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(54) **Title:** APPARATUS FOR AND METHOD OF SUPPLY INK VOLUME DETECTION IN AN INKJET PRINTING SYSTEM

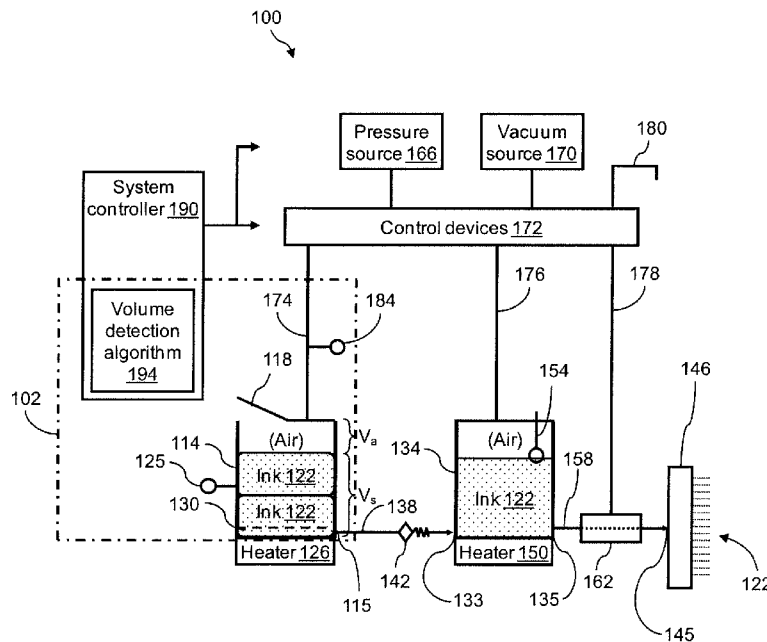


FIG. 1

(57) **Abstract:** A method of ink volume detection includes pressurizing a supply reservoir (114, 310), monitoring the pressure of the supply reservoir, measuring a transition time between first and second pressures of the supply reservoir during pressurization of the supply reservoir, and determining an ink volume (Vs) within the supply reservoir based on the transition time to pressurize the supply reservoir from the first pressure to the second pressure.

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Apparatus For And Method Of Supply Ink Volume Detection In An Inkjet Printing System

TECHNICAL FIELD

[0001] This disclosure relates to inkjet printing systems.

BACKGROUND

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[0002] In inkjet printing systems, such as hot-melt and liquid inkjet systems, information about the amount of ink in the supply reservoir is generally needed for warning an operator of a low supply ink volume condition. This warning may be used to prompt action to replenish the supply ink volume in the supply reservoir of the inkjet system in order to ensure uninterrupted operation. Current techniques of determining the supply ink volume in the supply reservoir use internal sensing devices, such as float-type or thermistor-type sensors. However, these types of sensing devices may be required to be in direct contact with the ink and may be suitable for use with liquid ink only. Consequently, these types of volume sensing devices are limited to liquid inkjet printing systems only and are not suitable for use in hot-melt inkjet printing systems wherein the supply ink may be in a solid state, liquid state, or partially solid and partially liquid state. Therefore, alternative approaches are needed that are suitable for determining the supply ink volume in both hot-melt and liquid inkjet printing systems.

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SUMMARY

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[0003] The present disclosure describes a mechanism suitable for determining the supply ink volume in both hot-melt and liquid inkjet printing systems.

[0004] In one aspect, an ink volume detector for an inkjet printing system includes a supply reservoir for holding ink, a pressure sensor for monitoring an internal pressure of the supply reservoir, and a system controller in communication with the pressure sensor. The system controller is configured to determine an ink volume of the supply reservoir based on at least one pressurizing transition time between first and second pressures of the supply reservoir.

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[0005] Implementations of this aspect of the disclosure may include one or more of the following features. In some implementations, the system controller is

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configured to determine an ink volume of the supply reservoir using a relationship of the volume of ink in the supply reservoir plus a volume of air above the ink in the supply reservoir equals a total fixed capacity of the supply reservoir, where the ink volume and the air volume are variable and the reservoir volume is substantially fixed. The system controller may be configured to determine an ink volume of the supply reservoir using a relationship between the supply reservoir volume and the pressurizing transition time. In some examples, a ratio of the supply reservoir volume to the pressurizing transition time equals a constant. In some implementations, the system controller is configured to determine an ink volume of the supply reservoir using a relationship between the volume of air above the ink in the supply reservoir volume and the pressurizing transition time. In some examples, a ratio of the volume of air above the ink in the supply reservoir volume to the pressurizing transition time equals a constant. The ink may comprise hot-melt or liquid ink. In the case of hot-melt ink, the ink may be used in form of solid blocks or pellets.

[0006] In another aspect, a method of ink volume detection includes pressurizing a supply reservoir, monitoring the pressure of the supply reservoir, measuring a transition time between first and second pressures of the supply reservoir during pressurization of the supply reservoir, and determining an ink volume with the supply reservoir based on the transition time to pressurize the supply reservoir from the first pressure to the second pressure.

[0007] Implementations of this aspect of the disclosure may include one or more of the following features. In some implementations, the method further includes determining whether the ink volume is below a threshold volume, and replenishing the ink in the supply reservoir when the ink volume is below the threshold volume. Determining the ink volume may include using a relationship of the volume of ink in the supply reservoir plus a volume of air above the ink in the supply reservoir equals a reservoir volume (e.g., total fixed capacity) of the supply reservoir, where the ink volume and the air volume are variable and the reservoir volume is substantially fixed. In some implementations, determining the ink volume comprises using a relationship between the supply reservoir volume and the pressurizing transition time. A ratio of the supply reservoir volume to the pressurizing transition time may equal a constant. In addition, determining the ink volume may include using a relationship between the volume of air above the ink in the supply reservoir volume and the

pressurizing transition time. In some examples, a ratio of the volume of air above the ink in the supply reservoir volume to the pressurizing transition time equals a constant. The ink may comprise hot-melt or liquid ink. In the case of hot-melt ink, the ink may be used in form of solid blocks or pellets.

5 [0008] In yet another aspect, a method of ink volume detection includes measuring a first transition time to pressurize an empty supply reservoir between first and second pressures, measuring a second transition time to pressurize a supply reservoir holding a volume of ink between the first pressure and the second pressure, and determining the volume of ink held by the supply reservoir based on the first and
10 second transition times.

[0009] Implementations of this aspect of the disclosure may include one or more of the following features. In some implementations, determining the volume of ink further includes using a relationship of the volume of ink in the supply reservoir plus a volume of air above the ink in the supply reservoir equals a reservoir volume
15 (e.g., total fixed capacity) of the supply reservoir, where the ink volume and the air volume are variable and the reservoir volume is substantially fixed. Determining the volume of ink may include using a relationship between the supply reservoir volume and the first pressurizing transition time. In some examples, a ratio of the supply reservoir volume to the first pressurizing transition time equals a constant.

20 Determining the volume of ink may include using a relationship between the volume of air above the ink in the supply reservoir volume and the second pressurizing transition time. In some examples, a ratio of the volume of air above the ink in the supply reservoir volume to the second pressurizing transition time equals a constant. The ink may comprise hot-melt or liquid ink.

25 [0010] The details of one or more implementations of the disclosure are set forth in the accompanying drawings and the description below. Other aspects, features, and advantages will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

30 [0011] FIG. 1 is a pneumatic diagram of an exemplary hot-melt inkjet printing system that includes a mechanism for detecting the ink level in the supply reservoir.

[0012] FIG. 2 is a flowchart that represents exemplary operations of a hot-melt inkjet printing system.

[0013] FIG. 3 is a pneumatic diagram of an exemplary liquid inkjet printing system that includes a mechanism for detecting the ink level in the supply reservoir.

[0014] FIG. 4 is a flow chart that represents exemplary volume detection operations of a volume detection algorithm.

5 [0015] FIG. 5 provides a plot, which is an example plot of the constant K for an example inkjet printing system.

[0016] FIG. 6 provides a plot, which shows a scenario in which the constant K of an inkjet printing system is not known.

[0017] FIG. 7 provides a flow chart that represents exemplary operations of
10 detecting an ink level in a supply reservoir of an inkjet printing system.

[0018] FIG. 8 provides an example plot of the actual volume vs. time to pressurize a heated supply reservoir at constant temperatures.

[0019] FIG. 9 provides an example plot of the real and compensated time to pressurize the empty supply reservoir at different temperatures.

15 [0020] FIG. 10 provides an example plot of comparison of actual and calculated supply reservoir ink volumes at different temperatures.

[0021] FIG. 11 provides an example plot of the actual volume vs. time to pressurize a heated supply reservoir at constant temperatures.

[0022] Like reference symbols in the various drawings indicate like elements.

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DETAILED DESCRIPTION

[0023] The present disclosure provides an apparatus for and method of supply ink volume detection in an inkjet printing system. In some implementations, an ink volume detector detects the ink volume in a supply reservoir without the use of internal sensing devices, such as float-type or thermistor-type sensors, which
25 generally require that the ink be in liquid state. In some examples, the ink volume detector includes an external pressure sensor for monitoring the pressure in a pressurized supply reservoir. The ink volume detector executes a volume detection algorithm for determining the ink volume in the supply reservoir. As a result, the ink volume detector may be used for determining the ink volume regardless of its state,
30 i.e., solid state, liquid state, and any combination thereof. In cases where the ink is in a solid state, the volume may be determined regardless of its shape. As a result, the ink volume detector may be used in both a hot-melt inkjet printing system and a liquid inkjet printing system.

[0024] FIG. 1 illustrates a pneumatic diagram of an exemplary hot-melt inkjet printing system 100 including an ink volume detector 102. In some implementations, the ink volume detector 102 includes a system controller 190 for executing a volume detection algorithm 194, a pressurized supply reservoir 114, and a pressure sensor 184
5 disposed on (e.g., external to) the supply reservoir 114 for determining a supply ink volume V_s of the supply reservoir 114, whether in solid state, liquid state, or any combination thereof. The supply reservoir 114 may include an access door 118 through which a quantity of hot-melt ink 122 may be loaded. The access door 118 may include a security latch (not shown) for preventing opening when the supply
10 reservoir 114 is pressurized, e.g., to provide a safely pressurized sealed reservoir. In some examples, a certain amount of air is present above the hot-melt ink 122 within the supply reservoir 114. In some examples, the supply reservoir 114 has a volume capacity of about 300 milliliters (ml).

[0025] In some implementation, the hot-melt ink 122 is standard hot-melt ink
15 that may be provided in a solid cold state and then heated for transitioning the hot-melt ink 122 to a liquid hot state suitable for jetting. For example, the hot-melt ink 122 may be initially installed into the supply reservoir 114 in a cold solid state, such as in the form of one or more solid blocks or pellets, as shown in FIG. 1.

Subsequently, a supply reservoir heater 126 associated with the supply reservoir 114
20 may be used to melt a certain amount of hot-melt ink 122 (e.g., an amount that is suitable to satisfy the primary reservoir 134) to a hot liquid state. In some examples, the supply reservoir heater 126 may be any commercially available surface heater that is thermally coupled to the supply reservoir 114, which may be formed of, for example, a thermally conductive aluminum housing. An example supplier of surface
25 heaters is Hotwatt, Inc. of Danvers, MA.

[0026] Optionally, an emersion heater 130 may be provided in place of or in combination with the supply reservoir heater 126. The emersion heater 130 may be a custom-made flat plat or flat screen emersion heater installed near an outlet 115 of the supply reservoir 114.

[0027] The outlet 115 of the supply reservoir 114 feeds an inlet 133 of the
30 primary reservoir 134 via a fluid line 138. Installed in fluid communication with the fluid line 138 upstream of the primary reservoir 134 is a check valve 142, which may be any commercially available check valve. In some examples, the check valve 142 is

a spring-loaded check valve biased shut to about 2 pounds per square inch (PSI). The primary reservoir 134 may be a vacuum/pressure chamber for holding a quantity of hot-melt ink 122 supplied from the supply reservoir 114. Hot-melt ink 122 from the primary reservoir 134 supplies a jetting assembly 146. In some implementations, the primary reservoir 134 is configured to hold about 20 ml of ink.

