

INK PRESSURE REGULATOR WITH BUBBLE POINT PRESSURE REGULATIONField of the Invention

5 The present invention relates to a pressure regulator for an inkjet printer. It has been developed primarily for generating a negative hydrostatic pressure in an ink supply system supplying ink to printhead nozzles.

Background of the Invention

10 The inkjet printheads described in the above cross referenced documents typically comprise an array of nozzles, each nozzle having an associated ink ejection actuator for ejecting ink from a nozzle opening defined in a roof of a nozzle chamber. Ink from an ink cartridge or other reservoir is fed to the chambers where the ejection actuators force droplets of ink through the nozzle opening for printing. Typically, an ink cartridge is a replaceable consumable in an
15 inkjet printer.

 Ink may be drawn into each nozzle chamber by suction generated after each drop ejection and by the capillary action of ink supply channels having hydrophilic surfaces (*e.g.* silicon dioxide surface). During periods of inactivity, ink is retained in the nozzle chambers by the surface tension of an ink meniscus pinned across a rim of each nozzle opening. If the ink
20 pressure is not controlled, it may become positive with respect to external atmospheric pressure, possibly by thermal expansion of the ink, or a tipping of the printer that elevates the ink above the level of the nozzles. In this case the ink will flood onto the printhead surface. Moreover, during active printing, ink supplied through the ink supply channels has a momentum, which is sufficient to surge out of the nozzles and flood the printhead face once printing stops. Printhead
25 face flooding is clearly undesirable in either of these scenarios.

 To address this problem, many printhead ink supply systems are designed so that a hydrostatic pressure of ink at the nozzles is less than atmospheric pressure. This causes the meniscus across the nozzle openings to be concave or drawn inwards. The meniscus is pinned at nozzle openings, and the ink cannot freely flow out of the nozzles, both during inactive periods.
30 Furthermore, face flooding as a result of ink surges are minimized.

 The amount of negative pressure in the chambers is limited by two factors. It cannot be strong enough to de-prime the chambers (*i.e.* suck the ink out of the chambers and back towards the cartridge). However, if the negative pressure is too weak, the nozzles can leak ink onto the printhead face, especially if the printhead is jolted. Aside from these two catastrophic events
35 requiring some form of remediation (*e.g.* printhead maintenance or re-priming), a sub-optimal

hydrostatic ink pressure will typically cause an array of image defects during printing, with an appreciable loss of print quality. Accordingly, inkjet printers may have a relatively narrow window of hydrostatic ink pressures, which must be achieved by a pressure regulator in the ink supply system.

Typically, ink cartridges are designed to incorporate some means for regulating hydrostatic pressure of ink supplied therefrom. To establish a negative pressure, some cartridges use a flexible bag design. Part of the cartridge has a flexible bag or wall section that is biased towards increasing the ink storage volume. USSN 11/014764 (Our Docket: RRB001US) and USSN 11/014769 (Our Docket: RRC001US) (listed above in the cross referenced documents) are examples of this type of cartridge. These cartridges can provide a negative pressure, but tend to rely on excellent manufacturing tolerances of an internal leaf spring in the flexible bag. Further, the requirement of an internal biasing means in a flexible bag presents significant manufacturing difficulties.

Another means of generating a negative ink pressure via the ink cartridge is shown in Figure 25. A piece of foam or porous material 2 is placed in the cartridge 1 over the outlet 3. The foam 2 has a section that is saturated with ink 4, and a section 5 that may be wet with ink, but not saturated. The top of the cartridge 1 is vented to atmosphere through the air maze 7. Capillary action (represented by arrow 6) draws the ink from the saturated section 4 into the unsaturated section 5. This continues until it is balanced by the weight of the increased hydrostatic pressure, or 'head' of ink drawn upwards by the capillary action 6. The hydrostatic pressure at the top of the saturated section 4 is less than atmospheric because of capillary action into the unsaturated section 5. From there, the hydrostatic pressure increases towards the outlet 3, and if connected to the printhead (not shown), it continues to increase down to the nozzle openings (assuming they are the lowest points in the printhead). By setting the proportion of saturated foam to unsaturated foam such that the hydrostatic pressure of the ink at the nozzle is less than atmospheric, the ink meniscus will form inwardly.

However, ink cartridges comprising foam inserts are generally unsuitable for high speed printing (*e.g.* print speeds of one page every 1-2 seconds) using the Applicant's pagewidth printheads, which print at up to 1600 dpi. In such high speed printers, there are a large number of nozzles having a higher firing rate than traditional scanning printers. Therefore the ink flow rate out of the cartridge is much greater than that of a scanning printhead. The hydraulic drag caused by the foam insert can starve the nozzles and retard the chamber refill rate. More porous foam would have less hydraulic drag but also much less capillary force. Further, accurate pressure control requires equally accurate control over the internal void dimensions, which is difficult to achieved by the stochastically formed void structures of most foam materials. Accordingly,

porous foam inserts are not considered to be a viable means for controlling ink pressure at high ink flow rates.

As an alternative (or in addition) to ink cartridges having integral pressure regulators, the ink supply system may comprise a pressure regulator in the ink line between the printhead and an ink reservoir. The present Applicant's previously filed US Application Nos. 11/293,806 (Attorney Docket No. RRD011US, filed on December 5, 2005) and 11/293,842 (Attorney Docket No. RRD008US, filed on December 5, 2005), the contents of which are herein incorporated by reference, describe an in-line pressure regulator comprising a diaphragm and biasing mechanism. This mechanical arrangement is used to generate a negative hydrostatic ink pressure at the printhead. However, this type of mechanical pressure regulator has the drawback of requiring extremely fine manufacturing tolerances for a spring, which opens and closes the diaphragm in response to fluctuations in ink pressure upstream and downstream of the diaphragm. In practice, this mechanical system of pressure control makes it difficult to implement in an ink supply system required to maintain a constant negative hydrostatic ink pressure within a relatively narrow pressure range.

It would therefore be desirable to provide a pressure regulator, which is suitable for maintaining a hydrostatic ink pressure within a relatively narrow pressure range. It would further be desirable to provide a pressure regulator, which is suitable for use at relatively high ink flow rates. It would further be desirable to provide a pressure regulator, which is simple in construction and which does not require a plethora of moving parts manufactured with high tolerances.

Summary of the Invention

In a first aspect the present invention provides an ink pressure regulator for regulating a hydrostatic pressure of ink supplied to an inkjet printhead, said regulator comprising:

- an ink chamber having an ink outlet for fluid communication with the printhead via an ink line;

- an air inlet open to atmosphere;

- a bubble outlet positioned for bubbling air into ink contained in the chamber; and

- an air channel connecting the air inlet and the bubble outlet,

wherein said bubble outlet is dimensioned to control a Laplace pressure of air bubbles drawn into said ink as result of supplying ink to the printhead, thereby regulating a hydrostatic pressure of the ink.

Optionally, said ink chamber is an ink reservoir for a printer.

Optionally, said ink chamber has an ink inlet port for fluid communication with an ink reservoir.

Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 10 mm H₂O less than atmospheric pressure.

5 Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 100 mm H₂O less than atmospheric pressure.

Optionally, said bubble outlet has a critical dimension controlling the Laplace pressure of the air bubbles exiting the bubble outlet.

10 Optionally, said bubble outlet is configured as a circular opening, such that a radius of said circular opening controls the Laplace pressure of the air bubbles.

Optionally, said bubble outlet is configured as a slot having a length dimension and a width dimension, such that said width dimension controls the Laplace pressure of the air bubbles.

Optionally, a width of said slot is less than 200 microns.

15 Optionally, each cross-sectional dimension of said air channel is greater than the width of the slot, thereby minimizing flow resistance in the air channel.

Optionally, said air channel is bent or tortuous for minimizing ink losses through the air inlet.

