

FIG. 1

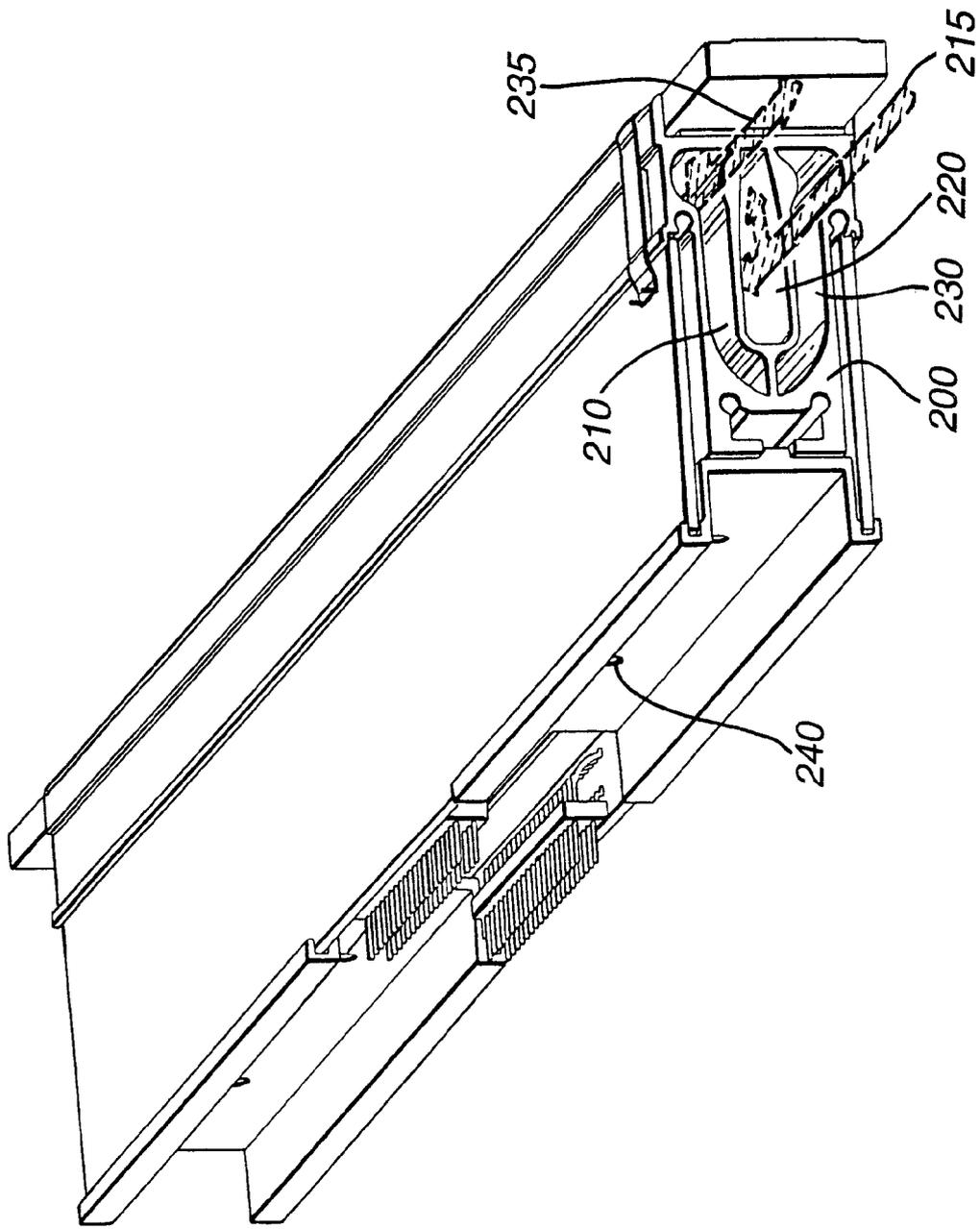


FIG. 2

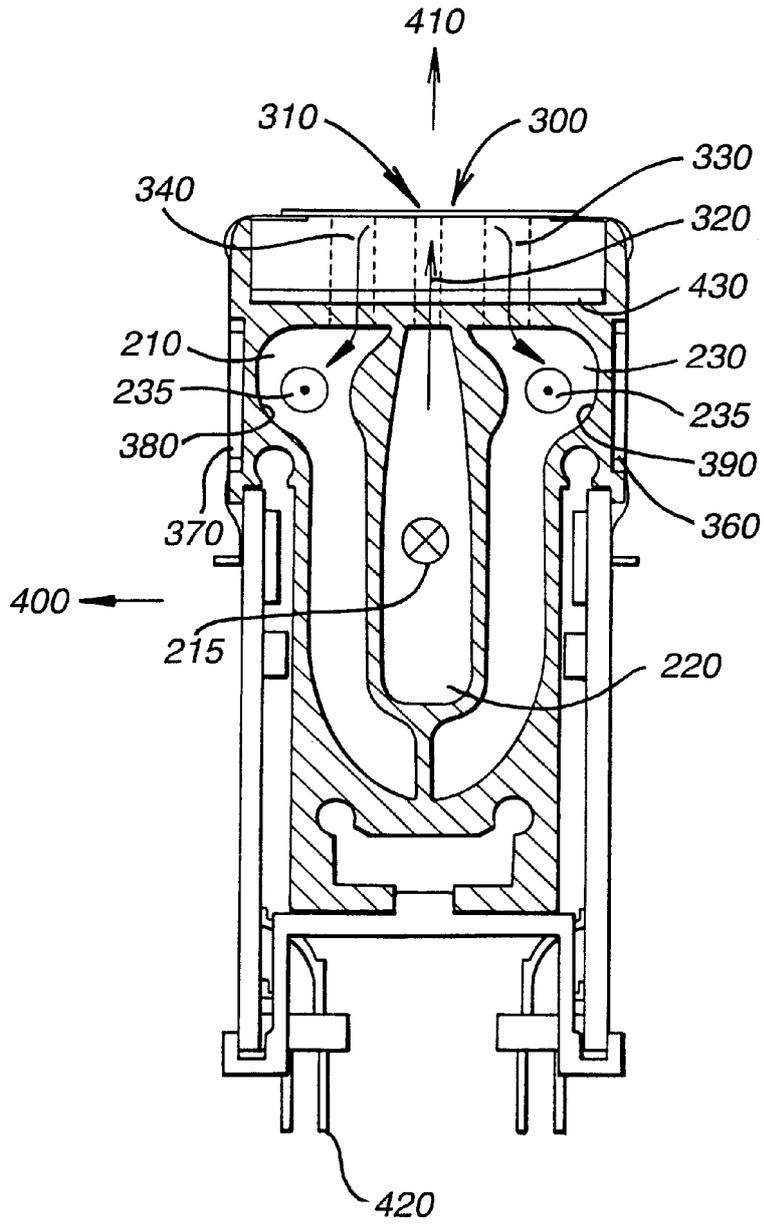


FIG. 3

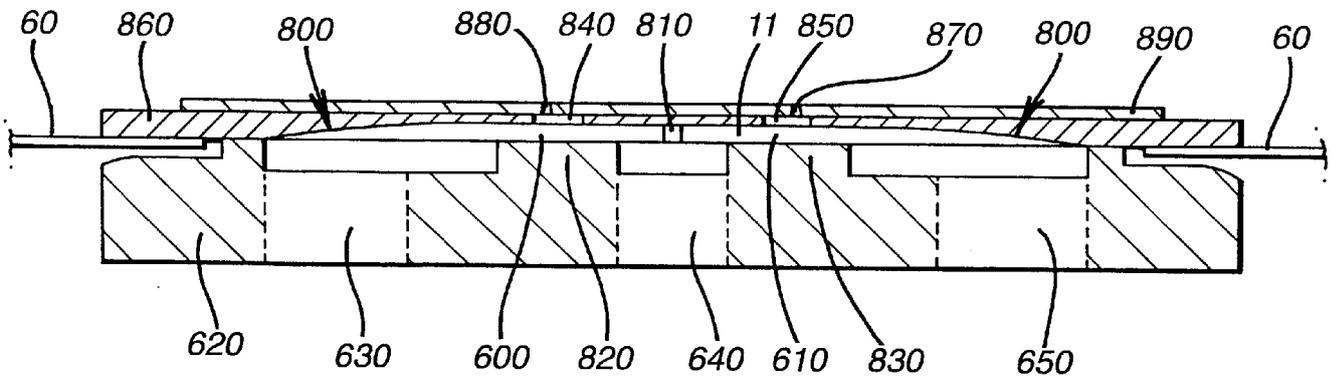


FIG. 4



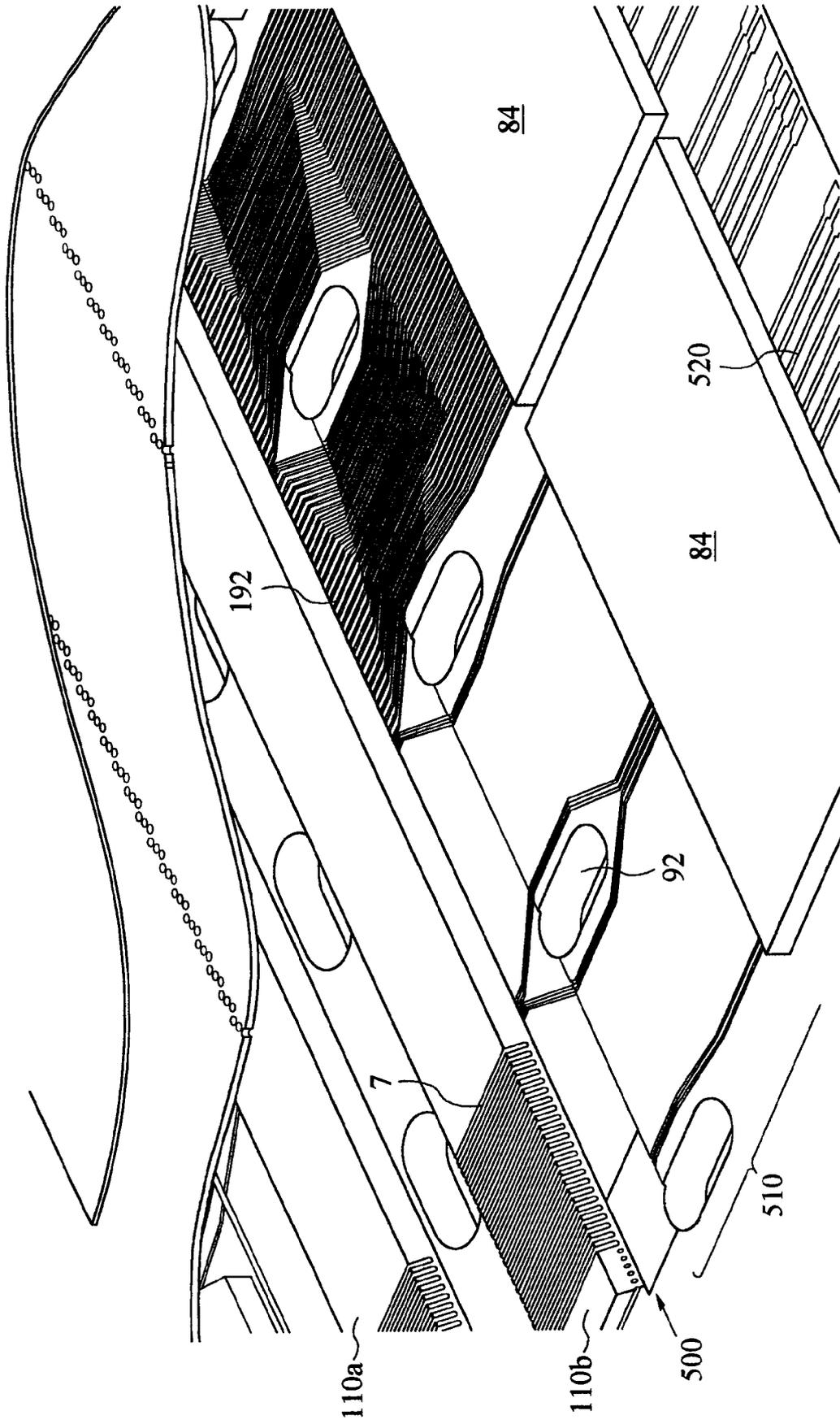


FIG. 6

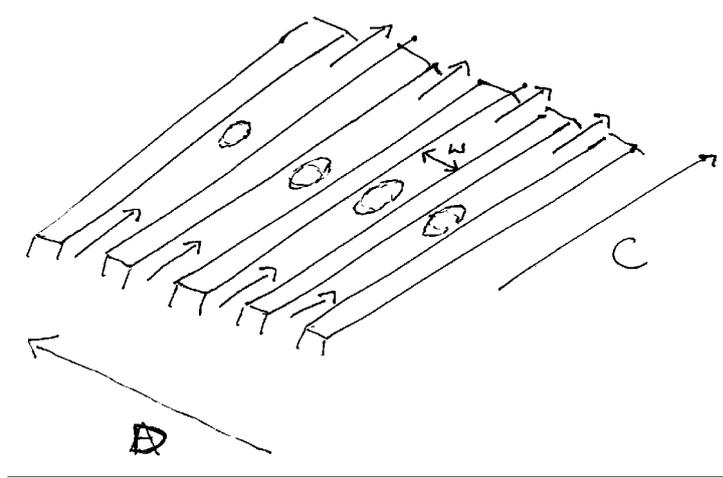


FIG. 7

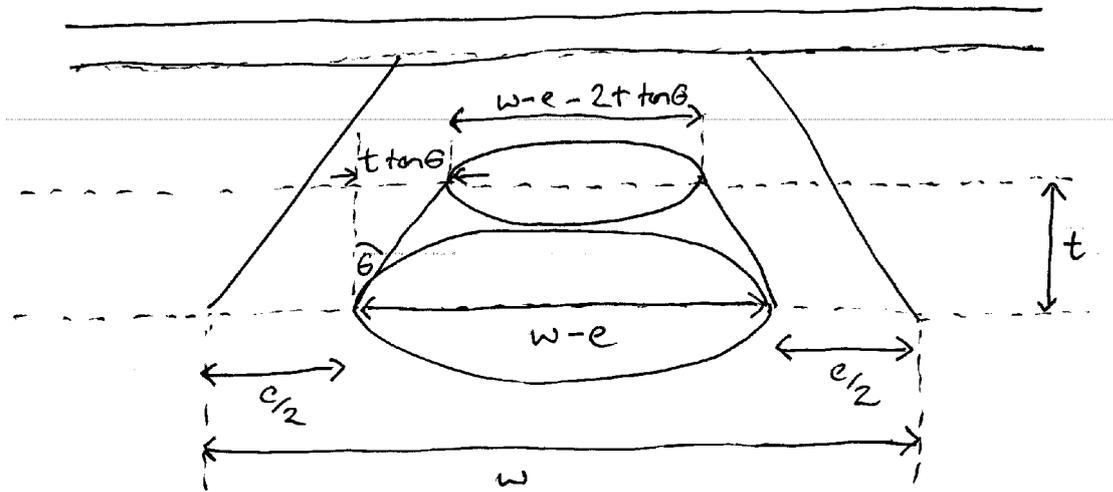


FIG. 8

*Experimental results at 6m/s droplet speed*

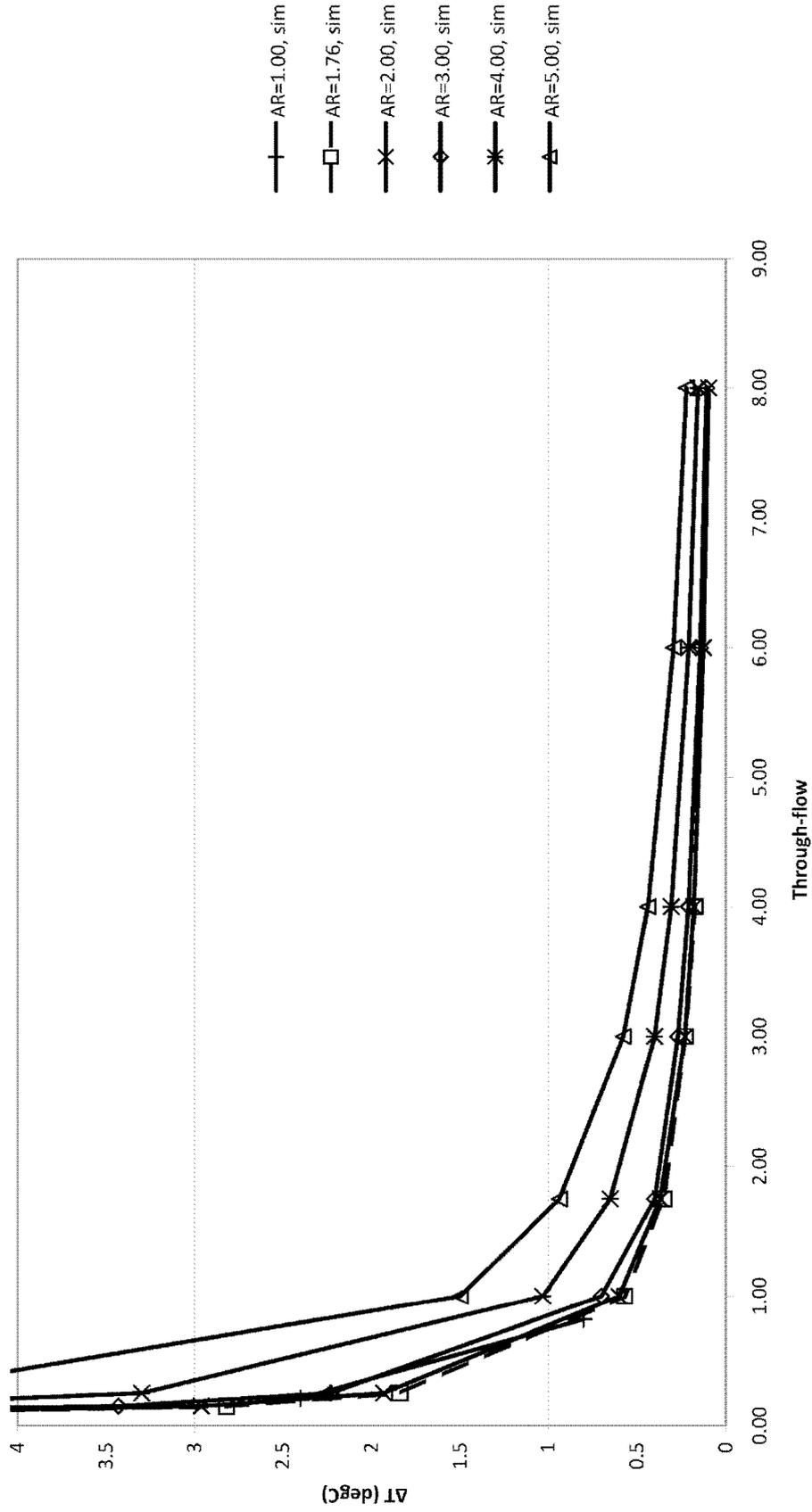
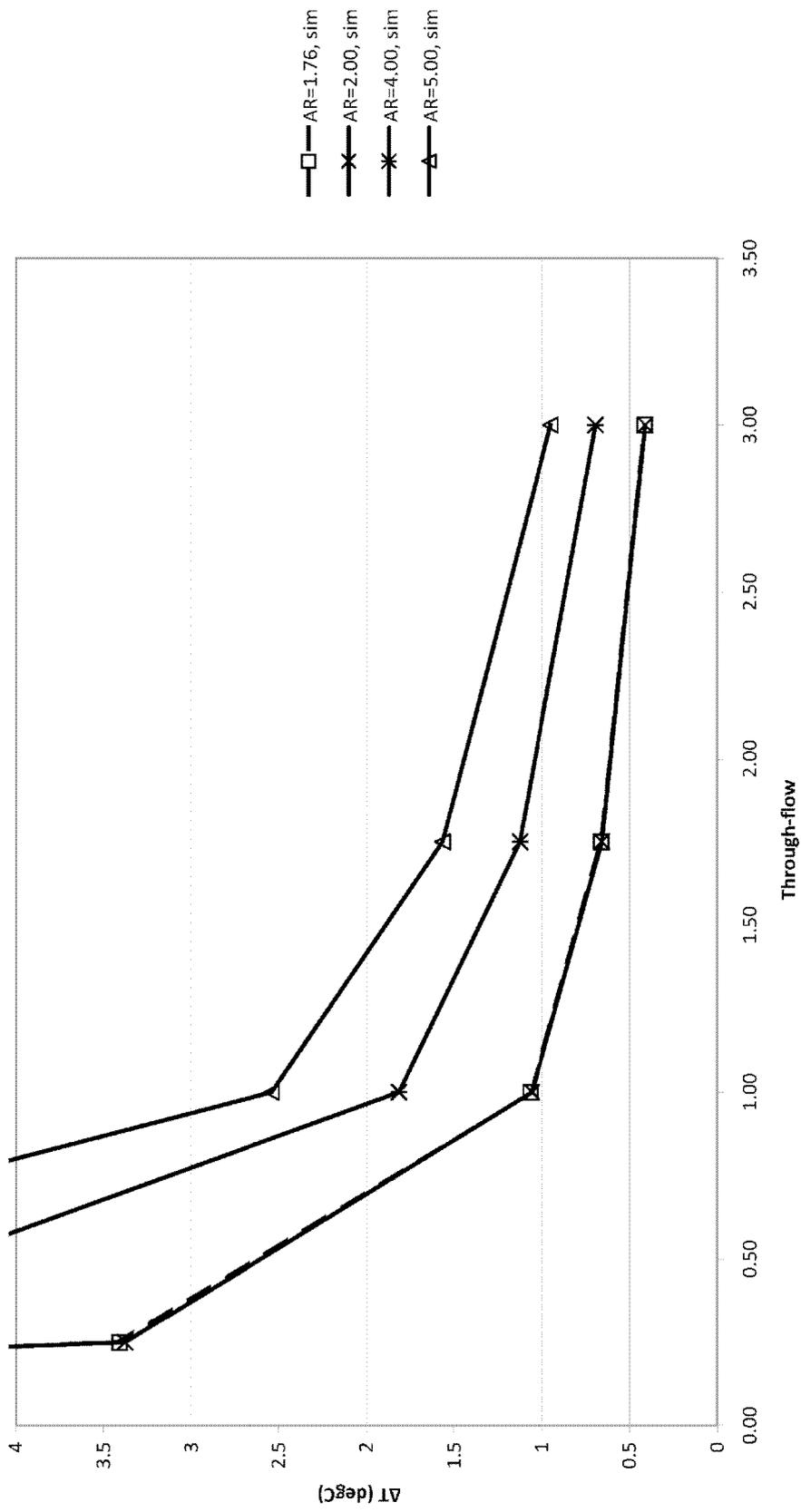
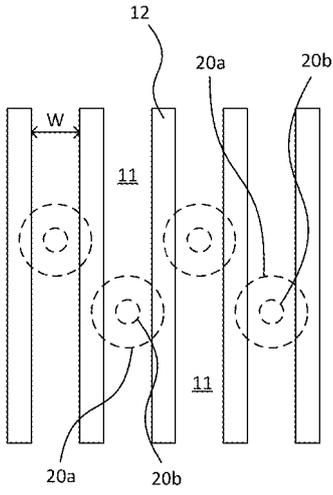


FIG. 9

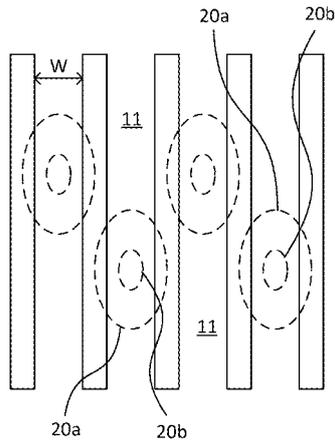
*Experimental results at 12m/s droplet speed*



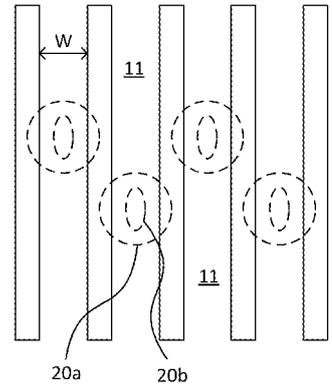
**FIG. 10**



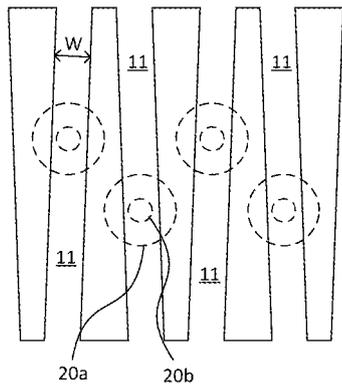
**FIG. 11(A)**



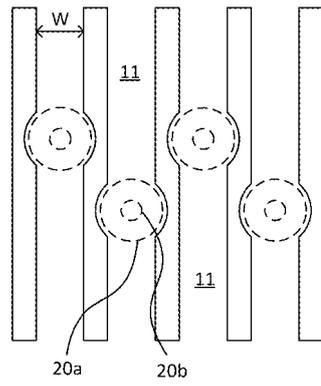
**FIG. 11(B)**



**FIG. 11(C)**



**FIG. 12(A)**



**FIG. 12(B)**

## DROPLET DEPOSITION APPARATUS AND METHOD FOR DEPOSITING DROPLETS OF FLUID

The present invention relates to droplet deposition apparatus and methods for depositing droplets of fluid. It may find particularly beneficial application in a droplet deposition apparatus comprising an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, with a common fluid inlet manifold and with a common fluid outlet manifold, together with means for generating a fluid flow into said inlet manifold, through each chamber in the array and into said outlet manifold.

