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(54) **APPARATUS AND METHODS FOR LIQUID-DESICCANT CONCENTRATION MEASUREMENT WITHIN MASS TRANSFER ASSEMBLIES**

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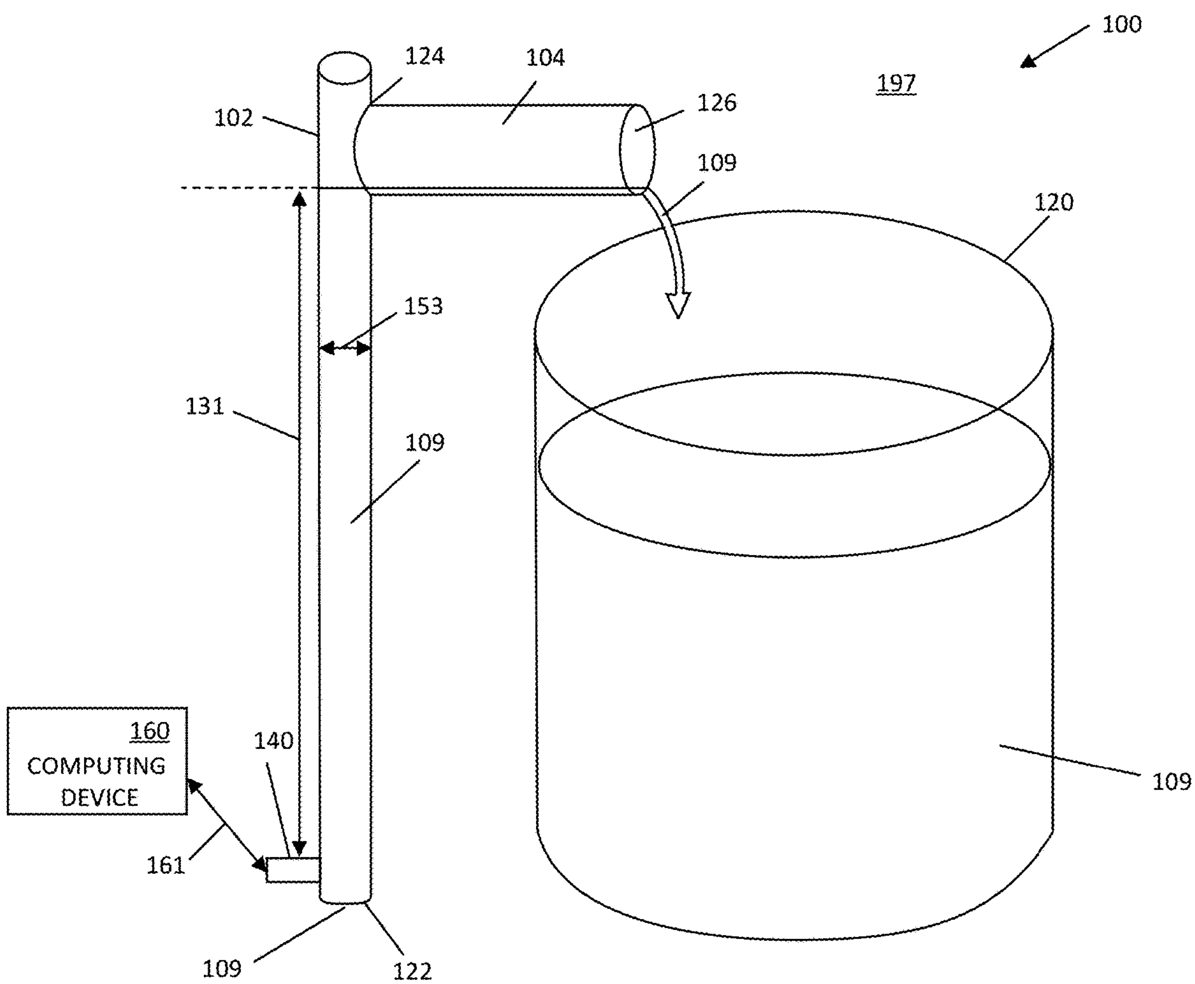
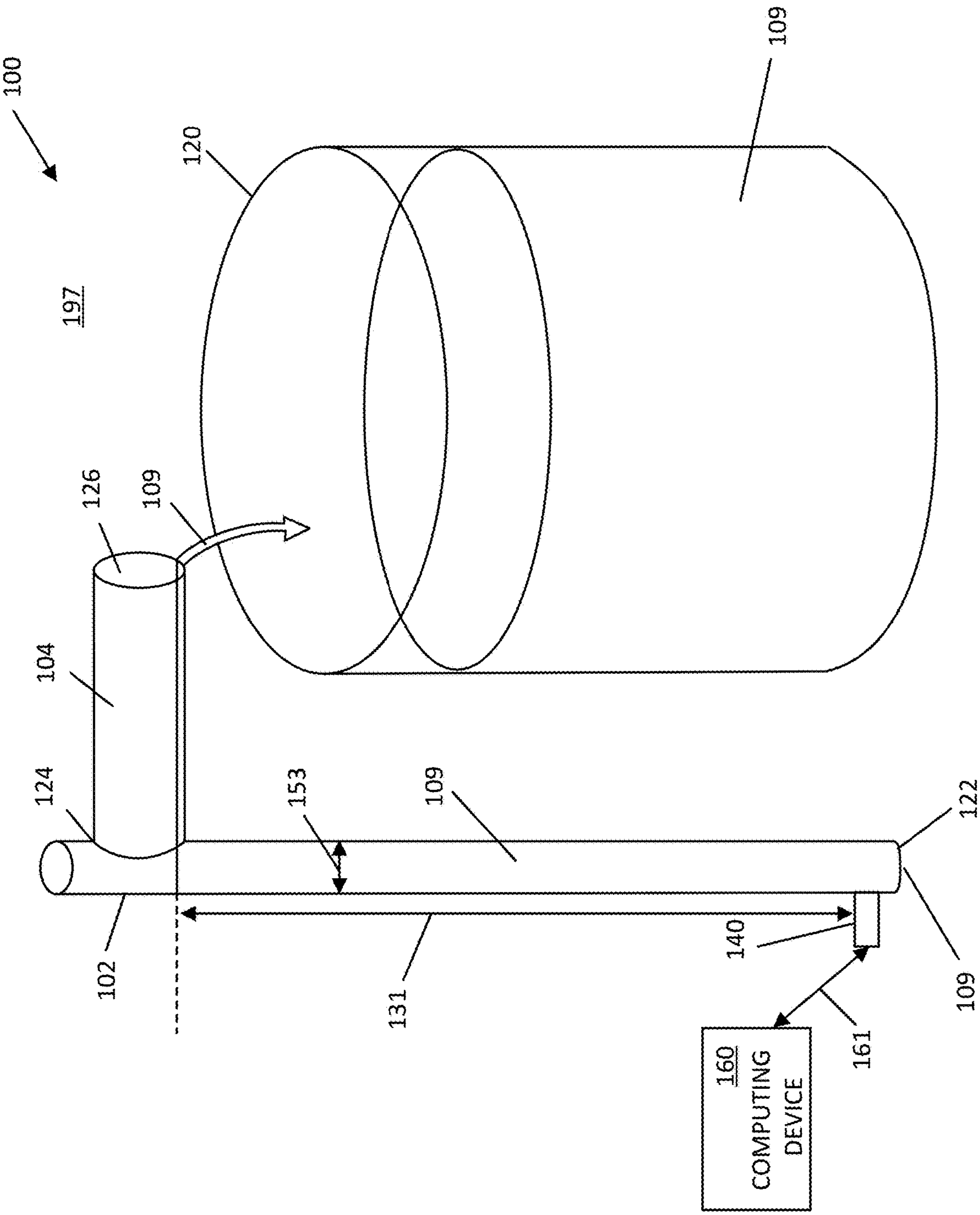
(57) **ABSTRACT**

The disclosure relates to heating ventilation and cooling systems that use liquid desiccant to remove moisture from air. In some examples, a system is configured to measure the density of a liquid. The system includes a measuring column having an inlet and an outlet. The inlet is a predetermined distance below the outlet, and the outlet is adapted such that liquid exits the outlet to low pressure. The system also includes a pressure sensor located proximate the inlet. Further, the system includes a processor adapted for receiving a reading from the pressure sensor and calculating a density of liquid flowing through the system using the reading.





