(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 March 2014 (06.03.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/036200 A1

(51) International Patent Classification: *C03B 17/04* (2006.01)

(21) International Application Number: PCT/US2013/057179

(22) International Filing Date: 29 August 2013 (29.08.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/694,920 30 August 2012 (30.08.2012) US

(71) Applicant: CORNING INCORPORATED [US/US]; 1 Riverfront Plaza, Corning, New York 14831 (US).

(72) Inventors; and
(71) Applicants : **BISSON, Antoine Gaston Denis** [FR/FR]; 20 bis rue de la Tuilerie, F-77520 Montigny Lencoup (FR). **GOLYATIN, Vladislav Yuryevich** [RU/FR]; 85 rue Rémy Dumoncel, F-77210 Avon (FR). **TELLIER, Xavier** [FR/FR]; 19 rue Puteaux, Avon, F-89690 Cheroy (FR).

(74) Agent: **BARRON, Jason A.**; Corning Incorporated, Intellectual Property Department, SP-Ti-03-01, Corning, New York 14831 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: APPARATUS AND METHODS OF MAKING A GLASS TUBE BY DRAWING MOLTEN GLASS

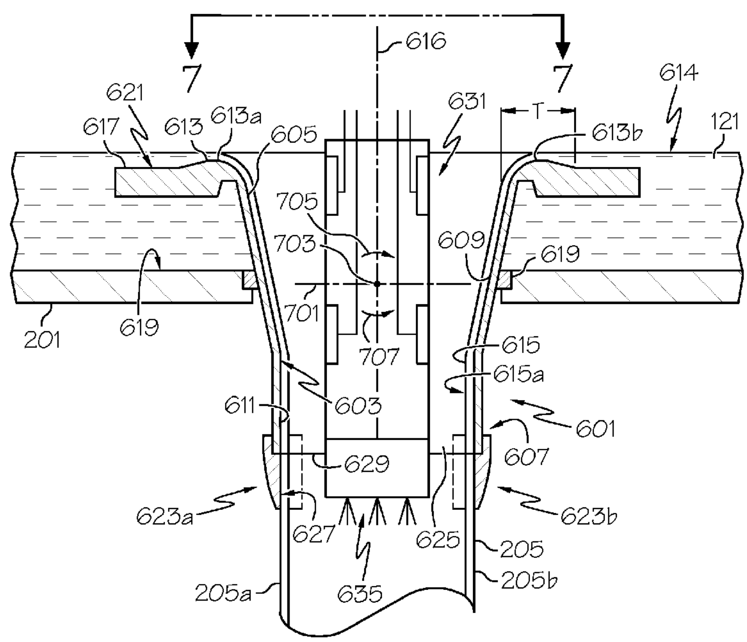

FIG. 6

(57) Abstract: Method and apparatus for making a glass tube 205 comprising the step of flowing molten glass 121 into a trough 201 such that the molten glass includes a free surface 614 within the trough, wherein a portion of the molten glass with a corresponding portion of the free surface overflows an endless weir 613 to form a molten glass tube 205 flowing down a cylindrical surface 603. The glass tube making apparatus comprises an endless weir 613 configured such that a free surface 614 of molten glass 121 within a trough 201 may overflow the endless weir 613 to form a molten glass tube 205 flowing down a cylindrical surface 603.

WO 2014/036200 A1

Published:

— *with international search report (Art. 21(3))*

APPARATUS AND METHODS OF MAKING A GLASS TUBE BY DRAWING MOLTEN GLASS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority under 35 U.S.C. § 119 of U.S. Provisional Application Serial No. 61/694,920 filed on August 30, 2012, the content of which is relied upon and incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present invention relates generally to apparatus and methods of making a glass tube and, more particularly, to apparatus and methods of making a glass tube wherein a portion of molten glass with a corresponding portion of a free surface of the molten glass overflows an endless weir to form a molten glass tube.

BACKGROUND

[0003] Conventional methods and apparatus are known to provide glass tubes. For example, glass tubes are known to be formed during an extrusion process, downwardly flowing molten glass over a tapered valve, and flowing molten glass over an outer surface of a cylindrical shell. Such conventional techniques can provide continuous manufacture of glass tubes during the manufacturing process.

SUMMARY

[0004] The following presents a simplified summary of the disclosure in order to provide a basic understanding of some example aspects described in the detailed description.

[0005] In accordance with a first example aspect, a method of making a glass tube comprises the step (I) of flowing molten glass into a trough such that the molten glass includes a free surface within the trough, wherein a portion of the molten glass with a corresponding portion of the free surface overflows an endless weir extending along an upstream circumference of a cylindrical surface to form a molten glass tube flowing down the cylindrical surface. The method further includes the step (II) of drawing the molten glass tube off a downstream portion of the cylindrical surface to form a glass tube with a predetermined shape.

[0006] In one example of the first aspect, during step (I), the free surface of the molten glass overflowing the endless weir forms an inner surface of the molten glass tube.

[0007] In another example of the first aspect, step (I) provides a drain member with the cylindrical surface defining an inner surface of the drain member.

[0008] In still another example of the first aspect, step (I) provides the endless weir to circumscribe the cylindrical surface of the drain member.

[0009] In another example of the first aspect, during step (I), the free surface of the molten glass overflowing the endless weir forms an outer surface of the molten glass tube.

[0010] In another example of the first aspect, step (I) provides a forming device with the cylindrical surface defining an outer surface of the forming device.

[0011] In a further example of the first aspect, step (I) further includes adjusting the temperature of the molten glass tube flowing down the cylindrical surface.

[0012] In still a further example of the first aspect, the method further comprises the step of adjusting a glass flow distribution overflowing the endless weir by adjusting an angle between the cylindrical surface and the trough.

[0013] In an example of the first aspect, the molten glass flowing into the trough during step (I) has a viscosity μ within a range of $10{,}000 \text{ P} \leq \mu \leq 500{,}000 \text{ P}$.

[0014] In another example of the first aspect, step (II) draws at least a portion of the molten glass tube off at least one edge director positioned at the downstream portion of the cylindrical surface.

[0015] In a further example of the first aspect, the predetermined shape of step (II) is circular.

[0016] In still a further example of the first aspect, the predetermined shape of step (II) is oblong.

[0017] Any examples of the first example aspect may be used alone or in combination with any number of the other examples of the first example aspect discussed above.

[0018] In a second example aspect, a glass tube making apparatus comprises a trough configured to receive molten glass and a forming device defining a cylindrical surface. An endless weir extends along an upstream circumference of the cylindrical surface. The endless weir is configured such that a free surface of the molten glass within the trough may overflow the endless weir to form a molten glass tube flowing down the cylindrical surface.