Examples of such droplet deposition apparatus are provided by WO 00/38928, from which Figures 1, 2, 3 and 4 are taken. Figure 1, for example illustrates a "pagewide" printhead 10, having two rows of nozzles 20, 30 (each having a circular profile) that extend (in the direction indicated by arrow 100) the width of a piece of paper and which allow ink to be deposited across the entire width of a page in a single pass. Ejection of ink from a nozzle is achieved by the application of an electrical signal to actuation means associated with a fluid chamber communicating with that nozzle, as is known e.g. from EP-A-0 277 703, EP-A-0 278 590 and, more particularly, WO 98/52763 and WO 99/19147. To simplify manufacture and increase yield, the "pagewide" row(s) of nozzles may be made up of a number of modules, one of which is shown at 40, each module having associated fluid chambers and actuation means and being connected to associated drive circuitry (integrated circuit ("chip") 50) by means e.g. of a flexible circuit 60. Ink supply to and from the printhead is via respective bores (not shown) in endcaps 90.

Figure 2 is a perspective view of the printhead of Figure 1 from the rear and with endcaps 90 removed to reveal the supporting structure 200 of the printhead incorporating ink flow passages 210,220,230 extending the width of the printhead. Via a bore in one of the endcaps 90 (omitted from the views of Figures 1 and 2), ink enters the printhead and the ink supply passage 220, as shown at 215 in Figure 2. As it flows along the passage, it is drawn off into respective ink chambers, as illustrated in Figure 3, which is a sectional view of the printhead taken perpendicular to the direction of extension of the nozzle rows. From passage 220, ink flows into first and second parallel rows of ink chambers (indicated at 300 and 310 respectively) via aperture 320 formed in structure 200 (shown shaded). Having flowed through the first and second rows of ink chambers, ink exits via apertures 330 and 340 to join the ink flow along respective first and second ink outlet passages 210,230, as indicated at 235. These join at a common ink outlet (not shown) formed in the end-cap and which

may be located at the opposite or same end of the printhead to that in which the inlet bore is formed.