20 Optionally, said air channel is dimensioned such that a maximum capillary volume of ink in said channel is less than about 0.1 mL.

Optionally, one wall of said chamber comprises an air intake plate, said plate comprising the air inlet, the air channel and the bubble outlet.

Optionally, said plate comprises a plurality of laminated layers, said layers cooperating to define the air inlet, the air channel and the bubble outlet.

25 Optionally, said plate comprises:

 a first layer having an air inlet opening defined therethrough and an elongate recess defined in a first face thereof, said recess extending longitudinally from said air inlet aperture to a terminus; and

30 a second layer laminated to said first face, said second layer having a bubble vent opening defined therethrough,

wherein said bubble vent opening is positioned for fluid communication with said terminus.

Optionally, a depth of said recess towards said terminus defines a critical dimension of said bubble outlet, said critical dimension controlling a Laplace pressure of air bubbles exiting said bubble outlet.

Optionally, said recess has a shallower portion at said terminus, said shallower portion providing a constriction in said air channel.

Optionally, said terminus is defined by a circular recess having a diameter greater than said bubble vent opening, thereby providing a bubble outlet defined by an annular slot.

5 Optionally, said first face has a moat defined therein, said moat protecting said recess from adhesive during lamination of the first and second layers.

In a further aspect there is provided a pressure regulator, further comprising a pressure release valve for releasing excess pressure in a headspace above ink in said chamber.

10 In a second aspect the present invention provides a printhead ink supply system comprising:
an inkjet printhead;
an ink reservoir;
an ink pressure regulator for regulating a hydrostatic pressure of ink supplied to said printhead, said regulator comprising:

15 an ink chamber having an ink outlet;
 an air inlet open to atmosphere;
 a bubble outlet for bubbling air bubbles into the chamber, each air bubble comprising an air cavity trapped inside a film or a body of ink, said bubble outlet being dimensioned to control a Laplace pressure of air bubbles drawn into said chamber as
20 result of supplying ink to the printhead, thereby regulating a hydrostatic pressure of the ink; and

 an air channel connecting the air inlet and the bubble outlet; and
a first ink line providing fluid communication between said ink outlet and an inlet channel of said printhead.

25 Optionally, said ink reservoir is defined by said ink chamber.

Optionally, said ink pressure regulator is a replaceable ink cartridge.

In a further aspect there is provided an ink supply system, further comprising an ink cartridge defining said ink reservoir, said ink cartridge having an ink supply port in fluid communication with an ink inlet port of said ink chamber.

30 In a further aspect there is provided an ink supply system, further comprising a second ink line providing fluid communication between an outlet channel of said printhead and a return inlet of said ink reservoir, such that said ink supply system is a loop.

Optionally, said return inlet comprises an ink filter for filtering returned ink.

Optionally, a first pump is positioned in said first ink line upstream of said printhead.

Optionally, said first pump is open and idle during printing, such that said pressure regulator determines the hydrostatic pressure of the ink in the printhead during printing.

Optionally, a second pump is positioned in said second ink line downstream of said printhead.

5 Optionally, said first and second pumps are independently configurable for priming, depriming, purging and printing operations.

Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 10 mm H₂O less than atmospheric pressure.

10 Optionally, said bubble outlet has a critical dimension controlling the Laplace pressure of the air bubbles exiting the bubble outlet.

Optionally, said bubble outlet is configured as a slot having a length dimension and a width dimension, such that said width dimension controls the Laplace pressure of the air bubbles.

Optionally, a width of said slot is less than 200 microns.

15 Optionally, the bubble outlet is positioned for bubbling air bubbles into ink contained in the chamber, each air bubble comprising an air cavity trapped inside a body of ink.

In a further aspect there is provided a pressure regulator, further comprising a pressure-release valve for releasing excess pressure in a headspace above ink in said chamber.

20 Optionally, said air channel is bent or tortuous for minimizing ink losses through the air inlet.

Optionally, the bubble outlet is positioned for bubbling air bubbles into a headspace above ink contained in the chamber, each air bubble comprising an air bubble trapped inside a film of ink.

25 In a further aspect there is provided a pressure regulator, further comprising a capillary channel in fluid communication with ink contained in the ink chamber, said capillary channel supplying ink from the chamber to the bubble outlet by capillary action.

In a third aspect the present invention provides an ink pressure regulator for regulating a hydrostatic pressure of ink supplied to an inkjet printhead, said regulator comprising:

30 an ink chamber having an ink outlet for fluid communication with the printhead via an ink line;

an air inlet open to atmosphere;

a bubble outlet positioned for bubbling air bubbles into a headspace of the chamber, each air bubble comprising an air cavity trapped inside a film of ink;

a capillary channel in fluid communication with ink contained in the ink chamber, said capillary channel supplying ink from the chamber to the bubble outlet by capillary action; and

an air channel connecting the air inlet and the bubble outlet,

5 wherein said bubble outlet is dimensioned to control a Laplace pressure of air bubbles drawn into said chamber as result of supplying ink to the printhead, thereby regulating a hydrostatic pressure of the ink.

Optionally, said ink chamber is an ink reservoir for a printer.

10 Optionally, said ink chamber has an ink inlet port for fluid communication with an ink reservoir.

Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 10 mm H₂O less than atmospheric pressure.

Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 100 mm H₂O less than atmospheric pressure.

15 Optionally, said bubble outlet has a critical dimension controlling the Laplace pressure of the air bubbles exiting the bubble outlet.

Optionally, said bubble outlet is configured as a circular opening, such that a radius of said circular opening controls the Laplace pressure of the air bubbles.

20 Optionally, said bubble outlet is configured as a slot having a length dimension and a width dimension, such that said width dimension controls the Laplace pressure of the air bubbles.

Optionally, a width of said slot is less than 200 microns.

In a further aspect there is provided a pressure regulator, further comprising a bubble vent adjacent said bubble outlet, said bubble vent opening into said headspace.

25 Optionally, said bubble outlet and said bubble vent cooperate such that each air bubble breaks through a meniscus of ink pinned across said bubble outlet and vents into said chamber via said bubble vent.

Optionally, one wall of said chamber comprises an air intake plate, said plate comprising the air inlet, the air channel, the bubble outlet and the bubble vent.

30 Optionally, said plate comprises a plurality of laminated layers, said layers cooperating to define the air inlet, the air channel, the bubble outlet and the bubble vent.

Optionally, said plate comprises:

35 a first layer having an air inlet opening defined therethrough and an elongate recess defined in a first face thereof, said recess extending longitudinally from a proximal end at said air inlet aperture to a distal end; and

a second layer laminated to said first face, said second layer having a capillary inlet opening and a bubble vent opening defined therethrough, wherein said capillary inlet opening is positioned towards said distal end of said recess and said bubble vent opening is positioned towards said proximal end of said recess.

5 Optionally, a depth of said recess at said proximal end defines a critical dimension of said bubble outlet, said critical dimension controlling a Laplace pressure of air bubbles exiting said bubble outlet.

 Optionally, said bubble vent opening is dimensioned to pin a meniscus of ink across the opening by surface tension.

10 Optionally, said bubble vent opening is adjacent said bubble outlet.

 Optionally, said recess is dimensioned to provide sufficient capillary pressure to raise a column of ink from said distal end to said proximal end.

 In a fourth aspect the present invention provides an ink pressure regulator for regulating a hydrostatic pressure of ink supplied to an inkjet printhead, said regulator comprising:

15 an ink chamber having an ink outlet for fluid communication with the printhead via an ink line;

 an air inlet open to atmosphere;

 a bubble outlet for bubbling air bubbles into the chamber, each air bubble comprising an air cavity trapped inside a film or a body of ink; and

20 an air channel connecting the air inlet and the bubble outlet,

 wherein said bubble outlet is dimensioned to control a Laplace pressure of air bubbles drawn into said chamber as result of supplying ink to the printhead, thereby regulating a hydrostatic pressure of the ink.