[0019] In one example of the second aspect, the forming device comprises a drain member with the cylindrical surface defining an interior surface of the drain member.

[0020] In another example of the second aspect, the endless weir circumscribes the cylindrical surface of the drain member.

[0021] In still another example of the second aspect, the cylindrical surface defines the outer surface of the forming device.

[0022] In another example of the second aspect, the apparatus further comprises a temperature control device configured to adjust the temperature of the molten glass tube flowing down the cylindrical surface.

[0023] In yet another example of the second aspect, the forming device is angularly adjustable relative to the trough to adjust a glass flow distribution overflowing the endless weir.

[0024] In still another example of the second aspect, the apparatus further comprises at least one edge director mounted with respect to a downstream portion of the forming device.

[0025] In another example of the second aspect, the edge director extends downstream from a lower edge of the forming device.

[0026] Any examples of the second example aspect may be used alone or in combination with any number of the other examples of the second example aspect discussed above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] These and other aspects are better understood when the following detailed description is read with reference to the accompanying drawings, in which:

[0028] **FIG. 1** is a schematic view of a first portion of a glass tube making apparatus in accordance with aspects of the disclosure;

[0029] **FIG. 2** is a schematic view of a second portion of the glass tube making apparatus in accordance with aspects of the disclosure;

[0030] **FIG. 3** is one example cross section along line 3-3 of the glass tube of **FIG. 2** illustrating an example oblong predetermined cross-sectional shape of the glass tube;

[0031] **FIG. 4** is another cross section along line 3-3 of the glass tube of **FIG. 2** illustrating another example oblong predetermined cross-sectional shape of the glass tube;

[0032] FIG. 5 is another cross section along line 3-3 of the glass tube of **FIG. 2** illustrating an example circular predetermined cross-sectional shape of the glass tube;

[0033] FIG. 6 is a cross section along line 6-6 of **FIG. 2** illustrating portions of an example forming device of the glass tube making apparatus of **FIGS. 1-2**;

[0034] FIG. 7 is a top view of **FIG. 6**; and

[0035] FIG. 8 is a schematic view of another second portion of the glass tube making apparatus in accordance with further aspects of the disclosure.

DETAILED DESCRIPTION

[0036] Examples will now be described more fully hereinafter with reference to the accompanying drawings in which example embodiments are shown. Whenever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts. However, aspects may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein.

[0037] FIGS. 1 and 2 illustrate a schematic view of portions of a glass tube making apparatus **101** for manufacturing a glass tube with a predetermined shape for various applications. **FIG. 1** illustrates an upstream portion of the glass tube making apparatus **101** while **FIG. 2** illustrates a downstream portion of the glass tube making apparatus **101**. As shown in **FIG. 1**, the glass tube making apparatus **101** can include a melting vessel **105** configured to receive batch material **107** from a storage bin **109**. The batch material **107** can be introduced by a batch delivery device **111** powered by a motor **113**. An optional controller **115** can be configured to activate the motor **113** to introduce a desired amount of batch material **107** into the melting vessel **105**, as indicated by arrow **117**. In one example, a glass metal probe **119** can be used to measure a molten glass **121** level within a standpipe **123** and communicate the measured information to the controller **115** by way of a communication line **125**.

[0038] The glass tube making apparatus **101** can also include a fining vessel **127**, such as a fining tube, located downstream from the melting vessel **105** and coupled to the melting vessel **105** by way of a first connecting tube **129**. A mixing vessel **131,** such as a stir chamber, can also be located downstream from the fining vessel **127**. As illustrated in **FIG. 2**, a delivery vessel **133**, such as a bowl, may be located downstream from the mixing vessel **131**. As shown, a second connecting tube **135** can couple the fining vessel **127** to the mixing vessel **131** and a third connecting tube **137** can couple the mixing vessel **131** to the delivery vessel **133**. As further illustrated, a downcomer **139** can be positioned to deliver molten glass **121** from the delivery vessel **133** to an inlet **141** of a trough **201**. As shown, the melting vessel **105**, fining vessel **127**, the mixing vessel **131**, delivery vessel **133**, and trough **201** are examples of molten glass stations that may be located in series along the glass tube making apparatus **101**.

[0039] As shown in **FIG. 2**, an elongated glass tube **205** may be continuously drawn from the forming device **601**, for example, by one or more drive rollers **207** that may be driven under the command of a controller **209** to obtain a proper drawing speed of the elongated glass tube **205** from the forming device **601**. An inspection device **211** may be used to help determine the thickness of the wall of the elongated glass tube **205** although the inspection device **211** may be used to measure other characteristics in further examples. Feedback from the inspection device **211** may be used as feedback to the controller **209**. The controller can then send command signals to the drive rollers **207** to help adjust the characteristics (e.g., wall thickness) of the elongated glass tube **205** being drawn from the forming device **601**. The drive rollers **207** can be located in a position where the shape of the glass tube has already been frozen into place. Alternatively, the drive rollers **207** can be located in a location where the rollers can help deform the glass tube to a final shape before the glass tube is frozen into the final shape configuration.

[0040] As further shown in **FIG. 2**, the elongated glass tube **205** maybe continuously drawn and periodically cut by a cutting device **213** into glass tube segments **203** that may be moved by a conveyor **215** or other material handling device to a remote location for storage or further processing.

[0041] As shown in **FIGS. 3-5**, the forming device **601** can be designed to produce glass tubes having a wide range of cross-sectional shapes. In one example, the glass tubes can have an oblong shape, such as an oval shape, an egg shape, a rectangular shape, or other oblong shape. **FIG 3** shows the glass tube **203** including an oblong shape comprising an oval shape **301**. **FIG. 4** shows the glass tube **203** including another oblong shape comprising a rectangular shape **401** although other oblong shapes may be provided in further examples. **FIG. 5** further shows the glass tube **203** including a circular cross sectional shape **501**. Other tube shapes may be provided in further examples such as a polygonal shape with three or more sides or other tube shape configurations. Aspects of the disclosure can produce cross-sectional shapes having various aspect ratios. By way of reference to **FIG. 3**, the cross-sectional aspect ratio of the glass tube can be considered the Width "**W**" relative to the height

"**H**". For instance, if the width "**W**" shown in **FIG. 3** is twice as large as the height "**H**", the cross-sectional aspect ratio of the glass tube would be 2:1. In some examples, glass tubes formed with apparatus and by methods of the disclosure can include aspect ratios from about 1:1 to about 10:1 although glass tubes including cross-sectional shapes with other alternative aspect ratios may be provided in further examples. Still further, glass tubes may have a wide range of sizes. By way of example, glass tubes may have a width "**W**" of from about 50 mm to about 100 mm although other width sizes may be provided in further examples.