Further detail of the chambers and nozzles of the particular printhead shown in Figures 1 to 3 is given in Figure 4, which is a sectional view taken along a fluid chamber of a module 40. The fluid chambers take the form of channels, 11, machined or otherwise formed in a base component 860 of piezoelectric material so as to define piezoelectric channel walls which are subsequently coated with electrodes, thereby to form channel wall actuators, as known e.g. from EP-A-0 277 703. Each channel half is closed along a length 600,610 by respective sections 820,830 of a cover component 620 which is also formed with ports 630,640,650 that communicate with fluid manifolds 210,220,230 respectively. A break in the electrodes at 810 allows the channel walls in either half of the channel to be operated independently by means of electrical signals applied via electrical inputs (flexible circuits 60). Ink ejection from each channel half is via openings 840,850 that communicate the channel with the opposite surface of the piezoelectric base component to that in which the channel is formed. Nozzles 870,880 for ink ejection are subsequently formed in a nozzle plate 890 attached to the piezoelectric component.

Those skilled in the art will appreciate that a variety of alternative fluids may be deposited by droplet deposition apparatus: droplets of ink may travel to, for example, a paper or other substrate, such as ceramic tiling, to form an image, as is the case in inkjet printing applications; alternatively, droplets of fluid may be used to build structures, for example electrically active fluids may be deposited onto a substrate such as a circuit board so as to enable prototyping of electrical devices, or polymer containing fluids or molten polymer may be deposited in successive layers so as to produce a prototype model of an object (as in 3D printing). Droplet deposition apparatus suitable for such alternative fluids may be provided with modules that are similar in construction to standard inkjet printheads, with some adaptations made to handle the specific fluid in question.

Figures 5 and 6 are exploded perspective views of a printhead employing a similar double-ended side-shooter construction to that of Figures 1 to 4, but taken from WO 01/12442. As may be seen, two rows of channels spaced relatively to one another in the media feed direction are used, with each row extending the width of a page in a direction transverse to the media feed direction.

The two rows of channels are formed in respective strips of piezoelectric material 110a, 110b, which are bonded to a planar surface 120 of substrate 86. Electrodes are provided on the walls of the channels, so that electrical signals may be selectively applied to the walls. The channel walls thus act as actuator members and may cause droplet ejection. Substrate 86 is formed with conductive tracks 192 which are electrically connected to the respective channel wall electrodes, (for example by solder bonds), and which extend to the edge of the substrate where respective drive circuitry (integrated circuits 84a, 84b) for each row of channels is located.

As may also be seen from Figures 5 and 6, a cover member 130 is bonded to the tops of the channel walls so as to create closed, "active" channel lengths which may contain pressure waves that allow for droplet ejection. Nozzle holes, each having a circular profile, are formed in cover member 130, which communicate with the channels to enable ejection of droplets.

The substrate 86 is also provided with ports 88, 90 and 92, which communicate to inlet and outlet manifolds. As with the construction described with reference to Figures 1 to 4, an inlet manifold may be provided in between two outlet manifolds, with the inlet manifold thus supplying ink to the channels via ports 90, and ink being removed from the two rows of channels to respective outlet manifolds via ports 88 and 92. As Figure 6 illustrates, the conductive tracks 192 may be diverted around the ports 88, 90 and 92.

The printheads disclosed in WO 00/38928 and WO 01/12442 may therefore be considered examples of droplet deposition apparatus that include an array of elongate fluid chambers, with each chamber communicating with an orifice for droplet ejection, with a common fluid inlet manifold and with a common fluid outlet manifold, together with means for generating a fluid flow into said inlet manifold, through each chamber in the array and into said outlet manifold.

The present invention relates to improvements in such droplet deposition apparatus.

Increase in process productivity in droplet deposition processes, such as printing applications and industrial deposition is a key driver in many industrial sectors. This demand for increased productivity may often be satisfied by increasing the frequency at which drops are ejected from the nozzle, or alternatively by increasing the size of each fluid drop.

A further approach to increase productivity is to increase the nozzle or orifice count (more nozzles deliver more ink) which can be achieved by producing a printhead having a higher density of nozzles in the array direction, or by using multiple suitably aligned droplet deposition modules (such as printheads) to address the substrate.

5 Depending on the particular application, these approaches may be combined so as to further increase productivity. However, while each of these approaches may – depending on the circumstances – be used to increase productivity there may in each case be real compromises to be considered. There may also be physical limitations on the increases in productivity that are available for a particular approach.

10 For example, increases in orifice density may be limited by a minimum size to which the actuating elements or the fluid chambers may be manufactured. In printheads such as those shown in Figures 1 to 5, there may be a limit on the density to which the channels may be sawn into the piezoelectric material. Further, increases in orifice density may impinge on the size of the actuating elements (particularly where  
15 the footprint of the device remains constant) and as a consequence the actuating element may be less powerful and thus the capability of the device compromised to some extent.

As noted above, multiple droplet ejection modules (such as printheads) may also be used to increase productivity. Droplet deposition apparatus including multiple  
20 modules may lessen the impact of restrictions on the minimum size of actuating elements, but the cost for the device may be prohibitive, given that it includes multiple high-cost droplet deposition modules.

Further, in some cases it may be appropriate to use droplet deposition modules with larger footprints in order to increase productivity. This may clearly relieve some of  
25 the limitations on the size of the actuating elements; however, the larger footprint may come at the cost of decreased resolution. Depending on the particular application, such a decrease in resolution may not be acceptable.

The present invention may ameliorate some of these problems. In some particular embodiments it may increase the productivity of droplet deposition apparatus, while  
30 in others different improvements may be experienced in addition or instead.

Thus, in accordance with a first aspect of the present invention there is provided droplet ejection apparatus comprising: an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an

array direction; a common fluid inlet manifold; a common fluid outlet manifold; and means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold; wherein each of said fluid chambers communicates at one longitudinal end with said common fluid inlet manifold and at the opposing longitudinal end with said common fluid outlet manifold; wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ; wherein each of said orifices is elongate in a direction parallel to the longitudinal axis of the respective one of said fluid chambers.

The elongation of the orifice parallel to the longitudinal axis of the respective fluid chamber may enable the orifice size to be increased without unduly impacting upon the orifice density in the array direction. The increased size of the orifice may allow the orifice to eject fluid droplets of increased volume, thus increasing the productivity of the apparatus.

There may be further advantages to this specific orientation of the orifice. For example, since the fluid chamber communicates at one longitudinal end with said common fluid inlet manifold and at the opposing longitudinal end with said common fluid outlet manifold, the through flow may be directed along its longitudinal length. Thus, the through flow and the direction of elongation of the orifice may be aligned. This may lead to particularly efficient removal of detritus, such as air bubbles and dust particles, from the vicinity of the orifice during use of the apparatus. Such removal of detritus may reduce the incidence of orifice blockages during use, thus improving the reliability of the apparatus.

Further, this orientation of the orifice may result in acoustic waves (which may be generated by the piezoelectric actuators during use of the apparatus) being present in the vicinity of the orifice for a longer period of time than with a circular orifice. Typically, such acoustic waves will be generated at each of the longitudinal ends of the chamber following actuation of the piezoelectric actuator and travel inwards towards the orifice. As the orifice is thus elongate in the direction of travel of the acoustic wave they may be present at the orifice for a relatively longer period of time, thus improving the efficiency of ejection.

Preferably, each of said fluid chambers has a width  $w$  in said array direction, thus defining a theoretical circular area  $A_T = \frac{1}{4}\pi w^2$ , the orifice outlet for each chamber having an area  $A_n$ , wherein  $0.48A_T > A_n > 0.2A_T$ .

5 It has been found that the through flow acts to cool the apparatus and in particular the actuator. In addition, the ejection flow may also act to cool the apparatus (specifically in the vicinity of the actuator) as heat transferred is to the fluid and then removed from the apparatus with the ejected droplets. It would therefore be expected that, with increasing orifice area, the cooling of the apparatus would improve as the size of the droplets being ejected would increase and thus more fluid  
10 would be removed from the chamber by means of ejection. However, the Applicant has found that, surprisingly, orifices with larger areas do not necessarily provide more efficient cooling and that, orifices with areas in this particular range provide more effective cooling of the apparatus and, in particular, of the piezoelectric actuators, than apparatus with orifices having larger areas. This cooling effect is  
15 typically provided with only modest values for the through-flow.

More preferably, the value of said through-flow is such that  $Q_{TF} > 0.25Q_E$ . The use of a through-flow in this range, with orifices as defined above, may allow the apparatus, and particularly the actuator, to be cooled to an extent such that the fluid passing through the chambers is typically heated only by 2 degrees or less. This indicates a  
20 temperature differential that may significantly improve the useable lifetime of the apparatus.