100
197
120
109
126
109
104
124
153
109
122
102
131
140
109
161
160
COMPUTING DEVICE

FIG. 1

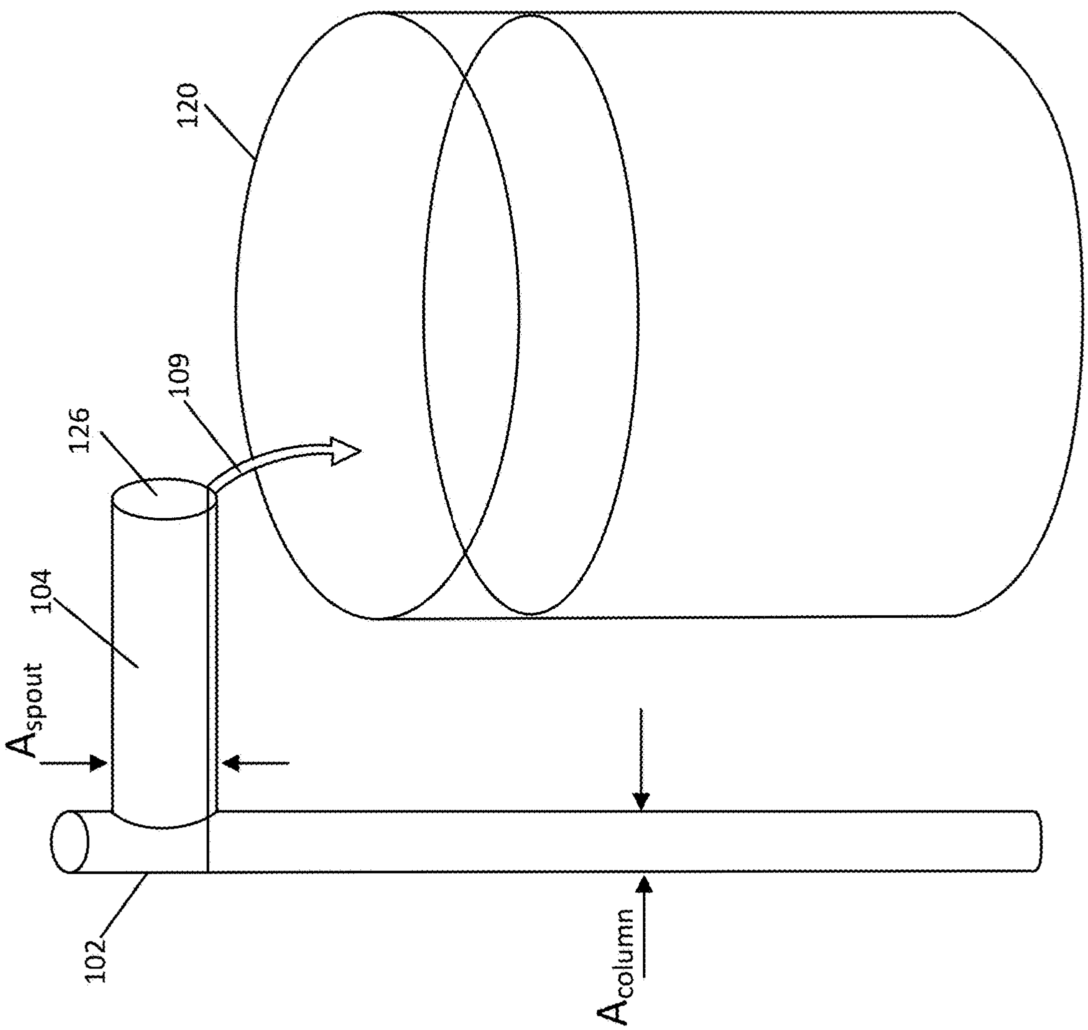


FIG. 2

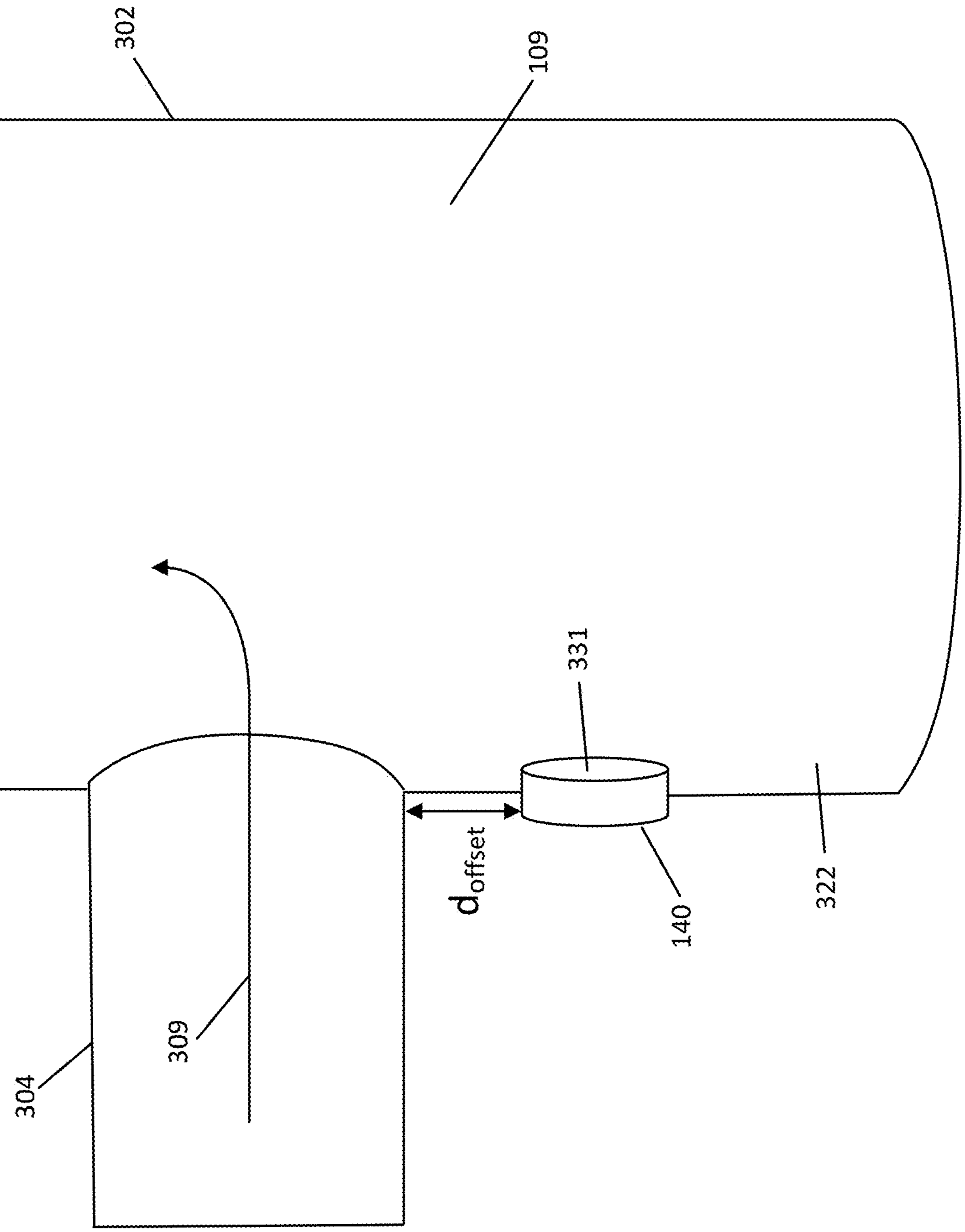


FIG. 3A

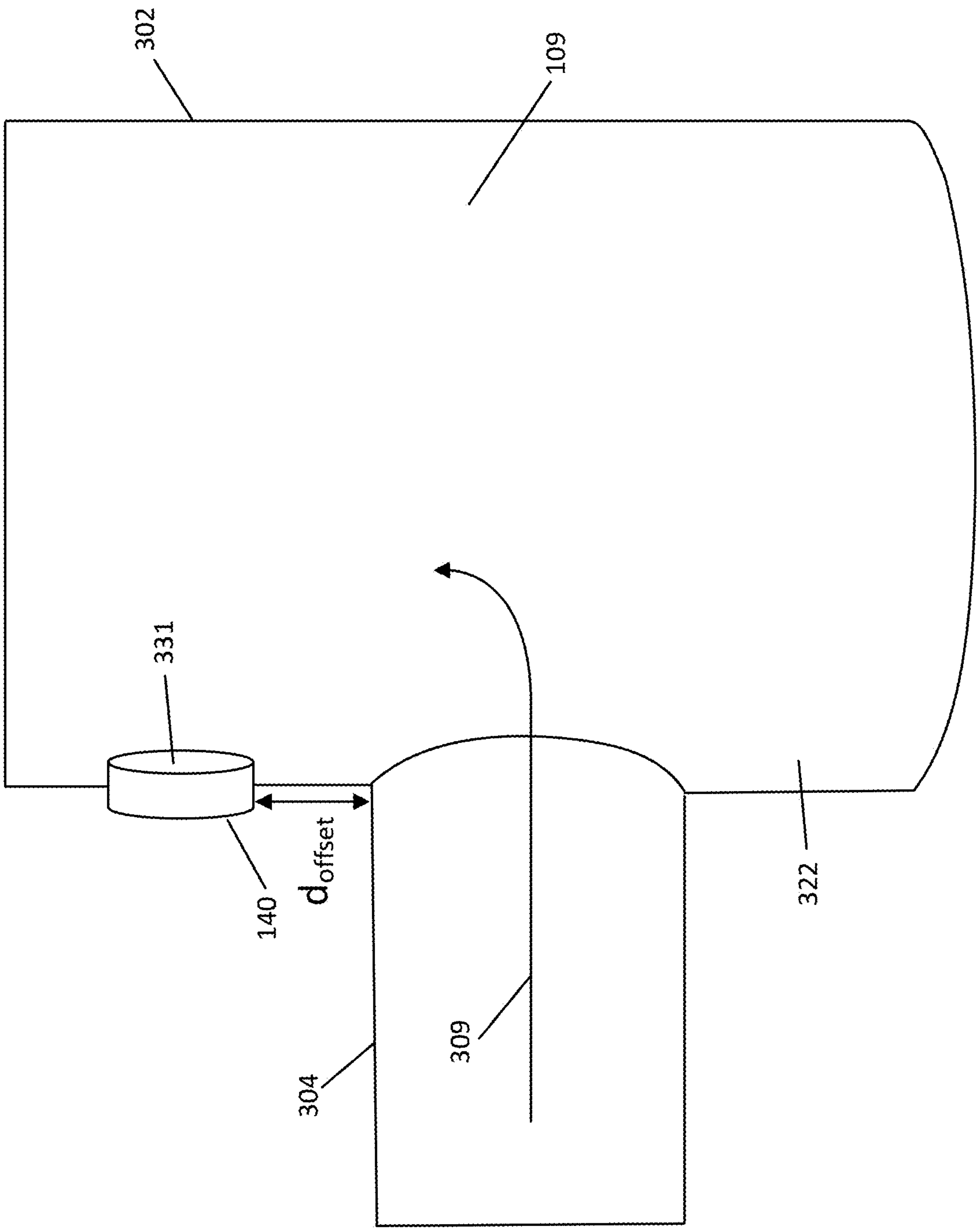


FIG. 3B

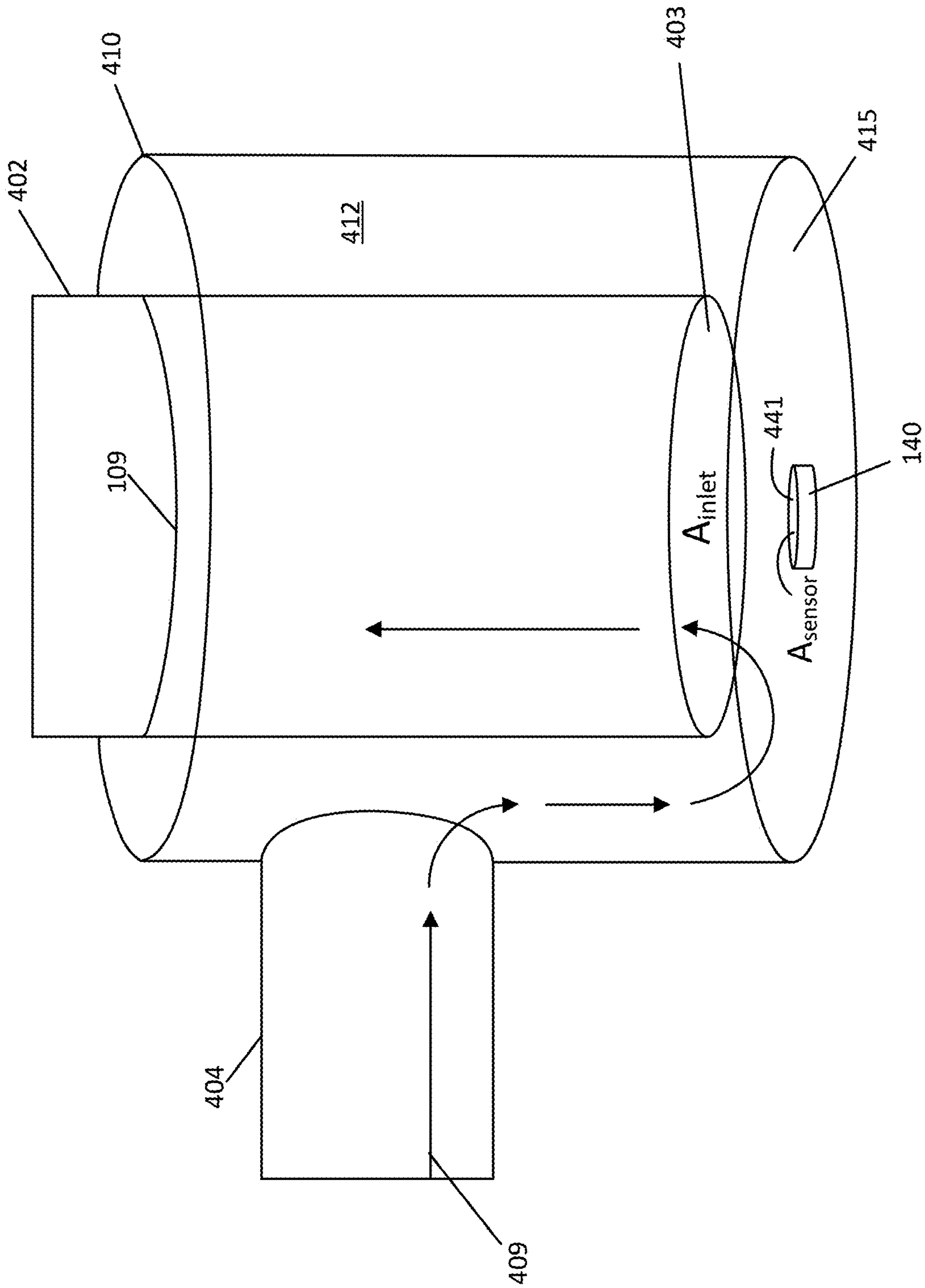


FIG. 4

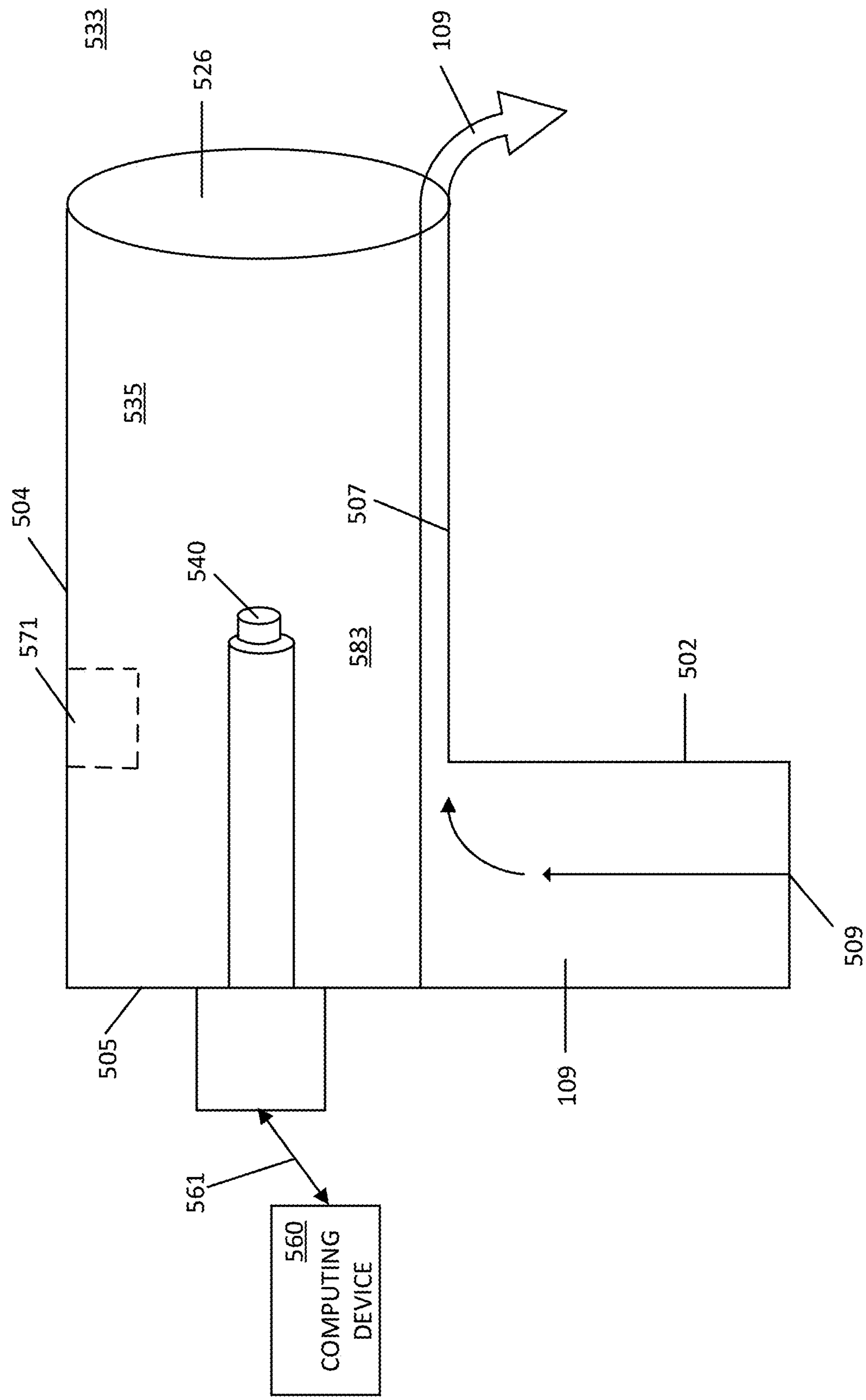

533
526
109
