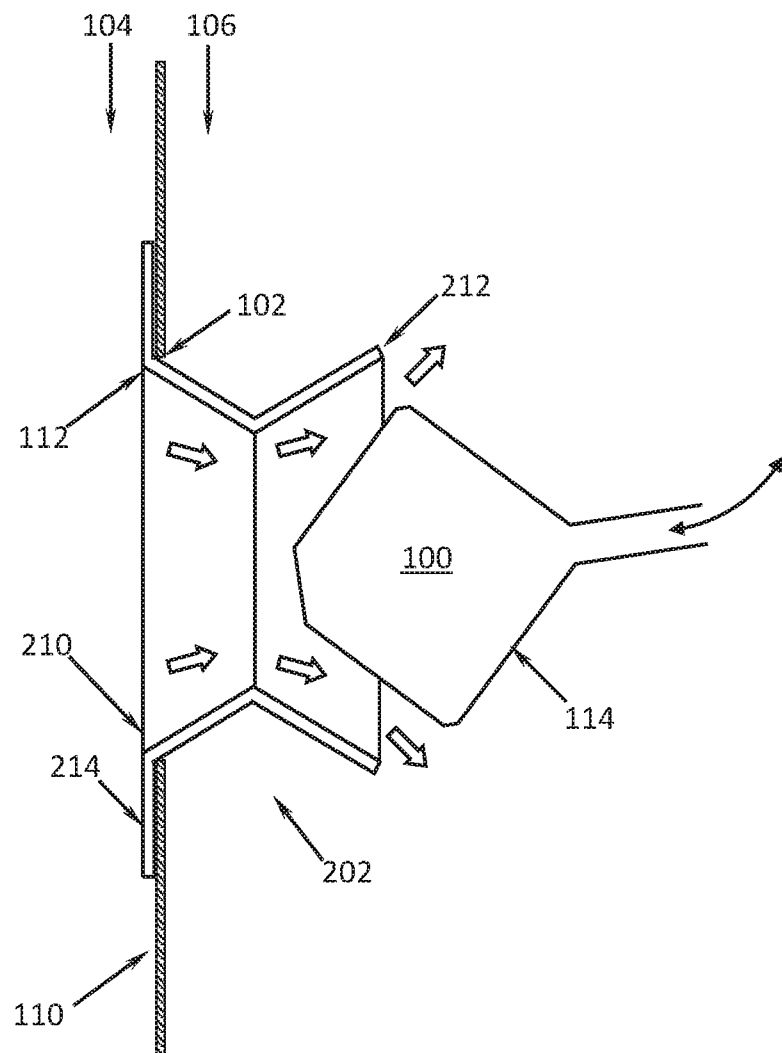


FIGURE 6

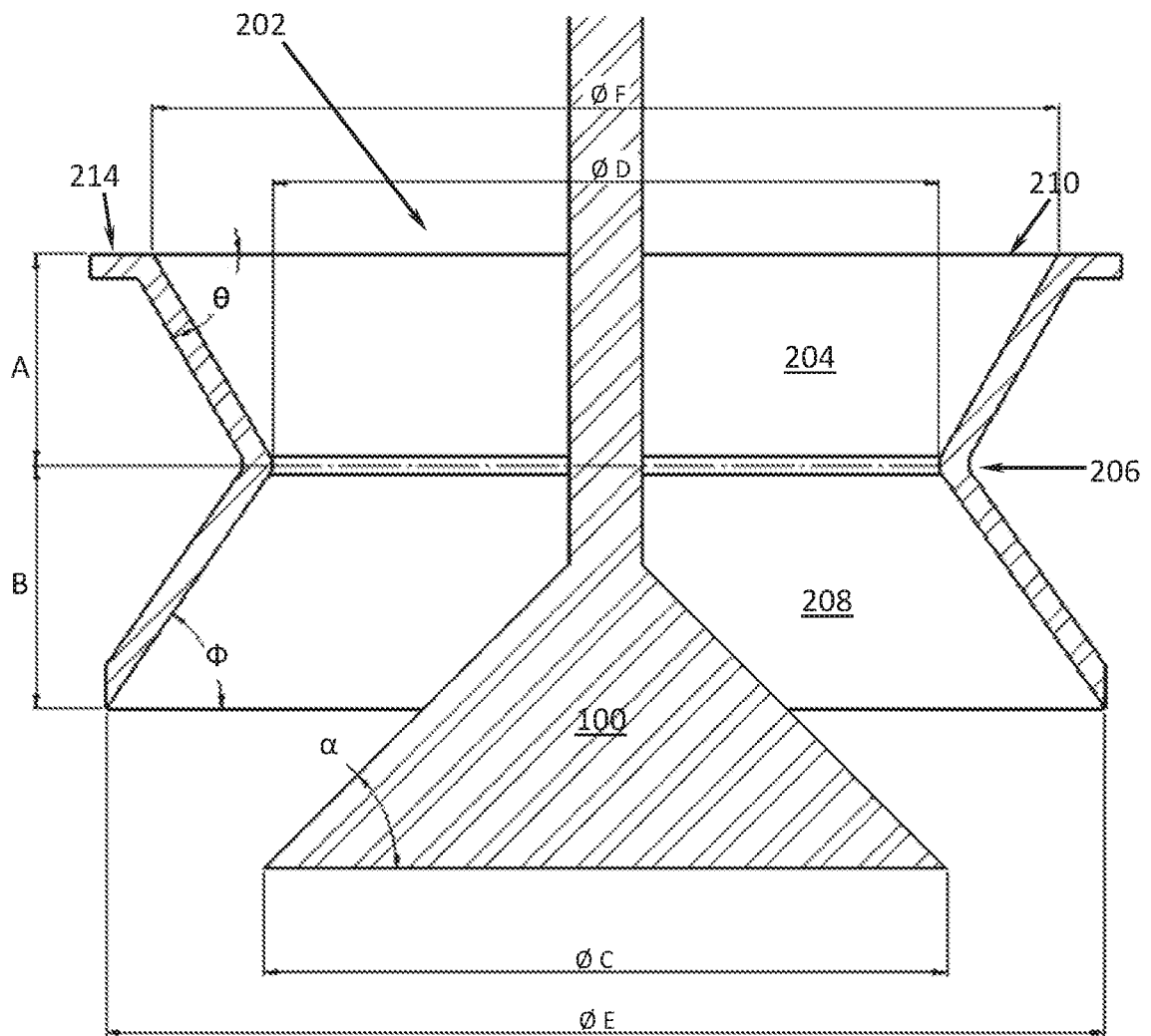


FIGURE 7

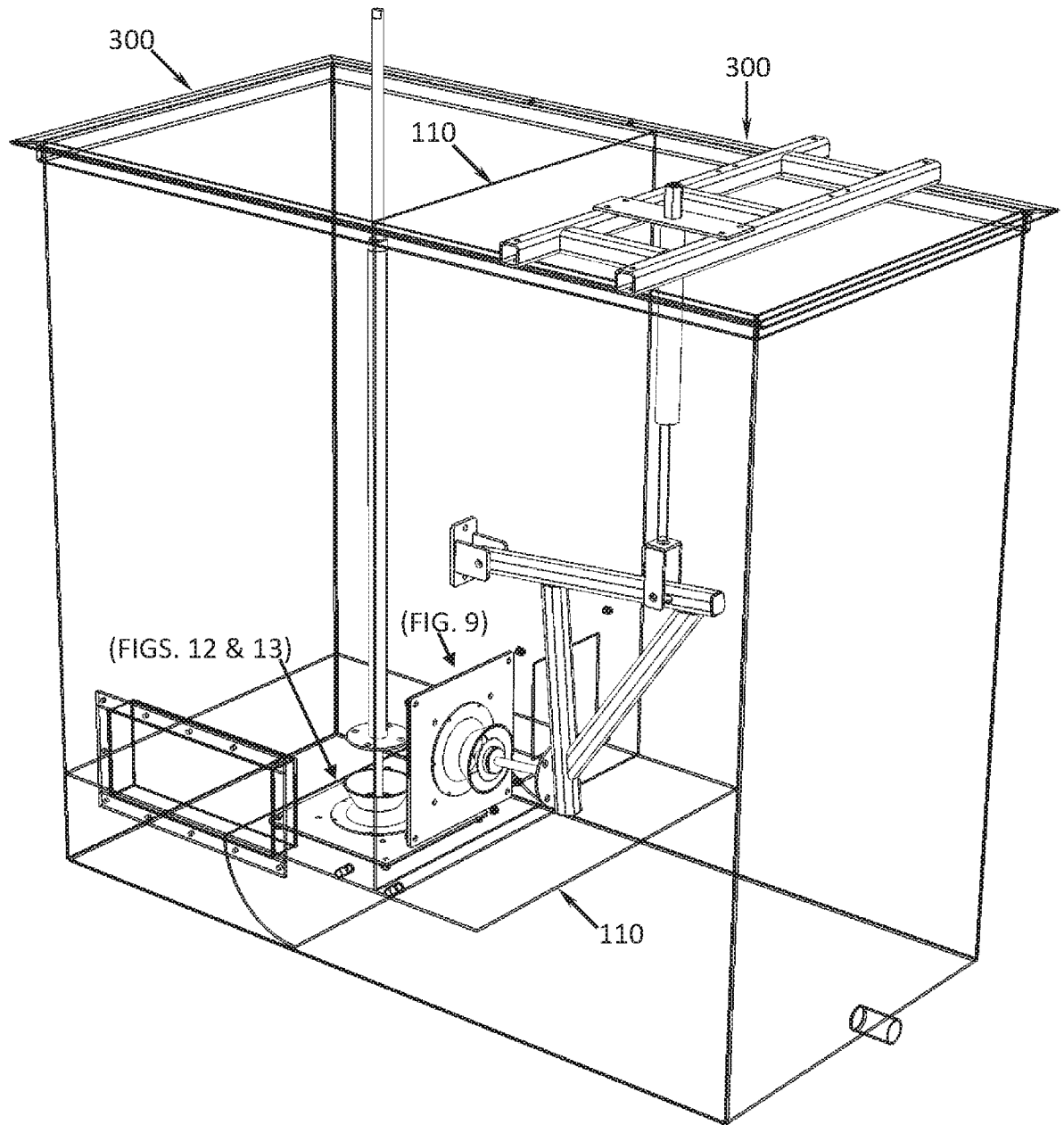