[0028] In some implementations, a primary reservoir heater 150 is associated with primary reservoir 134 for maintaining the hot-melt ink 122 in a liquid hot state suitable for jetting via the jetting assembly 146. Similar to the supply reservoir heater 126, the primary reservoir heater 150 may be any commercially available surface heater, such as a surface heater from Hotwatt, Inc. of Danvers, MA, that is thermally coupled to the primary reservoir 134, which may be formed of, for example, a thermally conductive aluminum housing. Additionally, a primary ink sensor 154 is installed within the primary reservoir 134 for detecting and/or monitoring the level of hot-melt ink 122 within the primary reservoir 134. The primary ink sensor 154 may be any commercially available float-type or thermistor-type sensor. When a low ink level is detected, the primary reservoir 134 is replenished with hot-melt ink 122 from the supply reservoir 114. A certain amount of air may be present above the hot-melt ink 122 within the primary reservoir 134. The primary ink sensor 154 may be any commercially available liquid level sensor, such as those supplied by Honeywell Sensing and Control of Golden Valley, MN.

[0029] An outlet 135 of the primary reservoir 134 feeds is in fluid communication with an inlet 145 of the jetting assembly 146 via a fluid line 158. The jetting assembly 146 has a plurality of orifices (not shown) oriented toward a target print media (not shown). The jetting assembly 146 delivers tiny streams of jetted hot-melt ink 122 onto the target print media, such as onto a piece of paper, a product package (e.g., a box or bag), a continuous-feed substrate for making product packaging, etc.

[0030] Installed in fluid communication with the fluid line 158 upstream of the jetting assembly 146 is a lung device 162. One of the difficulties of hot-melt inkjet systems is that air or air bubbles may accumulate in the system and may be ingested into the ink. For example, air bubbles may accumulate in a jetting chamber (not shown) of the jetting assembly 146, which takes energy away from the jetting process, and may eventually cause the jetting operation to fail. The lung device 162 is

used to remove air from the hot-melt ink 122, which reduces the relative concentration of air in the hot-melt ink 122, prior to its entry into the jetting chamber. This may be accomplished via air-permeable, ink-impermeable membranes within the lung device 162. The action of the lung device 162 allows the hot-melt ink 122 to quickly dissolve air bubbles in ink passages. The lung device 162 may be required for air removal in order to ensure fast, reliable startups, and to enable robust high frequency jetting. The lung device 162 may be any commercially available lung technology, such as that supplied by FUJIFILM Dimatix, Inc. of Santa Clara, CA.

[0031] In some implementations, the hot-melt inkjet printing system 100 further includes a pressure source 166 (e.g., any suitable commercially available pump) and a vacuum source 170 (e.g., any suitable commercially available vacuum pump) both pneumatically coupled to the supply reservoir 114, the primary reservoir 134, the jetting assembly 146, and the lung device 162 via, for example, an arrangement of control devices 172 for controlling the pressure and vacuum functions of the hot-melt inkjet printing system 100. In some examples, a vacuum/pressure line 174 feeds the supply reservoir 114, a vacuum/pressure line 176 feeds the primary reservoir 134, and a vacuum/pressure line 178 feeds the lung device 162. The control devices 172 may include any standard control devices typically found in ink jet systems, such as, but not limited to, flow valves, check valves, pressure sensors, vacuum sensors, accumulators, restrictors, filters, and any combinations thereof. Additionally, a vent 180 may be included for providing a path to atmosphere. Normal atmospheric pressure is generally defined as 1 atmosphere (atm), which equates to about 14.7 PSI. The vent 180 may be a restrictor device that has an orifice exiting to atmosphere and, in some examples, produces about 6.3 PSI of pressure.

[0032] In some implementations, the pressure sensor 184 is connected to the vacuum/pressure line 174 that feeds pressure to the supply reservoir 114. The pressure sensor 184 may be used to monitor the pressure at the supply reservoir 114 at any given time. The pressure sensor 184 may be any commercially available pressure sensor, such as those supplied by Honeywell Sensing and Control of Golden Valley, MN.

[0033] In some implementations, the system controller 190 is configured for executing the volume detection algorithm 194, and may be any commercially available controller, microprocessor, or digital signal processor (DSP) capable of executing

program instructions, such as those of the volume detection algorithm 194. The system controller 190 provides overall control of the hot-melt inkjet printing system 100 and is, therefore, in communication with most or all active components thereof. The volume detection algorithm 194 for determining the volume of hot-melt ink 122 in supply reservoir 114 entails using the relationship of the volume of hot-melt ink 122 (i.e., supply ink volume V_s) plus the volume of air above the hot-melt ink 122 (i.e., air-above-ink volume supply ink volume V_a) equals the total fixed capacity of the supply reservoir 114 (i.e., reservoir volume), where the supply ink volume V_s and the air-above-ink volume V_a are variable and the reservoir volume is fixed. More details of example calculations for determining the volume of hot-melt ink 122 in supply reservoir 114 are described with reference to Equations 1 through 5 herein.

[0034] Referring to FIG. 2, a flow chart 200 represents an arrangement of operations for operation of the hot-melt inkjet printing system 100. Operations include loading 202 one or more blocks of hot-melt ink 122 (i.e., in cold solid state) into the supply reservoir 114 via the access door 118, and sealing 204 the supply reservoir 114 (e.g., locking the access door 118) for pressurization. Operations further include, for example under the control of the system controller 190, activating 206 the heaters 126, 150 to melt the hot-melt ink 122 in the supply reservoir 114, which results in at least a portion of the hot-melt ink 122 transitioning from a cold solid state to a hot liquid state. Operations include pressurizing 208 the supply reservoir 114 (e.g., to about 6 PSI of pressure) by a pressure source 166 and vacuum/pressure line 174 in order to pump a quantity of liquid hot-melt ink 122 from supply reservoir 114 through fluid line 138 and into primary reservoir 134, where the liquid hot-melt ink 122 is maintained at an elevated temperature. This pressure is sufficiently strong to open check valve 142. Operations further include detecting 210 (e.g., via the primary ink sensor 154) a threshold level of hot-melt ink 122 within primary reservoir 134 sufficient for operation of the hot-melt inkjet printing system 100. Upon detecting the threshold level of hot-melt ink 122, operations include suspending 212 the ink cycle and closing 214 the check valve 142. Operations further include applying 216 a vacuum to the primary reservoir 134 (e.g., via vacuum source 170 and vacuum/pressure line 176) and jetting 218 onto print media (e.g., via the jetting assembly 146). Additionally, the jetting operation may include applying a vacuum to the lung device 162 (e.g., via vacuum source 170 and vacuum/pressure line

178) to continuously deaerate the hot-melt ink 122 prior to the hot-melt ink 122 entering the primary reservoir 134. Throughout the operations of the hot-melt inkjet printing system 100, the operations of the control devices 172 are appropriately managed according to the functions of the jetting process.

5 [0035] Periodically, standard inkjet printing operations may be interrupted and a jetting assembly purge operation may occur. In this case, pressure is applied by the pressure source 166 and the control devices 172 to the primary reservoir 134 and the jetting assembly 146. The check valve 142 prevents back flow into the supply reservoir 114 during purging. The pressure on the primary reservoir 134 and the
10 jetting assembly 146 pushes a quantity of hot-melt ink 122 through orifices (not shown) of jetting assembly 146, in order to clear any blocked or clogged orifices.

[0036] FIG. 3 illustrates a pneumatic diagram of an exemplary liquid inkjet printing system 300 that includes an ink volume detector 302 for detecting the ink level in a supply reservoir 114. The liquid inkjet printing system 300 is similar to the
15 hot-melt inkjet printing system 100 except that it excludes the lung device 162 and the hot-melt ink 122 is replaced with liquid ink 314, which is standard liquid ink suitable for use in liquid inkjet printing systems. Additionally, the supply reservoir 114 of the hot-melt inkjet printing system 100 is replaced with a supply reservoir 310 that is supplied by an upstream supply of liquid ink 314 that is held in a supply container
20 318. A check valve 320 is in fluid communication with the fluid line 322 between the supply container 318 and the supply reservoir 310. The check valve 320 may be any suitable commercially available check valve. The check valve 320 ensures that the flow of liquid ink 314 is only toward supply reservoir 310. The ink volume detector 302 includes the system controller 190 for executing the volume detection algorithm
25 194, the supply reservoir 310, and the pressure sensor 184 disposed external to the supply reservoir 310 for determining a supply ink volume V_s of the supply reservoir 310. The heaters 126, 150 may be included in the liquid inkjet printing system 300 to control the jetting viscosity. The temperature of the liquid ink 314 may be regulated at about 50° C, which is a temperature lower than that in a hot-melt inkjet printing
30 system. Optionally, if the liquid ink 314 in the liquid inkjet printing system 300 is of sufficient viscosity over the ambient temperature range, the heaters 126 and 150 may not be needed. Since not heaters are required in liquid inkjet printing systems, the supply reservoir 310 may be a liquid pressure vessel for holding a quantity of liquid

ink 314 that is always in a liquid state. A certain amount of air may be present above the liquid ink 314 within the supply reservoir 210. In some examples, the supply reservoir 310 holds about 600 ml of liquid ink 314.

[0037] Referring to FIGS. 1 and 3, usage of the ink volume detector 102, 302
5 in the hot-melt inkjet printing system 100 and the liquid inkjet printing system 300 is independent of the ink type (e.g., hot-melt or liquid) and of the ink state (e.g., solid, liquid, or partially solid and partially liquid). Both types of systems provide a pressurized supply reservoir 114, 310 in combination with an external pressure sensor 184 for monitoring the pressure therein, and a volume detection algorithm 194 for
10 determining the ink volume V_s in the supply reservoir 114, 310. Periodically during the continuous operation of the hot-melt inkjet printing system 100 and/or the liquid inkjet printing system 300, the supply ink volume V_s is determined by use of the ink volume detector 102, 302 to determine when hot-melt ink 122 in the supply reservoir 114 and/or liquid ink 314 in the supply reservoir 310 needs to be replenished. Under
15 the control of the volume detection algorithm 194, a supply ink volume V_s detection operation may occur that uses the pressure source 166 and the pressure sensor 184. If the supply ink volume V_s is above a threshold supply level, no action is required. However, if the supply ink volume V_s is below the threshold supply level, the volume detection algorithm 194 and/or the system controller 190 prompts an operator or user
20 to replenish the hot-melt ink 122 of the supply reservoir 114 and/or the liquid ink 314 in the supply reservoir 310.

[0038] The system controller 190 executes the volume detection algorithm 194 to determine whether the supply ink volume V_s is above threshold supply level. In some implementations, the volume detection algorithm 194 includes the
25 relationship that the volume V_s of supply ink 122, 314 in the supply reservoir 114, 310 plus the volume of air V_a above the ink 122, 314 in the supply reservoir 114, 310 equals the total fixed volume of the supply reservoir 114, 310, where the supply ink volume V_s and the air-above-ink volume V_a are variable and the reservoir volume V_r is fixed.

[0039] Referring to FIG. 4, a flow chart 400 represents an arrangement of
30 volume detection operations of the volume detection algorithm 194. Typically, the volume detection operations are executed on the system controller 190, and include:

1. Prompting 402 activation/deactivation of the pressure source (e.g., pressure source 166) in order to control the pressure of the supply reservoir (e.g., supply reservoir 114 and/or supply reservoir 310);
2. Monitoring 404 feedback from active components. In particular,
5 monitoring feedback from the supply pressure sensor (e.g., pressure sensor 184);
3. Measuring 406 the transition time between two pressure points at the supply reservoir by monitoring the supply pressure sensor;
4. Determining 408 a relationship of air-above-ink volume vs. time to
10 pressurize for a certain combination of system components, such as for a supply reservoir, a pressure source that outputs a flow through an orifice, and pressure control devices. The air-above-ink volume vs. time to pressurize relationship is heretofore referred to as K, which is substantially constant and unique for each certain combination of system components;
- 15 5. Determining 410 the ink supply ink volume V_s in the supply reservoir; and
6. Prompting 412 action to replenish the supply ink in the supply reservoir when it is determined that a low level condition is present.