535
504
507
540
571
583
502
509
505
109
561
560
COMPUTING
DEVICE

FIG. 5

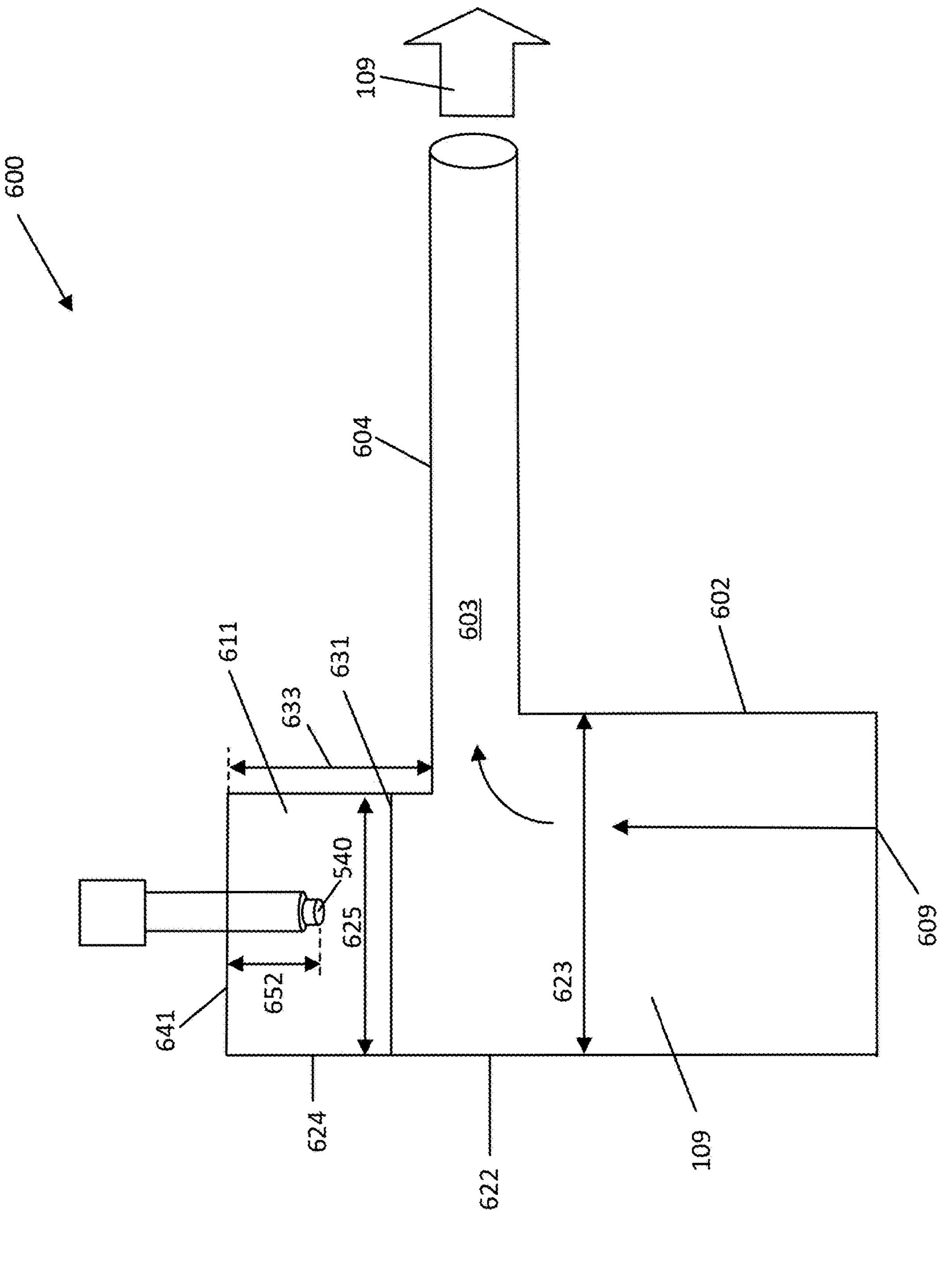
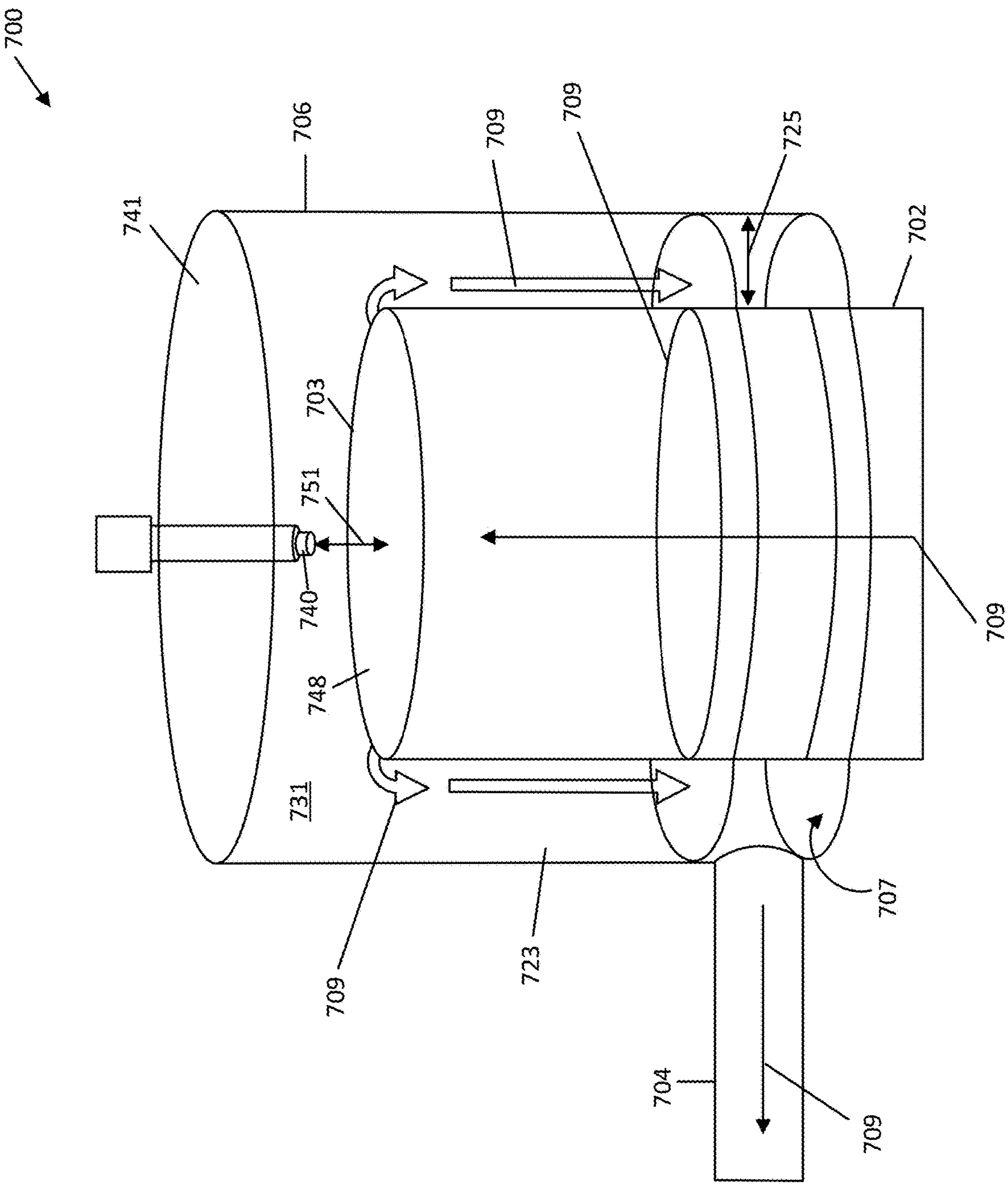

600
109
604
603
611
633
631
602
540
625
609
652
623
641
624
622
109

FIG. 6


700
706
741
709
709
725
702
703
751
740
748
731
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723
709
707
704
709