FIGURE 8

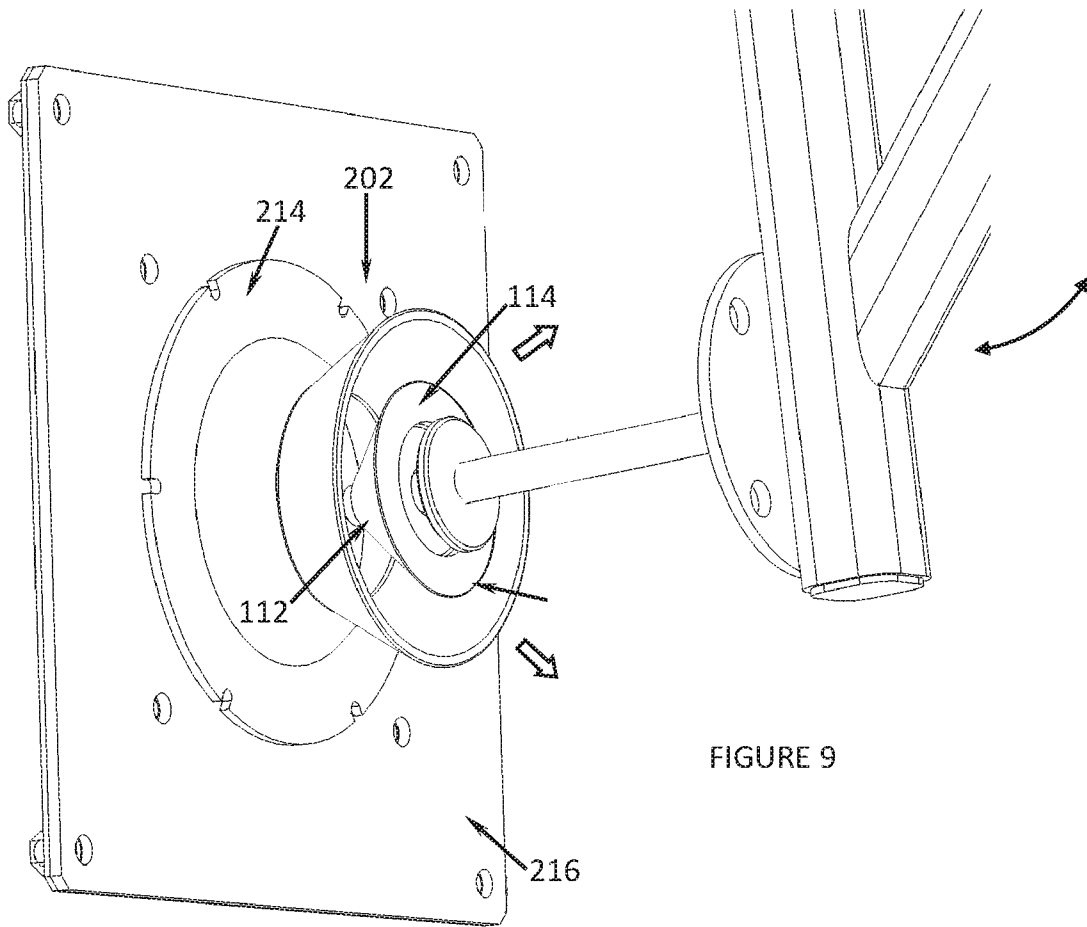


FIGURE 9

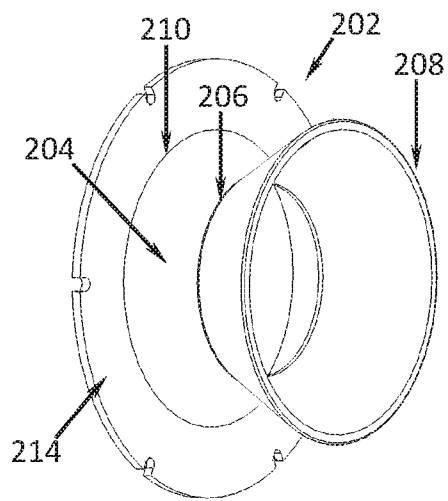


FIGURE 10