[0042] **FIG. 6** is a cross section along line 6-6 of **FIG. 2** illustrating portions of an example forming device **601** of the glass tube making apparatus **101**. As shown in **FIG. 6**, in one example, the forming device **601** can comprise a drain member with a cylindrical surface **603** defining an interior surface of the drain member. The cylindrical surface **603** can include and upstream circumference **605** and a downstream portion **607**. As shown, the cylindrical surface **603** can comprise a frustoconical portion **609** in an upstream portion of the cylindrical surface **603** and a cylindrical portion **611** within a downstream portion of the cylindrical surface **603**. While the cylindrical surface **603** is shown to include a tapering frustoconical portion that transitions into a non-tapering cylindrical portion, various other configurations maybe provided. For example, substantially the entire cylindrical surface **603** may comprise a tapered frustoconical portion or a non-tapered cylindrical portion. Furthermore, cylindrical surface **603** can include a wide range of shape configurations to facilitate formation of the predetermined shape of the tube and control the thickness of the tube walls. Modeling techniques and/or experiments maybe conducted to determine the optimal features of the cylindrical surface **603** to obtain the desired glass tube with predetermined shape.

[0043] As further illustrated in **FIG. 6**, the forming device **601** can also include an endless weir **613** extending along the upstream circumference **605** of the cylindrical surface **603**. The endless weir **613** is configured such that a free surface **614** of the molten glass **121** within the trough **201** may overflow the endless weir **613** to form a molten glass tube **615** flowing down the cylindrical surface **603** such that an inner surface **615a** of the molten glass tube **615** is defined by the free surface **614** of the molten glass **121** flowing over the endless weir **613**. The trough **201** can be considered any structure configured to provide the free surface **614**. The weir **613** can be considered at least a circumferential apex portion that the free surface **614** is configured to flow over. As such, the free surface **614** may freely flow over the endless weir **613** to form a pristine inner surface **615a** of the glass tube **615** that has not be contacted by another solid object when forming the pristine inner surface **615a**. As such, the inner pristine surface **615a** may be free from streaks, scratches, inclusions or other surface imperfections that may otherwise diminish the quality of the inner surface of the glass tube.

[0044] As shown, the endless weir can circumscribe the cylindrical surface of the drain member. For example, as shown in **FIGS. 6-7**, the endless weir **613** can circumscribe the entire cylindrical surface **603** of the drain member **601**. As further shown in **FIG. 7**, the endless weir **613** can include a shape that is geometrically similar, such as identical to the shape of the cylindrical surface **603** while circumscribing the entire cylindrical surface **603**.

[0045] As shown in **FIG. 6**, the weir is endless in that the weir comprises a ring with no beginning or end. The endless weir **613** can be configured such that a free surface 121 of the molten glass **121** within the trough **201** may overflow the endless weir **613** to form a molten glass tube **615** flowing down the cylindrical surface **603**. As shown in **FIGS. 6 and 7**, the endless weir **613** can include a radial thickness "**T**" along a radial direction towards an axis **616** of the cylindrical surface **603**. Like the features of the cylindrical surface **603**, the radial thickness "**T**" and other features of the endless weir **613** can also be adjusted to provide desireable flow characteristics to enhance the quality of the glass tube. The endless weir **613** can include a ring extending along various alternative paths. For example, although not required, the endless weir **613** may include a ring extending along a path having a shape that is geometrically similar, such as substantially identical to the cross sectional shape of the glass tube. For example, as shown in **FIG. 7**, the endless weir **613** may include an oval shape that is larger than, but geometrically similar to, the oval shape **301** of the glass tube **203** shown in **FIG. 3**.

[0046] An optional landing **617** may extend radially outward from the endless weir **613** although the illustrated landing **617** may not be provided in further examples. Moreover, in some examples, the landing **617** may optionally be flush or otherwise incorporated in with the bottom surface **619** of the trough **201**. For instance, the upwardly facing surface **621** of the illustrated landing **617** may comprise the bottom surface **619** of the trough **201** or may be designed to be flush with the bottom surface **619** of the trough **201**.

[0047] As further illustrated in **FIG. 6**, the forming device, such as the illustrated drain member **601**, can be angularly adjustable relative to the trough **201** to adjust a glass flow distribution overflowing the endless weir **613**. For example, with reference to **FIG. 7**, the drain member may be angularly adjusted relative to a first axis **701** and/or a second axis **703** of the trough **201** to adjust the flow distribution overflowing the endless weir. For example, if the inspection device **211** determines a first wall portion **205a** is too thick relative to a second wall portion **205b**, the controller **209** may send a signal to an actuator **217** (see **FIG. 2**) to automatically tilt the drain member **601** in direction **705** about the second axis **703**. As such, a relatively restricted flow would be achieved over a first weir portion **613a** when compared to a second weir portion **613b**. As such, the thickness of the first wall portion **205a** can be reduced when compared to the second wall portion **205b** to correct for undesirable differences in wall thicknesses. Likewise, if the inspection device **211** determines a first wall portion **205a** is too thin relative to a second wall portion **205b**, the controller **209** may send a signal to an actuator **217** (see **FIG. 2**) to automatically tilt the drain member **601** in direction **707** about the second axis **703**. As such, a relatively unrestricted flow would be achieved over a first weir portion **613a** when compared to a second weir portion **613b**. As such, the thickness of the first wall portion **205a** can be increased when compared to the second wall portion **205b** to correct for undesirable differences in wall thicknesses. Similar adjustments may be made by the actuator to correct for relative differences in thicknesses of the glass tube resulting in molten glass overflowing a third and/or fourth portion **613c, 613d** of the endless weir **613** as shown in **FIG. 7** by adjusting the drain member **601** about the first axis **701**. Still further, rotational adjustments of the drain member **601** in a clockwise or counterclockwise direction **709** about axis **616** may be further carried out to achieve the desired molten glass flow profile over the endless weir **613**.

[0048] As discussed above, the adjustment of the drain member **601** may be carried out automatically with the actuator **217** being controlled by the controller **209**. In further examples, the drain member **601** may be installed at a desired adjusted angle that may be changed at a later time. For example, an adapter **619** may be installed to mount the drain member **601** at a desired angular orientation relative to the trough **201**. In further examples, the illustrated adapter **619** may be replaced with another adapter to provide a different desired angular orientation relative to the trough **201**.