 Optionally, said ink chamber is an ink reservoir for a printer.

25 Optionally, said ink chamber has an ink inlet port for fluid communication with an ink reservoir.

 Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 10 mm H₂O less than atmospheric pressure.

30 Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 100 mm H₂O less than atmospheric pressure.

 Optionally, said bubble outlet has a critical dimension controlling the Laplace pressure of the air bubbles exiting the bubble outlet.

 Optionally, said bubble outlet is configured as a circular opening, such that a radius of said circular opening controls the Laplace pressure of the air bubbles.

Optionally, said bubble outlet is configured as a slot having a length dimension and a width dimension, such that said width dimension controls the Laplace pressure of the air bubbles.

Optionally, a width of said slot is less than 200 microns.

5 Optionally, the bubble outlet is positioned for bubbling air bubbles into ink contained in the chamber, each air bubble comprising an air cavity trapped inside a body of ink.

In a further aspect there is provided a pressure regulator, further comprising a pressure release valve for releasing excess pressure in a headspace above ink in said chamber.

10 Optionally, said air channel is bent or tortuous for minimizing ink losses through the air inlet.

Optionally, the bubble outlet is positioned for bubbling air bubbles into a headspace above ink contained in the chamber, each air bubble comprising an air bubble trapped inside a film of ink.

15 In a further aspect there is provided a pressure regulator, further comprising a capillary channel in fluid communication with ink contained in the ink chamber, said capillary channel supplying ink from the chamber to the bubble outlet by capillary action.

In a further aspect there is provided a pressure regulator, further comprising a bubble vent adjacent said bubble outlet, said bubble vent opening into said headspace.

20 In a fifth aspect the present invention provides an ink cartridge suitable for regulating a hydrostatic pressure of ink supplied to an inkjet printhead, said cartridge comprising:

an ink chamber having an ink outlet for fluid communication with the printhead via an ink line;

an air inlet open to atmosphere;

25 a bubble outlet for bubbling air bubbles into the chamber, each air bubble comprising an air cavity trapped inside a film or a body of ink; and

an air channel connecting the air inlet and the bubble outlet,

wherein said bubble outlet is dimensioned to control a Laplace pressure of air bubbles drawn into said chamber as result of supplying ink to the printhead, thereby regulating a hydrostatic pressure of the ink.

30 Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 10 mm H₂O less than atmospheric pressure.

Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 100 mm H₂O less than atmospheric pressure.

35 Optionally, said bubble outlet has a critical dimension controlling the Laplace pressure of the air bubbles exiting the bubble outlet.

Optionally, said bubble outlet is configured as a circular opening, such that a radius of said circular opening controls the Laplace pressure of the air bubbles.

Optionally, said bubble outlet is configured as a slot having a length dimension and a width dimension, such that said width dimension controls the Laplace pressure of the air
5 bubbles.

Optionally, a width of said slot is less than 200 microns.

Optionally, the bubble outlet is positioned for bubbling air bubbles into ink contained in the chamber, each air bubble comprising an air cavity trapped inside a body of ink.

In a further aspect there is provided an ink cartridge, further comprising a pressure
10 release valve for releasing excess pressure in a headspace above ink in said chamber.

Optionally, said air channel is bent or tortuous for minimizing ink losses through the air inlet.

Optionally, the bubble outlet is positioned for bubbling air bubbles into a headspace above ink contained in the chamber, each air bubble comprising an air bubble trapped inside a
15 film of ink.

In a further aspect there is provided an ink cartridge, further comprising a capillary channel in fluid communication with ink contained in the ink chamber, said capillary channel supplying ink from the chamber to the bubble outlet by capillary action.

In a further aspect there is provided an ink cartridge, further comprising a bubble vent
20 adjacent said bubble outlet, said bubble vent opening into said headspace.

In a further aspect there is provided an ink cartridge, which is a replaceable or disposable ink cartridge.

In a further aspect there is provided an ink cartridge, further comprising an ink inlet for receiving ink from the printhead.

In a further aspect there is provided an ink cartridge, further comprising an ink filter for
25 filtering the received ink.

In a sixth aspect the present invention provides a method of regulating a hydrostatic pressure of ink supplied to an inkjet printhead, said method comprising:

withdrawing a volume of ink from an ink chamber and simultaneously bubbling air
30 bubbles into the chamber via a bubble outlet to balance the withdrawn volume of ink, each air bubble being defined by an air cavity trapped by a film or a body of ink,

wherein the bubble outlet is dimensioned to control a Laplace pressure of the air bubbles, thereby regulating a hydrostatic pressure of the ink.

Optionally, said ink chamber is an ink reservoir for a printer.

Optionally, said ink chamber has an ink inlet port for fluid communication with an ink reservoir.

Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 10 mm H₂O less than atmospheric pressure.

5 Optionally, said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 100 mm H₂O less than atmospheric pressure.

Optionally, said bubble outlet has a critical dimension controlling the Laplace pressure of the air bubbles exiting the bubble outlet.

10 Optionally, said bubble outlet is configured as a circular opening, such that a radius of said circular opening controls the Laplace pressure of the air bubbles.

Optionally, said bubble outlet is configured as a slot having a length dimension and a width dimension, such that said width dimension controls the Laplace pressure of the air bubbles.

Optionally, a width of said slot is less than 200 microns.

15 Optionally, the bubble outlet is positioned for bubbling air bubbles into ink contained in the chamber, each air bubble comprising an air cavity trapped inside a body of ink.

Optionally, the bubble outlet is positioned for bubbling air bubbles into a headspace above ink contained in the chamber, each air bubble comprising an air bubble trapped inside a film of ink.

20 Optionally, a capillary channel supplies ink from the chamber to the bubble outlet by capillary action.

Optionally, a bubble vent adjacent said bubble outlet vents said air bubbles into said headspace.

25 Optionally, said volume of ink is withdrawn by a pumping effect of a printhead in fluid communication with an ink outlet of said chamber.

In a seventh aspect, there is provided an ink reservoir for an inkjet printhead, the reservoir comprising:

a container for maintaining a quantity of ink at a pressure less than ambient pressure;
an ink outlet for sealed fluid connection to the printhead; and,

30 an air inlet with a pressure regulator that allows air into the container at a predetermined pressure difference between the container interior and atmosphere.

Optionally the pressure regulator is a relief valve.

Optionally, the pressure regulator is a porous member with a first surface for exposure to atmosphere and a second surface for contacting the ink in the container; wherein during use, air
35 at the first surface moves to the second surface and forms bubbles.

Optionally, the pressure regulator is slightly elevated relative to the ink outlet location.

Optionally, the porous member is a membrane.

Optionally, the porous member is a mesh.

Optionally, the porous member is an open cell foam block.

5 Optionally, the threshold pressure is greater than 10mm.H₂O.

Optionally, the printhead is a pagewidth printhead and the threshold pressure is greater than 300mm.H₂O.

Optionally, the porous member is a pair of opposed membranes spaced from each other such that ink is retained between them if they are placed in an air space within the reservoir.

10 Optionally, the porous member is a membrane in a side wall of the reservoir, the membrane being positioned closely adjacent an internal wall such that ink is held between the wall and the membrane by capillary action when the ink level drops below the membrane.

Optionally, the internal wall is approximately 1 mm away from the membrane.

Optionally, the internal wall is made of a hydrophilic material.

15 Optionally, the ink reservoir further comprises a wicking material between the wall and the membrane to enhance capillary action.

Optionally, the wicking material is fabric, mesh or particulate material.

Optionally, the ink reservoir further comprises a filter over the outlet.

20 Optionally, the reservoir is a removeable ink cartridge for installation into an inkjet printer.

Optionally, the ambient pressure is atmosphere.