FIG. 7

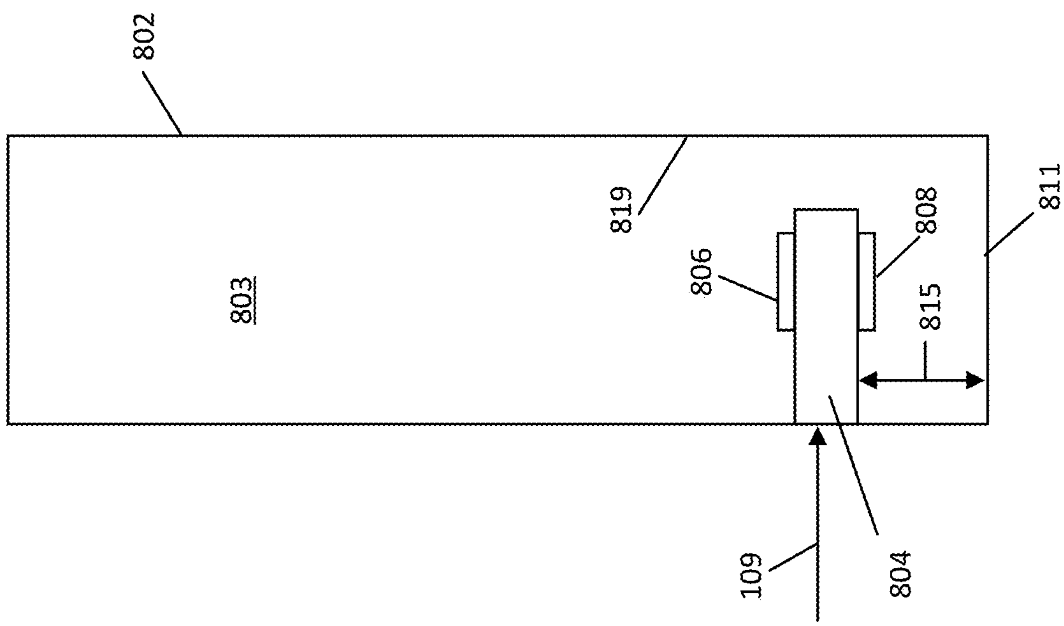


FIG. 8

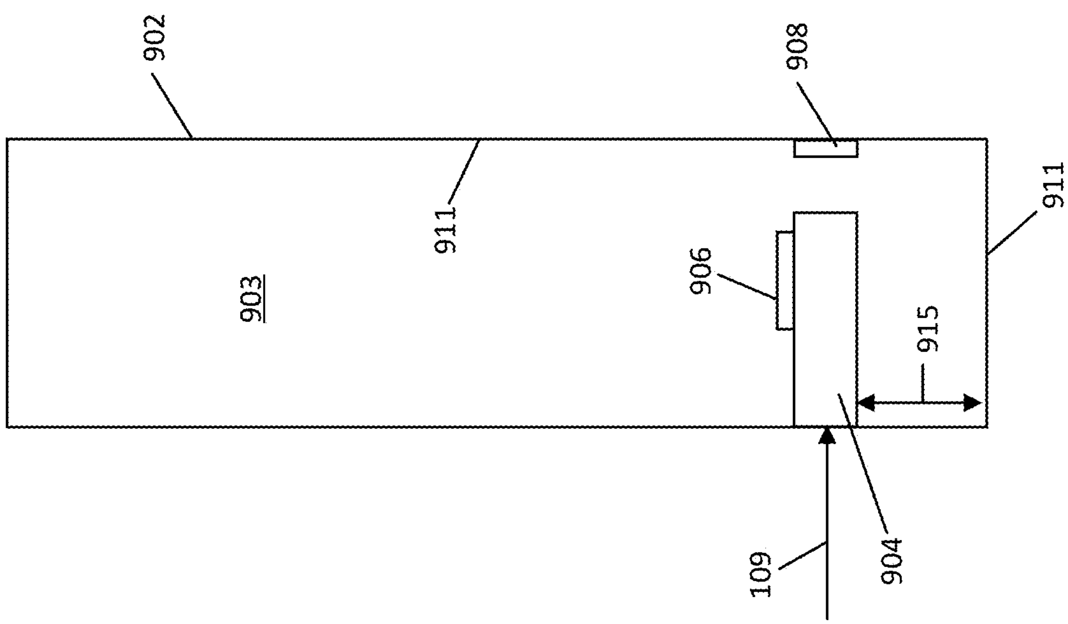


FIG. 9

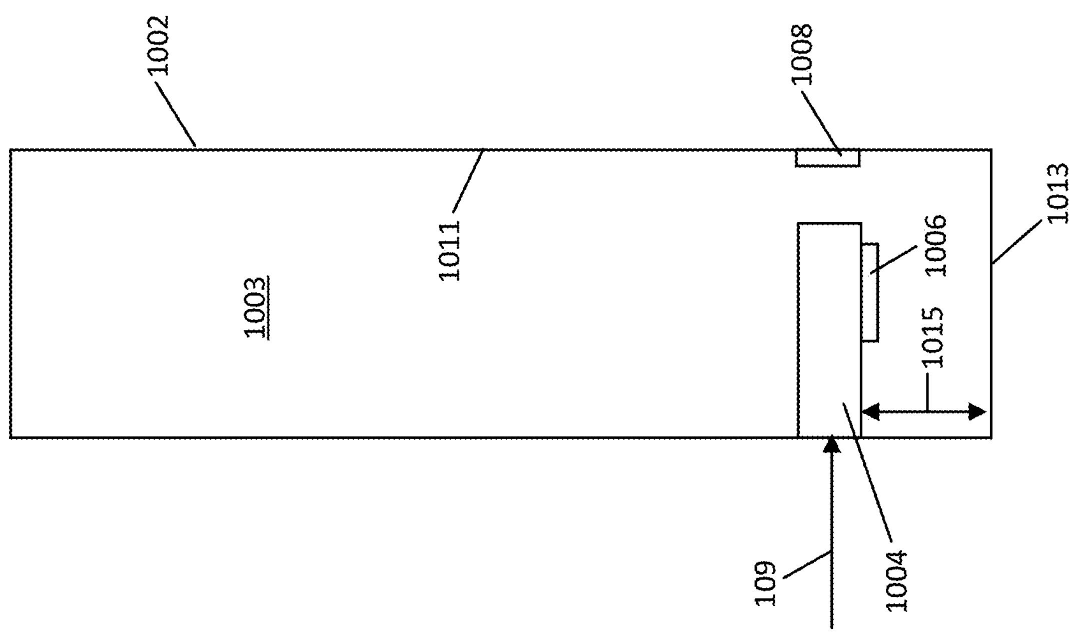


FIG. 10

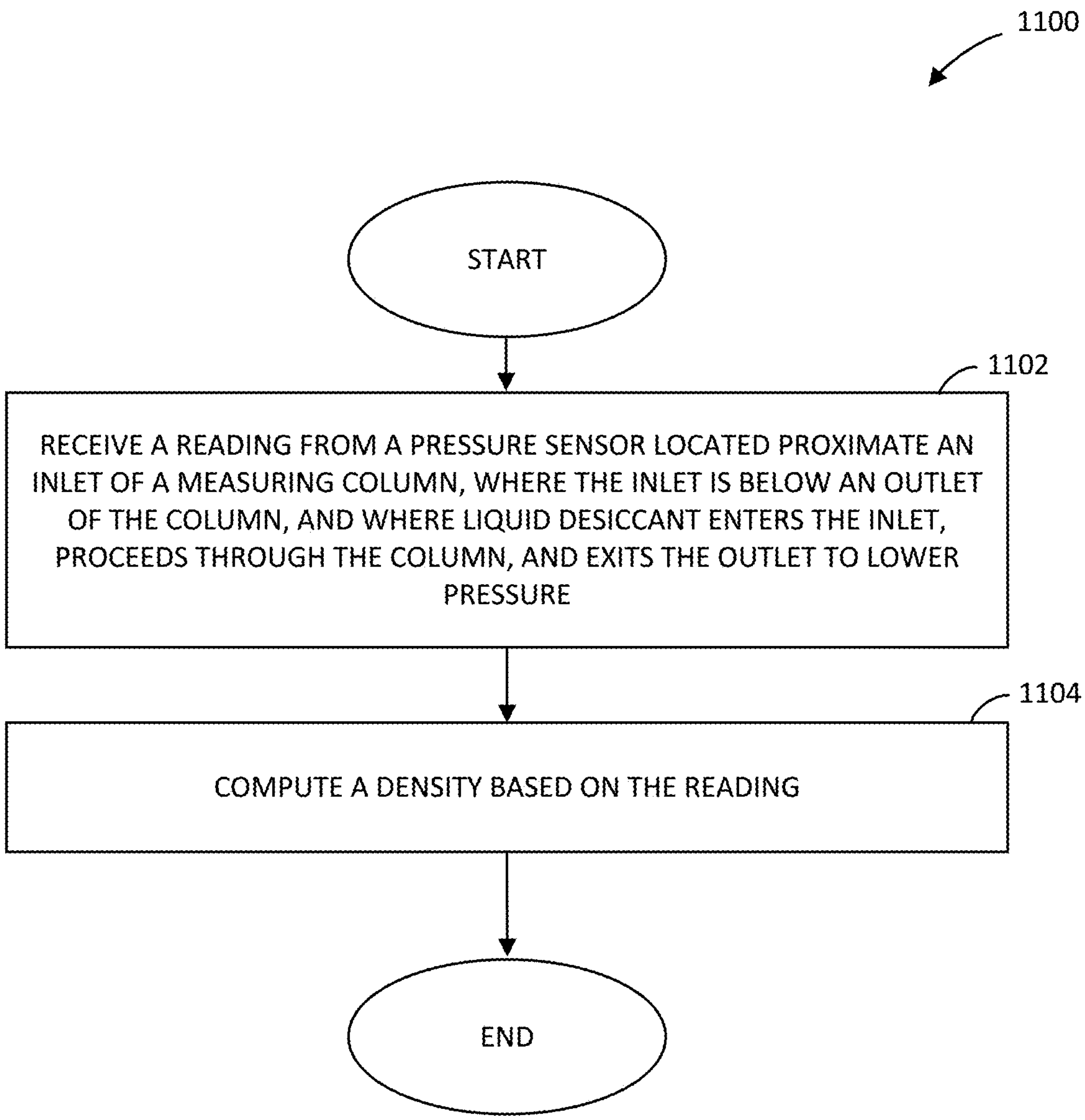

1100
START
1102
RECEIVE A READING FROM A PRESSURE SENSOR LOCATED PROXIMATE AN INLET OF A MEASURING COLUMN, WHERE THE INLET IS BELOW AN OUTLET OF THE COLUMN, AND WHERE LIQUID DESICCANT ENTERS THE INLET, PROCEEDS THROUGH THE COLUMN, AND EXITS THE OUTLET TO LOWER PRESSURE
1104
COMPUTE A DENSITY BASED ON THE READING
END

FIG. 11

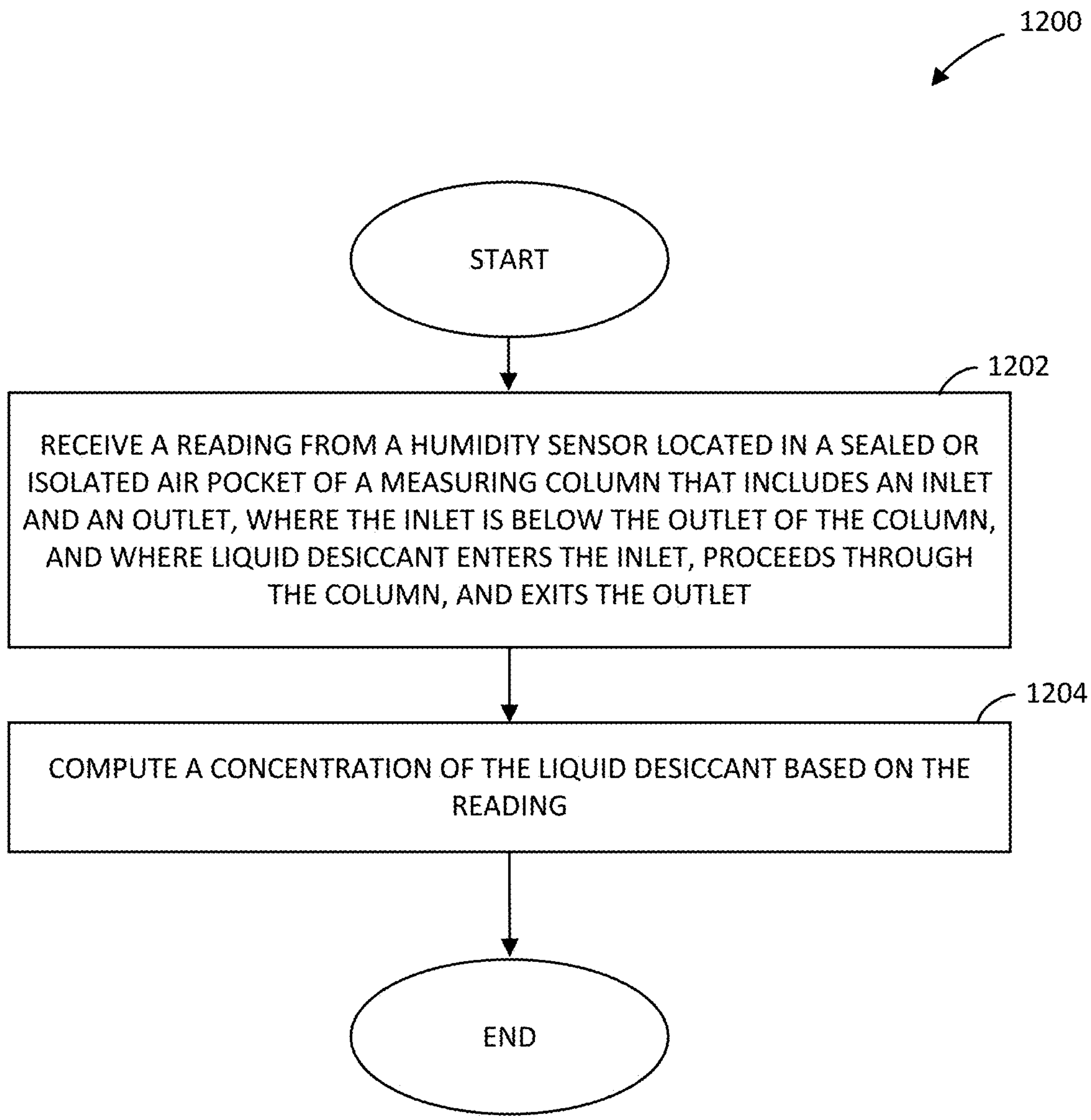

1200
START
1202
RECEIVE A READING FROM A HUMIDITY SENSOR LOCATED IN A SEALED OR ISOLATED AIR POCKET OF A MEASURING COLUMN THAT INCLUDES AN INLET AND AN OUTLET, WHERE THE INLET IS BELOW THE OUTLET OF THE COLUMN, AND WHERE LIQUID DESICCANT ENTERS THE INLET, PROCEEDS THROUGH THE COLUMN, AND EXITS THE OUTLET
1204
COMPUTE A CONCENTRATION OF THE LIQUID DESICCANT BASED ON THE READING
END