[0049] As further illustrated in **FIG. 6**, the apparatus can include at least one edge director **623a, 623b** mounted with respect to a downstream portion **625** of the forming device **601**. As shown, the edge directors can be designed to only extend about part of the periphery of the downstream portion **625**. As shown, a curved surface segment **627** can extend flush with respect to the corresponding portions of the cylindrical surface **603**. As such, the edge directors **623a, 623b** can extend downstream from a lower edge **629** of the downstream portion **625** to increase the overall effective cylindrical surface at predetermined locations of the downstream portion **625**. Such edge directors can help guide the flow and limit the loss of width and bring more stability to the draw occurring below the lower edge **629** of the downstream portion **625**. The edge directors, if provided, can be made from refractory ceramic but can also be made from precious metals (e.g. platinum) in further examples.

[0050] The apparatus **101** can further include a temperature control device **631** that may have a plurality of temperature control elements **633** configured to be operated together or independently to provide a desired temperature profile about a periphery of the molten glass tube **615** flowing down the cylindrical surface **603**. In one example, one or more of the temperature control elements comprise cooling elements. In another example, one or more of the temperature control elements comprise heating elements. Still further, the temperature control device **631** can include both heating and cooling elements configured to be operated together or independently to help control the temperature profile about the periphery of the glass tube **615**. For example, as shown in **FIG. 7**, the plurality of temperature control elements **633** can be radially arranged to independently control the temperature of predetermined radial locations of the glass tube. As such, a desired temperature profile can be achieved about the periphery of the glass tube to help control thickness and other attributes of the glass tube. Similarly, a temperature control device may be provided, for example, above the weir to control the temperature profile of the free surface as it spills over the weir and/or control the temperature profile of the glass flowing down the cylindrical surface. As such, a desired temperature profile can also be achieved at the free surface flowing over the weir and/or along the cylindrical surface to help control thickness and other attributes of the glass tube. In one example, the controller **209** may be designed to operate the temperature control device **631** based on feedback from the inspection device **211** to allow temperature adjustments to facilitate control of characteristics of the glass tube, such controlling thickness variations in the glass tube.

[0051] As shown in **FIG. 6**, a pressure device **635**, such as the illustrated pressurize air ports may be configured to provide a predetermined pressure within the interior of the glass tube. In the illustrated example, the pressure device can be integrated with the temperature control device **631**. In further examples, the pressure device **635** may be provided separately or alternatively to the temperature control device. The pressure device **635**, if provided may provide an overpressure of from about 0 millibars to about 50 millibars, such as from about 20 millibars to about 30 millibars although any desired pressure may be provided within the interior area of the tube.

[0052] **FIG. 8** is a schematic illustration of an alternative glass tube making apparatus **101b** including a trough **801** integrated with a forming device **803** including an outer surface comprising a cylindrical surface **805**. The apparatus **101b** further includes an endless weir **807**.

[0053] The endless weir **807** is configured such that a free surface **809** of the molten glass **121** within the trough **801** may overflow the endless weir **807** to form a molten glass tube **811** flowing down the cylindrical surface **805** such that an outer surface **813** of the molten glass tube **811** is defined by the free surface **809** of the molten glass flowing over the weir **807**. As such, the free surface **809** may freely flow over the endless weir **807** to form a pristine outer surface **813** of the glass tube **811** that has not be contacted by another solid object when forming the pristine outer surface **813**. As such, the outer pristine surface **813** may be free from streaks, scratches, inclusions or other surface imperfections that may otherwise diminish the quality of the outer surface of the glass tube. As shown, in one example, a support member **815** may hang the forming member **803** and trough **801** below the mixing vessel **131**.

[0054] The forming devices **601, 803** and other elements of the apparatus can comprise refractory ceramic machined to the desired shape (e.g., alumina or zirconia). In further examples, precious metal clad can also be used with various glass compositions. In some examples, a complete precious metal delivery may also be provided.

[0055] Methods of making a glass tube will now be described. Initially, molten glass **121** may be produced, for example, with portions of a glass tube making apparatus **101** shown in **FIG. 1**. Next, in one example, the molten glass **121** may enter an inlet **141** of a trough **201** as shown in **FIG. 2**. In one example the molten glass flowing into the trough 201 includes a viscosity μ within a range of $10,000 \text{ P} \leq \mu \leq 500,000 \text{ P}$, such as $50,000 \text{ P} \leq \mu \leq 400,000 \text{ P}$. As shown in **FIG. 6**, molten glass can flow into the trough **201** such that the molten glass **121** includes a free surface **614** within the trough **201**. Next, a portion of the molten glass **121** with a corresponding portion of the free surface **614** overflows the endless weir **613** to form the molten glass tube **615** flowing down the cylindrical surface **603**.

[0056] In the example shown in **FIG. 6**, the free surface **614** of the molten glass **121** overflowing the endless weir **613** forms the inner surface **615a** of the molten glass tube **615**.

As such, the glass tube **615** may be provided with a pristine inner surface **615a** that has not be contacted by another solid object when forming the pristine inner surface **615a**. As such, the inner pristine surface **615a** may be free from streaks, scratches, inclusions or other surface imperfections that may otherwise diminish the quality of the inner surface of the glass tube.

[0057] In another example, as shown in **FIG. 8**, the molten glass **121** may enter pass down from the downcomer **139** to flow into the trough **801** such that the molten glass **121** includes a free surface **809** within the trough **801**. In one example the molten glass flowing into the trough 801 includes a viscosity μ within a range of $10,000 \text{ P} \leq \mu \leq 500,000 \text{ P}$, such as $50,000 \text{ P} \leq \mu \leq 400,000 \text{ P}$. Next, a portion of the molten glass **121** with a corresponding portion of the free surface **809** overflows the endless weir **807** to form the molten glass tube **811** flowing down the cylindrical surface **805**. In the example shown in **FIG. 8**, the free surface **809** of the molten glass **121** overflowing the endless weir **807** forms the outer surface **813** of the molten glass tube **811**. As such, the glass tube **811** may be provided with a pristine outer surface **813** that has not be contacted by another solid object when forming the pristine outer surface **813**. As such, the outer pristine surface **813** may be free from streaks, scratches, inclusions or other surface imperfections that may otherwise diminish the quality of the inner surface of the glass tube

[0058] In the example shown in **FIG. 8**, the free surface **809** of the molten glass **121** overflowing the endless weir **807** forms the outer surface **813** of the molten glass tube **811**.

As such, the glass tube **811** may be provided with a pristine outer surface **813** that has not been contacted by another solid object when forming the pristine outer surface **813**. As such, the outer pristine surface **813** may be free from streaks, scratches, inclusions or other surface imperfections that may otherwise diminish the quality of the inner surface of the glass tube.