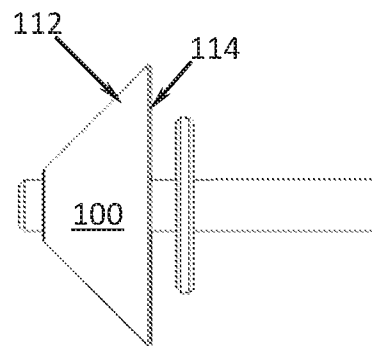
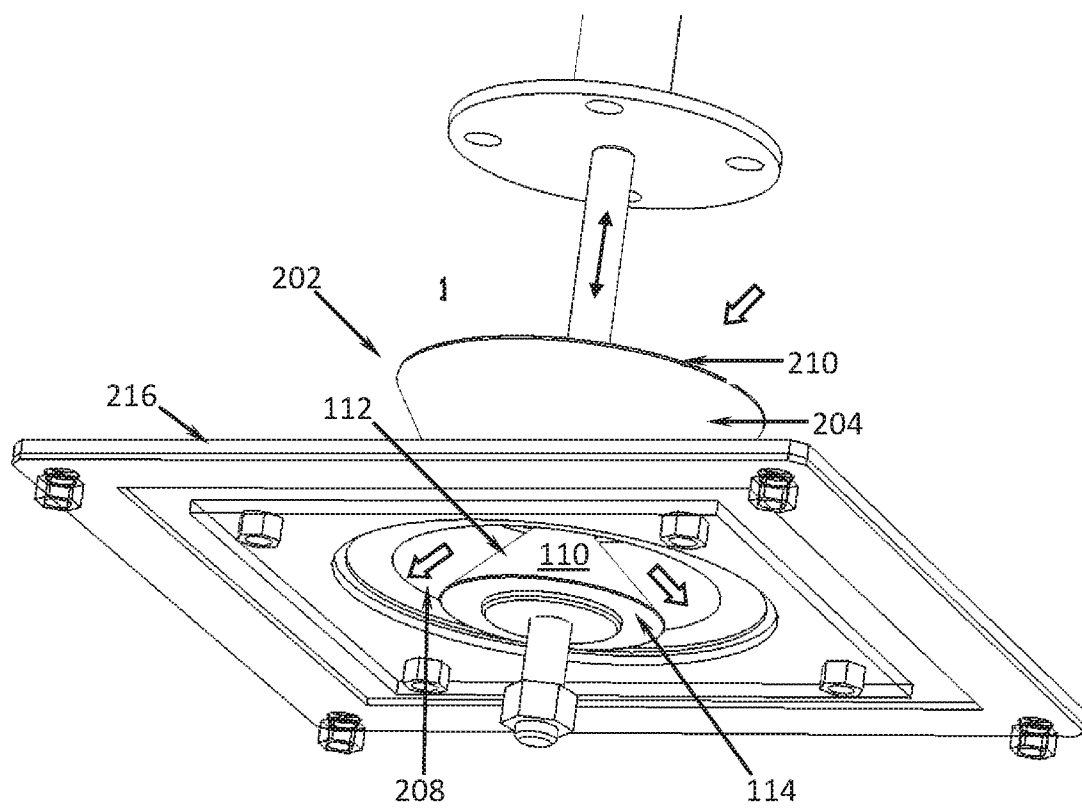
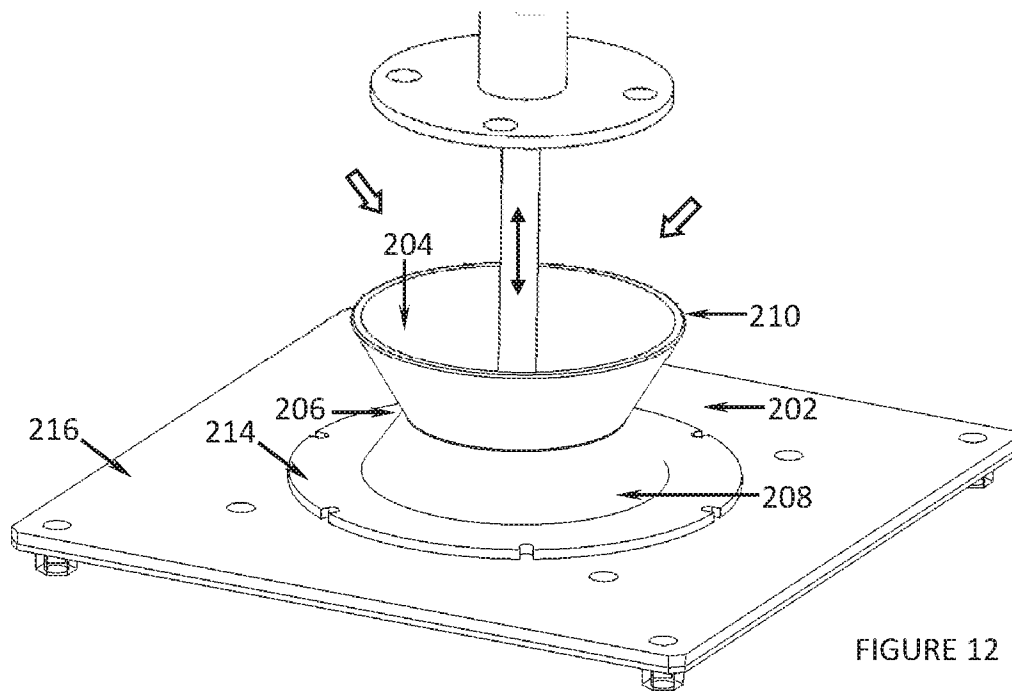