FIG. 12

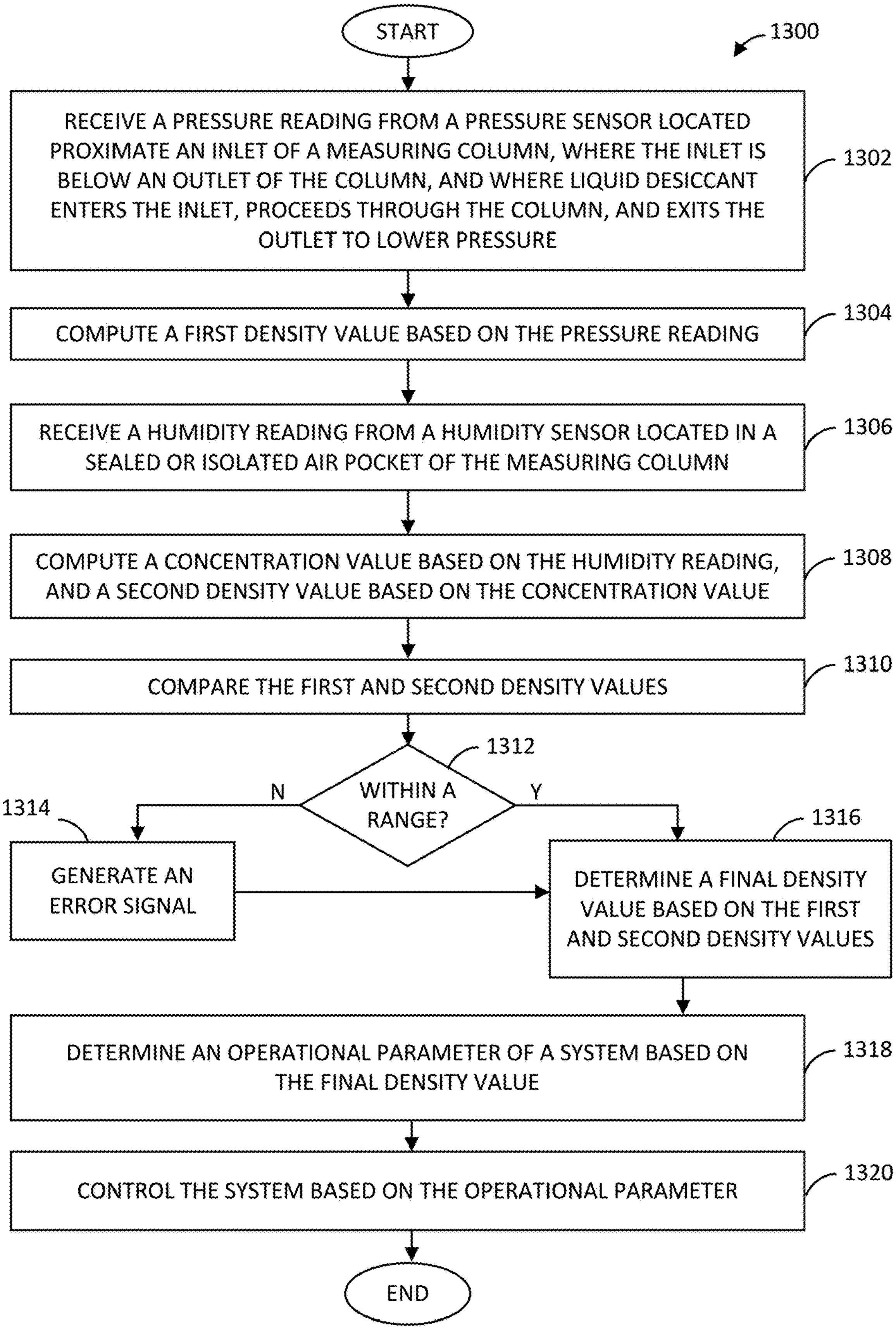
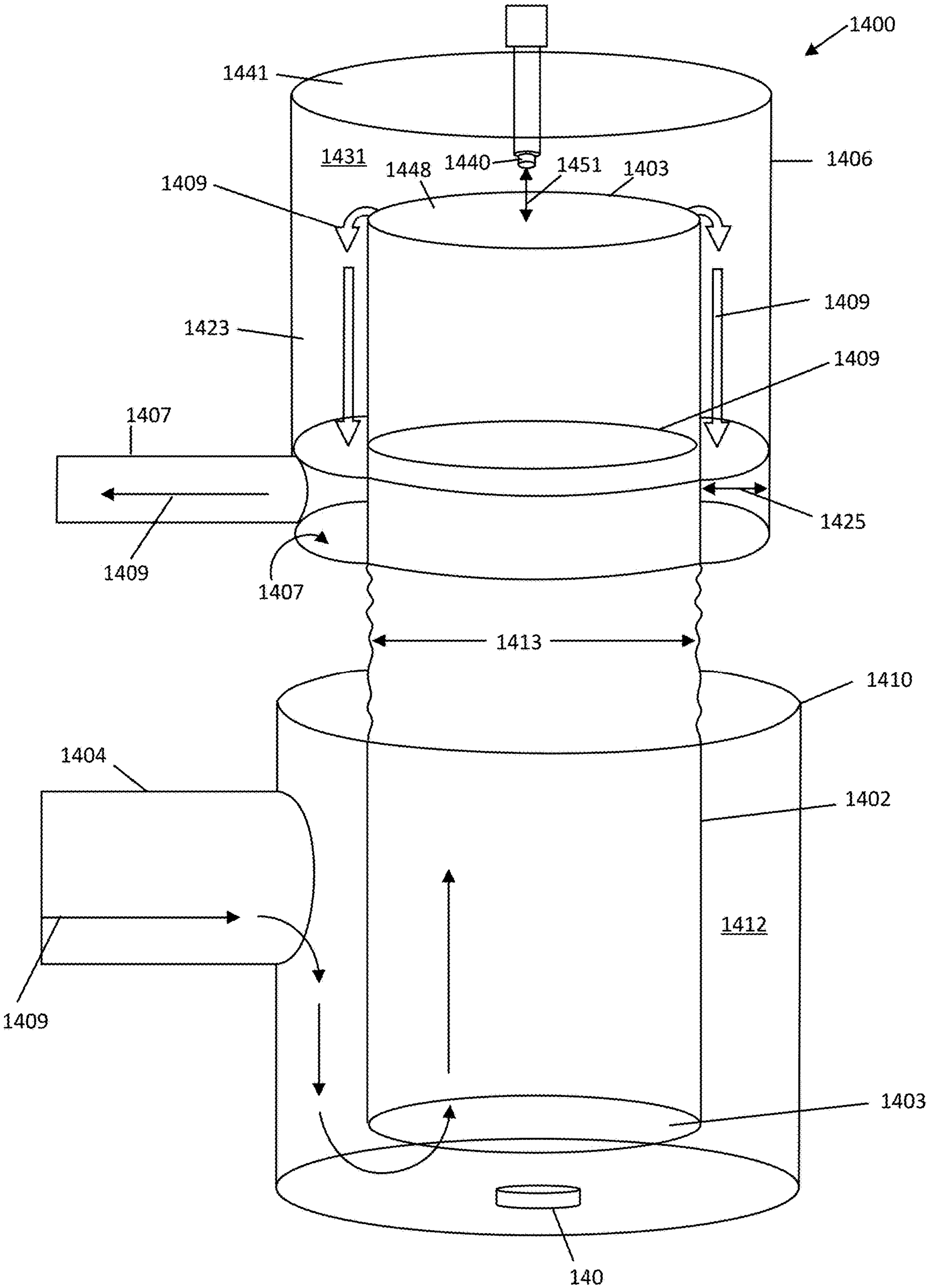

START
1300
RECEIVE A PRESSURE READING FROM A PRESSURE SENSOR LOCATED PROXIMATE AN INLET OF A MEASURING COLUMN, WHERE THE INLET IS BELOW AN OUTLET OF THE COLUMN, AND WHERE LIQUID DESICCANT ENTERS THE INLET, PROCEEDS THROUGH THE COLUMN, AND EXITS THE OUTLET TO LOWER PRESSURE
1302
COMPUTE A FIRST DENSITY VALUE BASED ON THE PRESSURE READING
1304
RECEIVE A HUMIDITY READING FROM A HUMIDITY SENSOR LOCATED IN A SEALED OR ISOLATED AIR POCKET OF THE MEASURING COLUMN
1306
COMPUTE A CONCENTRATION VALUE BASED ON THE HUMIDITY READING, AND A SECOND DENSITY VALUE BASED ON THE CONCENTRATION VALUE
1308
COMPARE THE FIRST AND SECOND DENSITY VALUES
1310
1312
WITHIN A RANGE?
N
Y
1314
GENERATE AN ERROR SIGNAL
1316
DETERMINE A FINAL DENSITY VALUE BASED ON THE FIRST AND SECOND DENSITY VALUES
DETERMINE AN OPERATIONAL PARAMETER OF A SYSTEM BASED ON THE FINAL DENSITY VALUE
1318
CONTROL THE SYSTEM BASED ON THE OPERATIONAL PARAMETER
1320
END

FIG. 13


1400
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1406
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1403
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1413
1410
1404
1402
1412
1409
1403
140

FIG. 14

APPARATUS AND METHODS FOR LIQUID-DESICCANT CONCENTRATION MEASUREMENT WITHIN MASS TRANSFER ASSEMBLIES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority to U.S. Provisional Patent Application No. 63/555,649, filed on Feb. 20, 2024, the entire disclosure of which is expressly incorporated herein by reference to its entirety.

TECHNICAL FIELD

[0002] The disclosure relates generally to device and method for making measurements of the concentration of a solute in a liquid (e.g., a salt in a liquid desiccant) flowing within a system.

BACKGROUND

[0003] Heating ventilation and air conditioning (HVAC) systems generally cool ambient or room temperature air using a vapor compression refrigeration cycle. The HVAC systems may include a heat exchanger that operates to remove heat from a refrigerant. For example, the heat exchanger may include plates or coils through which the refrigerant flows. A fan may blow air across the plates or coils to cool the refrigerant flowing within. Some heat exchangers include a liquid desiccant to dehumidify the air during the cooling process. The liquid desiccant may include a solute. The concentration of the solute can affect all aspects of the performance of the system. Thus, it is important to monitor the concentration of the solute in the liquid desiccant at various points during operation of the HVAC system.

SUMMARY

[0004] In some embodiments, a system to measure density of a liquid includes a measuring column having an inlet and an outlet, where the inlet is a distance below the outlet. In addition, the outlet is adapted such that liquid exits the outlet to low pressure. The system also includes a pressure sensor located proximate the inlet. Further, the system includes a processor adapted for receiving a reading from the pressure sensor and calculating a density of liquid flowing through the system using the reading.

[0005] In some embodiments, a method of determining a density of a liquid includes flowing a fluid through a measuring column having an inlet and an outlet, where the inlet is a distance below the outlet. In addition, the outlet is adapted such that the liquid exits the outlet to low pressure. The method also includes detecting a pressure on the fluid at a location proximate the inlet. Further, the method includes calculating a fluid density based on at least the detected pressure and the distance.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The following drawings are illustrative of particular embodiments of the present disclosure and therefore do not limit the scope of the present disclosure. The drawings are not to scale and are intended for use in conjunction with the explanations in the following detailed description.

[0007] FIG. **1** illustrates a liquid concentration measurement flow system, in accordance with one embodiment;

[0008] FIG. **2** illustrates further details of the liquid concentration measurement flow system of FIG. **1**, in accordance with one embodiment;

[0009] FIG. **3**A illustrates portions of a measuring column, in accordance with one embodiment;

[0010] FIG. **3**B illustrates portions of a measuring column, in accordance with one embodiment;

[0011] FIG. **4** illustrates further details of the concentration column of FIG. **3**A, in accordance with one embodiment

[0012] FIG. **5** illustrates portions of a measuring column, in accordance with one embodiment;

[0013] FIG. **6** illustrates further details of the measuring column of FIG. **5**, in accordance with one embodiment;

[0014] FIG. **7** illustrates portions of a measuring column, in accordance with one embodiment;

[0015] FIG. **8** illustrates portions of a measuring column, in accordance with one embodiment;

[0016] FIG. **9** illustrates portions of a measuring column, in accordance with one embodiment;

[0017] FIG. **10** illustrates portions of a measuring column, in accordance with one embodiment;

[0018] FIG. **11** is a flowchart for detecting liquid desiccant concentration, in accordance with one embodiment;

[0019] FIG. **12** is a flowchart for detecting liquid desiccant concentration, in accordance with one embodiment;

[0020] FIG. **13** is a flowchart for detecting liquid desiccant concentration, in accordance with one embodiment; and

[0021] FIG. **14** illustrates a liquid concentration measurement flow system, in accordance with one embodiment.