[0040] In some implementations of the volume detection algorithm 194, (1) the constant K is determined for a certain system that contains a supply reservoir that
20 has a known reservoir volume V_r , which then allows (2) the air-above-ink volume V_a to be determined, which then allows (3) the unknown reservoir ink volume V_x to be determined. These determinations may be accomplished according to the following calculations.

[0041] Constant K calculation:

K for a supply reservoir = V_r/t_r , where (Equation 1)

V_r = Empty reservoir volume;

t_r = Time to transition an empty supply reservoir from, for example, about 0 PSI to about 1.2 PSI;

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where volume is in milliliters and time is in seconds

(sec).

[0042] FIG. 5 illustrates an exemplary plot 500 of the constant K for an example inkjet printing system. An empty supply reservoir of the example inkjet printing system has a volume V_r of about 600 ml and a time t_r to transition from about 0 PSI to about 1.2 PSI of about 6 sec. Therefore, a substantially linear curve 510 of plot 500 has a slope of $K = V_r/t_r$, which is 600 ml/6 sec or $K =$ about 100 ml/sec.

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[0043] In the case of a supply reservoir that contains an unknown volume of ink, as opposed to an empty supply reservoir, the unknown reservoir ink volume V_x may be expressed as follows.

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[0044] Unknown reservoir ink volume V_x calculation:

$V_x = V_r - V_a$, where (Equation 2)

V_x = Unknown reservoir ink volume;

V_r = Empty reservoir volume; and

V_a = Air-above-ink volume.

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where volume is in milliliters and time is in seconds.

[0045] Once the value of K is determined, Equations 3 and 4 may be applied as follows in order to determine the unknown reservoir ink volume V_x of the supply reservoir that is not empty. The unknown reservoir ink volume V_x may be determined by measuring the time t_x that it takes to transition the supply reservoir having an unknown ink volume from, for example, about 0 PSI to about 1.2 PSI. Therefore, when the value of K is known

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[0046] Air-above-ink volume V_a calculation when K is known:

$$V_a = K * t_x, \text{ where} \quad (\text{Equation 3})$$

t_x = Time it takes to transition the supply reservoir having an unknown ink volume from, for example, about 0 PSI to about 1.2 PSI.

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then substituting Equation 3 into Equation 2,

$$V_x = V_r - (K * t_x) \quad (\text{Equation 4})$$

[0047] Continuing the example of FIG. 5, for $V_r=600$ ml, $K=100$ ml/sec, and if it takes, for example, 2.6 sec to transition the supply reservoir having an unknown ink volume from, for example, about 0 PSI to about 1.2 PSI, then $t_x=2.6$ sec; then in this example,

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$$V_x = 600 \text{ ml} - (100 \text{ ml/sec} \times 2.6 \text{ sec}) = \text{about } 340 \text{ ml.}$$

[0048] FIG. 6 illustrates plot 600, which shows a scenario in which the constant K of a certain inkjet printing system is not known. In this example, the empty reservoir volume V_r is known, but the constant K must first be determined in order to then determine the unknown reservoir ink volume V_x . The empty reservoir volume V_r may be, for example, 600 ml.

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[0049] Constant K calculation:

$$K = V_i / (t_x - t_i), \text{ where} \quad (\text{Equation 5})$$

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V_i = Known volume of ink added to reservoir (e.g., ~150 ml);

t_x = Time it takes to transition the supply reservoir having an unknown ink volume from, for example, about 0 PSI to about 1.2 PSI; and

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t_i = Time to transition a supply reservoir from, for example, about 0 PSI to about 1.2 PSI with known volume of ink V_i (e.g., ~150 ml) added to reservoir added to reservoir;

where volume is in milliliters and time is in seconds.

[0050] For example, if $V_i = 150$ ml, and if it takes about 2.6 sec to transition the supply reservoir having an unknown ink volume from about 0 PSI to about 1.2

PSI, then $t_x = 2.6$ sec; and if it takes about 1.1 sec to transition a supply reservoir from about 0 PSI to about 1.2 PSI with a known volume of ink V_i (e.g., ~150 ml) added to the reservoir, then $t_i = 1.1$ sec.

[0051] Therefore in this example, $K = 150 \text{ ml}/(2.6 \text{ sec}-1.1 \text{ sec}) = 150 \text{ ml}/1.5$
 5 sec = 100 ml/sec. Referring again to FIG. 6, a substantially linear curve 610 of plot 600 has a slope of $K = V_i/(t_x-t_i)$, which is about 100 ml/sec.

[0052] The volume V_i of ink that is added may be any volume as long as it is known and as long as it is large enough to produce an accurate result. Once the value of K is determined, Equations 2, 3, and 4 may be applied as follows in order to
 10 determine the unknown reservoir ink volume V_x .

[0053] For some inkjet printing systems, the K value whether determined by Equation 1 or by Equation 5 should be substantially the same (e.g., the examples shown in FIGS. 5 and 6).

[0054] Unknown reservoir ink volume V_x calculation:

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$$V_x = V_r - V_a, \text{ where} \quad \text{(Equation 2)}$$

$V_x =$ Unknown reservoir ink volume;

$V_r =$ Empty reservoir volume; and

$V_a =$ Air-above-ink volume.

where volume is in milliliters and time is in seconds.

20 [0055] Air-above-ink volume V_a calculation when K is known:

$$V_a = K * t_x, \text{ where} \quad \text{(Equation 3)}$$

$t_x =$ Time it takes to transition the supply reservoir having an unknown ink volume from, for example, about 0 PSI to about 1.2 PSI.

25 then substituting Equation 3 into Equation 2,

$$V_x = V_r - (K * t_x) \quad \text{(Equation 4)}$$

[0056] Continuing the example of FIG. 6, for $V_r = 600$ ml, $K = 100$ ml/sec, and if it takes, for example, 2.6 sec to transition the supply reservoir having an unknown ink volume from about 0 PSI to about 1.2 PSI, then $t_x = 2.6$ sec; then in this example,

$$V_x = 600 \text{ ml} - (100 \text{ ml/sec} \times 2.6 \text{ sec}) = \text{about } 340 \text{ ml}.$$

[0057] In Equations 1 and 5, the constant K is based on a pump (e.g., pressure source 166) outputting a constant flow through an orifice (e.g., vent 180) to the supply reservoir volume. Therefore, the time t_x that it takes to reach, for example, about 1.2
5 PSI from about 0 PSI is directly proportional to the air-above-ink volume V_a and inversely proportional to the unknown reservoir ink volume V_x .

[0058] Alternatively, for a system that is already installed in the field, rather than adding a known volume of ink and using equations 2, 3, 4, and 5, as illustrated in FIG. 6, the supply reservoir may be emptied and then equations 1, 2, 3, and 4 may be
10 used, as illustrated in FIG. 5, to determine the unknown reservoir ink volume V_x .

[0059] FIG. 7 a flow chart 700 represents an arrangement of operations for detecting the ink level in the supply reservoir of an inkjet printing system. The operations are suitable for use with either a hot-melt inkjet printing system, such as the exemplary hot-melt inkjet printing system 100 shown in FIG. 1, or a liquid inkjet
15 printing system, such as the exemplary liquid inkjet printing system 300 shown in FIG. 3. Operations include initiating 710 the ink volume detection operation, for example, by the system controller 190. Optionally, the ink volume detection operation may be initiated manually by an operator of the inkjet printing system. The frequency of the ink volume detection operation may depend on certain criteria, such
20 as, but not limited to, a threshold time interval, a threshold number of "primary ink cycles," and any combination thereof. Operations further include determining 712 whether the K value is known for a certain inkjet system with its unique set of components. For example, the volume detection algorithm 194 may query a data storage device (not shown) of the system controller 190 for a value of the constant K,
25 which may be a value stored in ml/sec. The data storage device may be, for example, a register or a memory device that has read and write capability. If a K value is found, the K value is read into the volume detection algorithm 194, the operations proceed to operation 720. If a K value is not found, the operations proceed to determining 714 whether the supply reservoir (e.g., the supply reservoir 114 of the
30 hot-melt inkjet printing system 100 or the supply reservoir 310 of the liquid inkjet printing system 300) is empty or substantially empty of ink.

[0060] If the supply reservoir is empty, operations proceed to operation 716. If the supply reservoir is not empty, operations proceed to operation 718. Operations may include determining 716 the value of K using the empty supply reservoir according to Equation 1, which is: $K = V_r/t_r$. The empty reservoir volume V_r is
5 known (e.g., provided by the manufacturer of the reservoir). Additionally, the time t_r to transition an empty supply reservoir from one pressure value to another pressure value is known (e.g., provided by the manufacturer of the reservoir). Optionally, the time t_r may be determined by the volume detection algorithm 194. For example, the system controller 190 sets the supply reservoir 144, 310 to a pressure of about 0 PSI,
10 then using pressure source 166 and vent 180 transitions the pressure of the supply reservoir 144, 310 from about 0 PSI to about 1.2 PSI, all the while the volume detection algorithm 194 monitors the pressure sensor 184 and measures the time t_r for the empty supply reservoir 144, 310 to transition between the two pressure values. In one example, the empty supply reservoir 144, 310 has a known volume V_r of about
15 600 ml and a time t_r of about 6 sec is measured by the volume detection algorithm 194, therefore $K = V_r/t_r = 600 \text{ ml}/6 \text{ sec}$ or $K = \text{about } 100 \text{ ml}/\text{sec}$. This K value may be logged by the volume detection algorithm 194. (For a some inkjet printing systems, the K value whether determined by operation 716 or by operation 718 should be substantially the same.) The operations may then proceed to operation 720.

[0061] Operations may include determining 718 the value of K using the supply reservoir 114, 310 that contains an unknown ink volume V_x , according to Equation 5, which is: $K = V_i/(t_x-t_i)$. V_i is a known volume of ink that is added to the supply reservoir 114, 310, t_x is the time that it takes to transition the supply reservoir 114, 310 having an unknown ink volume from one pressure value to another pressure
25 value, and t_i is the time it takes to transition the supply reservoir 114, 310 from one pressure value to another pressure value after adding the known volume of ink V_i to the supply reservoir 114, 310. For example, the system controller 190 sets the supply reservoir 114, 310 to a pressure of about 0 PSI, then using pressure source 166 and vent 180 transitions the pressure of the supply reservoir 114, 310 from about 0 PSI to
30 about 1.2 PSI, all the while the volume detection algorithm 194 monitors the pressure sensor 184 and measures the time t_x for the supply reservoir 114, 310 having an unknown ink volume V_x to transition between the two pressure values. In some examples, t_x is 2.6 sec. Then a known volume of ink V_i is added to the supply

reservoir 114, 310. In additional examples, V_i is 150 ml. Then system the controller 190 sets the supply reservoir 114, 310 to a pressure of about 0 PSI, then using the pressure source 166 and the vent 180 transitions the pressure of the supply reservoir 114, 310 from about 0 PSI to about 1.2 PSI, all the while the volume detection
 5 algorithm 194 monitors the pressure sensor 184 and measures the time t_i for the supply reservoir 114, 310 that has both the unknown ink volume V_x plus the known volume of ink V_i to transition between the two pressure values. In some examples, t_i is 1.1 sec. Therefore, $K = V_i/(t_x - t_i) = 150 \text{ ml}/(2.6 \text{ sec} - 1.1 \text{ sec}) = 150 \text{ ml}/1.5 \text{ sec}$ or $K =$ about 100 ml/sec. This K value may be logged by the volume detection algorithm
 10 194. (For some inkjet printing systems, the K value whether determined by operations 716 or 718 should be substantially the same.) The operations may proceed to operation 720.

[0062] In some implementations, operations include determining 720 the time to transition the supply reservoir 114, 310 from a first pressure level to a second
 15 pressure level by monitoring the supply reservoir pressure sensor 184. The second pressure level must be below a cracking pressure of check valve 142. In some examples, the time t_x that it takes to transition the supply reservoir 114, 310 having an unknown ink volume V_x from, for example, about 0 PSI to about 1.2 PSI is determined using the volume detection algorithm 194, which is monitoring the
 20 pressure sensor 184. In particular, the elapsed time is measured between the pressure sensor 184 reading about 0 PSI and the pressure sensor 184 reading about 1.2 PSI. This elapsed time is recorded as the time t_x . In some examples, the time t_x is about 2.6 sec. The operations may proceed to operation 722.