FIGURE 11



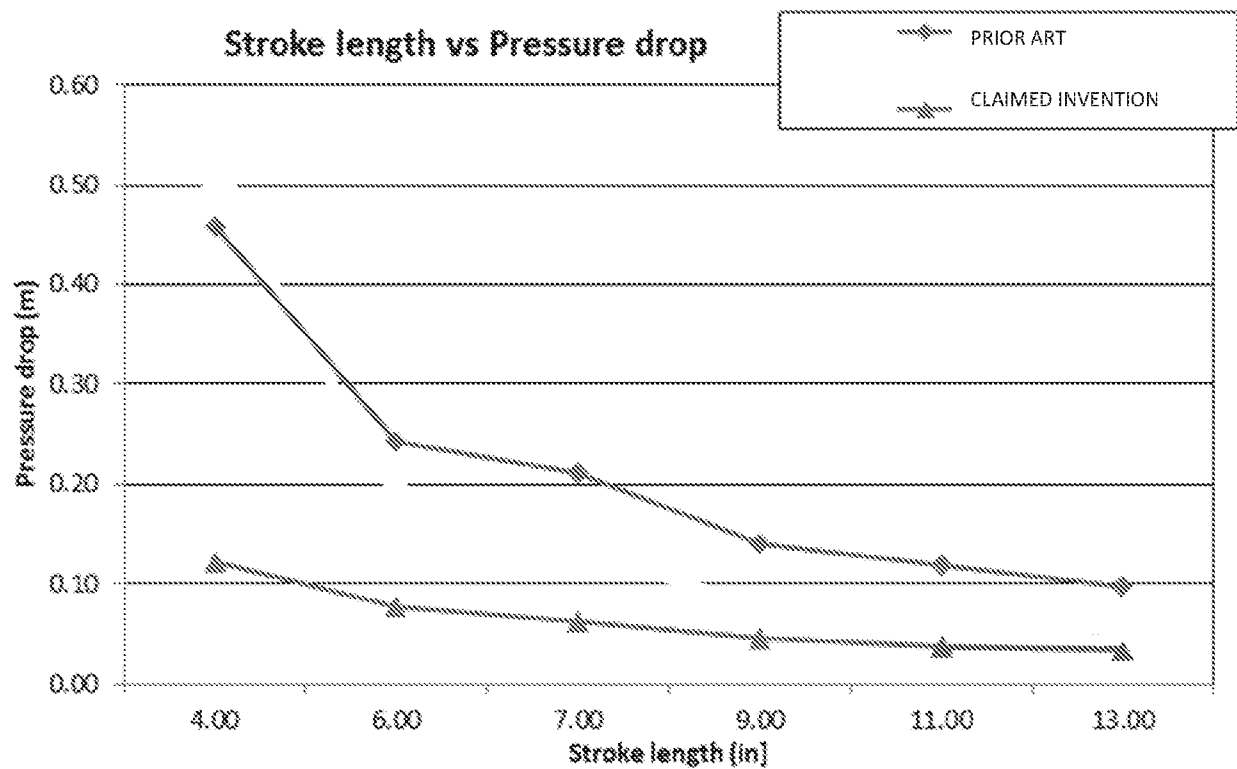


FIGURE 14

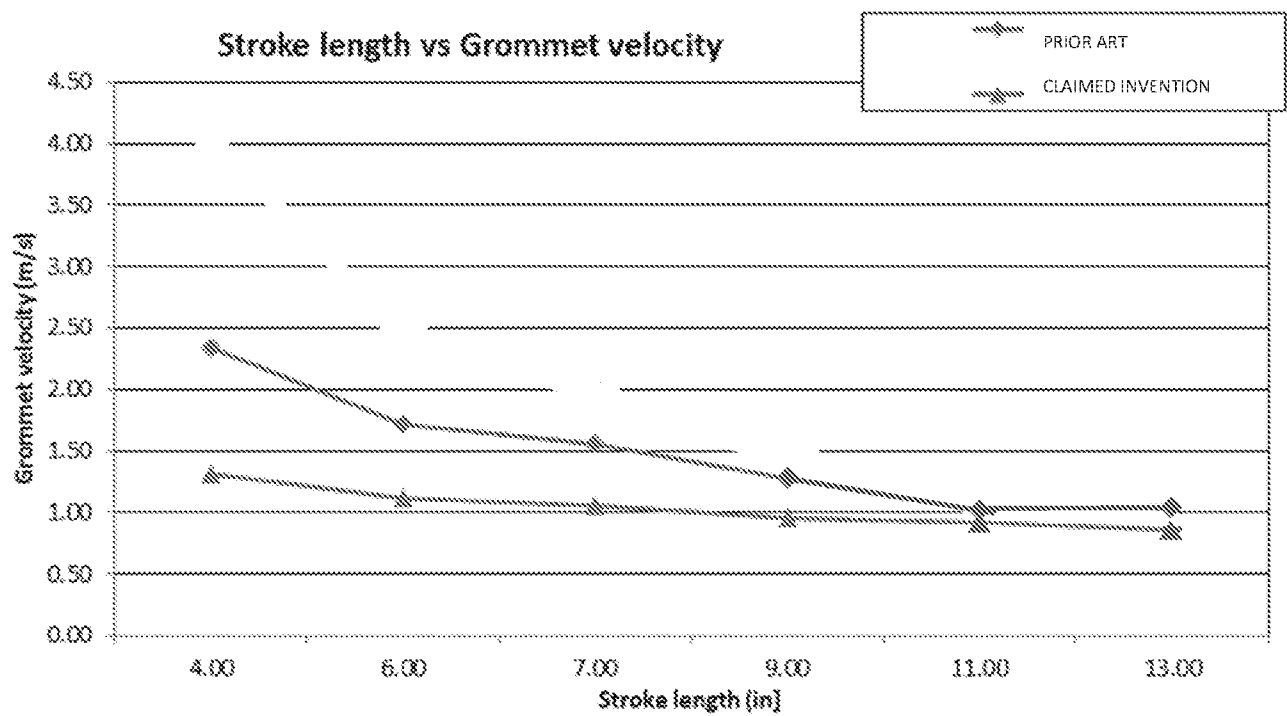


FIGURE 15

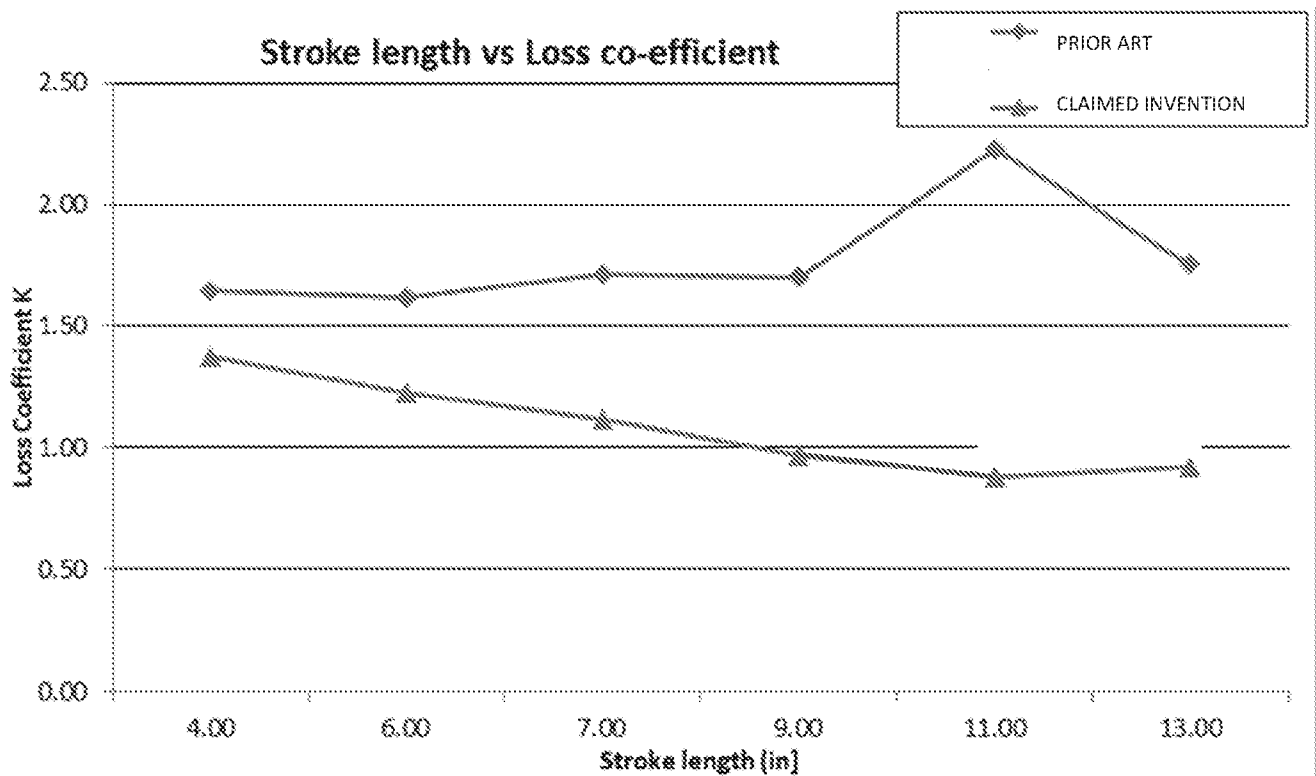


FIGURE 16

Flow Rate (m ³ /hr)	Head Loss PRIOR ART Hinged (mm)	Head Loss Claimed Invention Hinged (mm)	Head Loss Change (%)
6.3	6.0 @ 5.5"	4.5 @ 9.0"	-25.0
9.7	10.5 @ 5.5"	10.0 @ 9.0"	-4.8
13.1	18.0 @ 5.5"	17.0 @ 9.0"	-5.6

FIGURE 17

Opening Distance (inches)	Flow Rate (m ³ /hr)	Head Loss PRIOR ART (mm)	Head Loss Claimed Invention (mm)	Head Loss Change (%)
1.5	6.3	29.5	8.0	-72.9
1.5	9.7	65.0	17.0	-73.8
1.5	13.1	117.0	30.0	-74.4
1.5	16.4	192.0	46.0	-76.0
1.5	19.7	265.0	69.5	-73.8
2.0	6.3	17.0	6.0	-64.7
2.0	9.7	37.5	12.5	-66.7
2.0	13.1	66.0	21.5	-67.4
2.0	16.4	102.5	34.5	-66.3
2.0	19.7	145.0	50.0	-65.5
3.0	6.3	7.5	5.5	-26.7
3.0	9.7	15.5	12.0	-22.6
3.0	13.1	28.0	20.0	-28.6
3.0	16.4	44.0	32.0	-27.3
3.0	19.7	64.5	46.0	-28.7
4.0	6.3	6.0	4.5	-25.0
4.0	9.7	12.0	11.0	-8.3
4.0	13.1	19.0	18.5	-2.6
4.0	16.4	29.5	29.0	-1.7
4.0	19.7	42.0	41.0	-2.4