Optionally, the air inlet further comprises a tortuous air flow path from atmosphere to the pressure regulator.

25 Brief Description of the Drawings

Optional embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic side section of a pressure regulator according to the present invention having a needle-like bubble outlet;

30 Figure 2 is magnified view of the bubble outlet shown in Figure 1;

Figure 3A is a schematic perspective view of a slot-shaped bubble outlet;

Figure 3B shows the bubble outlet of Figure 3A partially blocked with debris;

Figure 4 is a schematic side section of a pressure regulator according the present invention having a slot-shaped bubble outlet;

35 Figure 5 is a magnified view of the bubble outlet shown in Figure 4;

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Figure 6 is an exploded perspective view of the air intake plate shown in Figure 4;

Figure 7 is a perspective view of an alternative air intake plate with protective moat;

Figure 8 is an exploded perspective view of an alternative tri-layered air intake plate;

Figure 9 is a schematic side section of the pressure regulator shown in Figure 4 connected
5 to a separate ink cartridge;

Figure 10 is a schematic side section of a pressure regulator with bubble outlet positioned
for bubbling air bubbles into a headspace;

Figure 11 is a magnified view of the bubble outlet shown in Figure 10 during bubble
formation;

10 Figure 12 is a magnified view of the bubble outlet shown in Figure 10 during an idle
period;

Figure 13 is a magnified view of the bubble outlet shown in Figure 10 during an instant
when the headspace is venting after having been positively pressurized;

Figure 14 is an exploded perspective view of the air intake plate shown in Figure 10;

15 Figure 15 shows schematically an ink supply according to the present invention;

Figure 16 is a schematic perspective view of an ink cartridge and pressure regulator
configured for minimal ink leakages;

Figure 17 is a schematic section view of an alternative ink cartridge according to the
present invention;

20 Figures 18 and 19 are partial schematic section views of alternatives to the ink cartridge
shown in Figure 17;

Figures 20 and 21 are schematic section views of a double membrane cartridge in
different orientations;

Figure 22 is a schematic section view of a cartridge with single membrane and
25 hydrophilic internal wall;

Figure 23 is a partial schematic section view of an alternative to cartridge shown in
Figure 22; and,

Figure 24 is a schematic sectioned perspective of a cartridge according to the invention
showing the possible configuration of the tortuous air inlet flow path; and

30 Figure 25 is a schematic side section of a prior art ink cartridge incorporating a foam
insert.

Detailed Description of Optional Embodiments

35 Pressure Regulator With Circular Bubble Outlet

Figure 1 shows the simplest form of the present invention, for the purposes of explaining the basic operating principle of the pressure regulator. In Figure 1, there is shown a pressure regulator 100 comprising an ink chamber 101 having an ink outlet 102 and air inlet 103. The ink chamber 101 is otherwise sealed. The ink outlet 102 is for supplying ink 104 to a printhead 105 via an ink line 106. A bubble outlet 107 is connected to the air inlet 103 via an air channel 108.

When ink 104 is drawn from the ink chamber 101 by the printhead 105, the displaced volume of ink must be balanced with an equivalent volume of air, which is drawn into the chamber via the air inlet 103. The bubble outlet 107, which is positioned below the level of ink, ensures that the air enters the chamber 101 in the form of air bubbles 109. The dimensions of the bubble outlet 107 determine the size of the air bubbles 109 entering the chamber 101.

As shown in Figure 2, the air channel 108 takes the form of a simple cylindrical channel, so that the bubble outlet 107 is defined by a circular opening at one end of the cylindrical channel. Accordingly, any air passing through the channel must at some point be bounded by a liquid surface with radius of curvature not greater than the internal radius of the channel.

During printing, the nozzles on the printhead 105 effectively act as a pump, drawing ink from the ink chamber 101 with each drop ejection. If the ink chamber were left freely open to atmosphere with an air vent (as in some prior art ink cartridges), the hydrostatic ink pressure of the ink supplied to the printhead would be simply be determined by the elevation of the ink reservoir above or below the printhead. However, in the ink chamber 101, each time a microscopic volume of ink is drawn from the chamber 101, it must overcome the pressure inside an air bubble 109 forming at the bubble outlet 107. Once the pumping effect of the nozzles generates sufficient pressure to match the pressure inside the air bubble 109 forming at the bubble outlet 107, then the air bubble can escape into the reservoir of ink 104 and ink can flow from the chamber 101 via the ink outlet 102.

Therefore, the air bubbles 109 forming at the bubble outlet 107 provide a back pressure against the pumping effect of the printhead nozzles. In other words, the effect of the bubble outlet 107 is to generate a negative hydrostatic ink pressure in the ink supply system.

The pressure inside the spherical air bubbles 109 is determined by the well-known Laplace equation:

$$\Delta P = 2\gamma/r$$

where:

ΔP is the difference in pressure between the inside of the air bubble and the ink;

r is the radius of the air bubble; and

γ is the surface tension of the ink-air interface.

The size of the air bubbles 109 can be varied by varying the dimensions of the bubble outlet 107. Therefore, the dimensions of the bubble outlet 107 provides a means of establishing a predetermined negative hydrostatic pressure of ink supplied to the printhead 105. Smaller bubble outlet dimensions provide a larger negative hydrostatic ink pressure by virtue of generating smaller air bubbles having a higher Laplace pressure.

In the pressure regulator 100 described above, the air channel 108 is a small-bored cylinder (*e.g.* hypodermic needle) having a circular opening defining the bubble outlet 107. However, a significant problem with this design is that the circular bubble outlet 107 has a very small area (of the order of about 0.01 mm²) and is susceptible to blockages by contaminants in the ink. It would be desirable to increase the area of the bubble outlet 107 so that it is more robust, even if there are contaminants in the ink.

Pressure Regulator With Slot-Shaped Bubble Outlet

As shown in Figure 3A, an improved design of bubble outlet 107 uses a slot 110, as opposed to a circular opening. The slot has a length dimension L and a width dimension W. The air bubbles 109 exiting the slot typically have a cylindrical front extending across the length of the slot. As explained below, the curvature of the air bubbles 109 exiting the slot and, hence, the Laplace pressure of the air bubbles, is determined primarily by the width dimension.

For non-spherical bubbles, the Laplace pressure is given by the expression:

$$\Delta P = \gamma/r_1 + \gamma/r_2$$

where:

ΔP is the difference in pressure between the inside of the air bubble and the ink;

r_1 is the radius of a width dimension of the air bubble;

r_2 is the radius of a length dimension of the air bubble;

γ is the surface tension of the ink-air interface.

In practice, the length of the slot is much greater than the width ($r_2 \gg r_1$), and so the Laplace pressure of the air bubbles exiting the slot with a cylindrical front becomes:

$$\Delta P = \gamma/r_1 \text{ or } 2\gamma/W \text{ (since } W = 2r_1\text{)}$$

It will therefore be appreciated that the width of the slot 110 is the only critical dimension controlling the Laplace pressure of the air bubbles 109 exiting the slot.

Figure 3B shows a hypothetical scenario where a piece of debris 111 has become stuck to the slot 110. However, unlike the case of a circular opening, the slot 110 is still able to control the critical curvature of bubbles exiting the slot. An air bubble 109 having a cylindrical front can still exit the slot 110 as shown in Figure 3B. Thus, the slot 110 provides a more robust design for the bubble outlet 107, whilst still maintaining excellent control of the hydrostatic ink pressure.

In the embodiments discussed so far, the dimensions of the air channel 108 mirror the dimensions of the bubble outlet 107. This is not an essential feature of the regulator and, in fact, may adversely affect the efficacy of the regulator, particularly at high flow rates. The inherent viscosity of air can cause a significant flow resistance or hydraulic drag in the air channel 108. According to Pouiseille's equation, flow rate has an r^4 relationship with pipe radius r . Hence, the problem of flow resistance is exacerbated in channels having very small radii.