[0063] Operations may include determining 722 the air-above-ink volume and
 25 the unknown supply reservoir ink volume. The air-above-ink volume V_a is determined according to Equation 3, which is $V_a = K * t_x$; where the K value of operation 716 or 718 and the time t_x of operation 720 is used. In some examples, when K is 100 ml/sec and time t_x is about 2.6 sec, then $V_a = 100 \text{ ml/sec} \times 2.6 \text{ sec} =$ 260 ml. Subsequently, the unknown reservoir ink volume V_x is determined according
 30 to Equation 2, which is $V_x = V_r - V_a$, where V_r is the known empty reservoir volume. In some examples, when the known empty reservoir volume V_r is 600 ml and the air-above-ink volume V_a is 260 ml, then $V_x = 600 \text{ ml} - 260 \text{ ml} = 340 \text{ ml}$. These

calculations may be performed using the volume detection algorithm 194. The operations may proceed to operation 724.

[0064] Operations may include determining 724 whether the supply ink volume determined in operation 726 is below a threshold limit. The threshold limit of ink volume for a supply reservoir 114, 310 and associated inkjet printing system 100, 300 is optimized such that sufficient ink volume is maintained in the supply reservoir 114, 310 and primary reservoir 134 to allow uninterrupted ink jetting for the period of time that is required to replenish the supply reservoir. In some examples, the threshold limit of ink volume for a 600 ml supply reservoir 114, 310 is 200 ml. The volume detection algorithm 194 compares the V_x value of operation 722 to the threshold limit value. If V_x is equal to or less than the threshold limit, operations may proceed to operation 726. If V_x is greater than the threshold limit, operations may return to operation 710.

[0065] Operations may include replenishing 726 or prompting replenishment of the ink 122, 314 in the supply reservoir 114, 310. In some examples, the volume detection algorithm 194 prompts an operator or user of the hot-melt inkjet printing system 100 to load one or more solid blocks of hot-melt ink 122 into the supply reservoir 114. In another example, the volume detection algorithm 194 prompts the system controller 190 of the liquid inkjet printing system 200 to replenish liquid ink 314 of the supply reservoir 310 by activating a pump (not shown) that pumps ink from the supply container 318 to the supply reservoir 310. The operations may proceed to operation 728.

[0066] Operations may include determining 728 whether the supply ink volume has been replenished. For example, in the hot-melt inkjet printing system 100, a sensor may be disposed on the latch of the access door 118 for sensing opening/closing to indicate that a block of hot-melt ink 122 has been added to the supply reservoir 114. In an additional example, in the liquid inkjet printing system 200, a sensor in communication with the pump associated with supply container 318 may be used to indicate whether the pump has been activated for indicating that an amount of liquid ink 314 has been added to the supply reservoir 310. If the supply ink volume has been replenished, the operations may return to operation 710, otherwise the operations may return to operation 726.

[0067] Referring to FIGS. 5-7 and equations 1-5, in some implementations, the ink volume detector 102, 302 is most accurate when the air entering the supply reservoir 114, 310 is near ambient temperature and is less accurate when the temperature of the air entering the supply reservoir 114, 310 is above the ambient
5 temperature. The overall accuracy of the ink volume detector 102, 302 may be greatest in a liquid inkjet printing system that is operating at, for example, 50° C and least in a hot-melt inkjet printing system that is operating at, for example, 125° C. In order to improve the overall accuracy of the ink volume detector 102, 302 for a heated supply reservoir 114, 310, certain corrections to compensate for the temperature of the
10 air entering the supply reservoir 114, 310 may be applied. The correction is necessary as a result of the air being heated as it enters the supply reservoir 114, 310 and, therefore, reaching a certain pressure, P, (e.g., 1.2 PSI) in less time than it would take in a similar unheated reservoir.

[0068] An empirical formula for determining the volume of ink in the supply reservoir 114, 310 can be based on careful observation of the time taken to pressurize the supply reservoir 114, 310 at various known ink volumes and supply reservoir temperatures. By accounting for the temperature of the supply reservoir 114, 310, the method for calculating the supply ink volume may provide a certain accuracy improvement as compared with the method that is described with reference to FIGS.
20 5-7.

[0069] An inkjet printing system, such as the hot-melt inkjet printing system 100 shown in FIG. 1 and the liquid inkjet printing system 300 shown in FIG. 2, may be calibrated by recording the time t_x to pressurize the supply reservoir (e.g., supply reservoir 114 and 310) from a first pressure (e.g., about 0 PSI) to a second pressure, P, (e.g., about 1.2 PSI) using two different, but known, volumes of ink. When
25 calibrating an inkjet printing system in the field, a supply reservoir that is empty (about 0 mL of ink) may be used for the first known volume and then, for example, two blocks of ink (e.g., ~150 mL each for a total of ~300 mL) may be added as the second known volume. The supply reservoir idle temperature should remain constant
30 (e.g., about 125° C) during the calibration. Furthermore, sufficient time should be allowed for any added ink to equilibrate to the temperature of the supply reservoir.

[0070] A temperature sensor 125 (shown in FIGS. 1 and 3), such as a thermistor device, may be mechanically and/or thermally coupled to the supply reservoir (e.g., supply reservoir 114 and 310) for monitoring the temperature thereof. For example, the volume detection algorithm 194 may monitor feedback from the temperature sensor 125 in order to determine the temperature of the supply reservoir 114, 310.

[0071] Three factors B, C, and M are used in the formula to calculate the volume of ink in the supply reservoir 114, 310. Factors B, C, and M can be found using the equations and procedure presented below. Because factors B, C, and M that are used to compensate for temperature are substantially constant, factors B, C, and M are independent of the inkjet printing system 100, 300.

[0072] The empirical formula:

$$V_x = C*(t_x + M*T_s) + B, \text{ where} \quad (\text{Equation 6})$$

V_x = Unknown reservoir ink volume;

C = Factor that compensates for differences of hardware in inkjet printing systems;

t_x = Time it takes to transition the supply reservoir having an unknown ink volume from, for example, about 0 PSI to about 1.2 PSI;

M = Factor that accounts for the temperature of the supply reservoir;

T_s = Temperature of the supply reservoir during an ink volume test; and

B = Factor that positions the linear curve (i.e., the maximum possible volume of ink, $t_x = 0$ sec).

[0073] The constants C and B:

$$C = (V_1 - V_2) / (t_1 - t_2) \quad (\text{Equation 7})$$

$$B = V_1 - C*(t_1 + M*T_s) \text{ or } B = V_2 - C*(t_2 + M*T_s) \quad (\text{Equation 8})$$

where

V_1 = Initial volume of ink in the supply reservoir;

V_2 = Final volume of ink in the supply reservoir;

t_1 = Time to pressurize the supply reservoir having an initial volume of ink present therein; and

5 t_2 = Time to pressurize the supply reservoir having a final volume of ink present therein.

[0074] FIG. 8 illustrates a plot 800, which is an example plot of the actual volume vs. time to pressurize a heated supply reservoir 114, 310 at constant temperatures of 80° C and 125° C. Plot 800 shows the actual volume of ink in the supply reservoir 114, 310 on the vertical axis and the time it takes to pressurize the supply reservoir 114, 310 to, for example, 1.2 PSI on the horizontal axis. The data represented by triangles was collected with the supply reservoir temperature at 80° C and the data represented by diamonds was collected with the supply reservoir temperature at 125° C. In all cases, sufficient time was given for the ink to equilibrate to the temperature of the supply reservoir 114, 310 before recording the time t_x to pressurize the supply reservoir 114, 310. Line 810 and line 812 of the plot 800 demonstrate the effect of the supply reservoir temperature on the time t_x to pressurize the system. The higher supply reservoir temperature resulted in less time to pressurize the system. The plot 800 also demonstrates that this trend is consistent at different ink volumes.

[0075] FIG. 9 illustrates a plot 900, which is an example plot of the real and compensated time to pressurize the empty supply reservoir 114, 310 at different temperatures. The plot 900 shows the time it takes to pressurize an empty supply reservoir 114, 310 on the vertical axis and the temperature of the supply reservoir 114, 310 on the horizontal axis. The slope of a line 910 through the diamond data points of the plot 900 indicates the relationship between the real time to pressurize and temperature of the supply reservoir 114, 310. This slope is the temperature compensation factor M of Equation 6. A line 912 through the square data points of the plot 900 represents the time taken to pressurize the system at different temperatures after compensating for the temperature. There is a linear relationship between the time to pressurize the system and the ink volume determined by the empirical formula, Equation 6. Therefore, in some implementations, Equation 6 can be applied

only when the time to pressurize the system is constant and independent of temperature. Compensating the time to pressurize the system with temperature and then using the compensated time values in place of the real time values in empirical the empirical formula, Equation 6, allows the formula to be accurate during all
5 temperature conditions.

[0076] FIG. 10 illustrates a plot 1000, which is an example plot of comparison of actual and calculated supply reservoir ink volumes at different temperatures. Plot 1000 shows the volume of ink on the vertical axis and the temperature of the supply reservoir 114, 310 on the horizontal axis. In this case, the actual volume of ink in the
10 supply reservoir 114, 310 was held constant at ~0 mL (i.e., line 1010 formed by the diamond data points). Line 1012 formed by the triangle data points indicate the ink volume predicted by the empirical formula, Equation 6, without compensating for temperature (i.e., line 814 formed by the diamond data points) with the temperature compensation. FIG. 10 indicates that the empirical formula, Equation 6, is accurate
15 when compensating for temperature.

[0077] FIG. 11 illustrates a plot 1100, which contains the same data as plot 800 of FIG. 8 but with the empirical formula, Equation 6, (including temperature compensation) applied. Plot 1100 shows the volume of ink in the supply reservoir 114, 310 is on the vertical axis and the time it takes to pressurize the inkjet printing
20 system is on the horizontal axis. The constants used to create line 1110 of plot 1100 are:

$$C = -0.0708;$$

$$M = 16.878; \text{ and}$$

$$B = 823$$

[0078] Various implementations of the systems and techniques described here (e.g., the ink volume detector 102, 302 and the system controller 190) can be realized in digital electronic circuitry, integrated circuitry, specially designed ASICs (application specific integrated circuits), computer hardware, firmware, software, and/or combinations thereof. These various implementations can include
25 implementation in one or more computer programs that are executable and/or interpretable on a programmable system including at least one programmable processor, which may be special or general purpose, coupled to receive data and
30

instructions from, and to transmit data and instructions to, a storage system, at least one input device, and at least one output device.

[0079] These computer programs (also known as programs, software, software applications or code) include machine instructions for a programmable processor, and can be implemented in a high-level procedural and/or object-oriented programming language, and/or in assembly/machine language. As used herein, the terms “machine-readable medium” “computer-readable medium” refers to any computer program product, apparatus and/or device (e.g., magnetic discs, optical disks, memory, Programmable Logic Devices (PLDs)) used to provide machine instructions and/or data to a programmable processor, including a machine-readable medium that receives machine instructions as a machine-readable signal. The term “machine-readable signal” refers to any signal used to provide machine instructions and/or data to a programmable processor.

[0080] Embodiments of the subject matter and the functional operations described in this specification can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Embodiments of the subject matter described in this specification can be implemented as one or more computer program products, i.e., one or more modules of computer program instructions encoded on a computer readable medium for execution by, or to control the operation of, data processing apparatus. The computer readable medium can be a machine-readable storage device, a machine-readable storage substrate, a memory device, a composition of matter effecting a machine-readable propagated signal, or a combination of one or more of them. The term “data processing apparatus” encompasses all apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, or multiple processors or computers. The apparatus can include, in addition to hardware, code that creates an execution environment for the computer program in question, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, or a combination of one or more of them. A propagated signal is an artificially generated signal, e.g., a machine-generated electrical, optical, or electromagnetic signal, that is generated to encode information for transmission to suitable receiver apparatus.