In this regard it should be appreciated that a small rise in the temperature of the fluid may indicate a substantial increase in the temperature of the apparatus, and in particular the actuator. Estimates for the lifetime of the apparatus may be based on  
25 the Arrhenius model, where chemical attack of the components is the dominant factor in the failure of the apparatus. Therefore, it will be appreciated that the lifetime of the apparatus may be sensitive to even smaller temperature differences.

It should further be appreciated that a large temperature differential may lead to undesirable effects on droplet ejection characteristics. It has been found by the  
30 Applicant that such characteristics are sensitive to the rheology of the fluid, which may be significantly influenced by even small changes in temperature.

Still more preferably, the value of said through-flow is such that  $Q_{TF} > Q_E$ . This may lead to significant increases in the reliability of the apparatus: as more fluid is passing

the orifice than flowing through it, even during maximal ejection, the through-flow is particularly effective at scouring away detritus from the vicinity of the nozzle.

Alternatively, each of said fluid chambers has a width  $w$  in said array direction, thus defining a theoretical circular area  $A_T = \frac{1}{4}\pi w^2$ , the orifice outlet for each chamber  
5 having an area  $A_n$ , and wherein  $0.80A_T > A_n > 0.20A_T$  and  $Q_{TF} > 4Q_E$ .

The Applicant has found that, with a through-flow in this range, apparatus with orifices having areas up to  $0.80A_T$  will typically have similar temperature differentials to apparatus with orifices having significantly smaller areas. Specifically, the  
10 temperature differential experienced within the apparatus with the larger orifices (those with areas up to up to  $0.80A_T$ ) will typically be within 0.2 degrees of temperature differential experienced in apparatus with the smaller orifices (those with areas greater than  $0.20A_T$ ). As 0.2 degrees is generally considered to be within the normal range of variation, it may – depending on the circumstances – be neglected, with the performance of the two apparatus in terms of lifetime and droplet  
15 characteristics being substantially the same.

Suitably, the longitudinal axes of said fluid chambers are parallel to a channel extension direction. Preferably, this channel extension direction is perpendicular to said array direction.

According to a second aspect of the present invention there is provided droplet  
20 ejection apparatus comprising: an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction; a common fluid inlet manifold; a common fluid outlet manifold; and means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;  
25 wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold; wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with  
30 said through flow, said ejection flow having a maximum value  $Q_E$ ; wherein each of said fluid chambers has a width  $w$  in said array direction, thus defining a theoretical circular area  $A_T = \frac{1}{4}\pi w^2$ , the orifice outlet for each chamber having an area  $A_n$ , wherein  $0.48A_T > A_n > 0.20A_T$ .

As discussed in detail above, orifices having areas in the range  $0.48A_T > A_n > 0.20A_T$  range may provide a particularly small temperature differential between fluid at the inlet manifold and fluid at the outlet manifold. This may correspond to particularly efficient cooling of the apparatus and, in particular, of the piezoelectric actuators, without requiring large values for the through-flow. Such effects do not necessarily rely upon the elongation of the orifice described above.

Preferably, the value of  $Q_{TF}$  is sufficient to ensure that the temperature of fluid returned to said outlet common manifold is substantially maintained within 0.2 degrees of the fluid entering the chambers from the common inlet manifold.

According to a further aspect of the present invention there is provided droplet ejection apparatus comprising: an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction; a common fluid inlet manifold; a common fluid outlet manifold; and means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold; wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold; wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ; wherein each of said fluid chambers has a width  $w$  in said array direction, thus defining a theoretical circular area  $A_T = \frac{1}{4}\pi w^2$ , the orifice outlet for each chamber having an area  $A_n$ , and wherein  $0.80A_T > A_n > 0.20A_T$  and  $Q_{TF} > 4Q_E$ .

As discussed above, the Applicant has found that, with a through-flow defined in the range  $Q_{TF} > 4Q_E$ , apparatus with orifices having areas up to  $0.80A_T$  will typically have similar temperature differentials to apparatus with orifices having significantly smaller areas. Specifically, the temperature differential experienced within the apparatus with the larger orifices (those with areas up to up to  $0.80A_T$ ) will typically be within 0.2 degrees of temperature differential experienced in apparatus with the smaller orifices (those with areas greater than  $0.20A_T$ ). As 0.2 degrees is generally considered to be within the normal range of variation, it may – depending on the circumstances – be neglected, with the performance of the two apparatus in terms of lifetime and droplet characteristics being substantially the same.

According to a still further aspect of the present invention there is provided droplet ejection apparatus comprising: an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction; a common fluid inlet manifold; a common fluid outlet manifold; and means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold; wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold; wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ; wherein said orifices are provided in an orifice plate, having a thickness of  $t$  microns, each orifice being tapered so as to define a taper angle  $\theta$ ; wherein each of said fluid chambers has a width of  $w$  microns in said array direction, thus defining a practical circular area  $A_P = \frac{1}{4}\pi(w-e-2t \tan \theta)^2$ , with  $e$  taking the value 10 microns, the orifice outlet for each chamber having an area  $A_n$ , wherein  $3A_P > A_n > 1.25A_P$ .

This value of  $e$  may correspond to the accuracy of the process by which the chambers and orifices are formed.

In embodiments, the taper angle  $\theta$  may take a value between 5 and 15° and preferably may take a value between 10 and 12°.

According to a still further aspect of the present invention there is provided droplet ejection apparatus comprising: an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction; a common fluid inlet manifold; a common fluid outlet manifold; and means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold; wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold; wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ; wherein said orifices are provided in an orifice plate, having a thickness of  $t$  microns, each orifice being tapered so as to define a taper angle  $\theta$ ; wherein each of said fluid chambers

has a width of  $w$  microns in said array direction, thus defining a theoretical circular area  $A_p = \frac{1}{4}\pi(w - e - 2t \tan \theta)^2$ , with  $e$  taking a value between 5 and 10 microns, the orifice outlet for each chamber having an area  $A_n$ , wherein  $5A_p > A_n > 1.25A_p$ , and  $Q_{TF} > 4Q_E$ .

- 5 This value of  $e$  may correspond to the accuracy of the process by which the chambers and orifices are formed.

In embodiments, the taper angle  $\theta$  may take a value between 5 and 15° and preferably may take a value between 10 and 12°.

- 10 According to yet a further aspect of the present invention there is provided droplet ejection apparatus comprising: an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction; a common fluid inlet manifold; a common fluid outlet manifold; and means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;
- 15 wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold; wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with
- 20 said through flow, said ejection flow having a maximum value  $Q_E$ ; wherein the orifice outlet for each chamber has an area  $A_n$  wherein  $1600 \mu\text{m}^2 > A_n > 650 \mu\text{m}^2$ .

- 25 According to yet a further aspect of the present invention there is provided droplet ejection apparatus comprising: an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction; a common fluid inlet manifold; a common fluid outlet manifold; and means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;
- 30 wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold; wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ; wherein the orifice

outlet for each chamber has an area  $A_n$ , and wherein  $2700 \mu\text{m}^2 > A_n > 650 \mu\text{m}^2$  and  $Q_{TF} > 4Q_E$ .

According to a still further aspect of the present invention there is provided a method for depositing droplets of fluid comprising the steps of: providing an apparatus  
5 according to any one of the preceding claims; operating said apparatus so as to provide said through-flow and said ejection-flow.

Preferably, in each of the aspects presented above, each of the orifices is tapered so that the area of the orifice outlet is less than the area of the orifice inlet. Optionally, the orifice inlet may be contained wholly within the fluid chamber, so that it does not  
10 overlap the chamber walls. The orifice inlet may be defined in a surface that faces towards the corresponding fluid chamber. This surface may enclose the top of the corresponding fluid chamber. The orifice outlet may be defined in an opposing surface, which may be parallel to the surface in which the orifice inlet is defined.

Preferably, the orifices may be provided in an orifice plate. This orifice plate may  
15 comprise two substantially planar opposing surfaces. One of these surfaces may provide the inlets of said orifices, while the other provides the outlets of said orifices. The surface in which the inlets are defined may enclose the tops of the array of fluid chambers.

Preferably, each of said elongate chambers is defined between two elongate  
20 chamber walls, with the top edges of said chamber walls together providing a substantially planar surface, said orifice plate being attached to said surface. Each chamber wall may comprise piezoelectric material and, optionally, this piezoelectric material may be poled so that the chamber wall will deform in response to an actuation signal so as to assume a chevron shape. Specifically, when actuated, the  
25 wall will have a chevron shape when viewed along the length of the chamber. This may be achieved by dividing the chamber wall into two halves along its length, with one half being poled in one direction and the other half being poled in the opposite direction.

In order to effect droplet ejection, the two chamber walls may both be actuated  
30 simultaneously. Electrodes may be formed on the two sides of the chamber walls which face towards the two chambers separated by the wall. Where the chamber walls comprise piezoelectric material, they may deform in shear mode. The electrodes and the direction poling of the piezoelectric material of the walls may be arranged to achieve this.

The chamber may have a width of, for example, between 20 and 150 microns, between 30 and 130 microns, between 40 and 110 microns, between 50 and 90 microns, or between 60 and 70 microns.