In the present invention, a critical dimension of the bubble outlet 107 is optionally less than about 200 microns, or optionally less than about 150 microns, or optionally less than about 100 microns, or optionally less than about 75 microns or optionally less than about 50 microns. Optionally, the critical dimension of the bubble outlet may be in the range of 10 to 50 microns or 15 to 40 microns. By "critical dimension" it is meant the dimension of the bubble outlet determining the curvature and, hence, the Laplace pressure of the air bubbles.

Such dimensions are necessary to provide the desired negative hydrostatic ink pressure, which is optionally at least 10 mmH₂O, or optionally at least 30 mmH₂O, or optionally at least 50 mmH₂O for a photo-sized printhead. For an A4-sized printhead, the desired negative hydrostatic ink pressure is optionally at least 100 mmH₂O, or optionally at least 200 mmH₂O, or optionally at least 300 mmH₂O. Optionally, the negative hydrostatic pressure may be in the range of 100 to 500 mmH₂O or 150 to 450 mmH₂O.

The air channel 108, having a width of, say, less than 200 microns, generates significant flow resistance for air entering the channel. If air is unable to pass through the channel 108 at the same flow rate as ink is supplied to the printhead 105, then a catastrophic deprime of the printhead would result at high print-speeds.

Accordingly, it is desirable to configure the air channel 108 so that each cross-sectional dimension of the air channel is larger than the critical dimension of the bubble outlet 107. So, for the slot-shaped bubble outlet 107 shown in Figure 3A, the air channel 108 should optionally have each cross-sectional dimension greater than the width W of the slot 110.

However, it is important that the volume of the air channel 108 is not too large. When the printhead 105 is idle, ink may rise up the air channel 108 by capillary action. This volume of ink must be pulled through the air channel 108 by the printhead 105 before air bubbles 109 are drawn into the ink chamber 101 and the optimal hydrostatic ink pressure for printing is reached.

Hence, a volume of ink drawn into the air channel 108 by capillary action during idle periods will be wasted, since it cannot be printed with optimal print quality.

The capillary volume of ink increases with the radius of the air channel. Accordingly, the cross-sectional dimensions (*e.g.* radius) of the air channel 108 should optionally not be so large that the maximum capillary volume exceeds about 0.1 mL of ink, which is effectively a dead volume of ink. Optionally, the maximum capillary volume of ink in the air channel is less than about 0.08 mL, or optionally less than about 0.05 mL, or optionally less than about 0.03mL.

Figure 4 shows an alternative ink pressure regulator 200 having a bubble outlet 207 and air channel 208 with the abovementioned design considerations taken into account. The pressure regulator 200 comprises an ink chamber 201 having an ink outlet 102. One sidewall of the ink chamber 201 is defined by a laminated air intake plate 210 comprising first and second planar layers 211 and 212. The first and second layers 211 and 212 have respective first and second faces 221 and 222 which cooperate to define the air inlet 203, the air channel 208 and the bubble outlet 207. The air inlet 203 may optionally comprise an air filter (not shown) for filtering particulates from air drawn into the ink chamber 201.

The ink chamber 201 also comprises a one-way pressure release valve 219, which is normally closed during operation of the pressure regulator 200. The valve 219 is configured to release any positive pressure in a headspace 240 above the ink 104, which may, for example, result from thermal expansion of a volume of air trapped in the headspace during typical day/night temperature fluctuations. A positive pressure in the headspace 240 is undesirable because it forces ink up the air channel 208 and out of the air inlet 203, leading to appreciable ink losses from the chamber 201.

Referring to Figure 6, the first layer 211 of the air intake plate 210 has an air inlet opening 213 defined therethrough and an elongate recess 214 in the form of a groove defined in the first face 221. The elongate recess 214 extends from the air inlet opening 213 to a recessed terminus region. The recessed terminus region comprises a circular recess 216 which has a relatively shallow depth compared to the elongate recess 214. Still referring to Figure 6, the second layer 212 has a bubble vent opening 217 defined therethrough. As will be appreciated from Figures 4 and 6, when the first and second faces 221 and 222 are laminated together, the recesses and openings cooperate to define the air inlet 203, the air channel 208 and the bubble outlet 207.

Figure 5 shows in detail a bubble outlet region 220 of the air intake plate 210. The circular recess 216, being shallower than the elongate recess 214, defines a constriction 218 in the air channel 108. This constriction 218, defined by the depth of the circular recess 216 in the first face 221, defines a critical width dimension for the bubble outlet 207. The bubble outlet 207

therefore takes the form of an annular slot with a length of the slot being defined by a circumference of the bubble vent opening 217 in the second layer 212.

An advantage of having an annular slot is that it maximizes the length of the slot, thereby improving the robustness of the bubble outlet 207 to particulate contamination. An advantage of having a relatively deep elongate recess 214 is that it minimizes flow resistance in the air channel 108 defined by cooperation of the recess 214 and the second face 222. Typically, the elongate recess 214 has a depth in the range of 0.2 to 1 mm or 0.2 to 0.5 mm, and a width in the range of 0.5 to 2 mm or 0.7 to 1.3 mm.

Still referring to Figure 5, it can be seen that inner faces 231 of the bubble vent opening 217 are beveled so as to optimize escape of bubbles from the bubble outlet 207.

Referring to Figure 7, the first layer 211 of the air intake plate 210 may have a moat 230 defined therein. The moat 230 surrounds the features defined in the first layer 211 and, importantly, protects the elongate recess 214 and circular recess 216 from any adhesive during the lamination process. The wicking of any excess adhesive between the first and second faces 221 and 222 is arrested by the moat 230 as capillary action can only transport liquids into of structures ever decreasing dimensions, and any path across the moat includes a region of increasing dimension. This prevents blocking of the air inlet channel 208 or the bubble outlet opening 207, which are defined by lamination of the two layers. Hence, the moat 230 is a feature, which facilitates manufacture of the air intake plate 210.

Of course, it will be appreciated that the air intake plate may take many different forms and may, for example, be defined by cooperation of more than two laminated layers. Figure 8 shows an air intake plate 250 defined by cooperation of three layers. A first layer 251 has an air inlet opening 252 defined therethrough; a second layer 253 has a bubble vent opening 254 defined therethrough; and a third film layer 255 is sandwiched between the first and second layers. The film layer 255 has an air channel opening 256 defined therethrough, so that when the three layers are laminated together a fluidic path is defined from an air inlet to the bubble vent. The thickness of the film layer 255 defines the depth of the air channel and the critical dimension of the bubble outlet at the terminus of the air channel.

Tables 1 to 4 below show measured hydrostatic ink pressures for the pressure regulator 200 shown in Figures 4 to 6. Four pressure regulators were constructed having different critical dimensions of the bubble outlet 207. Dynamic pressure measurements were made at various flow rates and static pressure measurements were made by stopping the flow of ink. The dynamic pressure loss is the difference between the dynamic regulating pressure and the static regulating pressure.

