

INK PRESSURE REGULATOR

Field of the Invention

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.

Cross References to Related Applications

Various methods, systems and apparatus relating to the present invention are disclosed in the following US Patents/ Patent Applications filed by the applicant or assignee of the present invention:

09/517539	6566858	6331946	6246970	6442525	09/517384	09/505951
6374354	09/517608	09/505147	6757832	6334190	6745331	09/517541
10/203559	10/203560	7093139	10/636263	10/636283	10/866608	10/902889
10/902833	10/940653	10/942858	10/727181	10/727162	10/727163	10/727245
7121639	10/727233	10/727280	10/727157	10/727178	7096137	10/727257
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10/727164	10/727161	10/727198	10/727158	10/754536	10/754938	10/727227
10/727160	10/934720	11/212702	11/272491	11/474278	11/488853	11/488841
10/296522	6795215	7070098	09/575109	6805419	6859289	6977751
6398332	6394573	6622923	6747760	6921144	10/884881	7092112
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11/248426	11/478599	11/499749	10/922846	10/922845	10/854521	10/854522
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10/854516	10/854508	10/854507	10/854515	10/854506	10/854505	10/854493
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11/499803	11/601757	11/544764	11/544765	11/544772	11/544773	11/544774
11/544775	11/544776	11/544766	11/544767	11/544771	11/544770	11/544769
11/544777	11/544768	11/544763	10/728804	7128400	7108355	6991322
10/728790	7118197	10/728970	10/728784	10/728783	7077493	6962402

10/728803	10/728780	10/728779	7118198	10/773204	10/773198	10/773199
6830318	10/773201	10/773191	10/773183	7108356	7118202	10/773186
10/773200	10/773185	10/773192	10/773197	10/773203	10/773187	10/773202
10/773188	7118201	7111926	10/773184	7018021	11/060751	11/060805
11/188017	7128402	11/298774	11/329157	11/490041	11/501767	11/499736
11/505935	11/506172	11/505846	11/505857	11/505856	11/524908	11/524938
11/524900	11/524912	11/592999	11/592995	6746105	10/407212	10/407207
10/683064	10/683041	11/097308	11/097309	11/097335	11/097299	11/097310
11/097213	11/210687	11/097212	7147306	11/545509	10/760272	10/760273
7083271	10/760182	7080894	10/760218	7090336	10/760216	10/760233
10/760246	7083257	10/760243	10/760201	10/760185	10/760253	10/760255
10/760209	7118192	10/760194	10/760238	7077505	10/760235	7077504
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10/760227	7108353	7104629	11/446227	11/454904	11/472345	11/474273
11/478594	11/474279	11/482939	11/482950	11/499709	11/592984	11/601668
11/603824	11/601756	11/601672	10/815625	10/815624	10/815628	10/913375
10/913373	10/913374	10/913372	10/913377	10/913378	10/913380	10/913379
10/913376	7122076	10/986402	11/172816	11/172815	11/172814	11/482990
11/482986	11/482985	11/454899	11/583942	11/592990	60/851754	11/003786
11/003616	11/003418	11/003334	11/003600	11/003404	11/003419	11/003700
11/003601	11/003618	11/003615	11/003337	11/003698	11/003420	6984017
11/003699	11/071473	11/003463	11/003701	11/003683	11/003614	11/003702
11/003684	11/003619	11/003617	11/293800	11/293802	11/293801	11/293808
11/293809	11/482975	11/482970	11/482968	11/482972	11/482971	11/482969
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10/760206	10/760267	10/760270	10/760259	10/760271	10/760275	10/760274
7121655	10/760184	10/760195	10/760186	10/760261	7083272	11/501771
11/583874	11/014764	11/014763	11/014748	11/014747	11/014761	11/014760
11/014757	11/014714	11/014713	11/014762	11/014724	11/014723	11/014756
11/014736	11/014759	11/014758	11/014725	11/014739	11/014738	11/014737
11/014726	11/014745	11/014712	11/014715	11/014751	11/014735	11/014734
11/014719	11/014750	11/014749	11/014746	11/014769	11/014729	11/014743
11/014733	11/014754	11/014755	11/014765	11/014766	11/014740	11/014720
11/014753	11/014752	11/014744	11/014741	11/014768	11/014767	11/014718
11/014717	11/014716	11/014732	11/014742	11/097268	11/097185	11/097184
11/293820	11/293813	11/293822	11/293812	11/293821	11/293814	11/293793
11/293842	11/293811	11/293807	11/293806	11/293805	11/293810	09/575197
7079712	09/575123	6825945	09/575165	6813039	6987506	7038797
6980318	6816274	7102772	09/575186	6681045	6728000	09/575145
7088459	09/575181	7068382	7062651	6789194	6789191	6644642
6502614	6622999	6669385	6549935	6987573	6727996	6591884
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09/575162	09/575172	09/575170	7106888	7123239	11/482953	11/482977
6238115	6386535	6398344	6612240	6752549	6805049	6971313
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7056038	6869172	7021843	6988845	6964533	6981809	11/060804
11/065146	11/155544	11/203241	11/206805	11/281421	11/281422	11/482981
11/014721	11/592996	D529952	11/482978	11/482967	11/482966	11/482988
11/482989	11/482982	11/482983	11/482984	11/495818	11/495819	11/482980
11/563684	11/518238	11/518280	11/518244	11/518243	11/518242	11/246707
11/246706	11/246705	11/246708	11/246693	11/246692	11/246696	11/246695
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11/482974	11/482957	11/482987	11/482959	11/482960	11/482961	11/482964
11/482965	11/482976	11/482973	11/495815	11/495816	11/495817	11/124158
11/124196	11/124199	11/124162	11/124202	11/124197	11/124154	11/124198
11/124153	11/124151	11/124160	11/124192	11/124175	11/124163	11/124149
11/124152	11/124173	11/124155	11/124157	11/124174	11/124194	11/124164
11/124200	11/124195	11/124166	11/124150	11/124172	11/124165	11/124186