5 The apparatus may be actuable to eject droplets with a speed  $v$ , where  $v$  is between 2 and 20m/s, between 3 and 18 m/s, between 4 and 16m/s, or between 5 and 14m/s.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 illustrates a prior art inkjet printer;

10 Figure 2 is a perspective view of the printhead of Figure 1 from the rear with endcaps removed to reveal the flow of ink through the printhead;

Figure 3 is a sectional view of the printhead of Figures 1 and 2, taken perpendicular to the direction of extension of the nozzle rows;

Figure 4 is a sectional view of the inkjet printer of Figures 1 to 3 taken along a fluid chamber of a module;

15 Figures 5 illustrates a further example of a prior art printhead, employing a similar double-ended side-shooter construction to that of Figures 1 to 4;

Figure 6 is an exploded perspective view of the printhead of Figure 5, which shows the conductive tracks used to apply electrical signals to the actuator elements;

20 Figure 7 shows an exploded perspective view of a printhead according to a first embodiment of the present invention, which has nozzles elongated in the chamber extension direction;

Figure 8 is a perspective view along the length of a chamber of an inkjet printhead and shows the dimensions of a tapered nozzle relative to the dimensions of the fluid chamber of the printhead;

25 Figure 9 shows the results of a series of tests carried out on printheads of differing nozzle areas, for different value of through-flow, the printheads ejecting droplets with a speed of 6m/s;

Figure 10 shows the results of a similar series of tests to those whose results are shown in Figure 9, but with printheads ejecting droplets with a speed of 12m/s.

Figure 11 is a plan view of a series of further embodiments according to the present invention, where alternative nozzle geometries to those shown in Figure 7 are utilised; and

5 Figure 12 is a plan view of a series of still further embodiments according to the present invention, where alternative chamber geometries to those shown in Figure 7 are utilised.

The present invention may be embodied in an inkjet printer. Figure 7 therefore illustrates an exploded view of an inkjet printhead within an inkjet printer according to a first embodiment of the present invention. As may be seen from the figure, the inkjet printhead includes a single array of fluid chambers, each defined between a pair of elongate chamber walls. Each of the fluid chambers is elongate in a channel extension direction (C), with the chamber walls also being elongate in this direction. The array extends in an array direction (D), which is perpendicular to the chamber extension direction (C). As also shown in Figure 7, during use of the apparatus fluid enters each chamber at one longitudinal end of the chamber from a common inlet manifold, flows along the length of the chamber past the orifice, which is provided towards the middle of the chamber with respect its longitudinal ends, and leaves the chamber at its other longitudinal end to return to a common outlet manifold. There may also be provided one or more fluid conduits to recirculate ink from the common outlet manifold to the common inlet manifold.

25 The inkjet printer may have a similar structural features to those described above with reference to Figures 1 to 6, such as providing two arrays of ports in the surface of a substrate which communicate respectively with the common inlet and common outlet manifolds. The manifolds may also be provided within a single substantially cylindrical housing, as shown in Figures 1 to 3.

In order to provide the flow through the chambers, an ink supply system may apply a constant first pressure to the ink in the common inlet manifold, whilst simultaneously applying a constant second, lower pressure to the ink in the common outlet manifold. Such constant pressures may be provided by reservoirs vertically offset with respect to the orifices, as is know from WO 00/38928, or simply by respective fluid pressurizers. As also know from WO 00/38928, the fluid supply system may impose a negative pressure (with respect to atmospheric pressure) at the nozzles. Those skilled in the art will recognise that this may require the difference in value between

the first and second pressures to be negative. This negative pressure may prevent the weeping of fluid from the nozzles during non-ejection periods.

5 The chamber walls may be formed from piezoelectric material, as described above with reference to Figures 1 to 6, with electrodes being formed on part of the chambers walls so that actuation signals may be applied to the chamber walls. However, those skilled in the art will recognise that alternative piezoelectric actuators may be utilised, with the chambers being defined in a non-piezoelectric material. For example, the chambers may be defined in a non-piezoelectric material using a photolithographic process, with piezoelectric actuators being provided within these  
10 chambers at an earlier or later stage, as desired.

As indicated in Figure 7, the opposing faces of the chamber walls defining each chamber are separated by a width  $w$ , so that the chamber may be said to have a width equal to  $w$ . Using circular nozzles, as with the constructions of Figures 1 to 6, the theoretical maximum area that a nozzle could take whilst still remaining within the  
15 chamber would therefore be equal to a value  $A_T = \frac{1}{4}\pi w^2$ .

It will be appreciated that, since this width defines the extent of the fluid chambers, where the chamber walls include one or more coating layers (for example an electrode and/or a passivation layer), the width should be measured from the outermost coating layer of one wall to the outermost coating layer of the other wall.

20 In practice, however, it may not possible to reliably form a circular nozzle having this theoretical maximum area, as this would require the nozzle to match exactly the width and shape of the chamber with one hundred percent accuracy. It may therefore be necessary to take account of common sources of manufacturing error so as to determine a practically achievable maximum area for the nozzle.

25 A first source of such errors is the process by which the nozzles themselves are formed. It is common to use an optical process to define the shape and size of the nozzles; for example, photo-lithography may be used form a complete nozzle plate from a photoresist material, or the photoresist may serve as a negative to define the shape of nozzle bores, with a metal nozzle plate being electroformed around  
30 photoresist posts, as known from WO 2005/014292. Equally, the nozzles may be ablated directly within a nozzle plate, which may be formed from a metal, a polymer, or combinations of the two. Although such optical processes are relatively accurate, they will still introduce an uncertainty of the order of several microns.

A further source of manufacturing errors is the process by which the chambers are formed. For example, this may, as described above with reference to Figures 1 to 6, include sawing channels in strips of piezoelectric material, but may also include moulding and sintering of piezoelectric material, or, where a non-piezoelectric material is utilised to define the channels an optical method may be used. There will be uncertainty not only in the size and shape of the chambers, but also in the spacing of each chamber within the array.

Furthermore, the combination of the two processes, specifically the registration or alignment of each nozzle with respect to its corresponding chamber will also introduce uncertainty into the manufacturing process.

Taken in combination, these errors may be of the order of 10 microns. It will therefore typically be necessary for the edges of the nozzle to nominally be spaced a distance of 5 microns from the respective chamber walls. This is especially the case where the process utilised for nozzle formation may cause damage to the chamber walls. For example, where laser ablation is used to form the nozzles, scorching of the walls and their overlying layers may occur.

While processes have been proposed that reduce the incidence of such damage (such as those disclosed in WO 2012/017248), these may only protect the interior walls of the chamber and may not protect the top edges of the chamber walls, including any coating layers. As is discussed in WO 2012/017248, damage to the coating layers, such as the electrode and passivation layers may significantly impact upon the performance of the apparatus: damage to the electrode layer may cause the chamber to have lower activity than other chambers within the array, or even to be altogether inactive; damage to the passivation layer may lead to chemical attack of the underlying layers, which may impact upon the lifespan of the apparatus. Thus, even where protective processes such as those taught in WO 2012/017248 are available it may nonetheless be important to space the nozzle inlet from the chamber walls.

While the size of the nozzle inlet may be related to the dimensions of the chamber, it has been found that the size of the nozzle outlet may be related to the productivity of the apparatus. Specifically, the area of the nozzle outlet is believed to determine (amongst other factors) the size of the droplets ejected by the apparatus. Further, it has been found to be desirable in some circumstances to form the nozzle with a taper; this may result in improved stability of the fluid meniscus at the nozzle. Thus,

the area of the nozzle outlet may be related to the area of the nozzle inlet and, specifically, it may be smaller than the area of the nozzle inlet.

Figure 8, which is a perspective view along the length of a chamber of an inkjet printhead, shows the dimensions of such a tapered nozzle relative to the dimensions of the fluid chamber. As may be seen, the inlet of the nozzle communicates with a fluid chamber of width  $w$ . The nozzle tapers towards its outlet, which is formed in an opposing surface of a nozzle plate.

As may be seen from Figure 8, the width of the nozzle inlet is taken to be  $w-e$ , where  $e$  is a value chosen to substantially increase the likelihood that the nozzle inlet will lie wholly within the width of the chamber. The value of  $e$  is therefore chosen so as to take into account the various sources of errors in nozzle and chamber formation discussed above and may thus take a suitable value, such as 10, 7, or 5 microns.

The width of the nozzle outlet is then smaller still, as a result of the taper of the nozzle, which is defined by an angle  $\theta$ . As shown in Figure 8, the taper angle  $\theta$  may be defined at the point where a line parallel to the array direction and passing through the centre of the nozzle inlet intersects with the perimeter of the nozzle inlet. As also shown in Figure 8, the taper angle may be defined with respect to a direction that is perpendicular to both the array direction and the chamber extension direction. In a typical inkjet printhead, the taper angle for the nozzle may be between 5 and 15 degrees and in some cases may be between 10 and 12 degrees.

As further shown by Figure 8, the nozzle plate in which the nozzles are formed has a thickness of  $t$ . In a typical inkjet printhead, the thickness of the nozzle plate may be in the region of 50 to 150 microns, though those skilled in the art will appreciate that a number of other values may be appropriate.

As is clear from the diagram in Figure 8, the difference in width between the nozzle inlet and the nozzle outlet is  $2t \tan \theta$ , so that the nozzle inlet has a width of  $(w-e-2t \tan \theta)$ . The outlet therefore has an area defined by the following relationship:

$$A_P = \frac{1}{4}\pi(w-e-2t \tan \theta)^2$$

Thus, where it is desired that the nozzle inlet is contained within the width of the fluid chamber, the maximum value that a circular nozzle outlet may in practice take may be  $A_P$ , as defined in this equation.