Table 1 – 35 micron bubble outlet

Flow Rate (ml/sec)	Dynamic Regulating Pressure (mm H ₂ O)	Static Regulating Pressure (mm H ₂ O)	Dynamic Pressure Loss (mm H ₂ O)
0.05	-203	-178	-25
0.04	-196	-175	-21
0.03	-194	-178	-16
0.02	-189	-173	-16
0.01	-185	-175	-10
0.005	-172	-165	-7
		-174 (Average)	

Table 2 – 70 micron bubble outlet

Flow Rate (ml/sec)	Dynamic Regulating Pressure (mm H ₂ O)	Static Regulating Pressure (mm H ₂ O)	Dynamic Pressure Loss (mm H ₂ O)
0.05	-110	-84	-26
0.04	-104	-79	-25
0.03	-100	-84	-16
0.02	-91	-79	-12
0.01	-84	-83	-1
0.005	-80	-76	-4
		-81 (Average)	

5

Table 3 – 105 micron bubble outlet

Flow Rate (ml/sec)	Dynamic Regulating Pressure (mm H ₂ O)	Static Regulating Pressure (mm H ₂ O)	Dynamic Pressure Loss (mm H ₂ O)
0.05	-65	-38	-27
0.04	-65	-44	-21
0.03	-56	-40	-16
0.02	-51	-38	-13
0.01	-43	-38	-5
0.005	-38	-36	-2
		-39 (Average)	

Table 4 – 140 micron bubble outlet

Flow Rate (ml/sec)	Dynamic Regulating Pressure (mm H ₂ O)	Static Regulating Pressure (mm H ₂ O)	Dynamic Pressure Loss (mm H ₂ O)
0.05	-60	-32	-28
0.04	-56	-34	-22
0.03	-54	-36	-18
0.02	-51	-37	-14
0.01	-38	-34	-4
0.005	-34	-31	-3
		-34 (Average)	

5 Excellent control of ink pressure was achievable simply by varying the dimensions of the bubble outlet.

Moreover, the pressure measurements confirmed that the air bubbles were being generated in accordance with the Laplace equation. The average static regulating pressures were found to obey the equation:

10

$$P = -0.0067/W + 18.3$$

where:

P is the average static regulating pressure in millimeters of water head;

15 W is the width of the bubble outlet in micron; and

18.3 is an offset pressure due to the level of ink in the chamber.

20 Substituting the first term into the Laplace equation, the surface tension γ of the ink was calculated as 33.5 mN/m. Independent surface tension measurements of the ink correlated well with this calculated figure.

Ink Cartridge Comprising Pressure Regulator

25 As shown in Figure 4, the pressure regulator 200 comprises an ink chamber 201, which defines an ink reservoir for the printhead. Due to the simplicity and low-cost manufacture of the pressure regulator 200, it may be constructed as a replaceable ink cartridge for an inkjet printer. Hence, each time the ink cartridge is replaced, the pressure regulator is replaced. An advantage

of this design is that long-term fouling of the pressure regulator 200 is avoided, because it is periodically replaced during the lifetime of the printer.

Replaceable Ink Cartridge Connected to Pressure Regulator

5 In an alternative embodiment, the pressure regulator may be a permanent component of a printer. In this alternative embodiment, the pressure regulator is configured for connection to a replaceable ink cartridge. Hence, in the embodiment shown in Figure 9, the pressure regulator 200 is connected to a replaceable ink cartridge 280 via a pair of connectors. An ink connector 281 connects an ink supply port 282 of the ink cartridge 280 with an ink inlet port 283 of the ink chamber 201. The ink supply port 282 and corresponding ink inlet port 283 are positioned
10 towards a base of the ink cartridge 280 and ink chamber 201 respectively, to maximize usage of ink 104 stored in the cartridge.

A pressure-equalizing connector 285 is positioned to equalize pressure in the headspace 240 of the ink chamber 201 and a headspace 241 of the ink cartridge 280. Corresponding
15 pressure-equalizing ports 286 and 287 are positioned towards a roof of the ink chamber 201 and ink cartridge 280, respectively.

When the ink cartridge 280 is empty, it is disconnected from the ink connector 281 and the pressure-equalizing connector 285, and removed from the printer. A new ink cartridge can then be installed in the printer by the reverse process. Although only shown schematically in
20 Figure 9, it will be readily appreciated that the ink cartridge 280 may have suitable connection ports 282 and 287, which are configured for sealing engagement with the ink connector 281 and pressure-equalizing connector 285, respectively, when the ink cartridge is installed in the printer. Connection ports suitable for such sealing engagement are well known in the art.

As shown in Figure 9 the ink inlet port 283 and pressure-equalizing port 286 are defined
25 in a sidewall of the ink chamber 201 which is opposite to the air intake plate 210. However, the ports 283 and 286, may of course be defined in the air intake plate 210 so as to simplify construction of the pressure regulator 200.

Bubble Outlet Positioned in Headspace

30 In the pressure regulator described in Figure 4, the bubble outlet 207 is positioned so as to bubble air bubbles 209 into a body of ink 104 contained in the ink chamber 201. Typically, the bubble outlet 207 is positioned towards a base of the chamber 201 in order to maximize ink usage at optimal hydrostatic pressure, with the air inlet 203 being positioned towards a roof of the chamber. A problem with this arrangement is that ink 104 contained in the chamber 201 can
35 easily escape up the air channel 208 and out of the air inlet 203 during idle periods as a

consequence of temperature fluctuations, whereby heating air in the headspace 240 increase the headspace pressure and forces ink up the air channel 208 and out of the air inlet 203. Such temperature fluctuations are unavoidable and can result in significant ink wastage.

As already alluded to above, one means of addressing this problem is by incorporating a pressure-release valve 219 into the ink chamber 201. This valve 219 is configured to release any positive pressure in the headspace 240. However, valves of this type add significantly to the cost and complexity of the pressure regulator. Hence, the pressure-release valve 219 makes the pressure regulator 200 less amenable for incorporation into a disposable ink cartridge.

It would therefore be desirable to provide an ink pressure regulator, which does waste quantities of ink during temperature fluctuations and does not require a pressure-release valve, and which is therefore more amenable for incorporation into a disposable ink cartridge.

Figure 10 shows an ink pressure regulator 300, which meets the above-mentioned criteria. The ink pressure regulator is similar in design to that shown in Figure 4 and still relies on controlling the Laplace pressure of air bubbles entering the ink chamber. However, rather than air bubbles bubbling into a body of ink contained in the chamber, the air bubbles enter the chamber via the headspace above the body of the ink. This design enables any excess pressure in the headspace to vent through the air inlet during idle periods, as will be explained in more detail below.

Referring to Figure 10, the ink pressure regulator 300 comprises an ink chamber 301 having an ink outlet 302. One sidewall of the ink chamber 301 is defined by a laminated air intake plate 310 comprising first and second planar layers 311 and 312, which cooperate to define an air inlet 303, a bubble outlet 307, a bubble vent 305, an air channel 308, a capillary channel 315 and a capillary inlet 316. The bubble outlet 307 and bubble vent 305 are positioned above the level of ink in the chamber 301 so that air bubbles 309 enter the headspace 340 of the chamber via the bubble vent. The bubble outlet 307 is connected to the air inlet 303 via the air channel 308. The bubble outlet 307 is generally slot-shaped and is critically dimensioned to control the Laplace pressure of air bubbles 309 as ink is drawn from the ink outlet 302.

However, in contrast to previous embodiments, the air bubbles 309 are formed by air breaking through a meniscus of ink pinned across the bubble outlet 307 and adjacent bubble vent 305, as shown more clearly in Figure 11. The so-formed air bubbles 309 emerging from the bubble outlet 307 escape through the bubble vent 305 and into the headspace 340 of the ink chamber 301. Since the air must break through an ink meniscus, the air bubbles 309 are defined by an air cavity trapped inside a film of ink, rather than a whole body of ink. Regardless, the same Laplacian pressure control is still achievable, as described above.

The capillary inlet 316 provides fluid communication between the body of ink 104 in the chamber 301 and the capillary channel 315 defined between the two layers 311 and 312. The capillary channel 315 is configured to provide sufficient capillary pressure such that a column of ink 304 rises up the channel at least as high as the bubble outlet 307, thereby ensuring formation of air bubbles 309 by air breaking through a meniscus of ink. The capillary pressure is sufficiently high to re-form a meniscus across the bubble outlet 307 and bubble vent 305 after each air bubble 309 has vented into the headspace 340.