11/124185	11/124184	11/124182	11/124201	11/124171	11/124181	11/124161
11/124156	11/124191	11/124159	11/124175	11/124188	11/124170	11/124187
11/124189	11/124190	11/124180	11/124193	11/124183	11/124178	11/124177
11/124148	11/124168	11/124167	11/124179	11/124169	11/187976	11/188011
11/188014	11/482979	11/228540	11/228500	11/228501	11/228530	11/228490
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11/228483	11/228521	11/228517	11/228532	11/228513	11/228503	11/228480
11/228535	11/228478	11/228479	11/246687	11/246718	11/246685	11/246686
11/246703	11/246691	11/246711	11/246690	11/246712	11/246717	11/246709
11/246700	11/246701	11/246702	11/246668	11/246697	11/246698	11/246699
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6428147	6416170	6402300	6464340	6612687	6412912	6447099
7090337	11/478585	6913346	10/853336	11/000936	7032998	6994424
7001012	7004568	7040738	11/026136	7131715	11/026125	11/026126
7097285	7083264	7147304	11/450445	11/472294	11/503084	6227652
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6416168	6220694	6257705	6247794	6234610	6247793	6264306
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6239821	6338547	6247796	6557977	6390603	6362843	6293653
6312107	6227653	6234609	6238040	6188415	6227654	6209989
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6260953	6267469	6588882	6742873	6918655	09/835707	6547371
6938989	6598964	6923526	09/835448	6273544	6309048	6420196
6443558	6439689	6378989	6848181	6634735	6299289	6299290
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6457812	10/296434	6428133	11/144778	7080895	11/144844	11/478598
11/599341	IJ69US	IJ70US	IJ71US	IJ72US	IJ73US	IJ74US

IJ75US	10/882774	10/884889	10/922890	10/922875	10/922885	10/922888
10/922882	10/922876	10/922886	10/922877	11/071251	11/071261	11/159193
11/491378	6938992	6994425	6863379	11/015012	7066577	7125103
11/450430	11/545566	6746105	6764166	6652074	10/510093	6682174
6648453	6682176	6998062	6767077	10/760214	10/962413	6988789
11/006733	11/013881	7083261	7070258	11/026046	11/064011	11/064013
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11/442190	11/525857	11/585947	6485123	6425657	6488358	7021746
6712986	6981757	6505912	6439694	6364461	6378990	6425658
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6916082	6786570	10/753478	6848780	6966633	10/728924	6969153
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6890059	10/913325	7125102	7028474	7066575	6986202	7044584
7032992	7140720	11/030964	11/048748	7008041	7011390	7048868
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11/231876	11/298635	11/329167	11/442161	11/442126	11/478588	11/525861
11/583939	11/545504	11/583894	10/882775	6932459	7032997	6998278
7004563	6938994	10/959135	10/959049	10/962415	7077588	6918707
6923583	6953295	6921221	10/992758	11/008115	11/012329	11/084752
11/084753	11/185720	11/177395	7147303	7101020	11/336796	11/442191
11/525860	6945630	6830395	6641255	10/309036	6666543	6669332
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11/454901	11/442134	11/499741	11/525859	6866369	6886918	10/882763
6921150	6913347	11/033122	7093928	11/072518	7086721	11/171428
11/165302	7147307	7111925	11/455132	11/546437	11/584619	

The disclosures of these applications and patents are incorporated herein by reference. Some of the above applications have been identified by their filing docket number, which will be substituted with the corresponding application number, once assigned.

Background of the Invention

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 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 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 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. 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 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 17. 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 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.

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.

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.

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.

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.

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.

In a second 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.

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.

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.

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.

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

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.

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.

In a third 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:

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 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.

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.

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.

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.

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.

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.

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.

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 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:

- 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,

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.

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.

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.

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.

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.

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:

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.

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.

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 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;

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.

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.

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.

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 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 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 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 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 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.

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.

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.

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.

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

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;

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;

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

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 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;

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;

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; and

Figure 17 is a schematic side section of a prior art ink cartridge incorporating a foam insert.

Detailed Description of Optional Embodiments

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 the 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 Poiseuille'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 an 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	Static Regulating	Dynamic Pressure
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	Pressure (mm H ₂ O)	Pressure (mm H ₂ O)	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)	

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)	

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:

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

where:

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

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.

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

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

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 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 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 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 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

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 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.

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:
 - 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 a headspace above ink contained in the chamber, each air bubble comprising an air cavity trapped inside a film of ink; and
 - an air channel connecting the air inlet and the bubble outlet,wherein said bubble outlet is positioned in the headspace of the ink chamber and 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.
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.
4. 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 10 mm H₂O less than atmospheric pressure.
5. The pressure regulator of claim 1, wherein said bubble outlet has a critical dimension controlling the Laplace pressure of the air bubbles exiting the bubble outlet.
6. The pressure regulator of claim 1, wherein 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.
7. The pressure regulator of claim 1, wherein 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.

8. The pressure regulator of claim 7, wherein a width of said slot is less than 200 microns.
9. The pressure regulator of claim 1, 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.
10. The pressure regulator of claim 1, further comprising a bubble vent adjacent said bubble outlet, said bubble vent opening into said headspace.