DETAILED DESCRIPTION

[0022] The following discussion omits or only briefly describes conventional features of heat and mass exchangers that are apparent to those skilled in the art. It is noted that various embodiments are described in detail with reference to the drawings, in which like reference numerals represent like parts and assemblies throughout the several views. Reference to various embodiments does not limit the scope of the claims attached hereto. Additionally, any examples set forth in this specification are intended to be non-limiting and merely set forth some of the many possible embodiments for the appended claims. Further, particular features described herein can be used in combination with other described features in each of the various possible combinations and permutations.

[0023] Unless otherwise specifically defined herein, all terms are to be given their broadest reasonable interpretation including meanings implied from the specification as well as meanings understood by those skilled in the art and/or as defined in dictionaries, treatises, etc. It must also be noted that, as used in the specification and the appended claims, the singular forms “a,” “an” and “the” include plural referents unless otherwise specified, and that the terms “includes” and/or “including,” when used in this specification, specify the presence of stated features, elements, and/or components, but do not preclude the presence or addition of one or more other features, steps, operations, elements, components, and/or groups thereof. In the description, relative terms such as “horizontal,” “vertical,” “up,” “down,” “top,” and “bottom” as well as derivatives thereof (e.g., “horizontally,” “downwardly,” “upwardly,” etc.) should be construed to refer to the orientation as then described or as shown in the drawing figure under discussion. These relative terms are for convenience of description and normally are not intended to require a particular orientation. Terms including "above" versus "below," "inwardly" versus "outwardly," "longitudinal" versus "lateral," and the like are to be interpreted relative to one another or relative to an axis of elongation, or an axis or center of rotation, as appropriate. Terms concerning attachments, coupling, and the like, such as "connected" and "interconnected," refer to a relationship wherein structures are secured or attached to one another either directly or indirectly through intervening structures, as well as both movable or rigid attachments or relationships, unless expressly described otherwise. The terms "operatively connected," "operably connected," and the like are such attachments, couplings, or connections that allow the pertinent structures to operate as intended by virtue of that relationship.

[0024] Embodiments of the present disclosure relate generally to heating ventilation and air conditioning (HVAC) systems and, more particularly, to HVAC systems that use a conditioning fluid, such as liquid desiccant, to dehumidify and transfer heat from a fluid, such as air. The mass fraction of solute within a liquid desiccant (which can be referred to as a "concentration" of solute within the liquid desiccant) is an important parameter to know during the operation of an HVAC unit. For instance, the concentration of the solute within a liquid desiccant can affect the efficiency of desiccant regeneration, as well as the rate of moisture removal. The concentration of the solute can also affect crystallization of the liquid desiccant, which ideally is to be avoided within these HVAC systems.

[0025] The concentration measurement system disclosed herein may include a vertical columnar tube within the flow path of the desiccant. The vertical columnar tube may be configured such that it has the same liquid height, or nearly the same liquid height, regardless of the flow rate of liquid desiccant (even when not flowing). The vertical columnar tube may include a pressure sensor near the bottom portion. The pressure sensor may indicate a pressure of the liquid desiccant at the level within the tube that the pressure sensor is located. Based on the detected pressure and the height of the vertical columnar tube, a fluid density of the liquid desiccant can be determined. In some examples, a temperature sensor (e.g., a liquid temperature sensor) detects a temperature of the liquid desiccant. Based on the fluid density and temperature of the liquid desiccant, a concentration of the liquid desiccant can be computed.

[0026] The concentration of the liquid desiccant may have a strong correlation to its equilibrium humidity. As such, in some examples, the liquid desiccant system includes an air temperature and relative humidity (TRH) sensor that measures the relative humidity of the air above the liquid desiccant. The TRH sensor is strategically placed so as to measure a humidity value indicative of the liquid desiccant's equilibrium value. Based on the measured relative humidity of the air, the concentration of the liquid desiccant can be computed.

[0027] While the description provided herein discusses how the system measures the concentration of a solute (e.g., ionic species, such as a salt) species within a liquid desiccant, it will be understood that the concepts, systems, and techniques described herein can be used with other liquids containing any solute where the density of the fluid is related to the concentration of the solute.

[0028] Referring now to the drawings, FIG. **1** illustrates a liquid concentration measurement flow system **100** that includes a measuring column **102**, an exit tube **104**, a liquid desiccant tank **120**, a pressure sensor **140** in fluid communication with liquid in the measuring column, and a computing device **160**. As illustrated, a liquid desiccant **109** may be pumped through an inlet **122** of the measuring column **102**. The measuring column **102** may be generally vertical, i.e., 90 degrees to the ground. In some examples, the measuring column **102** may be less than or equal to 10 degrees from vertical. In some examples, the measuring column **102** may be less than or equal to 7.5 degrees from vertical. In some examples, the measuring column **102** may be less than or equal to 5 degrees from vertical. In some examples, the measuring column **102** may be less than or equal to 2.5 degrees from vertical. In some examples, the measuring column **102** may be less than or equal to 1 degree from vertical.

[0029] The liquid desiccant **109** flows up through the measuring column **102** and out an outlet **124**. The outlet **124** may be a predetermined distance **131** above the pressure sensor **140**. For example, the distance **131** may be at least 5 times a diameter **153** of the measuring column **102**. In some examples, the distance **131** may be at least at least 10, 12.5, 15, 17.5, or 20 times the diameter **153**. The liquid desiccant **109** proceeds into the exit tube **104**, and flows through the exit tube **104** and out an exit tube outlet **126** to an ambient area **197** with low pressure (e.g., lower pressure than within measuring column **102**). For instance, ambient area **197** may have a pressure less than 1.15 atmosphere (atm), less than 1.1 atm, less than 1.05 atm, or less than 1.02 atm.

[0030] Further, the liquid desiccant **109** exits out the exit tube outlet **126**, and flows into a liquid desiccant tank **120** or other portion of the liquid desiccant flow path within the system. Of particular interest, the liquid desiccant **109** exiting the measuring column is exiting without back-pressure. Thus, the pressure measured by the pressure sensor **140** is produced exclusively or almost exclusively by the weight of fluid in the measuring column **102**. This enables for accurate measurement of the density of the fluid in the measuring column **102**.

[0031] In some examples, the measuring column **102** and the exit tube **104** may each be in the form of a circular tube. For instance, they each may have a fixed or uniform corresponding inside cross-sectional area throughout. Moreover, the bottom of the exit tube **104** may form an angle **171** with the measuring column **102**. In some examples, the angle **171** may be near 90 degrees. In some examples, the angle **171** may be less than 90 degrees. In some examples, the measuring column **102** and/or the exit tube **104** are pipes. As described herein, the inside cross-sectional area of the exit tube **104** may be greater than the inside cross-sectional area of the measuring column **102**. For instance, an inside diameter of the exit tube **104** may be greater than an inside diameter of the measuring column **102**. In addition, they each may be manufactured from any suitable rigid material, such as metal, glass, plastic, and ceramic materials.

[0032] Because the overflow path provided by the exit tube **104** is sufficiently open, the overflow path allows for a significant exit flow rate for relatively small increases in liquid desiccant **109** level height above its bottom. In some instances, when the angle **171** is less than 90 degrees (e.g., in the range of 75 to 89 degrees), gravity allows the liquid desiccant **109** to flow freely into the liquid desiccant tank

120. The height **131** of the liquid desiccant **109** can be estimated as the distance from the pressure sensor **140** to the bottom of the exit tube **140**, or to a distance above the bottom of the exit tube **104**. Based on the height **131**, the density of the liquid desiccant **109** can be computed.

[0033] For instance, the formula for hydrostatic pressure is $P=\rho\cdot g\cdot h$, where P is the pressure, ρ is the fluid density, g is the acceleration of gravity, and h is the height of a fluid column, e.g., distance **131**. Based on this hydrostatic pressure formula, the fluid density can be determined according to $\rho=P/(g\cdot h)$. Thus, to determine the fluid density, the pressure P and the height h need to be known (the acceleration of gravity g is known).

[0034] Referring back to FIG. **1**, to determine the density of the liquid desiccant **109**, the liquid concentration measurement flow system **100** may include a pressure sensor **140** that detects a pressure of the liquid desiccant **109** within the measuring column **102**. For instance, and as further described below, the pressure sensor **140** may be located near the inlet **122** of the measuring column **102**. Based on a pressure reading from the pressure sensor **140** and the known height **131**, a density and/or concentration of the liquid desiccant **109** can be computed.

[0035] For example, computing device **160** may be communicatively coupled to the pressure sensor **140** over one or more wired or wireless communication channels **161** (e.g., a WiFi® or BlueTooth® connection). The computing device **160** may include one or more processors that execute instructions to carry out operations, such as any of the operations described herein. The computing device **160** may receive a reading characterizing a detected pressure from the pressure sensor **140** (e.g., periodically, based on a schedule, etc.). Based on the reading, the computing device **160** may compute the density of the liquid desiccant **109**. For example, the computing device **160** may perform operations to divide the reading by a predetermined height, which in this example may correspond to the height **131**, and to divide the result by the acceleration of gravity (i.e., acceleration of gravity g), to compute a density value characterizing the density of the liquid desiccant **109**. In some examples, the computing device **160** may compute a concentration value characterizing a concentration of the liquid desiccant **109** based on the density value. For example, the computing device **160** may apply any suitable density to concentration formula to the density value to compute the concentration value, such as any of the known formulas (e.g., algorithms) recognized by persons of ordinary skill in the art.

[0036] Further, in some examples, the computing device **160** determines a parameter for operating a liquid desiccant regenerator based on the computed concentration value and/or density value. For example, the parameter may relate to or inform whether a regenerator is on or off, a value for a liquid desiccant flow rate through a conditioner or a regenerator, a value for an air flow rate through a conditioner or a regenerator, or a value for an operating temperature of a conditioner or a regenerator.

[0037] FIG. **2** identifies a cross-sectional area A_{column} of the measuring column **102** and a cross-sectional area A_{spout} of the exit tube **104**. As such, the measuring column **102** is manufactured to have a cross-sectional area A_{column} that is based on expected liquid desiccant **109** flow rates so as to prevent the negative impacts of high velocity liquid desiccant **109** flow. For instance, if A_{column} is too large, it may take too long for changes in concentration to be detected. Alternately, if A_{column} is too small, the flow rate may increase pressure that is not a result of changes in density of the liquid in the measuring column **102**. The pressure sensor **140**, being positioned near the inlet **122** of the measuring column **102**, may detect an average density of the liquid desiccant **109** within the measuring column **102**. In some embodiments, the measuring column **102** and the exit tube **104** are manufactured such as to have a cross-sectional area ratio of A_{spout} to A_{column} of 1, or 2, or 5, or 10, or larger.

[0038] FIG. **3**A illustrates a measuring column **302** with an entrance tube **304** that provides the liquid desiccant **109** to an interior of the measuring column **302**. In this example, a pressure sensor **140** is placed below the entrance tube **304** by an amount identified as d_{offset}. By placing the pressure sensor **140** below the entrance tube **304** by at least the d_{offset} amount, the pressure sensor **140** may avoid affects from any eddies formed from the flow **309** of liquid desiccant **109** entering the measuring column **302** and any direct impacts caused by the flow of liquid desiccant **109** into the measuring column **302**.

[0039] Because liquid desiccant **109** in a bottom portion **322** of the measuring column **302** that is below the entrance tube **304** may be stagnant, its concentration may be less likely to change as the concentration of the liquid desiccant **109** coming into the measuring column **302** through the entrance tube **304** changes. For instance, a portion of the liquid desiccant **109** within the measuring column **302** will have a density that is not representative of the density of the liquid desiccant **109** proceeding upward through the measuring column **302**. To offset these potential causes of error, in some examples, the pressure sensor **140** is positioned at a maximum of a d_{offset} amount to keep any potential pressure sensor **140** errors below a minimum threshold. The d_{offset} amount may be determined empirically for a given measuring column **302** configuration, for example. In some examples, the d_{offset} amount is less than 3 inches, less than 2 inches, or less than 1 inch. The density can then be measured based on the height **131** starting from the sensor **140** to the exit tube **104**.

[0040] As illustrated in FIG. **3**B, in some examples, the pressure sensor **140** is placed above the entrance tube **304** by a d_{offset} amount. In this example, the pressure sensor **140** is located in a location where the liquid desiccant **109** is not stagnant, as the liquid desiccant **109** flows up through the measuring column **302**. The density can then be measured based on the height of the column **131** starting from the sensor **140** to the exit tube **104**.

[0041] Because the flow of the liquid desiccant **109** is parallel, or nearly parallel, to the surface **331** of the pressure sensor **140**, any affects from the flow of liquid desiccant **109** into the measuring column **302** may be minimal. Moreover, because the pressure sensor **140** is located within the measuring column **302** and above the entrance tube **304**, the pressure readings by the pressure sensor **140** are based on non-stagnant liquid desiccant **109** flow. Because the pressure sensor **140** is located higher up along the measuring column **302** compared to when placed under the entrance tube **304**, any variations in liquid desiccant height (as measured from the pressure sensor **140** upward to an upper surface of the liquid desiccant **109** entering the exit tube **104**) may be a larger percentage of the nominal liquid desiccant **109** height within the measuring column **302**.