[0059] In the examples of **FIGS. 6 and 8**, various techniques may be used to help control the thickness, dimensions and/or quality of the glass tube being drawn from the forming device. For example, the method can include the step of adjusting the temperature of the molten glass tube **615, 811** flowing down the cylindrical surface **603, 805**. A temperature control device (e.g., see **631** in **FIG. 6**) may be used although other temperature control devices may be used in further examples to selectively adjust portions of the molten glass tube. Such localized precise temperature control can effect flow of the molten glass and therefore may help fine tune the thickness of the glass tubes in that area. As such, localized temperature control can help fine tune thickness control of the glass tube about the periphery of the tube. Temperature control can be carried out on several independent zones surrounding the delivery to obtain desired thickness uniformity, for example. Cooling blocks such as air cooled boxes, high temperature heat pipes and/or direct impinging jets may be used to influence locally the temperature of the glass (e.g., by radiation and/or convection) to change the flow distribution appropriately.

[0060] The examples of **FIGS. 6 and 8** can also include the optional step of adjusting a glass flow distribution overflowing the endless weir **613, 807** by adjusting an angle between the cylindrical surface **603, 805** and the trough **201, 801**. Adjusting may occur manually or automatically, for example, as discussed with respect to the example of **FIG. 6** discussed above.

[0061] As such, **FIGS. 6 and 8** demonstrate methodologies that may help control the thickness and/or quality of the glass tube being drawn off the forming device. For example, referring to **FIG. 2**, the method can include the step of inspecting the drawn glass tube **205** for tube characteristics (e.g., thickness). Based on the measured values, the controller **209** may adjust the drive rollers **207** and/or the tilt angle between the cylindrical surface and the trough. In some examples, the apparatus (e.g., by way of the controller **209** and inspection device **211**) may be designed to provide a glass tube with a substantially constant thickness about the periphery of the glass tube. In further examples, portions of the glass tube may be selected to be thicker than other portions of the glass tube. As such, in further examples, apparatus of the present invention can also provide differing thicknesses of the glass tube about the periphery of the glass tube.

[0062] As mentioned with respect to **FIG. 6** above, the glass tube **615** may be provided with a pristine inner surface **615a** that is substantially free from streaks, scratches, inclusions or other surface imperfections that may otherwise diminish the quality of the inner surface of the glass tube. Providing an inner pristine surface can be desireable to minimize undesirable distortions of light passing through the glass tube from a display device positioned within the tube. For example, glass tubes of the present disclosure may be used as a housing for an electronic device (e.g., a smartphone or other hand-held device). Images from the display may freely pass through the pristine inner surface **615a** without being obscured by streaks, scratches, inclusions or other imperfections that may otherwise exist.

[0063] As mentioned with respect to **FIG. 8** above, the glass tube **811** may also be provided with a pristine outer surface **813** that may be substantially free from streaks, scratches, inclusions or other surface imperfections that may otherwise diminish the quality of the inner surface of the glass tube. Providing an outer pristine surface may be desirable to help reduce interruption of optical imperfections of light entering or leaving the outer surface of the glass tube.

[0064] It will be apparent to those skilled in the art that various modifications and variations can be made without departing from the spirit and scope of the claimed invention.

CLAIMS

What is claimed is:

1. A method of making a glass tube comprising the steps of:

(I) flowing molten glass into a trough such that the molten glass includes a free surface within the trough, wherein a portion of the molten glass with a corresponding portion of the free surface overflows an endless weir extending along an upstream circumference of a cylindrical surface to form a molten glass tube flowing down the cylindrical surface; and

(II) drawing the molten glass tube off a downstream portion of the cylindrical surface to form a glass tube with a predetermined shape.

2. The method of claim 1, wherein, during step (I), the free surface of the molten glass overflowing the endless weir forms an inner surface of the molten glass tube.

3. The method of claim 1 or claim 2, wherein step (I) provides a drain member with the cylindrical surface defining an inner surface of the drain member.

4. The method of claim 3, wherein step (I) provides the endless weir to circumscribe the cylindrical surface of the drain member.

5. The method of any of claims 1-4, wherein, during step (I), the free surface of the molten glass overflowing the endless weir forms an outer surface of the molten glass tube.

6. The method of any of claims 1-5, wherein step (I) provides a forming device with the cylindrical surface defining an outer surface of the forming device.

7. The method of any of claims 1-6, wherein step (I) further includes adjusting the temperature of the molten glass tube flowing down the cylindrical surface.

8. The method of any of claims 1-7, further comprising the step of adjusting a glass flow distribution overflowing the endless weir by adjusting an angle between the cylindrical surface and the trough.

9. The method of any of claims 1-8, wherein the molten glass flowing into the trough during step (I) has a viscosity μ within a range of $10,000\ P \leq \mu \leq 500,000\ P$.

10. The method of any of claims 1-9, wherein step (II) draws at least a portion of the molten glass tube off at least one edge director positioned at the downstream portion of the cylindrical surface.

11. The method of any of claims 1-10, wherein the predetermined shape of step (II) is circular.

12. The method of any of claims 1-11, wherein the predetermined shape of step (II) is oblong.

13. A glass tube making apparatus comprising:

a trough configured to receive molten glass;

a forming device defining a cylindrical surface; and

an endless weir extending along an upstream circumference of the cylindrical surface,

wherein the endless weir is configured such that a free surface of the molten glass within the trough may overflow the endless weir to form a molten glass tube flowing down the cylindrical surface.

14. The apparatus of claim 13, wherein the forming device comprises a drain member with the cylindrical surface defining an interior surface of the drain member.

15. The apparatus of claim 13 or claim 14, wherein the endless weir circumscribes the cylindrical surface of the drain member.

16. The apparatus of any of claims 13-15, wherein the cylindrical surface defines the outer surface of the forming device.

17. The apparatus of any of claims 13-16, further comprising temperature control device configured to adjust the temperature of the molten glass tube flowing down the cylindrical surface.

18. The apparatus of any of claims 13-17, wherein the forming device is angularly adjustable relative to the trough to adjust a glass flow distribution overflowing the endless weir.

19. The apparatus of any of claims 13-18, further comprising at least one edge director mounted with respect to a downstream portion of the forming device.