[0081] A computer program (also known as a program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program does not necessarily correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program in question, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer program can be deployed to be executed on one computer or on multiple computers that are located at one site or distributed across multiple sites and interconnected by a communication network.

[0082] The processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit).

[0083] Processors suitable for the execution of a computer program include, by way of example, both general and special purpose microprocessors, and any one or more processors of any kind of digital computer. Generally, a processor will receive instructions and data from a read only memory or a random access memory or both. The essential elements of a computer are a processor for performing instructions and one or more memory devices for storing instructions and data. Generally, a computer will also include, or be operatively coupled to receive data from or transfer data to, or both, one or more mass storage devices for storing data, e.g., magnetic, magneto optical disks, or optical disks. However, a computer need not have such devices. Moreover, a computer can be embedded in another device, e.g., a mobile telephone, a personal digital assistant (PDA), a mobile audio player, a Global Positioning System (GPS) receiver, to name just a few. Computer readable media suitable for storing computer program instructions and data include all forms of non volatile memory, media and memory devices, including by way of example semiconductor memory devices, e.g., EPROM, EEPROM, and flash memory devices; magnetic disks, e.g.,

internal hard disks or removable disks; magneto optical disks; and CD ROM and DVD-ROM disks. The processor and the memory can be supplemented by, or incorporated in, special purpose logic circuitry.

[0084] Embodiments of the subject matter described in this specification can be implemented in a computing system that includes a back end component, e.g., as a data server, or that includes a middleware component, e.g., an application server, or that includes a front end component, e.g., a client computer having a graphical user interface or a Web browser through which a user can interact with an implementation of the subject matter described in this specification, or any combination of one or more such back end, middleware, or front end components. The components of the system can be interconnected by any form or medium of digital data communication, e.g., a communication network. Examples of communication networks include a local area network (“LAN”) and a wide area network (“WAN”), e.g., the Internet.

[0085] The computing system can include clients and servers. A client and server are generally remote from each other and typically interact through a communication network. The relationship of client and server arises by virtue of computer programs running on the respective computers and having a client-server relationship to each other.

[0086] While this specification contains many specifics, these should not be construed as limitations on the scope of the invention or of what may be claimed, but rather as descriptions of features specific to particular embodiments of the invention. Certain features that are described in this specification in the context of separate embodiments can also be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable sub-combination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a sub-combination or variation of a sub-combination.

[0087] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be

performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products.

[0088] A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the disclosure. Accordingly, other implementations are within the scope of the following claims. For example, the actions recited in the claims can be performed in a different order and still achieve desirable results.

WHAT IS CLAIMED IS:

1. An ink volume detector (102, 302) for an inkjet printing system (100, 300), the ink volume detector (102, 302) comprising:
 - a supply reservoir (114, 310) for holding ink (122, 314);
 - 5 a pressure sensor (184) for monitoring an internal pressure of the supply reservoir (114, 310); and
 - a system controller (190) in communication with the pressure sensor (184), the system controller (190) configured to determine an ink volume (V_s) of the supply reservoir (114, 310) based on at least one pressurizing transition time between first
 - 10 and second pressures of the supply reservoir (114, 310).

2. The ink volume detector (102, 302) of claim 1, wherein the system controller (190) is configured to determine an ink volume (V_s) of the supply reservoir (114, 310) using a relationship of the volume of ink (V_s) in the supply reservoir (114, 310) plus a
- 15 volume of air (V_a) above the ink (122, 314) in the supply reservoir (114, 310) equals a reservoir volume (V_r) of the supply reservoir (114, 310), wherein the ink volume (V_s) and the air volume (V_a) are variable and the reservoir volume (V_r) is substantially fixed.

- 20 3. The ink volume detector (102, 302) of claim 1 or claim 2, wherein the system controller (190) is configured to determine an ink volume (V_s) of the supply reservoir (114, 310) using a relationship between the supply reservoir volume (V_r) and the pressurizing transition time.

- 25 4. The ink volume detector (102, 302) of claim 3, wherein a ratio of the supply reservoir volume (V_r) to the pressurizing transition time equals a constant.

5. The ink volume detector (102, 302) of any of the preceding claims, wherein the system controller (190) is configured to determine an ink volume (V_s) of the
- 30 supply reservoir (114, 310) using a relationship between the volume of air (V_a) above the ink (122, 314) in the supply reservoir (114, 310) and the at least one pressurizing transition time.

6. The ink volume detector (102, 302) of claim 5, wherein a ratio of the volume of air (V_a) above the ink (122, 314) in the supply reservoir (114, 310) to the at least one pressurizing transition time equals a constant.
- 5 7. The ink volume detector (102, 302) of any of the preceding claims, wherein the ink (122, 314) comprises hot-melt ink (122).
8. A method of ink volume detection comprising:
pressurizing a supply reservoir (114, 310);
10 monitoring the pressure of the supply reservoir (114, 310);
measuring a transition time between first and second pressures of the supply reservoir (114, 310) during pressurization of the supply reservoir (114, 310); and
determining a volume (V_s) of ink (122, 314) within the supply reservoir (114, 310) based on the transition time to pressurize the supply reservoir (114, 310) from
15 the first pressure to the second pressure.
9. A method of ink volume detection comprising:
measuring a first transition time to pressurize an empty supply reservoir (114, 310) between first and second pressures;
20 measuring a second transition time to pressurize a supply reservoir (114, 310) holding a volume (V_s) of ink (122, 314) between the first pressure and the second pressure; and
determining the volume (V_s) of ink (122, 314) held by the supply reservoir (114, 310) based on the first and second transition times.
25
10. The method of claim 8 of claim 9, further comprising:
determining whether the ink volume (V_s) is below a threshold volume; and
replenishing the ink (122, 314) in the supply reservoir (114, 310) when the ink volume (V_s) is below the threshold volume;
30
11. The method of any of claims 8-10, wherein determining the ink volume (V_s) comprises using a relationship of the volume (V_s) of ink (122, 314) in the supply reservoir (114, 310) plus a volume of air (V_a) above the ink (122, 314) in the supply

reservoir (114, 310) equals a reservoir volume (V_r) of the supply reservoir (114, 310), wherein the ink volume (V_s) and the air volume (V_a) are variable and the supply reservoir volume (V_r) is substantially fixed.

5 12. The method of any of claims 8-11, wherein determining the ink volume (V_s) comprises using a relationship between the supply reservoir volume (V_r) and the pressurizing transition time.

10 13. The method of claim 12, wherein a ratio of the supply reservoir volume (V_s) to the pressurizing transition time equals a constant.

14. The method of any of claims 8-13, wherein determining the ink volume (V_s) comprises using a relationship between the volume of air (V_a) above the ink (122, 314) in the supply reservoir (114, 310) and the pressurizing transition time.

15

15. The method of any of claims 8-14, wherein a ratio of the volume of air (V_a) above the ink (122, 314) in the supply reservoir (114, 310) to the pressurizing transition time equals a constant.

20 16. The method of any of claims 8-15, wherein the ink (122, 314) comprises hot-melt ink (122).