The bubble vent 305 is dimensioned such that the column of ink 304 has a meniscus pinned across the vent by surface tension, as shown in Figures 11 and 12. However, the bubble vent 305 should not be so small that it is susceptible to blockage by particulates. A bubble vent 305 having a diameter of the order of about 1 mm has been found to be suitable.

In practice, during idle periods when there is no significant pressure in the headspace 340 of the ink chamber 301, the column of ink 304 rises above the bubble outlet 307 and typically pins across the entrance to the air channel 308, as shown in Figure 12.

A significant advantage of the present embodiment is demonstrated in Figure 13. Figure 13 shows the situation where a positive pressure is built up in the headspace 340 during an idle period. The pressurized air forces any ink from the air channel 308 and the air escapes from the chamber 301 via the air inlet 303. Accordingly, only minute quantities of ink escape from the chamber 301 when the headspace 340 becomes pressurized due to temperature rises.

A further advantage of the present embodiment is that the air channel 308 is relatively short, thereby minimizing any flow resistance in the air channel and allowing high flow rates of ink from the chamber 301 with optimal pressure control. Any flow resistance problems (such as those described above in connection with the embodiment shown in Figure 4) are therefore avoided.

Ink Supply System

It will be readily appreciated that the pressure regulators described herein may be incorporated into an ink supply system for an inkjet printer. The Applicant has developed previously a circulatory ink supply system comprising a pair of peristaltic pumps. The pumps are configurable for priming, depriming and printhead purging operations. This ink supply system is described in US Application No. 11/415,819, the contents of which is herein incorporated by reference.

Figure 15 shows schematically a circulatory ink supply system incorporating an ink pressure regulator according to the present invention. As shown in Figure 15, the ink pressure regulator 300 is connected to a replaceable ink cartridge 280 via an ink connector 281 and a

pressure-equalizing connector 285. However, it will of course be appreciated that the ink pressure regulator 300 may be incorporated into a replaceable ink cartridge, as already described above.

The ink supply system comprises a printhead 105 connected to an upstream pump 150 and a downstream pump 151. The ink cartridge 280 and ink pressure regulator 300 complete the circuit.

During normal printing, the upstream pump 150 is left open and the ink pressure regulator 300 controls the hydrostatic ink pressure in the system.

During storage, both pumps 150 and 151 are shut off to isolate the printhead 105.

Priming of the printhead 105 can be achieved by pumping ink to the printhead using the upstream pump 150. Similarly, depriming of the printhead 105 can be achieved by pumping ink from the printhead back to the ink cartridge 280 using downstream pump 151. The ink cartridge 280 typically comprises a filter for filtering any ink returned to it by the downstream pump 151.

The printhead 105 may also be purged with air supplied from air inlet 152 by opening check valve 153 and pumping the downstream pump 151 in a reverse direction. The air purge generates a froth or foam of ink at the printhead face, which is used for maintenance operations, as described in our copending US Application Nos. 11/495,815, 11/495,816 and 11/495,817, the contents of which are herein incorporated by reference.

Minimizing Ink Leakages

From the foregoing, it will be appreciated that the pressure regulator and/or ink cartridge are required to have a plurality of apertures or ports (*e.g.* bubble outlet, pressure-release valve, ink return inlet *etc.*). Each of these represents a potential leakage point for ink, especially if the pressure regulator and/or ink cartridge is tipped. Any leakage of ink, other than in the supply of ink to the printhead, is clearly undesirable.

Accordingly, the pressure regulator and/or ink cartridge should be designed in such a way as to minimize undesirable leakages via, for example, the bubble outlet. Certain design criteria are immutable: if the bubble outlet bubbles air into the ink, then it must be positioned towards the base of the ink chamber; the ink outlet must also be positioned towards the base of the ink chamber; the pressure-release outlet must be positioned towards a roof of the ink chamber.

Figure 16 shows schematically a combined pressure regulator/ink cartridge system of the type shown in Figure 9, which is suitable for use in the ink supply system shown in Figure 15. The system comprises an ink chamber 201, an ink cartridge 280 and an air intake plate 210. In use, the air intake plate 210 is fixed to the ink chamber 201 and the ink cartridge 280 is removably engaged with the air intake plate.

Ink is supplied from ink chamber 201 via ink outlet 202 and ink is returned to the ink cartridge 280 via ink return inlet 290, which feeds ink to an ink return opening 291 in the air intake plate 210 and into a return conduit 292 extending longitudinally in the headspace 241 of the ink cartridge 280. A pressure-equalizing conduit 293 adjacent the ink return conduit 292 communicates with the headspace 241 in the ink chamber via pressure-equalizing ports 286 and 287. Ink is fed from the ink cartridge 280 to the ink chamber 201 via an ink outlet port 282 communicating with a corresponding ink inlet port 283 in the ink chamber. An ink supply conduit 294 extends longitudinally along the base of the ink cartridge and supplies ink to the ink outlet port 282. The use of longitudinal conduits 294, 293 and 292 in the ink cartridge minimizes ink leakages when the cartridge is tipped.

The air intake plate 210 comprises the bubble outlet 207 in a first corner and the pressure-release valve 219 in an opposite second corner. In order to minimize ink leakages via the bubble outlet 207, the air inlet 203 is positioned at the second corner and the air channel 208 is bent towards the second corner. Likewise, a pressure-release outlet 296 is positioned at the first corner and a pressure-release channel 297 communicating with the pressure-release valve 219 is bent towards the first corner.

Alternative Bubble Point Pressure Regulation

Figures 17-24 show alternative embodiments of the present invention employing bubble point pressure regulation.

In Figure 17, a membrane 1016 is positioned near a floor 1012 of a cartridge 1001. The hydrostatic pressure is set by the bubble point of the membrane 1016. As the skilled person will be aware, the bubble point of porous material is the gas pressure that needs to be applied to one side to force liquid from the largest wetted pore on the immersed side.

When the cartridge is installed, the nozzles can fire into a blotter or the like to lower the pressure in the cartridge. When the pressure at a control level 1013 drops to the bubble point, small bubbles 1015 will form on the internal surface of the membrane 1016 and rise into the head space 1014. This slightly increases the pressure in the cartridge and the bubbles 1015 stop forming on the membrane 1016. Once bubbles start forming on the inside of the membrane 1016, the hydrostatic pressure at control level 1013 is known. Likewise, if a different pressure regulator is used, once the printhead has initially established the required negative pressure, the control level 1013 keeps a constant hydrostatic pressure (equal to the regulator threshold pressure).

As ink is consumed by the printhead, the negative pressure at the control level 1013 (and therefore at the outlet 1003) will remain effectively constant. Of course, if the ink level drops

below the control level 1013, the membrane 1016 is no longer covered by ink and the cartridge vents to atmosphere. To avoid this, the printer should stop printing before the ink level reaches the control level. However, there are methods for keeping the membrane wet when it is exposed to the air of the headspace 1014. These are discussed in detail below.

5 The embodiment shown in Figure 18 uses a small block of dense open cell foam 1017 instead of the membrane 1016 of the previous embodiment. The bubble point of the foam sets the hydrostatic pressure at the control level 1013 and the cartridge 1001 operates in way as the membrane embodiment.

10 The foam is denser than that used in some prior art cartridges so that the bubble point is high enough to generate the required negative pressure. However, it absorbs some ink and will stay wet (temporarily at least) if it is exposed to the air in the headspace. It will be appreciated that the foam can be easily exposed to the air in the cartridge when the printhead is moved or transported.

15 In these embodiments of the invention, an air inlet 1007 has an air maze structure. If ink happens to permeate through the porous material (membrane 1016 in Fig. 17 and foam element 1017 in Fig. 18), it does not leak to the exterior of the cartridge. The ink outlet 1003 may have a filter 1023 covering to stop air bubbles from getting to the nozzles. However, the filter should not create a significant flow restriction for the ink. The outlet 1003 is not obstructed by a foam insert and so can supply ink at a high flow rate. As previously discussed, high speed pagewidth
20 printheads require high ink flow rates.