20. The apparatus of claim 19, wherein the edge director extends downstream from a lower edge of the forming device.

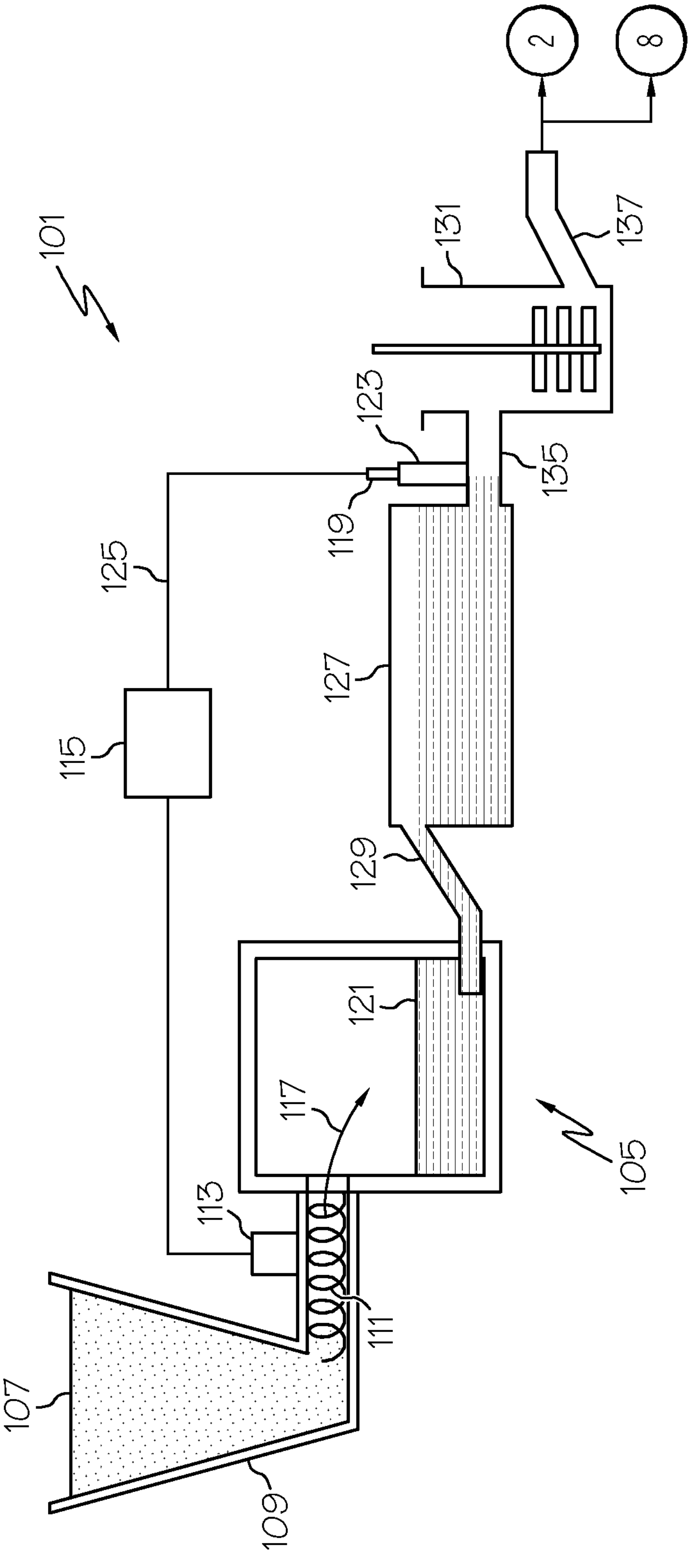
101
2
8
131
137
123
135
119
125
115
127
129
121
117
105
113
111
107
109

FIG. 1

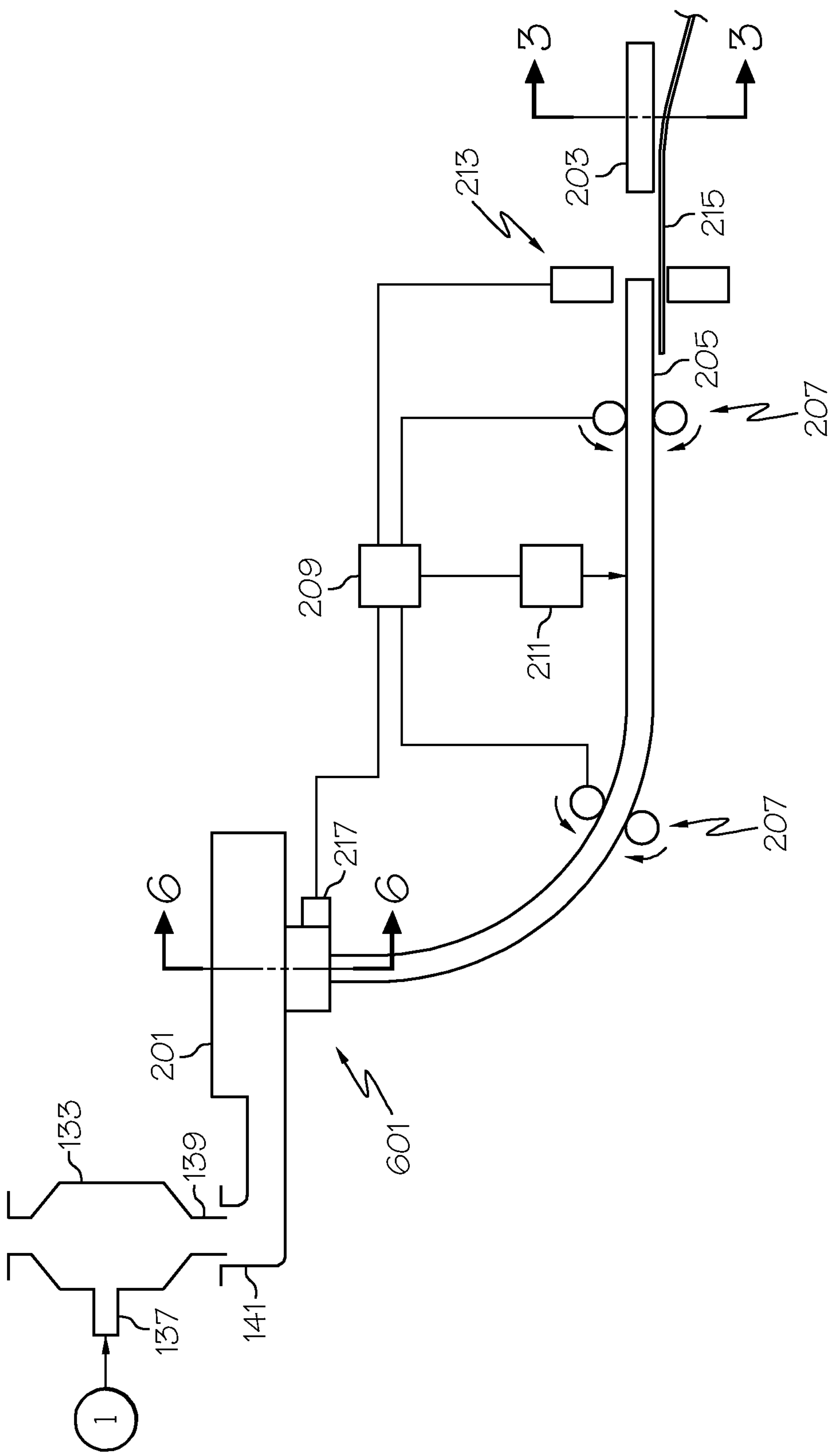
3
3
203
213
215
205
207
209
211
207
217
6
6
201
601
133
139
137
141
1