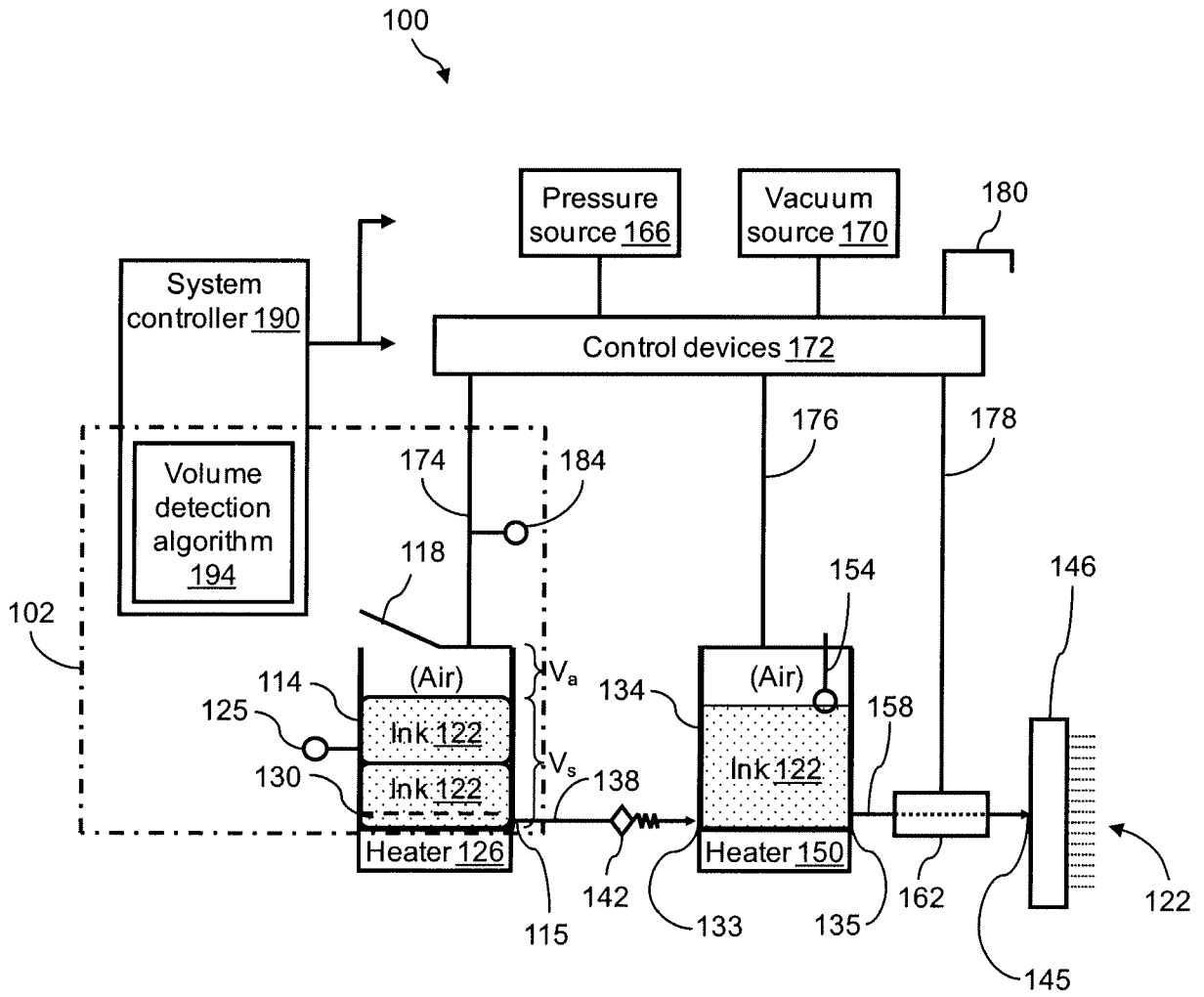


FIG. 1

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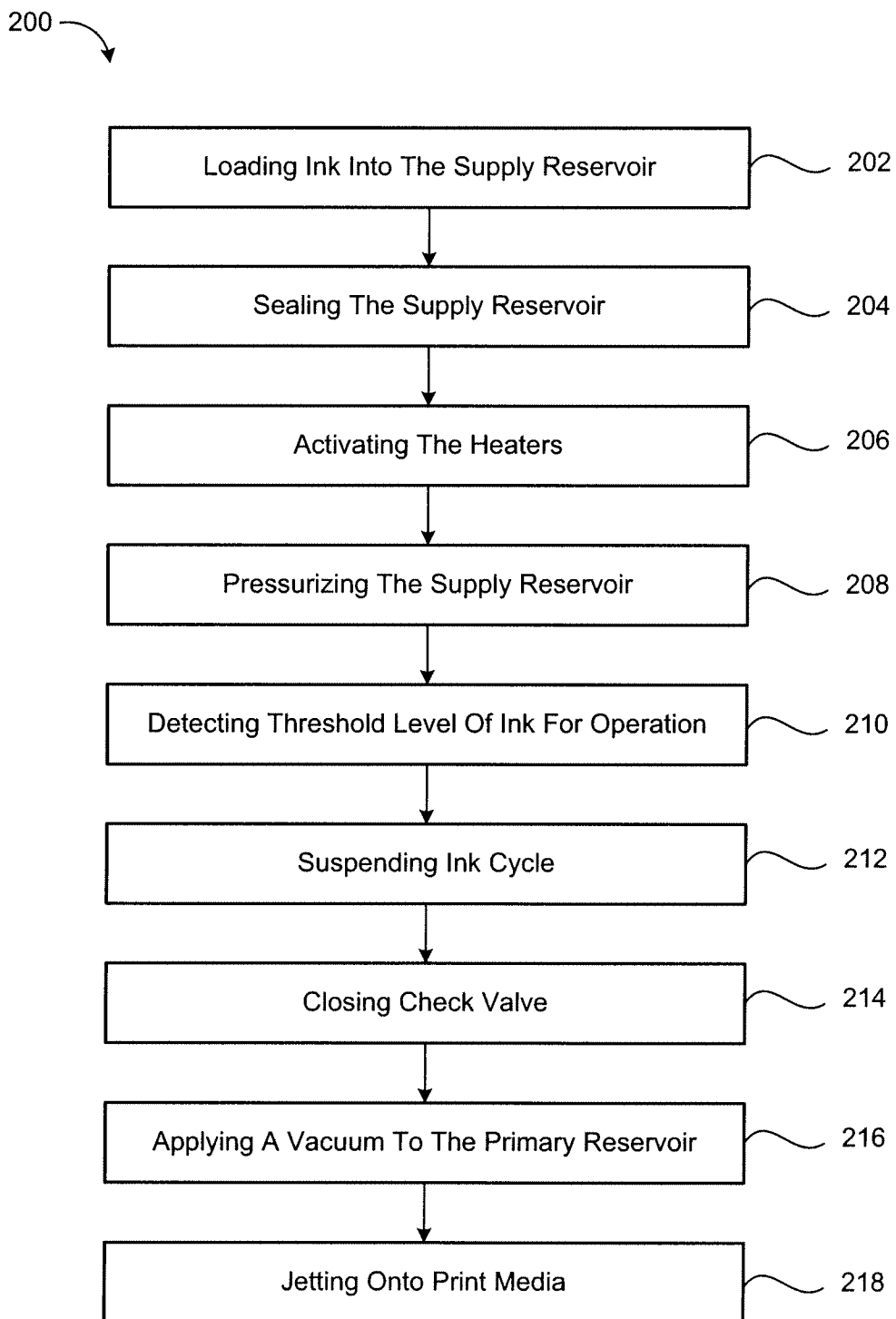


FIG. 2

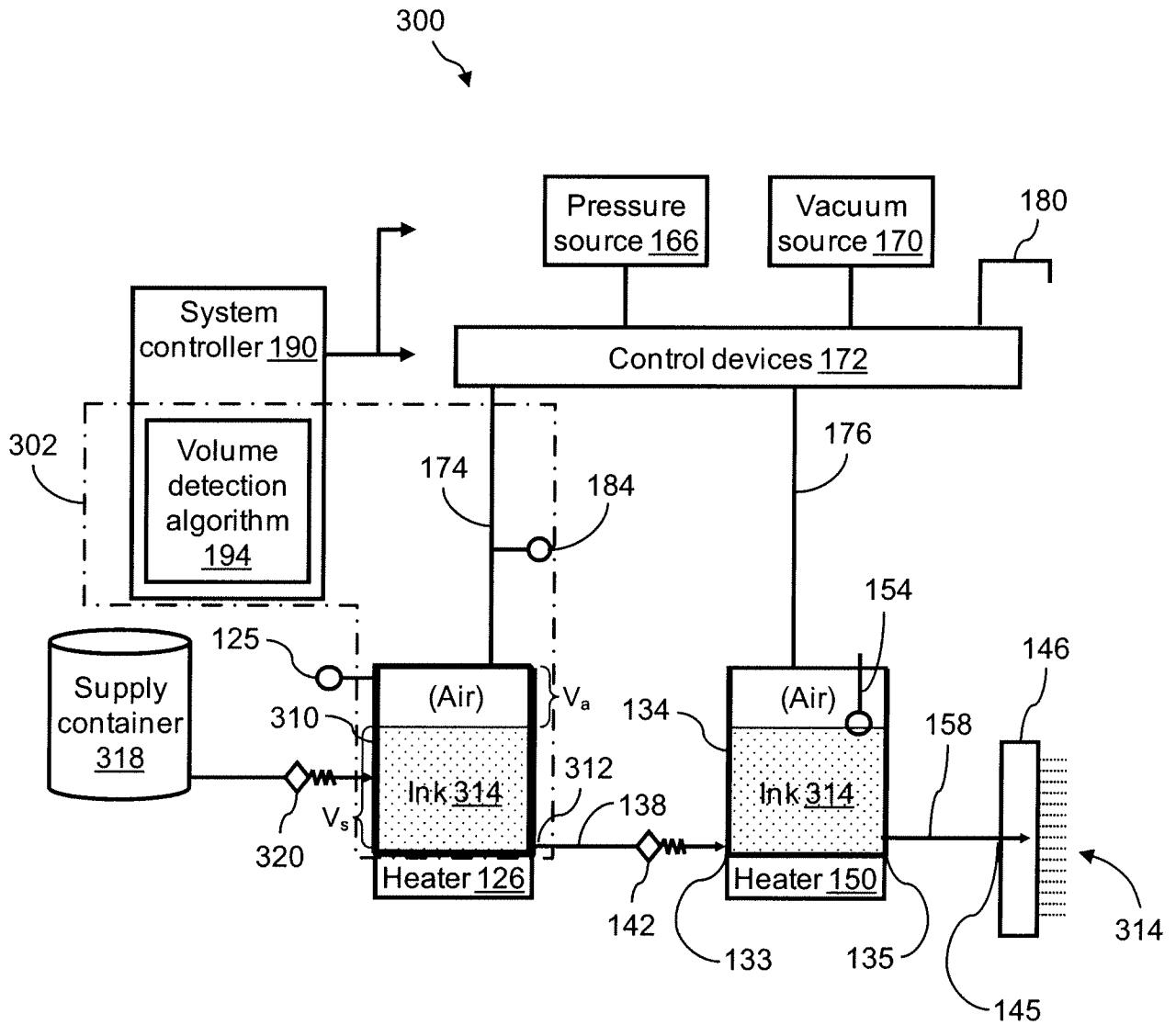


FIG. 3

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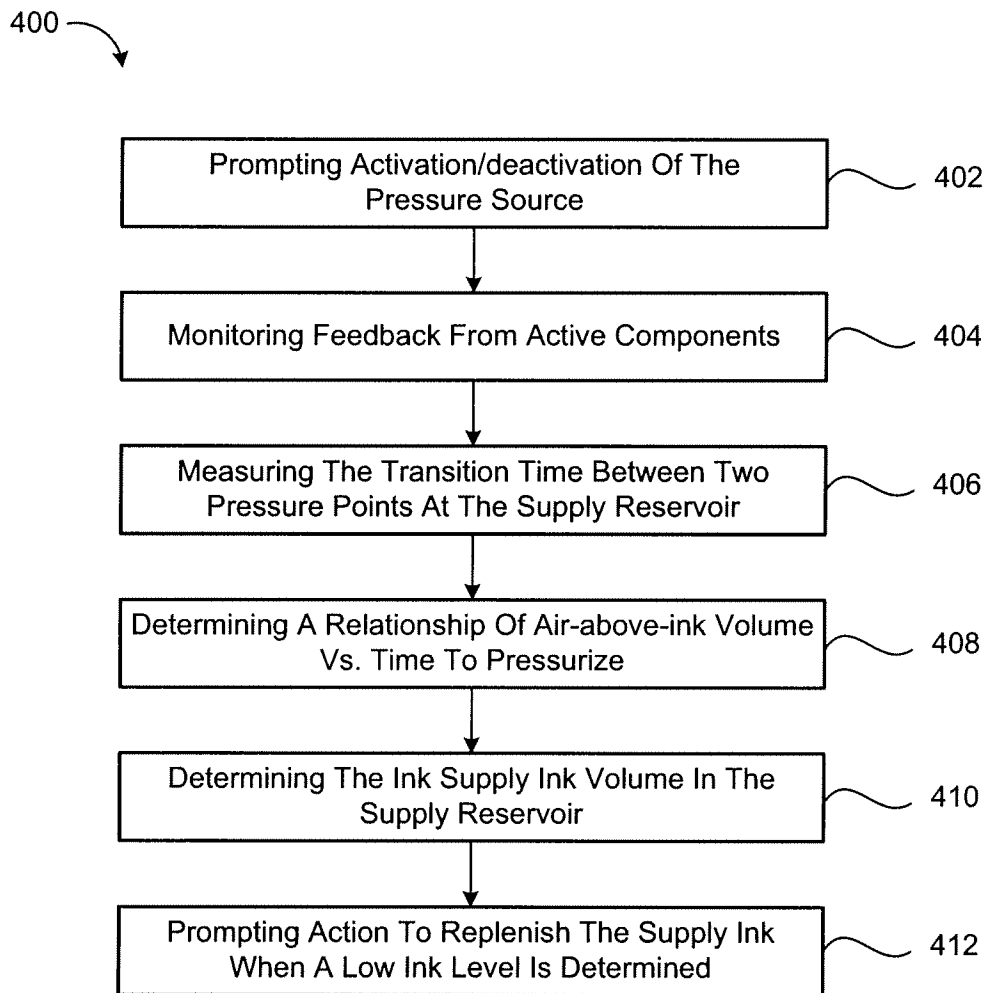