[0042] FIG. **4** illustrates a measuring column **402** that extends into a base cap **410** that forms a concentric annulus region **412** with the measuring column **402**. For instance, the base cap **410** encircles a lower end of the measuring column **402**. A flow **409** of the liquid desiccant **109** proceeds from an entrance tube **404** into the concentric annulus region **412**, and continues downward through the concentric annulus region **412** before proceeding up through inlet **403** into the measuring column **402**. In other words, the liquid desiccant **109** is fed to the inlet **403** from the base cap **410** (e.g., feed conduit) encircling the lower end of the measuring column **402**.

[0043] A pressure sensor **140** can be positioned on a base surface **415** of the base cap **410**. Although the flow **409** of liquid desiccant **109**, when proceeding downward towards the base surface **415** of the base cap **410**, may impart pressure on a surface **441** of the pressure sensor **140**, the effects of this pressure can be reduced (e.g., kept to a minimum) by reducing a ratio of the cross-sectional area A_{sensor} of the pressure sensor **140** to the cross-sectional area A_{inlet} of the inlet **403**. For instance, the measuring column **402** and base cap **410** may be manufactured such as to have a ratio of A_{sensor} to A_{inlet} below a maximum threshold (i.e., A_{sensor}/A_{inlet}<Max Value). This ratio may be empirically determined, for example. In some examples, a ratio of A_{inlet} to A_{sensor} is at least 4. In some examples, the ratio is at least 8. In some examples, the ratio is at least 16. In some examples, the ratio is at least 32. In some examples, the ratio is at least 64. In some examples, the ratio is at least 128. In some examples, the ratio is at least 256.

[0044] In some examples, the pressure sensor **140** is coupled to a base surface **415** of the base cap **410**. In some examples, at least a portion of the pressure sensor **140** is within an area of the inlet **403**, i.e., A_{inlet}. In some examples, at least a portion of the pressure sensor **140** is outside the area of the inlet **403**.

[0045] The arrangement of FIG. **4** is provided to minimize flow effects on the pressure detected by the sensor **140**. The momentum of the liquid exiting the entrance tube **404** is redirected around the outer surface of the measuring column **402**. The liquid then flows around the lower edges of the measuring column **402**. By reducing the area of the sensor **140**, the impact of the liquid flow on the pressure measured by the sensor **140** is minimized.

[0046] As described herein, liquid desiccant concentration may be determined, refined, or confirmed using equilibrium humidity. For example, FIG. **5** illustrates a flow **509** of liquid desiccant **109** that proceeds upwards through a measuring column **502** and into a cavity **583** of an exit tube **504**, before proceeding out through exit tube outlet **526** (e.g., to flow into a liquid path). In this example, a cross-sectional area of the exit tube **504** is larger than a cross-sectional area of the measuring column **502**. For instance, the cross-sectional area of the exit tube **504** may be 1, 1.5, 2, or 3 times greater than the cross-sectional area of the measuring column **502**. In other examples, the cross-sectional area of the exit tube **504** is smaller than the cross-sectional area of the measuring column **502**.

[0047] Further, a humidity sensor **540** (e.g., a relative humidity sensor) is positioned within the exit tube **504**, and is configured to detect a humidity within the exit tube **504**. The humidity sensor **540** may, for example, be attached to a wall **505** of the exit tube **504**, and may be positioned horizontally above the flow (e.g., horizontal flow) of liquid desiccant **109**. Further, the humidity sensor **540** may be communicatively coupled to a computing device **560** over one or more wired or wireless communication channels **561** (e.g., a WiFi® or BlueTooth® connection). The computing device **560** may receive humidity data from the humidity sensor **540**. The humidity data may characterize a detected humidity level. The computing device **560** may compute a concentration value characterizing a concentration of the liquid desiccant **109** based on the humidity data.

[0048] For example, the computing device **560** may execute any known algorithm to compute the concentration value based on the humidity data. In some examples, the computing device **560** may determine the concentration value based on a stored table that includes ranges of humidity levels and corresponding concentration values. For instance, the computing device **560** may compare the humidity data to a range of humidity levels stored in memory, determine that the humidity data falls within the range, and retrieve the concentration value corresponding to the range from the memory. Further, in some examples, the computing device **560** may compute a density value characterizing a density of the liquid desiccant **109** based on the concentration value, as described herein.

[0049] In some examples, the computing device **560** determines a parameter for operating a liquid desiccant regenerator based on the computed concentration value and/or density value. For example, the parameter may characterize whether the regenerator is on or off, a liquid desiccant flow rate, an air flow rate, or an operating temperature.

[0050] In some examples, the humidity sensor **540** is positioned within the cavity **583** of the exit tube **504**. The cavity **583** may include a relatively small volume of air **535** (e.g., an isolated pocket of air of the measuring column **502**), thereby reducing the time it takes the humidity sensor **540** to reach equilibrium humidity. In addition, the humidity sensor **540** may be exposed to a relatively large surface area of the liquid desiccant **109**, thereby increasing the rate of moisture transfer and the rate of approach to humidity equilibrium. In some examples, the surface of the liquid desiccant **109** exposed to the volume of air **535** within the cavity **583** is flowing. As such, the flowing liquid desiccant **109** is in contact with the volume of air that the humidity sensor **540** is measuring.

[0051] In some examples, the volume of air within exit tube **504** is in contact with (e.g., has access to) other volumes of air, such as ambient air **533**, whose humidity does not represent the desiccant's equilibrium. Further, in some examples, the humidity sensor **540** is positioned a minimum distance above a bottom surface **507** of the exit tube **504**, thereby ensuring that the humidity sensor **540** is not at risk of coming in contact with (e.g., getting wet by) the liquid desiccant **109**.

[0052] In some examples, a temperature sensor **571** is positioned within the exit tube **504**. The computing device **560** may receive temperature readings from the temperature sensor **571** and humidity readings from the humidity sensor **540**. In some embodiments, the humidity sensor **540** can be a relative humidity sensor, which measures both temperature and humidity. In such embodiments, the temperature sensor **571** may be unnecessary. The computing device **560** may calculate a density of the liquid desiccant **109** using the humidity readings from the humidity sensor **540** and the temperature readings from the temperature sensor **571**.

[0053] In some examples, the computing device **560** may determine if the first density is within a predetermined range. If the first density is not within the predetermined range, the computing device **560** may generate and transmit an error signal indicating the discrepancy (e.g., causing a display to display a warning message).

[0054] In some examples, the cross-sectional area of an exit tube is smaller than the cross-sectional area of a measuring column, thereby providing a greater tendency for the exit tube to fill with liquid desiccant. More importantly, this arrangement can be used to create an isolated and sealed section to measure humidity, temperature, or both of the area above the liquid desiccant **109**.

[0055] For example, FIG. **6** illustrates a liquid concentration measurement flow system **600** that can provide a flow **609** of liquid desiccant **109** that proceeds upwards through a measuring column **602** and into a cavity **603** of an exit tube **604**. In this example, a cross-sectional area of the exit tube **604** is smaller than a cross-sectional area of the measuring column **602**. For instance, the cross-sectional area of the exit tube **604** be 1.5, 2, or 3 times smaller than the cross-sectional area of the measuring column **602**.

[0056] In this example, the measuring column **602** includes a bottom portion **622** and a top portion **624**. In some, but not all embodiments, the bottom portion has a diameter **623** that is greater than a diameter **625** of the top portion **624**. The diameter **625** may be, for example, between 15% and 45% (e.g., 25%) less than the bottom diameter **623**. In addition, the top portion **624** includes sealed air section **611** designed so that the liquid desiccant **109** does not contact the humidity sensor **540** directly. For instance, assuming no leaks, the sealed air section **611** would tend to pressurize when the flow rate of liquid desiccant **109** increases, which would force the liquid desiccant **109** out of the exit tube **604** at a faster rate.

[0057] In some examples, a height **633** of the top portion **624** is in the range of 5% to 50% of the height of the measuring column **602**. Further, a humidity sensor **640** is positioned within the sealed air section **611** to detect humidity. For example, the humidity sensor **640** may proceed through a top surface **641** of the top portion **624**. In addition, the humidity sensor **640** may proceed into the measuring column **602** up to a maximum offset distance **652**. A computing device, such as computing device **560**, may receive humidity data from the humidity sensor **640**.

[0058] FIG. **7** illustrates an example of a liquid concentration measurement flow system **700** that includes a measuring column **702** and an overflow housing **706**. The overflow housing **706** includes a liquid collection portion with a floor **707** that is below the upper end of the measuring column **702** and an upper surface above the upper end of the measuring column **702**. In some examples, the floor **707** attaches (e.g., and is sealed to) an outer wall of the measuring column **702**.

[0059] A flow **709** of liquid desiccant **109** flows up the measuring column **702**, overflows over its top edge **703**, and falls down towards an annulus **723** formed by an interior wall of the overflow housing **706** and an outer wall of the measuring column **702**. For example, the difference between the radius of the overflow housing **706** and the radius of the measuring column **702** determines a width **725** of the annulus **723**. Moreover, the overflow housing **706** and measuring column **702** provide a sealed air pocket housing **731** that prevents, for example, contamination from ambient air. Air within the air pocket housing **731** is in fluid communication liquid desiccant **109** exiting through an outlet **748** of the measuring column **702**. The outlet **748** may be an upper end of the measuring column **702**. The flow **709** of the liquid desiccant **109**, after falling into the annulus **723**, may then exit out an exit tube **704**.

[0060] Further, in this example, a humidity sensor **740** is positioned within the sealed air pocket housing **731** to detect humidity. For example, the humidity sensor **740** may proceed through a top surface **741** of the overflow housing **706**. In addition, the humidity sensor **740** may be distanced from the outlet **748** of the measuring column **702** by at least a minimum offset distance **751**. A computing device, such as computing device **560**, may receive humidity data from the humidity sensor **740**.

[0061] In some examples, any of the liquid concentration measurement flow systems **600**, **700** may, additionally or alternatively, include a pressure sensor, such as pressure sensor **140**. Likewise, any of the liquid concentration measurement flow systems described with respect to any of FIGS. **1**, **2**, **3**, and **4** may, additionally or alternatively, include a humidity sensor, such as any of humidity sensors **540**, **640**, **740**. For example, a bottom portion of a measuring column can be dedicated to accommodating a pressure sensor (e.g., as illustrated by measuring column **402** in FIG. **4**) and the top portion can be dedicated to accommodating a humidity sensor (e.g., as illustrated by measuring column **702** in FIG. **7**).

[0062] For instance, FIG. **14** illustrates a liquid concentration measurement flow system **1400** that includes a measuring column **1402** that extends into a base cap **1410** at one end and an overflow housing **1406** at an opposite end. The measuring column **1402** may be of any suitable height, and the distance between the base cap **1410** and the overflow housing **1406** is not necessarily shown to scale, as indicated by squiggly lines **1413**. The base cap **1410** forms a concentric annulus region **1412** with the measuring column **1402**. For instance, the base cap **1410** encircles a lower end of the measuring column **1402**. A flow **1409** of the liquid desiccant **109** proceeds from an entrance tube **1404** into the concentric annulus region **1412**, and continues downward through the concentric annulus region **1412** before proceeding up through inlet **1403** into the measuring column **1402**. In other words, the liquid desiccant **109** is fed to the inlet **1403** from the base cap **1410** (e.g., feed conduit) encircling the lower end of the measuring column **1402**. As illustrated, a pressure sensor **140** can be positioned on a base surface **1415** of the base cap **1410**.

[0063] Further, the overflow housing **1406** includes a liquid collection portion with a floor **1407** that is below the upper end of the measuring column **1402** and an upper surface above the upper end of the measuring column **1402**. In some examples, the floor **1407** attaches (e.g., and is sealed to) an outer wall of the measuring column **1402**. The flow **1409** of liquid desiccant **109** continues to flow up the measuring column **1402**, overflows over its top edge **1403**, and falls down towards an annulus **1423** formed by an interior wall of the overflow housing **1406** and an outer wall of the measuring column **1402**. Moreover, the overflow housing **1406** and measuring column **1402** provide a sealed air pocket housing **1431** that prevents, for example, contamination from ambient air. Air within the air pocket housing **1431** is in fluid communication liquid desiccant **1409** exiting through an outlet **1448** of the measuring column **1402**. The outlet **1448** may be an upper end of the measuring column **1402**. The flow **1409** of the liquid desiccant **109**, after falling into the annulus **1423**, may then exit out an exit tube **1407**.