FIG. 2

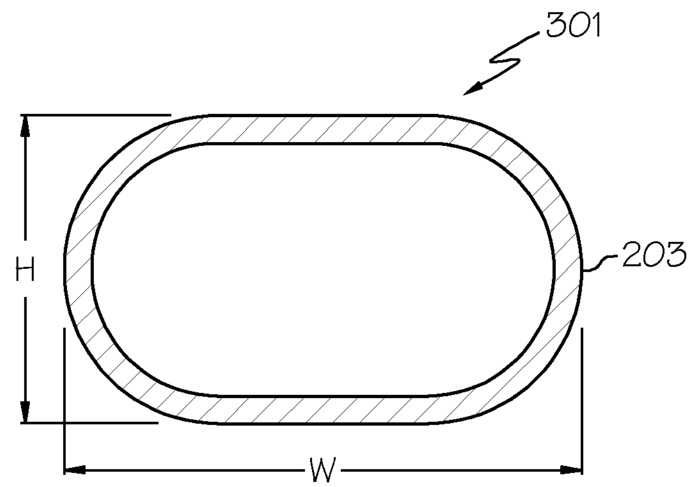

FIG. 3

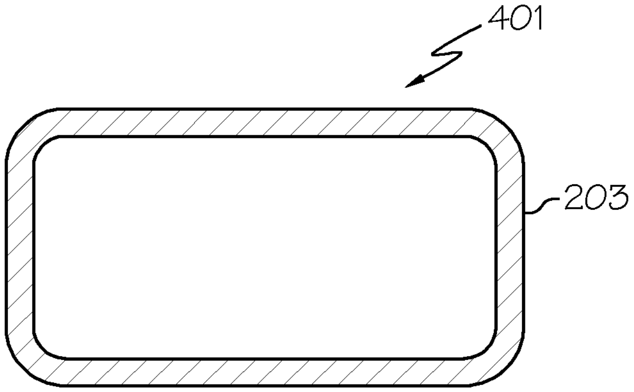

FIG. 4

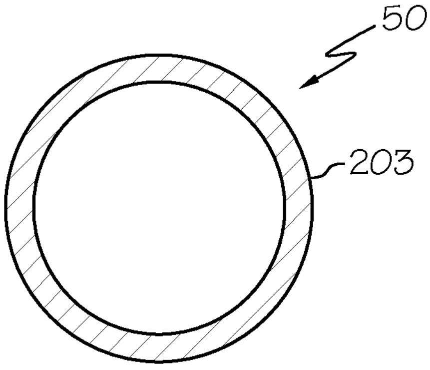

FIG. 5

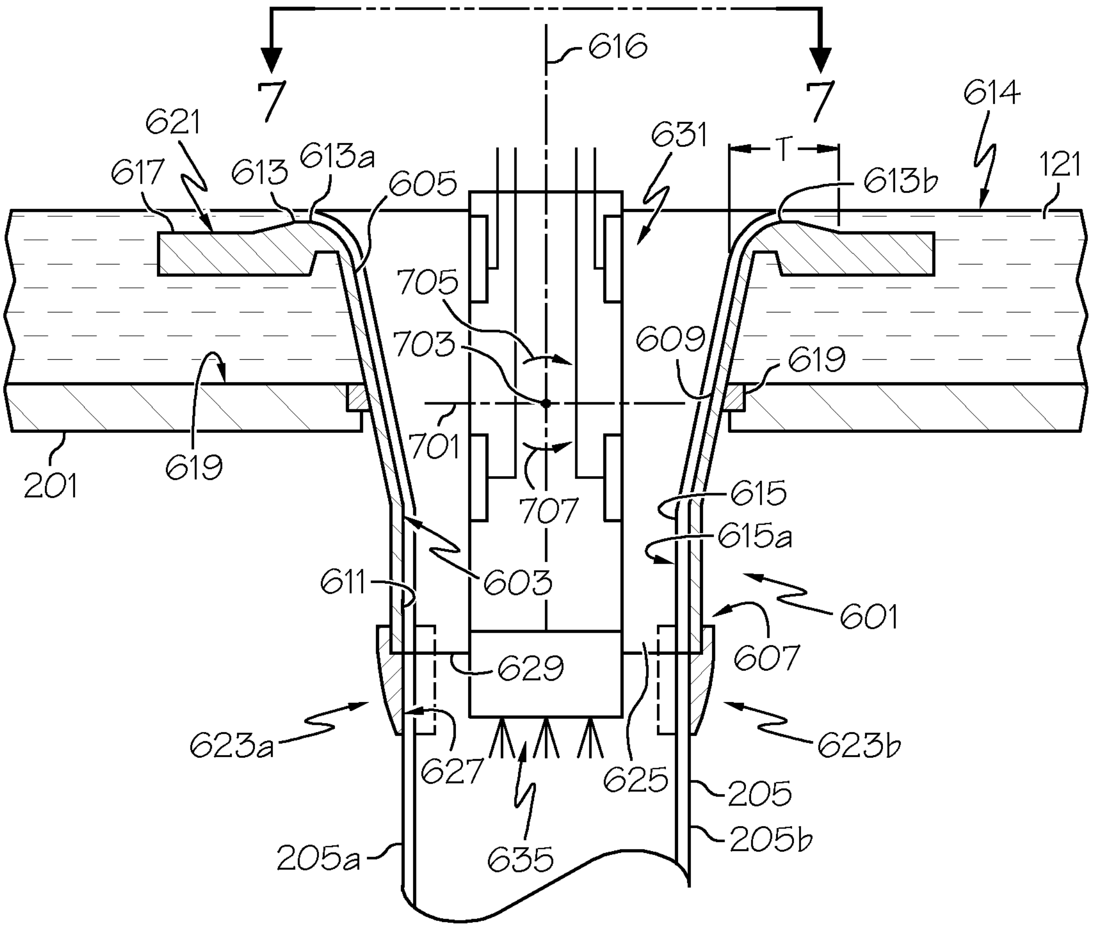
7
7
616
614
621
617
613
613a
605
631
T
613b
121
705
703
609
619
701
707
201
619
615
615a
611
603
601
607
629
623a
627
625
623b
205
635
205a
205b