 The embodiment shown in Figure 19 is even simpler in the sense that it does not need an inlet air maze 1007 or internal passage covered by a membrane, mesh or foam element. Instead, a pressure relief valve 1018 in the wall of the cartridge opens at a threshold pressure which sets the hydrostatic pressure at the control level 1013. Furthermore, if the internal side of the valve is
25 exposed to the air in the cartridge, it does not vent to atmosphere like a dry membrane or foam. It opens when the pressure difference reaches the specified threshold and so maintains a negative pressure in the cartridge even after the ink has dropped below the control level 1013 (although the pressure at the outlet 1003 will slightly decrease as the level drops below the valve 1018).

 The pressure relief valve 1018 can be a simple ball-type check valve that is biased into its
30 seat to keep the unit cost to a minimum. It is unlikely to be cheaper than a membrane or foam element however it does provide a convenient means for initially charging the cartridges with ink and allows the cartridge to be very compact.

 Returning to the membrane embodiment, Figures 20 and 21 show a solution to the problem of membrane drying discussed above. Instead of a single membrane, a pair of
35 membranes 1019 and 1020 is used. The membranes are closely spaced so that the ink between

them does not drain out if the cartridge is positioned such that they are in the air of the headspace 1014 (see Fig. 21). As long as the internal surface of the outer membrane 1019 stays wet, the cartridge 1001 will not vent to atmosphere.

Figures 22 and 23 show another version of the membrane embodiment that also avoids the membrane drying problem. The cartridge of Figure 22 has a membrane 1016 in the wall of the cartridge 1001. Closely adjacent the internal surface of the membrane 1016 is an internal wall 1021. For water based inks, the internal wall 1021 should be approximately 1 mm away from the membrane. The internal wall 1021 is made of a hydrophilic material so that ink is held between the wall and the membrane 1016 by capillary action when the ink level drops below the membrane. The tiny air bubbles 1015 permeating through the membrane 16 rise up through the ink held the wall 1021 and into the air space 1014.

In Figure 23, wicking material 1022 is placed between the wall 1021 and the membrane 1016 to enhance the capillary action. The wicking material can be fabric, mesh or particulate material. By enhancing the capillary action the ink level can drop further below the membrane before its internal surface dries out. The wicking material also damps any jolts or impacts to the printhead that might otherwise dislodge the ink from between the membrane 1016 and the wall 1021.

Cartridges according to the invention are particularly suited to use with the Applicant's range of pagewidth printheads. These printheads will typically generate 1200mm.H₂O of suction pressure per color which is much higher than that generated by a scanning type printhead. As the present invention uses the printhead to establish negative pressure in the cartridge, a strong suction allows the threshold pressure of the valve of air permeable material to be relatively high, which in turn allows a stronger negative pressure in the cartridge. A stronger negative pressure in the cartridge makes the nozzles less prone to leakage, particularly the lowest nozzles of a pagewidth printhead that is moved from it horizontal orientation. Furthermore, as discussed above, the unobstructed outlets allow a high ink flow rate to the nozzles.

Figure 24 shows how the air inlet maze might work in practice. The container 1008 holds a quantity of ink 1010 and encloses the inlet maze 1026, the air expansion chamber 1027, inlet membrane 1016 and outlet filter 1023. Inlet opening 1025 is open to atmosphere and the outlet 1003 forms a sealed fluid connection with the printhead when the cartridge is installed. The cartridge is filled through a sealable fill hole 1028 in the top wall. The entire container 1008 can be rigid or, parts of the container can be flexible material to lower materials costs. For example the large side walls 1030 and 1031 can be air and ink impermeable film sealed to the periphery of a rigid wall middle section.

The air inlet tube 1026 follows a tortuous path to the membrane 1016. The tortuous path has irregular changes in direction so that any ink seeping into the tube 1026 is very unlikely to leak out of the inlet opening 1025 even if the cartridge is rotated through different orientation during transport. For ink in the lower section of the tube 1026 to reach the opening 1025, the cartridge needs to go through a precise sequence of rotations in different directions. The risk of this happening by chance during transport and handling is negligible.

The air inlet tube 1026 incorporates an air expansion chamber 1027. The cartridge is expected to be exposed to a wide range of temperatures – approximately 35°C. Any ink trapped in the line 1026 can be forced to the opening 1025 by the increased air pressure. The air expansion chamber 1027 is relatively large compared to the tube 1026 and so has more capacity to accommodate an expanding gas.

The inlet membrane 1016 and the associated chamber 1029 is smaller than that of the ink outlet (1023 and 1024 respectively). This accounts for the high rate of ink supply required by the pagewidth inkjet printheads whilst also filtering the ink that leaves through the outlet 1003.

The large diameter filter 1023 and associated chamber 1024 means that the filter surface area is high so that the filter can keep a small pore size to remove all detrimental contaminants, without being an undue flow constriction in the ink supply.

The tortuous air inlet path 1026 and air expansion chamber 1027 effectively prevent ink leakage during transport and handling, with minimal added complexity and cost. The membrane is at the floor of the cartridge so that the negative ink pressure at the outlet 1003 will be the bubble point of the membrane regardless of the amount of ink 1010 that has been consumed. Furthermore, the vast majority of the ink will be consumed before the membrane is exposed and vents the interior to atmosphere. At this point the cartridge needs to be replaced however, only a small amount of ink will remain in the cartridge when it is discarded.

It will, of course, be appreciated that the present invention has been described purely by way of example and that modifications of detail may be made within the scope of the invention, which is defined by the accompanying claims.

CLAIMS

1. An ink pressure regulator for regulating a hydrostatic pressure of ink supplied to an inkjet printhead, said regulator comprising:

5 an ink chamber having an ink outlet for fluid communication with the printhead via an ink line;

an air inlet open to atmosphere;

a bubble outlet for bubbling air bubbles into the chamber, each air bubble comprising an air cavity trapped inside a film or a body of ink; and

10 an air channel connecting the air inlet and the bubble outlet,

wherein said bubble outlet is dimensioned to control a Laplace pressure of air bubbles drawn into said chamber as result of supplying ink to the printhead, thereby regulating a hydrostatic pressure of the ink.

15 2. The pressure regulator of claim 1, wherein said ink chamber is an ink reservoir for a printer.

3. The pressure regulator of claim 1, wherein said ink chamber has an ink inlet port for fluid communication with an ink reservoir.

20

4. The pressure regulator of claim 1, wherein said bubble outlet is defined by any one of the group comprising: an end of the air channel; a porous membrane; a mesh; and an open cell foam block.

25 5. The pressure regulator of claim 1, wherein said bubble outlet is dimensioned such that a hydrostatic pressure of ink in the chamber is at least 100 mm H₂O less than atmospheric pressure.

6. The pressure regulator of claim 1, wherein said bubble outlet is configured as a slot
30 having a length dimension and a width dimension, such that said width dimension controls the Laplace pressure of the air bubbles.

7. The pressure regulator of claim 6, wherein a width dimension of said slot is less than 200 microns.

35

8. The pressure regulator of claim 1, wherein the bubble outlet is positioned for bubbling air bubbles into ink contained in the chamber, each air bubble comprising an air cavity trapped inside a body of ink.
- 5 9. The pressure regulator of claim 1, wherein the bubble outlet is positioned for bubbling air bubbles into a headspace above ink contained in the chamber, each air bubble comprising an air bubble trapped inside a film of ink.
- 10 10. The pressure regulator of claim 9, further comprising a capillary channel in fluid communication with ink contained in the ink chamber, said capillary channel supplying ink from the chamber to the bubble outlet by capillary action.