[0064] Further, a humidity sensor **1440** is positioned within the sealed air pocket housing **1431** to detect humidity. For example, the humidity sensor **1440** may proceed through a top surface **1441** of the overflow housing **1406**. In addition, the humidity sensor **1440** may be distanced from the outlet **1448** of the measuring column **1402** by at least a minimum offset distance **1451**. A computing device, such as computing device **560**, may receive humidity data from the humidity sensor **1440** and pressure data from the pressure sensor **140**.

[0065] FIG. **8** illustrates a measuring column **802** that includes a projection **804** through which a liquid desiccant **109** passes into, and proceeds to enter into a cavity **803** of the measuring column **802** through an inlet **806** positioned on an upper side of the projection **804**. A sensor **808**, such as a pressure sensor or temperature sensor, is positioned on the bottom side of the projection **804**. As such, the inlet **806** and the sensor **808** are within an interior of the measuring column **802**. The projection **804** may be positioned a predetermined distance **815** from a bottom surface **811** of the measuring column **802**.

[0066] In some examples, the projection **804** is a tube, and the inlet **806** is on a top of the projection **804**. In some examples, the inlet **806** is on a bottom of the projection **804**. In some examples, the sensor **808** is on a face of the projection **804**. In some examples, the sensor **808** is adjacent the inlet **806**. In some examples, the sensor **808** is on a side of the projection **804** and opposite the inlet **806**. In some examples, the sensor **808** is on a wall **819** of the measuring column **802**.

[0067] FIG. **9** illustrates a measuring column **902** that includes a projection **904** through which a liquid desiccant **109** passes into, and proceeds to enter into a cavity **903** of the measuring column **902** through an inlet **906** positioned on an upper side of the projection **904**. A sensor **908**, such as a pressure sensor, is positioned on an interior wall **911** of the measuring column **902**. The projection **904** may be positioned a predetermined distance **915** from a bottom surface **911** of the measuring column **902**.

[0068] FIG. **10** illustrates a measuring column **1002** that includes a projection **1004** through which a liquid desiccant **109** passes into, and proceeds to enter into a cavity **1003** of the measuring column **1002** through an inlet **1006** positioned on a lower side of the projection **1004**. A sensor **1008**, such as a pressure sensor, is positioned on an interior wall **1011** of the measuring column **1002**. The projection **1004** may be positioned a predetermined distance **1015** from a bottom surface **1013** of the measuring column **1002**.

[0069] FIG. **11** illustrates a flowchart of a method **1100** of detecting liquid desiccant concentration desiccant. The method may be carried out by one or more processors, such as one or more processors of computing device **160**. Beginning at block **1102**, a reading is received from a pressure sensor located proximate an inlet of a measuring column, where the inlet is below an outlet of the column, and where liquid desiccant enters the inlet, proceeds through the column, and exits the outlet to lower pressure. At block **1104**, a density is computed based on the reading.

[0070] FIG. **12** illustrates a flowchart of a method **1200** of detecting liquid desiccant concentration desiccant. The method may be carried out by one or more processors, such as one or more processors of computing device **160**. Beginning at block **1202**, a reading is received from a humidity sensor located in a sealed or isolated air pocket of a measuring column that includes an inlet and an outlet, where the inlet is below the outlet of the column, and where liquid desiccant enters the inlet, proceeds through the column, and exits the outlet. At block **1204**, a concentration of the liquid desiccant is computed based on the reading.

[0071] FIG. **13** illustrates a flowchart of a method **1300** of detecting liquid desiccant concentration desiccant. The method may be carried out by one or more processors, such as one or more processors of computing device **160**. Beginning at block **1302**, a pressure reading is received from a pressure sensor located proximate an inlet of a measuring column, where the inlet is below an outlet of the column, and where liquid desiccant enters the inlet, proceeds through the column, and exits the outlet to lower pressure. At block **1304**, a first density value is computed based on the pressure reading. Further, at block **1306**, a humidity reading is received from a humidity sensory located in a sealed or isolated air pocket of the measuring column. At block **1308**, a concentration value is computed based on the humidity reading, and a second density value is computed based on the concentration value. For example, the second density value may be computed using any known algorithm that converts concentration values to density values.

[0072] Proceeding to block **1310**, the first density value and second density value are compared. At block **1312**, if the first density value and second density value are within a range (e.g., 10% of each other, a predetermined density amount, etc.), the method proceeds to block **1316**. Otherwise, if the first density value and second density value are not within the range, the method proceeds to block **1314**, where an error signal is generated. For example, the error signal may cause a message (e.g., email, text, etc.) to be sent indicating an error that the density values were not within the range. As another example, the error signal may cause a user interface to display an indication of the error. In yet other examples, the error signal may be used to indicate an uncertainty for the computed density values. For example, the error signal may indicate that the first density value and second density value, while still being used to compute a final density value (see block **1316**, below), differ from each other by greater than a range of uncertainty (e.g., a predetermined range of uncertainty). The method then proceeds to block **1316**.

[0073] At block **1316**, a final density value is determined based on the first and second density values. For example, the final density value may be an average of the first and second density values. In some examples, a weight is applied to one or more of the first and second density values, and the final density value is computed based on the one or more weighted first and second density values. For example, a first weight may be applied to any of the first and second density values when they are within range (e.g., an expected range), and a second weight may be applied to any of the first and second density values when they are outside the range. The final density value may then be computed based on an average of the first and second density values if and as weighted.

[0074] The method then proceeds to block **1318** where an operational parameter of a system, such as a liquid desiccant regenerator or conditioner, is determined based on the final density value. For example, the operational parameter may determine whether a liquid desiccant regenerator or conditioner is on or off, a liquid desiccant flow rate through the liquid desiccant regenerator, an air flow rate through the liquid desiccant regenerator, or an operating temperature of the liquid desiccant regenerator. Further, and at block **1320**, the system is controlled based on the operational parameter (e.g., the system is turned on or off, the liquid desiccant flow rate is adjusted, the air flow rate is adjusted, or the system is adjusted to the operating temperature).

[0075] In some examples, a system to measure density of a liquid includes a measuring column having an inlet and an outlet, where the inlet is a distance (h) below the outlet. The system also includes a pressure sensor located proximate the inlet, where the outlet is adapted such that liquid exits the outlet to low pressure. Further, the system includes a processor adapted for receiving a reading from the pressure sensor and calculating a density of liquid flowing through the system using the reading.

[0076] In some examples, the measuring column is ≤15 degrees from vertical. In some examples, the distance (h) is at least 5 times a diameter (d) of the measuring column. In some examples, the pressure sensor is located below the inlet. In some examples, the inlet is an opening in a wall of the measuring column.

[0077] In some examples, the inlet is within an interior of the measuring column. In some examples, the system includes a projection extending from a wall of the measuring column, wherein the projection comprises the inlet.

[0078] In some examples, the system includes a liquid temperature sensor adapted for measuring a temperature of liquid flowing through the system.

[0079] In some examples, the inlet is a lower end of the measuring column. In some examples, the liquid is fed to the inlet from a feed conduit encircling the lower end of the measuring column. In some examples, the feed conduit has a base surface below the lower end and the pressure sensor is below the lower end. In some examples, an area of the pressure sensor (A_{sensor}) is less than a cross-sectional area of the measuring column (A_{column}). In some examples, the system includes a liquid temperature sensor adapted for measuring a temperature of liquid flowing through the system, wherein the liquid temperature sensor is coupled to the feed conduit.

[0080] In some examples, the system includes an air pocket housing in fluid communication with the liquid exiting the measuring column, and a humidity sensor adapted for measuring vapor pressure within the air pocket housing. In some examples, the system includes a temperature sensor adapted for measuring a temperature within the air pocket housing. In some examples, the air pocket housing is enclosed and isolated from an external atmosphere.

[0081] In some examples, the outlet is an upper end of the measuring column, and the liquid exiting the measuring column flows over upper edges of the measuring column. In some examples, the upper end is encircled by an overflow housing adapted to capture liquid exiting the measuring column. In some examples, the overflow housing includes a liquid collection portion below the upper end of the measuring column and an upper surface above the upper end. In some examples, the system includes a humidity sensor adapted for measuring a humidity of air within the overflow housing. In some examples, the system includes a temperature sensor adapted for measuring a temperature within the overflow housing.

[0082] In some examples, the outlet is an upper end of the measuring column, and the liquid exiting the measuring column flows over upper edges of the measuring column. In some examples, the upper end is encircled by an overflow housing adapted to capture the liquid exiting the measuring column.

[0083] In some examples, the system includes a spout in liquid communication with the outlet, wherein a cross-sectional area of the spout (A_{spout}) is larger than a cross-sectional area of the measuring column (A_{MC}).

[0084] In some examples, a method of determining a density of a liquid includes flowing a fluid through a measuring column having an inlet and an outlet, wherein the inlet is a distance (h) below the outlet. The method also includes detecting a pressure on the fluid at a location proximate the inlet, where the outlet is adapted such that the liquid exits the outlet to low pressure. Further, the method includes calculating a fluid density based on at least the detected pressure and the distance (h). In some examples, the fluid density is used to determine a parameter for operating a liquid desiccant regenerations.

[0085] The various embodiments described above are provided by way of illustration only and should not be construed to limit the claims attached hereto. Those skilled in the art will readily recognize various modifications and changes that may be made without following the example embodiments and applications illustrated and described herein, and without departing from the spirit and scope of the following claims.

What is claimed is:

1. A system to measure density of a liquid, comprising:
a measuring column having an inlet and an outlet, wherein the inlet is a distance (h) below the outlet;
a pressure sensor located proximate the inlet, wherein the outlet is adapted such that liquid exits the outlet to low pressure; and
a processor adapted for receiving a reading from the pressure sensor and calculating a density of liquid flowing through the system using the reading.

2. The system of claim **1**, wherein the measuring column is ≤15 degrees from vertical.

3. The system of claim **1**, wherein the distance (h) is at least 5 times a diameter (d) of the measuring column.

4. The system of claim **1**, wherein the pressure sensor is located below the inlet.

5. The system of claim **1**, wherein the inlet is an opening in a wall of the measuring column.

6. The system of claim **1**, wherein the inlet is within an interior of the measuring column.

7. The system of claim **6**, comprising a projection extending from a wall of the measuring column, wherein the projection comprises the inlet.

8. The system of claim **1**, further comprising a liquid temperature sensor adapted for measuring a temperature of liquid flowing through the system.

9. The system of claim **1**, wherein the inlet is a lower end of the measuring column.

10. The system of claim **9**, wherein the liquid is fed to the inlet from a feed conduit encircling the lower end of the measuring column.

11. The system of claim **10**, wherein the feed conduit has a base surface below the lower end and the pressure sensor is below the lower end.

12. The system of claim **11**, wherein an area of the pressure sensor (A_{sensor}) is less than a cross-sectional area of the measuring column (A_{column}).

13. The system of claim **11**, further comprising a liquid temperature sensor adapted for measuring a temperature of liquid flowing through the system, wherein the liquid temperature sensor is coupled to the feed conduit.

14. The system of claim **1**, further comprising an air pocket housing in fluid communication with the liquid exiting the measuring column, and a humidity sensor adapted for measuring vapor pressure within the air pocket housing.

15. The system of claim **14**, further comprising a temperature sensor adapted for measuring a temperature within the air pocket housing.

16. The system of claim **14**, wherein the air pocket housing is enclosed and isolated from an external atmosphere.

17. The system of claim **1**, wherein the outlet is an upper end of the measuring column, and the liquid exiting the measuring column flows over upper edges of the measuring column.

18. The system of claim **17**, wherein the upper end is encircled by an overflow housing adapted to capture liquid exiting the measuring column.

19. The system of claim **18**, wherein the overflow housing includes a liquid collection portion below the upper end of the measuring column and an upper surface above the upper end.

20. The system of claim **19**, further comprising a humidity sensor adapted for measuring a humidity of air within the overflow housing.

21. The system of claim **20**, further comprising a temperature sensor adapted for measuring a temperature within the overflow housing.

22. The system of claim **1**, further comprising a spout in liquid communication with the outlet, wherein a cross-sectional area of the spout (A_{spout}) is larger than a cross-sectional area of the measuring column (A_{MC}).

23. A method of determining a density of a liquid,

flowing a fluid through a measuring column having an inlet and an outlet, wherein the inlet is a distance (h) below the outlet;

detecting a pressure on the fluid at a location proximate the inlet, wherein the outlet is adapted such that the liquid exits the outlet to low pressure; and

calculating a fluid density based on at least the detected pressure and the distance (h).

24. The method of claim **23**, wherein the fluid density is used to determine a parameter for operating a liquid desiccant regenerations.

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