FIG. 6

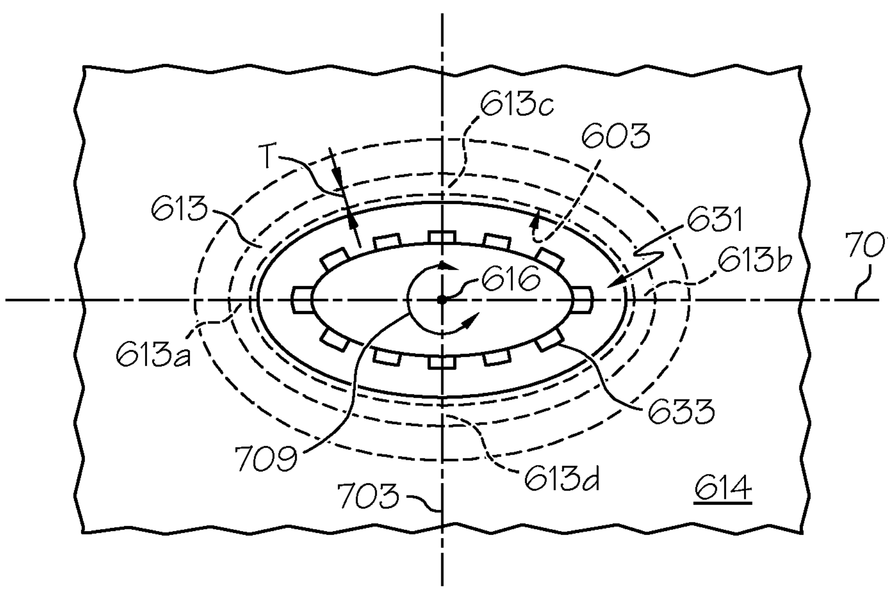
613c
603
T
613
631
613b
701
616
613a
633
709
613d
703
614

FIG. 7

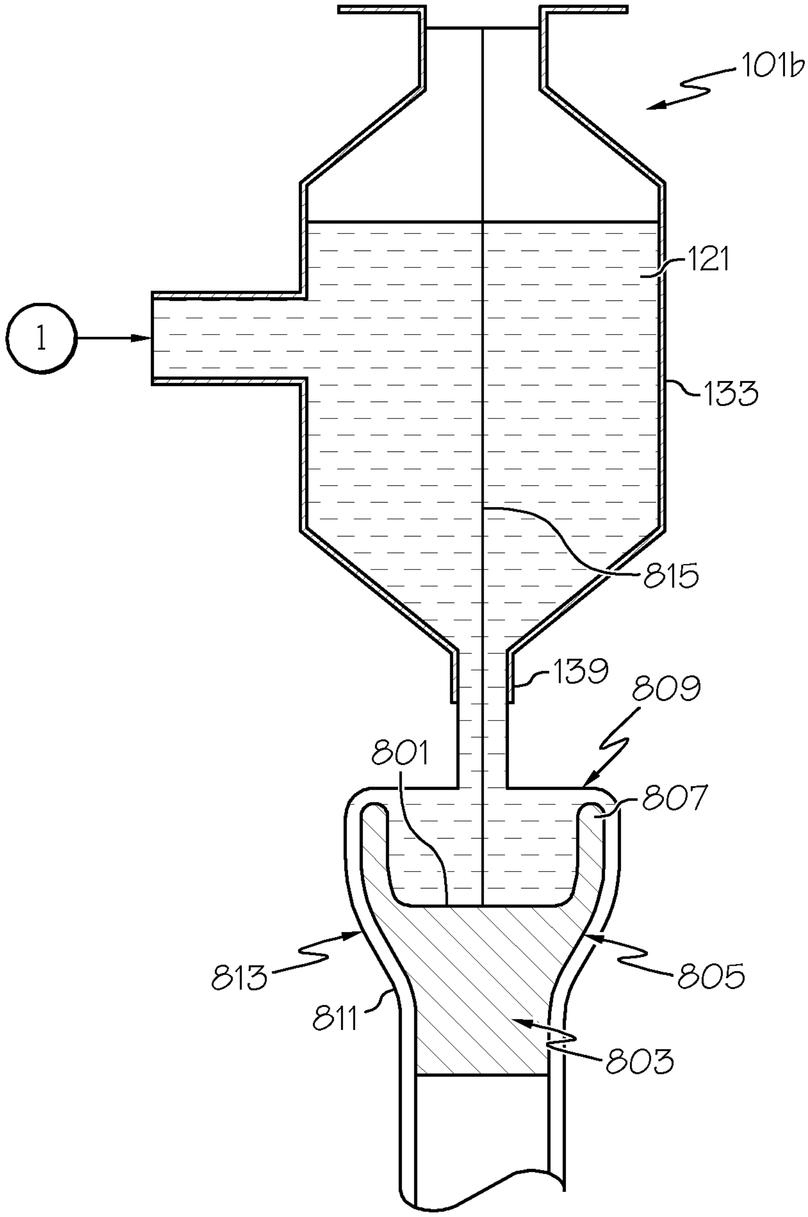

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/057179

A. CLASSIFICATION OF SUBJECT MATTER
INV. C03B17/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 1 872 542 A (CHARLES WILCOX ALLEN) 16 August 1932 (1932-08-16)	1,5-7,9, 11-13, 16,17
A	the whole document	8,10, 18-20

A	US 4 525 194 A (RUDOI BORIS L [US]) 25 June 1985 (1985-06-25) abstract; figures 1-9	1,13

X	FR 673 990 A (HARTFORD EMPIRE CO) 22 January 1930 (1930-01-22)	1-4,9, 11-15
A	the whole document	8,10, 18-20

	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 November 2013	14/11/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Stroud, Jeremy

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/057179

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 1 949 037 A (JEAN CARDOT) 27 February 1934 (1934-02-27) the whole document	1-4,9, 11-15 8,10, 18-20
X A	FR 711 161 A (LEOPOLDO SANCHEZ-VELLO) 4 September 1931 (1931-09-04) page 2, lines 5-31; figures 3-6	1-3,9, 11-14 4,8,10, 15,18-20
X A	GB 662 720 A (CARLOS HUGO POPP) 12 December 1951 (1951-12-12) page 2, lines 16-45; figure 2	1-3,9, 11-14 4,8,10, 15,18-20
A	FR 708 709 A (PAUL-GABRIEL TRIQUET) 28 July 1931 (1931-07-28) the whole document	1,13
A	GB 348 857 A (JOHN REGINALD CLARIDGE JORGENS) 21 May 1931 (1931-05-21) the whole document	1,13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/057179

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 1872542	A	16-08-1932	NONE	
US 4525194	A	25-06-1985	NONE	
FR 673990	A	22-01-1930	NONE	
US 1949037	A	27-02-1934	NONE	
FR 711161	A	04-09-1931	NONE	
GB 662720	A	12-12-1951	NONE	
FR 708709	A	28-07-1931	NONE	
GB 348857	A	21-05-1931	NONE	