FIGURE 18

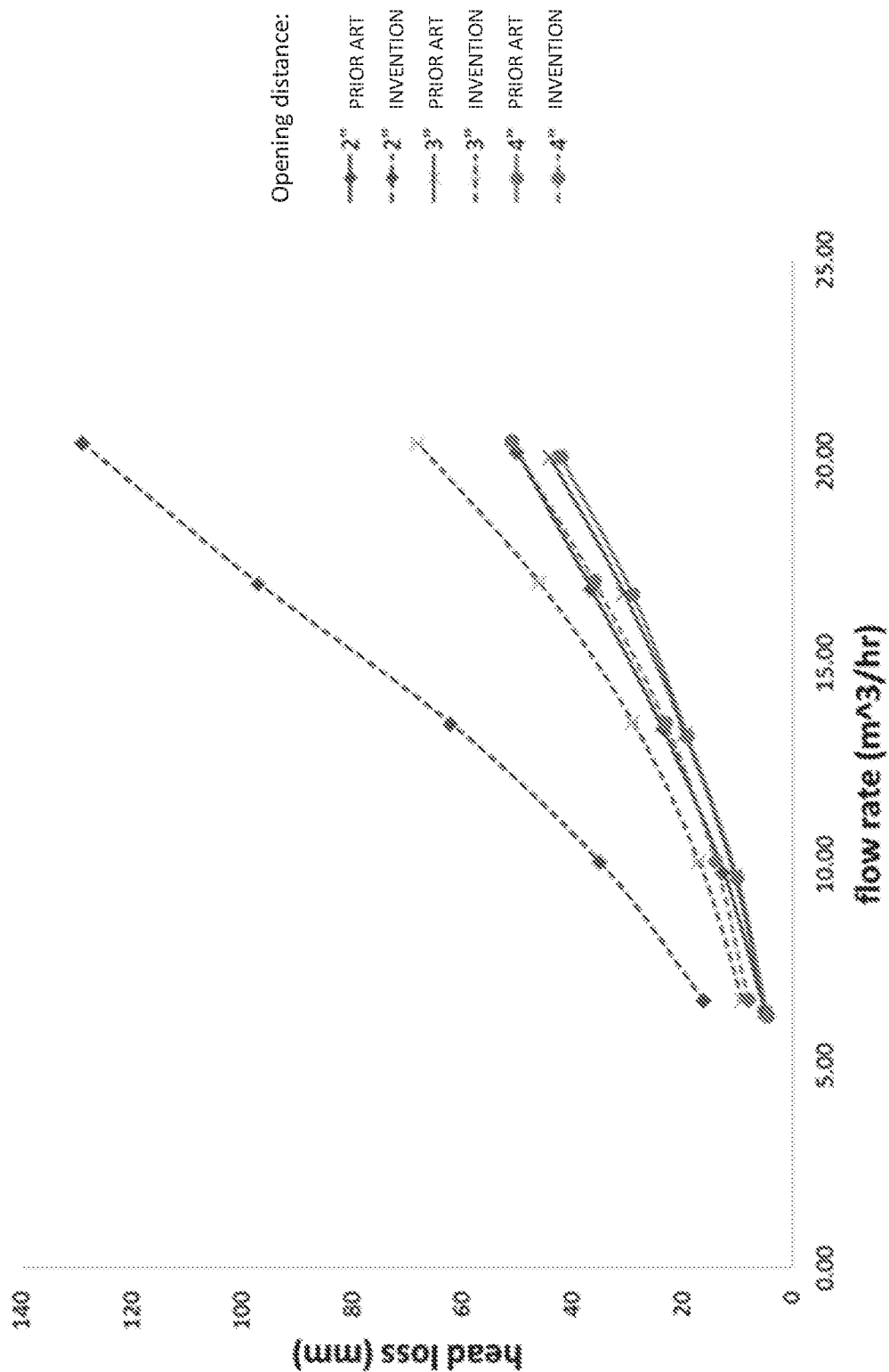


FIGURE 19

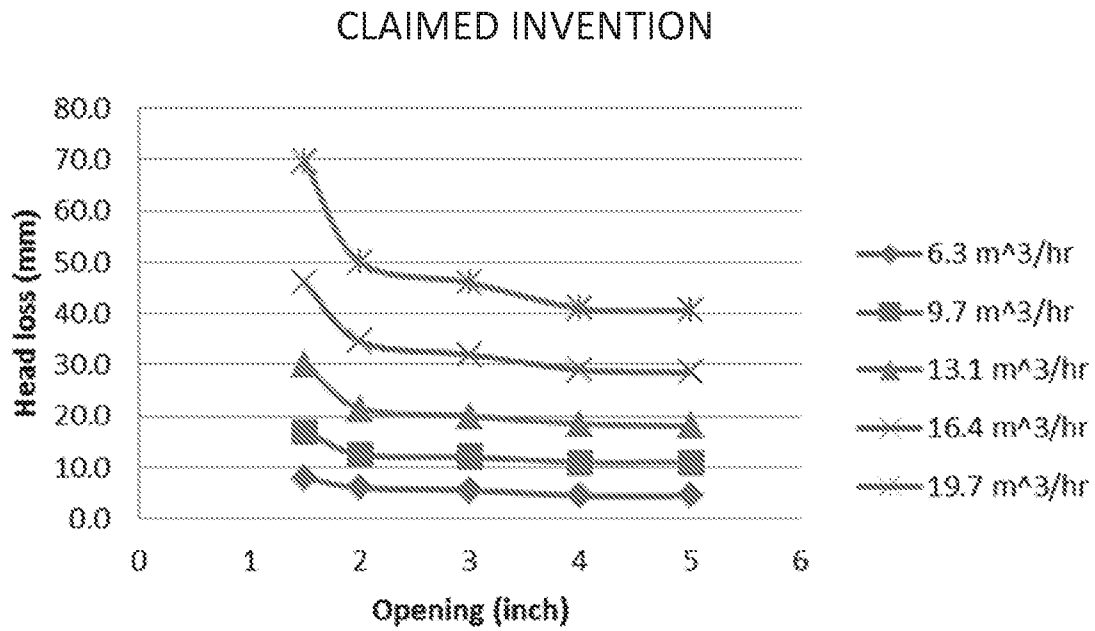


FIGURE 20