FIG. 4

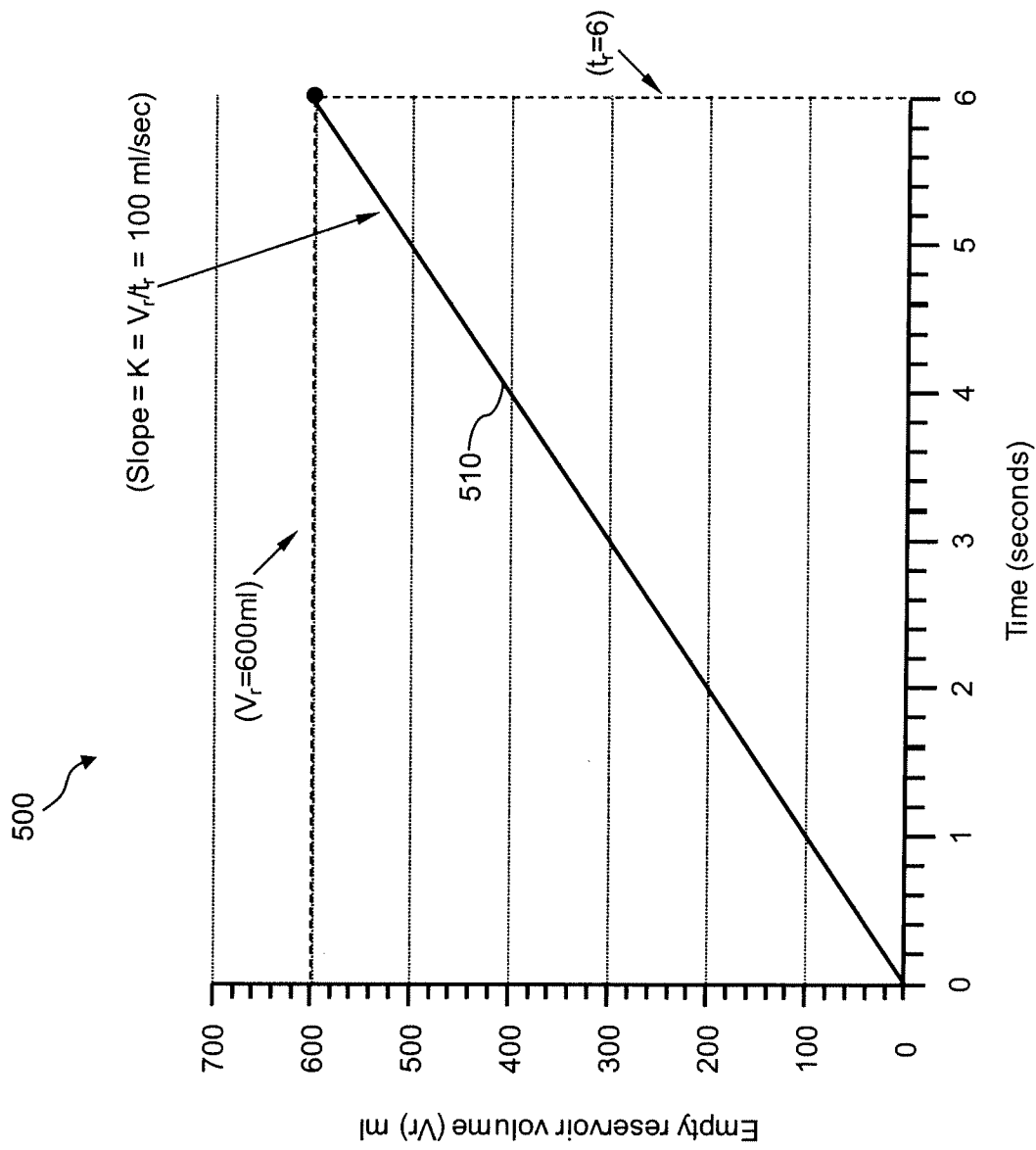


FIG. 5

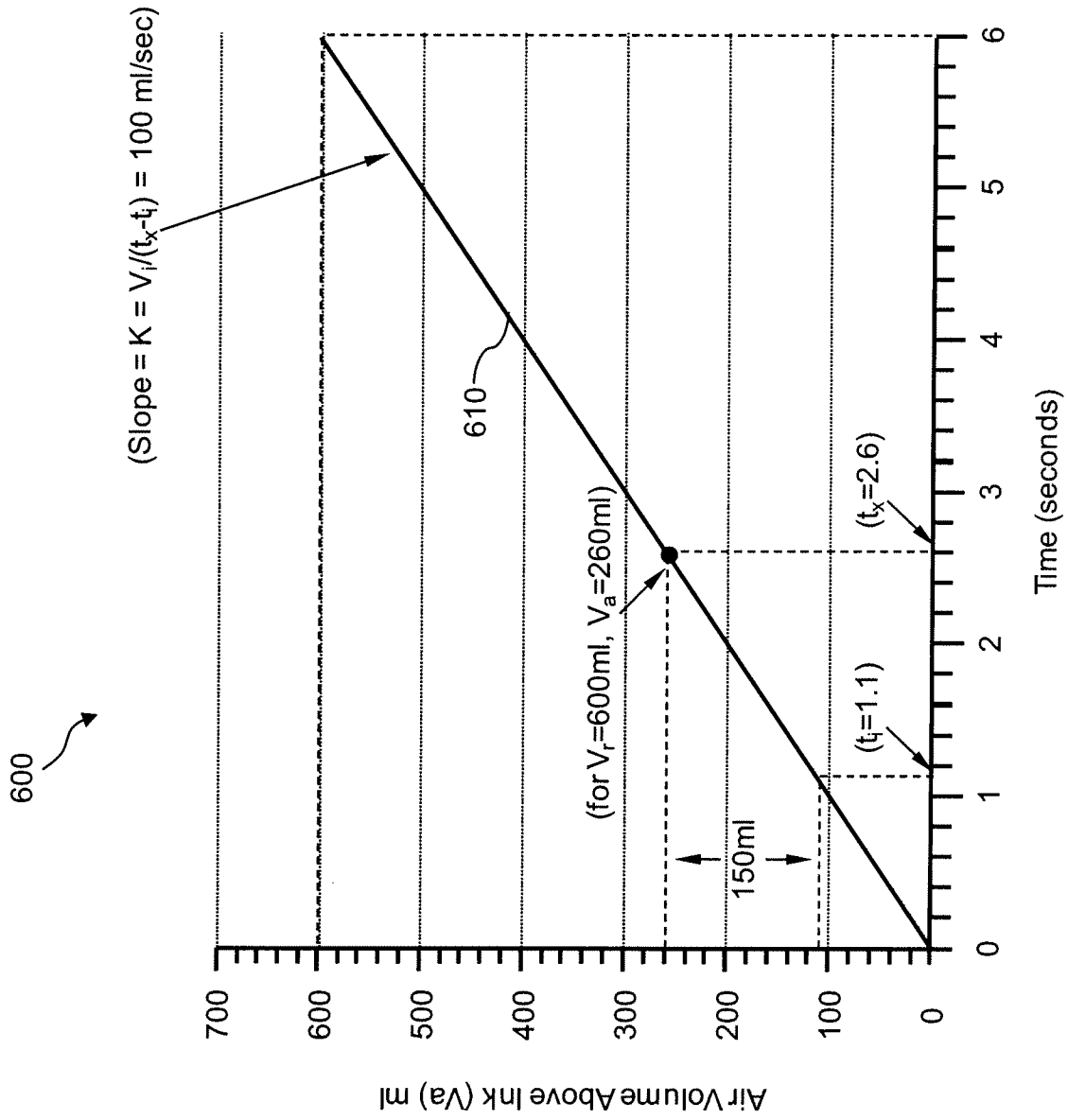


FIG. 6

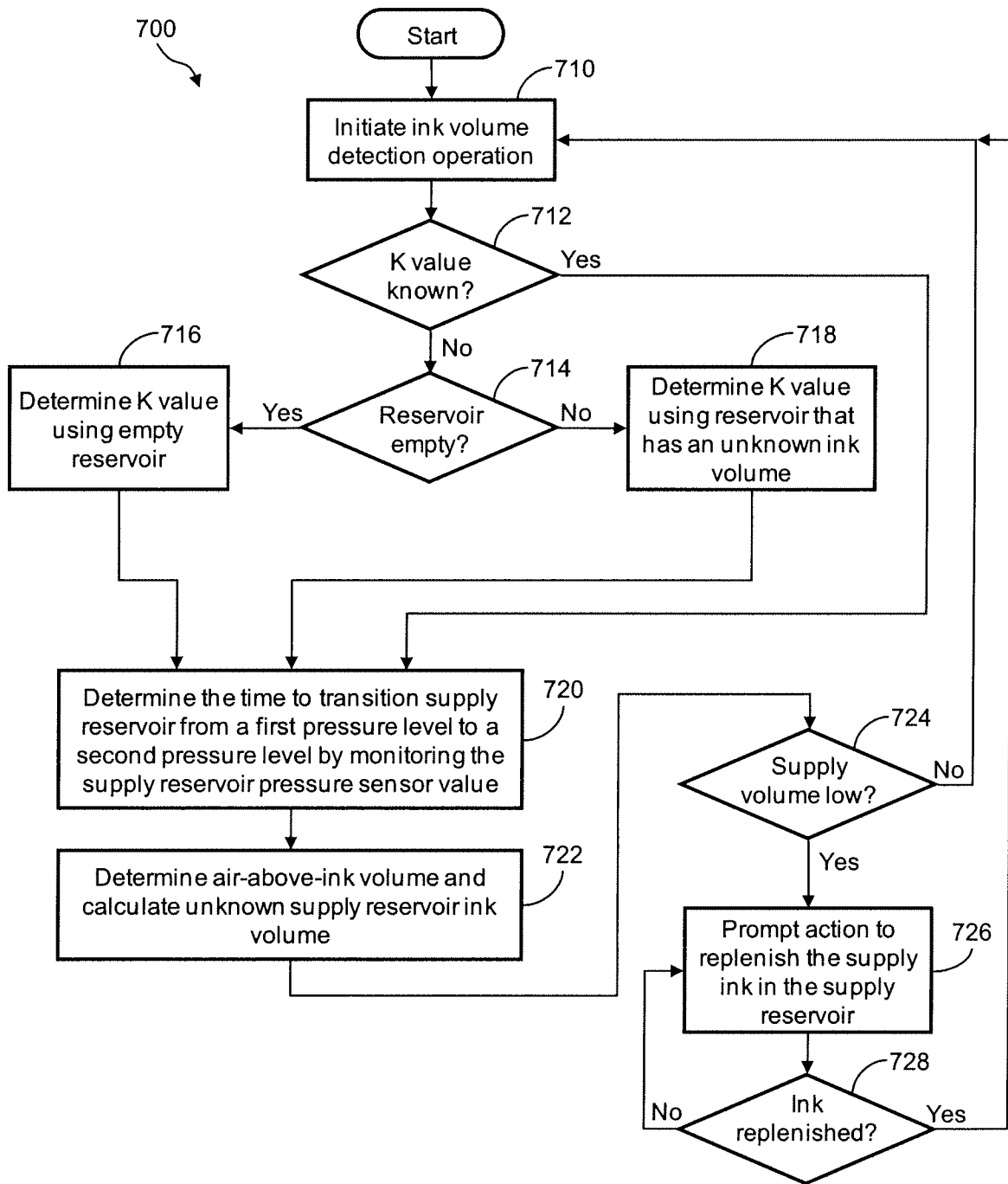


FIG. 7

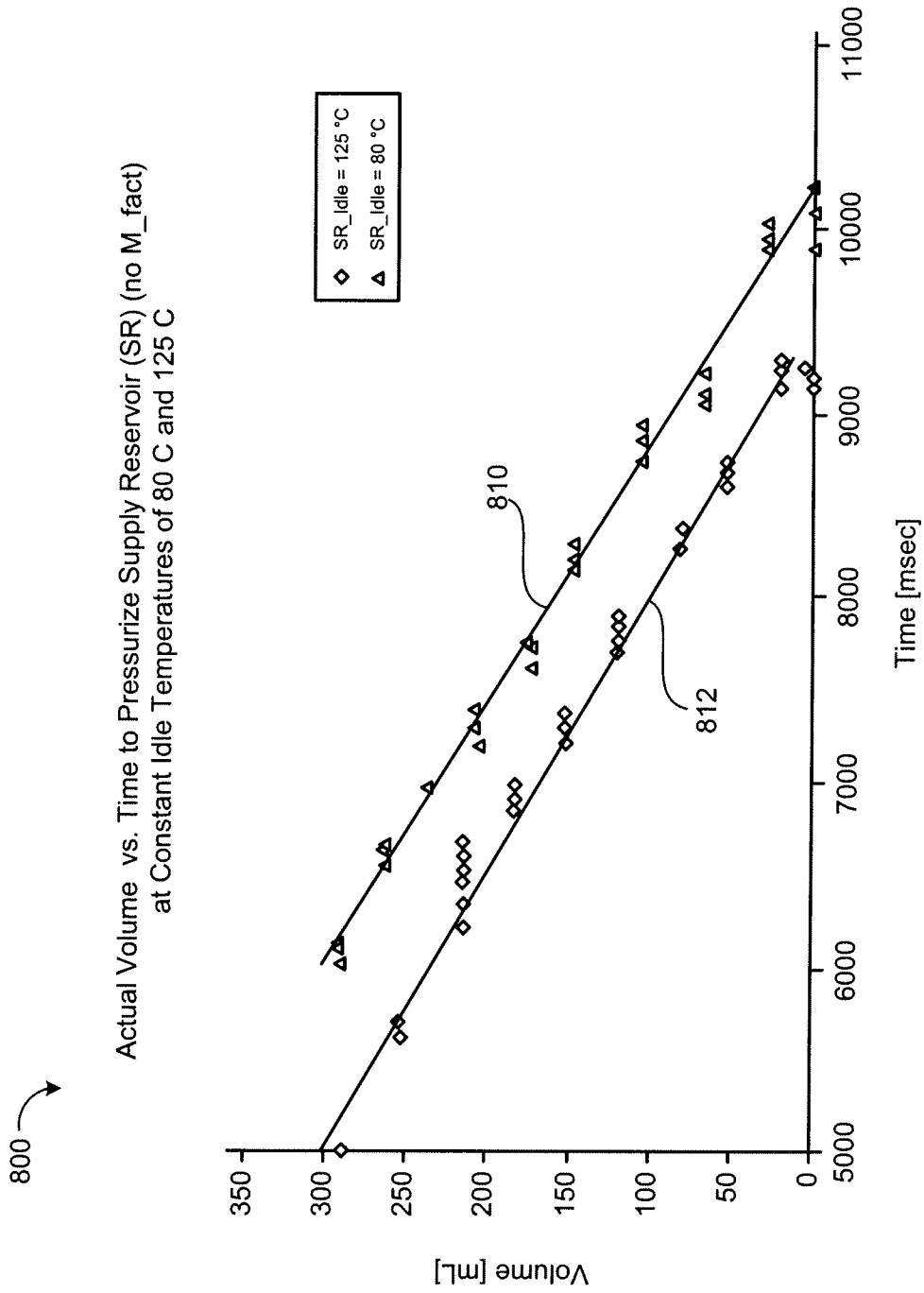


FIG. 8

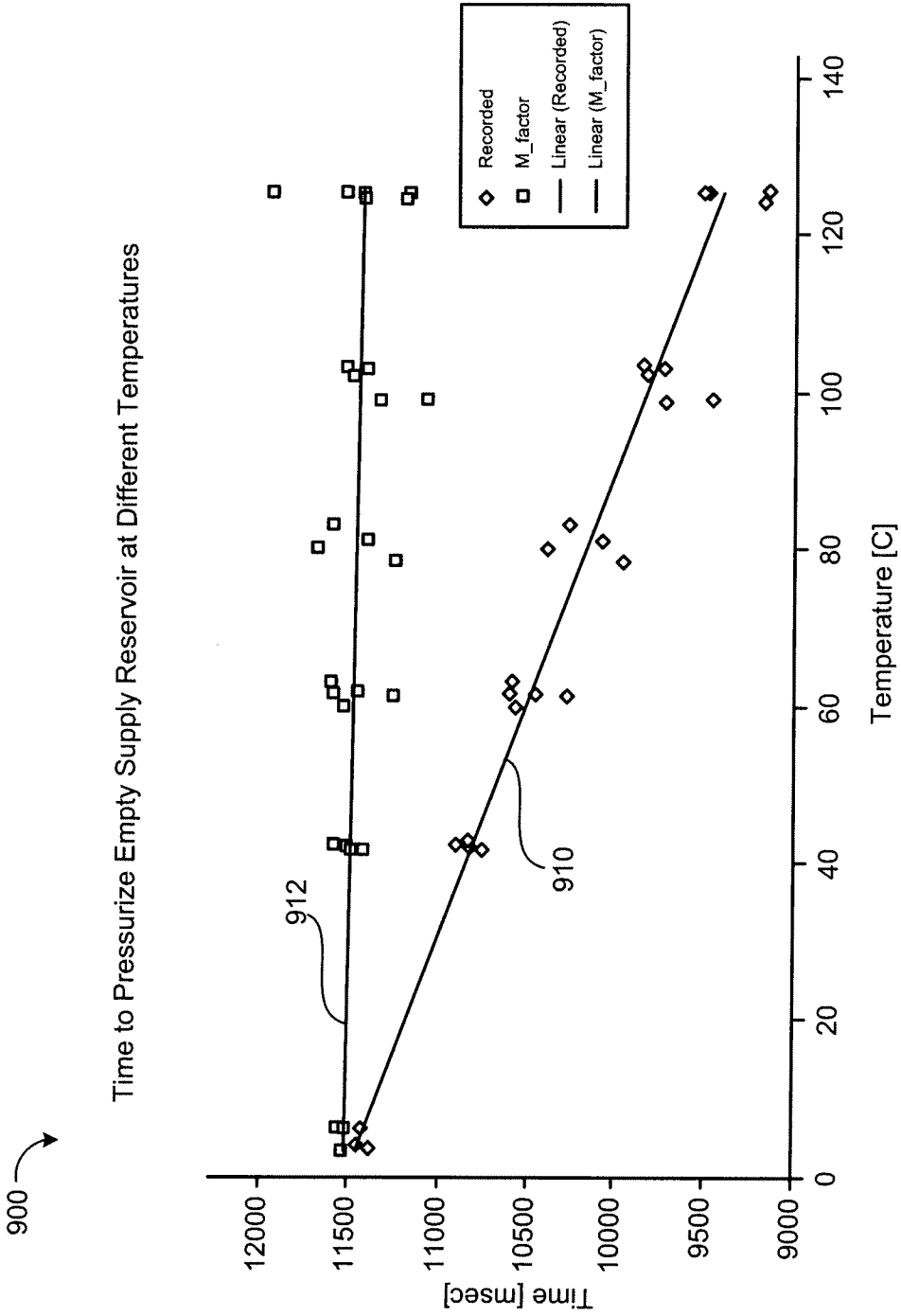


FIG. 9

1000 →

Comparison of Actual and Calculated Supply Reservoir Volumes at Different Temperatures

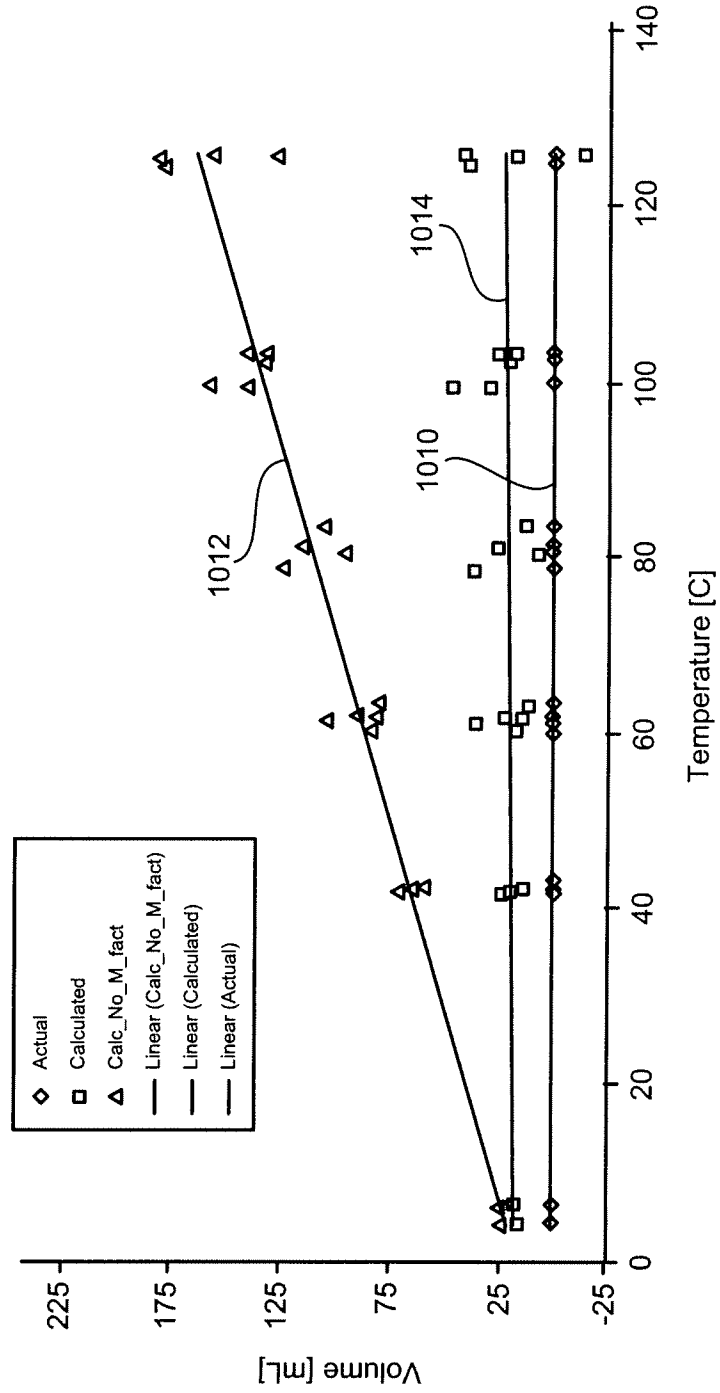


FIG. 10

1100 →

Implementation of Idle Temp Compensation Algorithm (Normalized to Idle = 0)

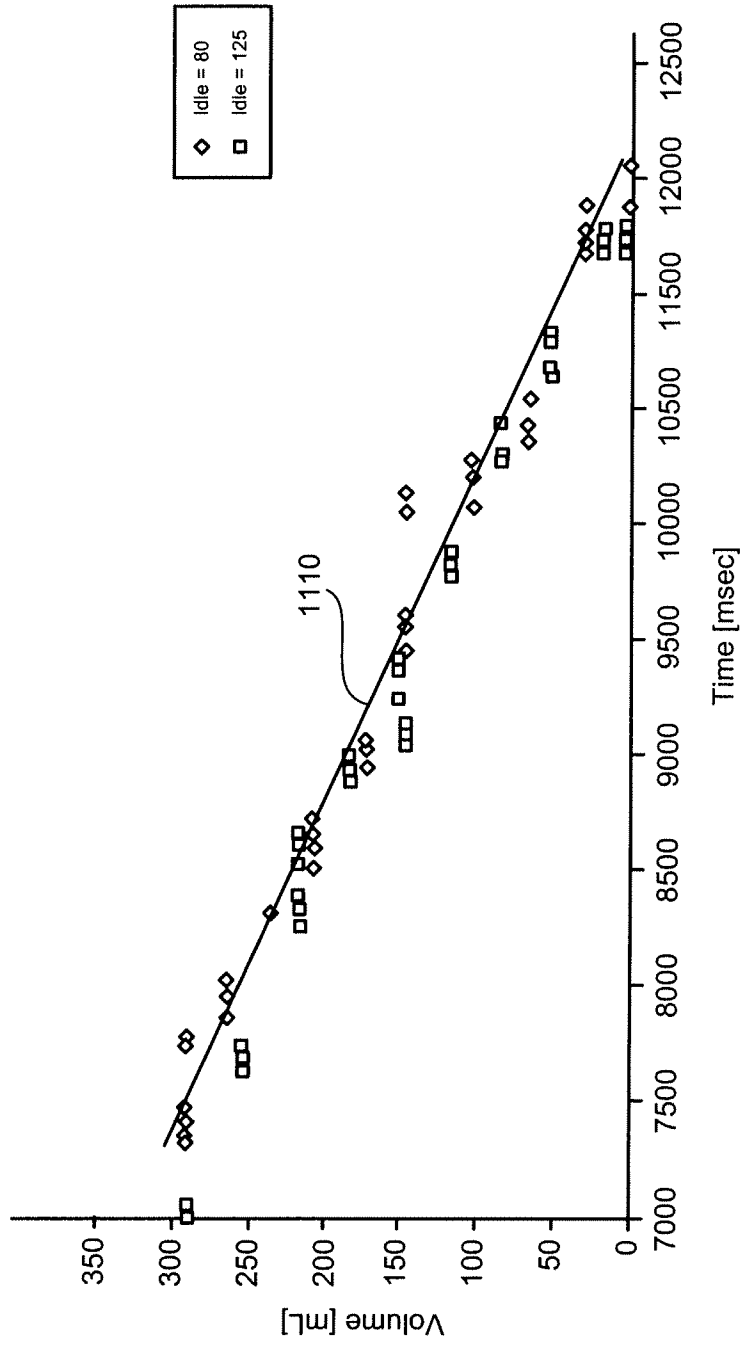


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/051218

A. CLASSIFICATION OF SUBJECT MATTER
 INV. B41J2/175 G01F22/02 G01F23/14

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)
 B41J G01F

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 practical, 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	EP 0 840 098 A (HEWLETT PACKARD CO [US]) 6 May 1998 (1998-05-06) page 9, line 23 - page 10, line 33; figure 5	1-16
A	WO 2004/072586 A (SHELDON MICHAEL L [US]) 26 August 2004 (2004-08-26) the whole document	1-16
A	EP 1 238 811 A (HEWLETT PACKARD CO [US]) 11 September 2002 (2002-09-11) the whole document	1-16
A	US 2002/145650 A1 (PAN YICHUAN [US] ET AL) 10 October 2002 (2002-10-10) the whole document	1-16
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Further documents are listed in the continuation of Box C. 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	*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
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O document referring to an oral disclosure, use, exhibition or other means	*&* document member of the same patent family
P document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 23 November 2009	Date of mailing of the international search report 01/12/2009
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Axters, Michael
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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2009/051218

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

information on patent family members

International application No

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