For a typical droplet deposition apparatus, specifically an inkjet printhead, this practical maximum area for a circular nozzle may be in the region of 530 square microns. This is based on a chamber width  $w$  of 65 microns, taking account of a coating layer of 5 microns on each chamber wall (the spacing between the chamber walls themselves thus being 75 microns).

By contrast, the theoretical maximum value for a circular nozzle in such an apparatus ( $A_T = \frac{1}{4}\pi w^2$ ) may therefore be calculated to be about 3320 square microns based on these values, which is clearly considerably larger than the value of  $A_P$ .

Returning to the embodiment of Figure 7, as noted above, the nozzles are elongated in the chamber extension direction (C). Therefore, their areas relative to both the theoretical maximum and practical maximum values are increased, as these maximum values are based on circular nozzles. As noted above, the increased area of the nozzles, specifically of the nozzle outlets, may lead to an increase in the volume of each droplet ejected, thus increasing the productivity of the printhead. More, because the nozzles are elongate in the same direction as the flow of fluid through the chamber, the flow through the chamber is able to scour detritus away from the vicinity of the nozzle particularly effectively. This may lead to improvements in the reliability of the printhead. This improvement in reliability may also be experienced with nozzles that are not in excess of the practical maximum area  $A_P$ , though it will be appreciated that such printheads would not necessarily benefit from improvements in productivity.

In order to have an appreciable effect on the productivity of the printhead it has been found that it will typically be necessary to increase the area of each nozzle by 25%. This may impose a lower limit of  $1.25A_P$  on the area of nozzles, in order to improve the productivity of the printhead. This lower limit may correspond, in the inkjet printhead described above, to approximately 650 square microns.

Further, as the area of the nozzles is increased and thus more ink is ejected from the chamber, it is expected that the chambers will be cooled more effectively. Heat from the apparatus, and in particular the actuator elements will be transferred to the ink during use, with the ejection of this fluid thus acting to remove heat from the chamber in the vicinity of the actuator elements. Thus, as the area of the nozzles is increased, and thus the amount of flow through the nozzles in the form of droplets is also increased, the rate at which heat is transferred away from the actuator should

increase, thus resulting in improved cooling of the apparatus in addition to improved productivity.

In order to quantify this cooling effect, tests were carried out for a series of printheads, with the different printheads each having nozzles of a specific area. The behaviour of each of these printheads was tested at different rates of flow through the chambers. The results of these experiments are shown in Figure 9.

The chambers of the printheads had the same typical value for the chamber width discussed above, namely a chamber width  $w$  of 65 microns. The practical maximum value for the nozzle outlet was taken to be 530 square microns, also as discussed above.

The printheads included an array of elongate chambers as depicted in Figure 7, with a flow along the length of each chamber being provided during use from a common inlet manifold to a common outlet manifold. This through-flow occurs simultaneously with ejection of droplets from the nozzle, which, although droplets are of course discrete volumes of fluid may be considered equivalent to a further, ejection flow. For each printhead, the difference in temperature between ink at the inlet manifold and ink at the outlet manifold was measured, for various values of flow through the chambers.

The rates of through-flow for the printheads are shown on the abscissa of Figure 9. The rates of flow for the printheads are expressed relative to the maximum flow through the nozzle owing to ejection. This corresponds to the chambers printing droplets at maximum ejection frequency, with the printhead imparting a speed of 6m/s to each droplet. A value of 1 on the abscissa therefore corresponds to the flow through each chamber and to the outlet manifold being equal to the maximum ejection flow. As the ejection-flow and through-flow occur simultaneously, during maximum ejection there would be an equal amount of fluid returning to the outlet manifold as being ejected from the nozzle.

The values shown on the ordinate of Figure 9 represent the difference in temperature ( $\Delta T$ ) in degrees Celsius between ink at the inlet manifold and ink at the outlet manifold. This temperature differential may be used to indicate the cooling effect within the printhead in question.

Each line on the graph of Figure 9 thus represents a different printhead, with a respective nozzle outlet area. The legend for the graph therefore shows these

respective nozzle areas for the chambers using the dimensionless quantity area ratio (AR), which is the ratio of the nozzle area in question to the practical maximum nozzle area ( $A_p$ ). As noted above, the value of the practical maximum nozzle area ( $A_p$ ) was 530 square microns. The nozzles were made progressively more elongate, so as to provide increases in area.

As may be seen from Figure 9, surprisingly, the larger nozzle areas are not found to remove heat most effectively from the chamber. In fact, at modest values of through-flow, they perform significantly worse than nozzles with areas of  $3A_p$  or less.

It is also expected that the amount of through-flow in the chambers will also act to improve the cooling of the chambers. It is therefore particularly surprising that nozzles having larger areas have worse performance at similar through-flow values, since the through-flow values are relative to the ejection flow, and thus the same through-flow value for a larger nozzle area corresponds to a far greater amount of flow in absolute terms.

The results do however indicate that effectiveness of cooling decreases substantially for nozzles having an area of greater than  $3A_p$ . Thus, the results indicate that nozzles having areas less than  $3A_p$  may be particularly efficient at cooling the apparatus. Accordingly, apparatus with nozzles having areas in the range  $1.25 A_p$  -  $3 A_p$  may afford improvements in productivity whilst also allowing the apparatus to be cooled particularly effectively. This range of areas may also be expressed in terms of the theoretical maximum area for the chamber –  $A_T$  – which, based on the chamber width value of 65 microns is calculated (according to the formula  $A_T = \frac{1}{4}\pi w^2$ ) to be about 3320 square microns. Therefore, the range for the nozzle outlet area may be restated as  $0.48A_T > A_n > 0.20A_T$ . Alternatively, in terms of absolute values, this range may be stated as  $1600 \mu\text{m}^2 > A_n > 650 \mu\text{m}^2$ .

It will be appreciated that, while the test results shown in Figure 9 appear to indicate a point of inflection at  $3A_p$ , there may be some uncertainty in this value. Therefore, advantageous upper limits for the nozzle area may take values less than  $3A_p$ , such as 2.5, 2.6, 2.7, 2.8, or 2.9  $A_p$ , which correspond respectively to 0.40, 0.42, 0.43, 0.45, and 0.46  $A_T$ , or absolute values of approximately 1330, 1380, 1430, 1487, and 1540 square microns. Equally, advantageous upper limits may take values greater than  $3A_p$ , such as 3.1, 3.2, 3.3, 3.4, or 3.5  $A_p$ , which correspond respectively to 0.50, 0.51, 0.53, 0.54 and 0.56  $A_T$ , or absolute values of approximately 1650, 1700, 1750, 1810, and 1860 square microns.

Similarly, while for productivity reasons a lower limit of  $1.25 A_P$  may be appropriate, in some situations a relatively larger lower limit may be appropriate so as to provide an appreciable improvement in productivity. Thus, lower limits of 1.30, 1.35, 1.40, 1.45 and  $1.50 A_P$  may be desirable, which correspond respectively to 0.21, 0.22, 0.22, 0.23, and  $0.24 A_T$ , or absolute values of 690, 720, 740, 770, and 800 square microns.

As may be seen from Figure 9, as the amount of through-flow is increased the difference between the different printheads decreases. In particular, as the through-flow exceeds a value of 4 times the ejection flow, the thermal differential experienced in the  $5A_P$  printhead (corresponding to  $0.8A_T$  or approximately 2655 square microns) is within 0.2 degrees of the value for the thermal differential experienced in the other printheads. As 0.2 degrees is generally considered to be within the normal range of variation, it may – depending on the circumstances – be neglected, with the performance of the two apparatus in terms of lifetime and droplet characteristics being substantially the same.

Figure 10 illustrates the results of a further set of similar tests, but with the printheads ejecting droplets with speeds of 12m/s. The same pattern of less efficient cooling for larger nozzle areas as that shown in Figure 9 may also be seen in Figure 10.

It is believed that the worsening in the cooling provided by printheads with larger nozzle areas is a result of a higher actuation voltage being required in order to eject the correspondingly larger droplets. Specifically, in order to achieve the same velocity of ejection for a larger droplet a larger amount of energy is required to overcome the relatively larger inertia of the droplet. This larger amount of energy may therefore result in increased heating of the ink within the chamber. For typical values of through-flow this heating effect appears to dominate the increased flow of heat out of the chamber owing to the larger ejection flow.

It may therefore be appreciated that similar effects should be expected with a number of nozzle geometries, and not necessarily with elongate nozzles. Figures 11 and 12 therefore display embodiments with alternative geometries for the nozzle and also for the chamber, which may experience similar improvements in productivity in combination with good thermal control.

Figure 11(a), for example, provides circular nozzles whose inlets (20a) have diameters that are larger than the width ( $w$ ) of the chamber (11) with which they

communicate, in contrast to the embodiments described above, for example with reference to Figure 7. Such a nozzle may be manufactured by an “ex-situ” process, where the nozzles are formed in a nozzle plate component prior to being attached to the edges of the chamber walls to enclose the chambers. In this way, there is little risk that the nozzle formation process will damage the chamber walls.