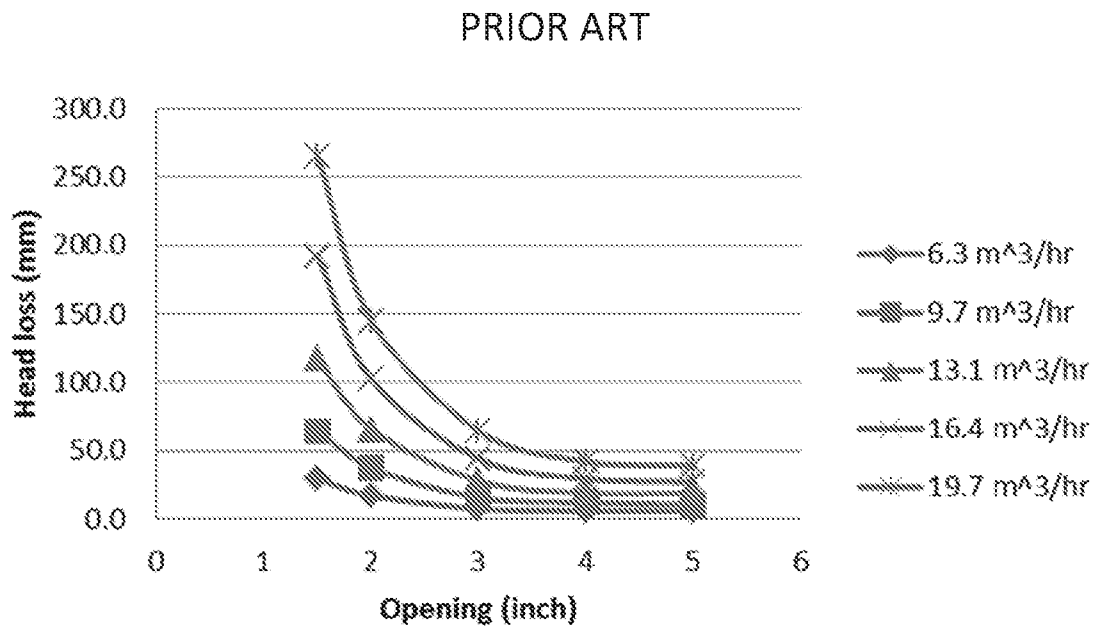
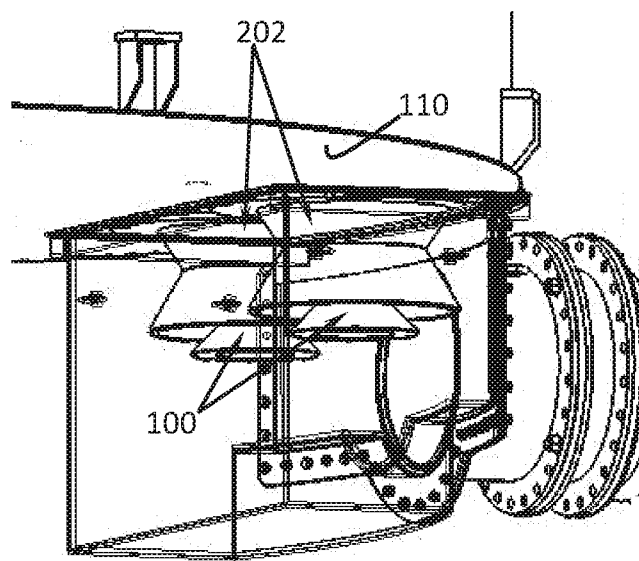
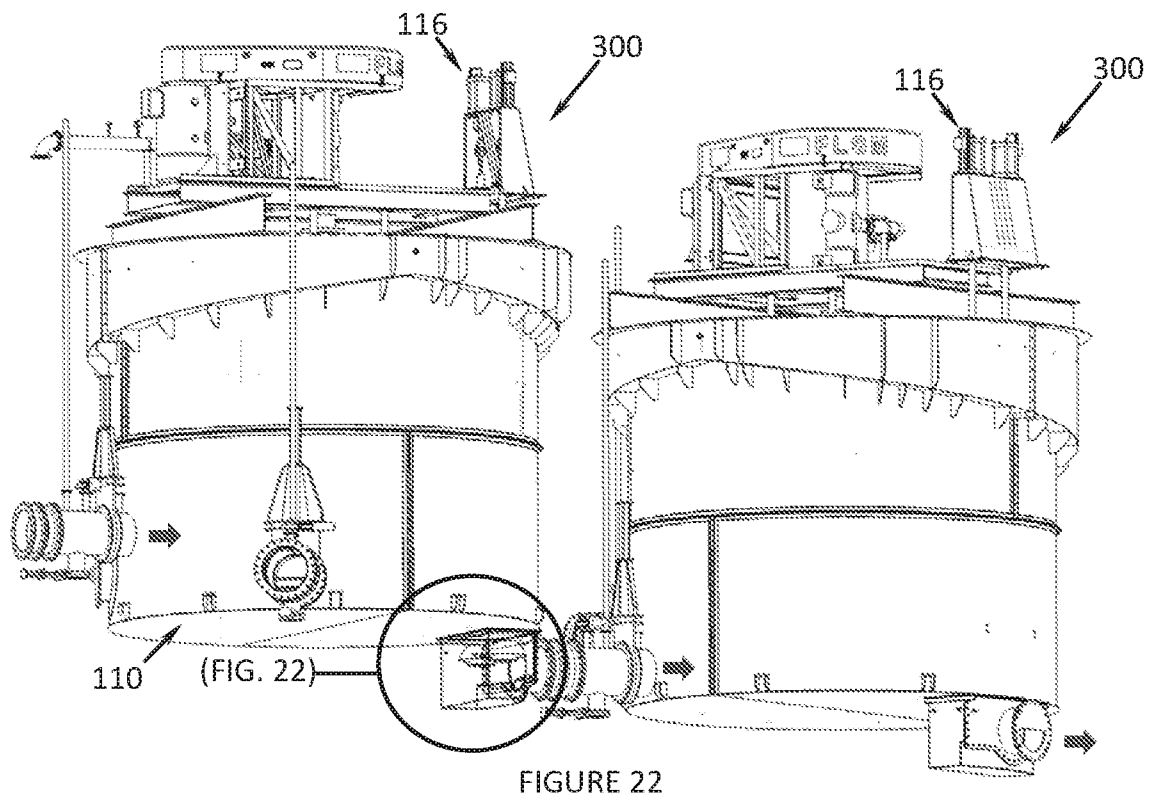


FIGURE 21



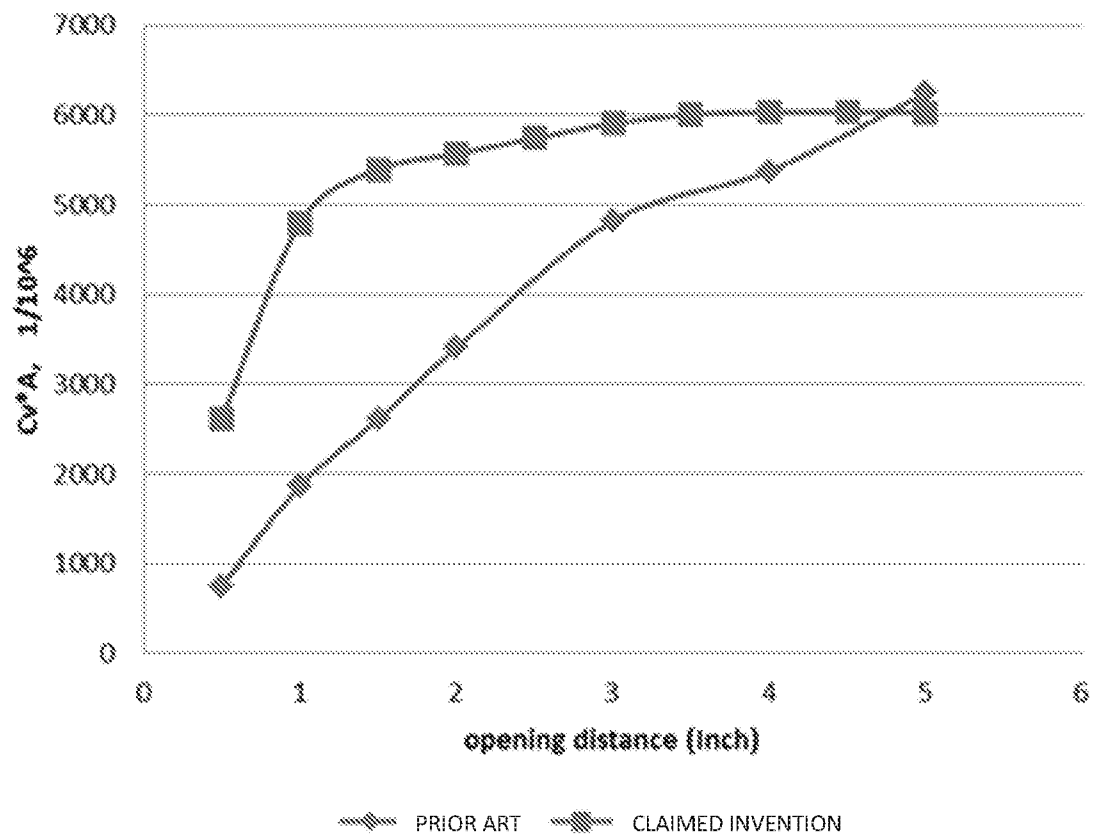


FIGURE 24

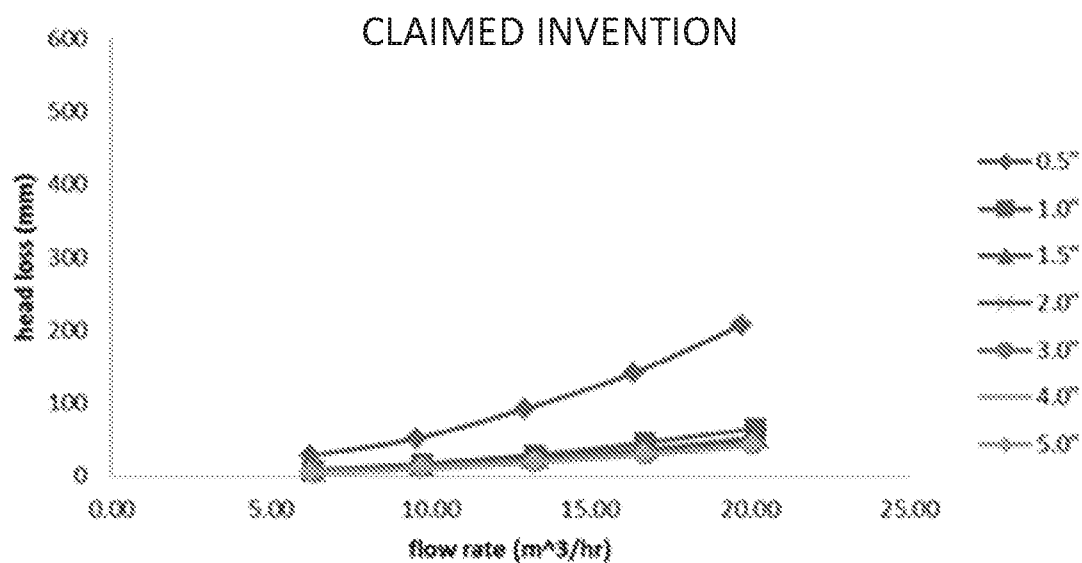


FIGURE 25

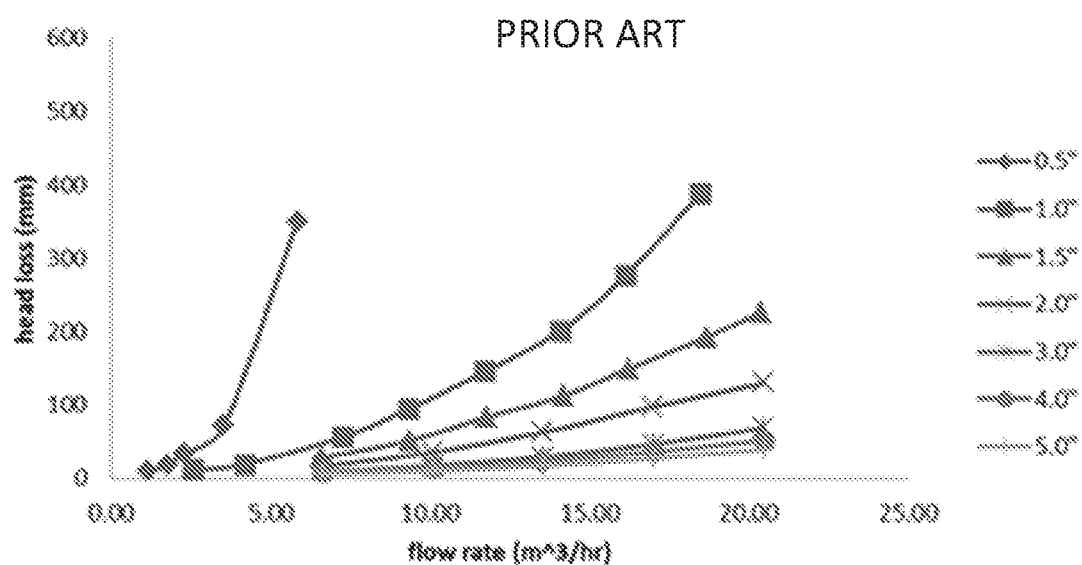


FIGURE 26