Although the nozzle inlet (20a) has a larger width than the chamber (11) with which it communicates and therefore has an area larger than the theoretical maximum  $A_T = \frac{1}{4}\pi w^2$  quoted above, the nozzle outlet (20b) nonetheless has an area that lies in one of the ranges discussed above, which provide benefits in terms of providing improved productivity with desirable levels of temperature control. For example, the nozzle outlet (20b) may have an area defined in the range  $0.48A_T > A_n > 0.20A_T$ , or alternatively, in terms of absolute values,  $1600 \mu\text{m}^2 > A_n > 650 \mu\text{m}^2$ .

Figure 11(b) illustrates a similar embodiment to Figure 10(a), but with nozzles that are elongate in the same direction as the fluid chambers. This may provide improvements in reliability as discussed above.

Figure 11(c) shows a further embodiment where the outlets (20b) of the nozzles are elongate, whereas the inlets (20a) are circular. As with the embodiment of Figure 11(a), the diameters of the inlets (20a) are larger than the widths of the chambers (11).

Figure 12(a) illustrates a still further embodiment, where the chamber walls are tapered along their lengths, with the direction of the taper alternating between neighbouring chamber walls. This results in chambers (11) that have a substantially constant width, but which do not lie parallel to one another. More specifically, the length of each chamber is angularly offset with respect to the array direction, with the sense of the angular offset alternating between neighbouring chambers (11).

Figure 12(b) illustrates a still further embodiment, where, as with the embodiment of Figure 11(a) circular nozzles are provided. However, in this embodiment the chamber includes a portion in the vicinity of the nozzle having a relatively larger width than the remainder of the chamber. Specifically, the portion of the chamber in the vicinity of chamber follows a similar profile to the nozzle itself, which may assist in ensuring that the inlet is confined between the chamber walls.

Those skilled in the art will appreciate that the foregoing teaching may be applied to a wide range of droplet deposition apparatus, rather than being specific to printers.

Thus, disclosure with regard to printers and/or printheads should be understood, unless otherwise stated, to apply more generally to droplet deposition apparatus. Specifically, disclosure with regard to printheads should be understood, unless stated otherwise, to apply to other droplet deposition apparatus, which comprise: an array of  
5 elongate fluid chambers , where each chamber communicates with an orifice for droplet ejection, and the array extends in an array direction; a common fluid inlet manifold; a common fluid outlet manifold; and means for generating a through-flow of fluid from said common fluid inlet manifold, through each chamber in said array and  
10 into said common fluid outlet manifold.

## CLAIMS

1. Droplet ejection apparatus comprising:  
an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction;  
a common fluid inlet manifold;  
a common fluid outlet manifold; and  
means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;  
wherein each of said fluid chambers communicates at one longitudinal end with said common fluid inlet manifold and at the opposing longitudinal end with said common fluid outlet manifold;  
wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ;  
wherein each of said orifices is elongate in a direction parallel to the longitudinal axis of the respective one of said fluid chambers.
2. Apparatus according to Claim 1, wherein actuation of each of said piezoelectric actuators generates acoustic waves at each of the longitudinal ends of the respective chamber, said acoustic waves thereafter travelling towards said orifice.
3. Apparatus according to Claim 1 or Claim 2, wherein each of said fluid chambers has a width  $w$  in said array direction, thus defining a theoretical circular area  $A_T = \frac{1}{4}\pi w^2$ , the orifice outlet for each chamber having an area  $A_n$ , wherein  $0.48A_T > A_n > 0.2A_T$
4. Apparatus according to Claim 3, wherein the value of  $Q_{TF}$  is sufficient to ensure that the temperature of fluid returned to said outlet common manifold is substantially maintained within  $2^\circ\text{C}$  of the fluid entering the chambers from the common inlet manifold.
5. Apparatus according to Claim 3 or Claim 4, wherein the amount of said through-flow is such that  $Q_{TF} > 0.25Q_E$ , and preferably wherein  $Q_{TF} > Q_E$ .

6. Apparatus according to Claim 1 or Claim 2, wherein each of said fluid chambers has a width  $w$  in said array direction, thus defining a theoretical circular area  $A_T = \frac{1}{4}\pi w^2$ , the orifice outlet for each chamber having an area  $A_n$ , and wherein  $0.80A_T > A_n > 0.20A_T$  and  $Q_{TF} > 4Q_E$ .

7. Droplet ejection apparatus comprising:  
an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction;  
a common fluid inlet manifold;  
a common fluid outlet manifold; and  
means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;  
wherein each of said fluid chambers communicates at one end longitudinal end with said common fluid inlet manifold and at the opposing longitudinal end with said common fluid outlet manifold;  
wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ;  
wherein each of said fluid chambers has a width  $w$  in said array direction, thus defining a theoretical circular area  $A_T = \frac{1}{4}\pi w^2$ , the orifice outlet for each chamber having an area  $A_n$ , wherein  $0.48A_T > A_n > 0.20A_T$ .

8. Droplet ejection apparatus comprising:  
an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction;  
a common fluid inlet manifold;  
a common fluid outlet manifold; and  
means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;  
wherein each of said fluid chambers communicates at one end longitudinal end with said common fluid inlet manifold and at the opposing longitudinal end with said common fluid outlet manifold;

wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ;

wherein said orifices are provided in an orifice plate, having a thickness of  $t$  microns, each orifice being tapered so as to define a taper angle  $\theta$ ;

wherein each of said fluid chambers has a width of  $w$  microns in said array direction, thus defining a practical circular area  $A_P = \frac{1}{4}\pi(w-e-2t \tan \theta)^2$ , with  $e$  taking a value between 5 and 10 microns, the orifice outlet for each chamber having an area  $A_n$ , wherein  $3A_P > A_n > 1.25A_P$ .

9. Droplet ejection apparatus comprising:

an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction;

a common fluid inlet manifold;

a common fluid outlet manifold; and

means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;

wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold;

wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ;

wherein the orifice outlet for each chamber has an area  $A_n$  wherein  $1600 \mu\text{m}^2 > A_n > 650 \mu\text{m}^2$ .

10. Apparatus according to any one of claims 7 to 9, wherein the value of  $Q_{TF}$  is sufficient to ensure that the temperature of fluid returned to said outlet common manifold is substantially maintained within  $2^\circ\text{C}$  of the fluid entering the chambers from the common inlet manifold.

11. Apparatus according to any one of claims 7 to 10, wherein the amount of said through-flow is such that  $Q_{TF} > 0.25Q_E$ . and preferably wherein  $Q_{TF} > Q_E$ .

12. Droplet ejection apparatus comprising:

an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction;  
a common fluid inlet manifold;  
a common fluid outlet manifold; and  
means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;  
wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold;  
wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ;  
wherein each of said fluid chambers has a width  $w$  in said array direction, thus defining a theoretical circular area  $A_T = \frac{1}{4}\pi w^2$ , the orifice outlet for each chamber having an area  $A_n$ , and wherein  $0.80A_T > A_n > 0.20A_T$  and  $Q_{TF} > 4Q_E$ .

13. Droplet ejection apparatus comprising:

an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction;  
a common fluid inlet manifold;  
a common fluid outlet manifold; and  
means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;  
wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold;  
wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ;  
wherein said orifices are provided in an orifice plate, having a thickness of  $t$  microns, each orifice being tapered so as to define a taper angle  $\theta$ ;  
wherein each of said fluid chambers has a width of  $w$  microns in said array direction, thus defining a theoretical circular area  $A_P = \frac{1}{4}\pi(w - e - 2t \tan \theta)^2$ , with  $e$  taking a value between 5 and 10 microns, the orifice outlet for each chamber having an area  $A_n$ , wherein  $5A_P > A_n > 1.25A_P$ , and  $Q_{TF} > 4Q_E$ .

14. Droplet ejection apparatus comprising:  
an array of elongate fluid chambers, each chamber communicating with an orifice for droplet ejection, the array extending in an array direction;  
a common fluid inlet manifold;  
a common fluid outlet manifold; and  
means for generating a through-flow of fluid ( $Q_{TF}$ ) from said common fluid inlet manifold, through each chamber in said array and into said common fluid outlet manifold;  
wherein each of said fluid chambers communicates at one end with said common fluid inlet manifold and at the opposing end with said common fluid outlet manifold;  
wherein each chamber is associated with at least one piezoelectric actuator for effecting droplet ejection from said orifice, resulting in an ejection flow of fluid from said chamber and out of said orifice, said ejection flow occurring simultaneously with said through flow, said ejection flow having a maximum value  $Q_E$ ;  
wherein the orifice outlet for each chamber has an area  $A_n$  and wherein  $2700 \mu\text{m}^2 > A_n > 650 \mu\text{m}^2$  and  $Q_{TF} > 4Q_E$ .

15. Apparatus according to any preceding claim, wherein said orifices are provided in an orifice plate.

16. Apparatus according to Claim 15, wherein each of said elongate chambers is defined between two elongate chamber walls, with the top edges of said chamber walls together providing a substantially planar surface, said orifice plate being attached to said surface.

17. Apparatus according to any one of claims 1 to 14, wherein each of said elongate chambers is defined between two elongate chamber walls.

18. Apparatus according to Claim 16 or Claim 17, wherein each of said piezoelectric actuators extends along the length of a corresponding chamber.

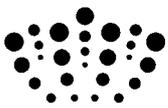
19. Apparatus according to Claim 18, wherein each of said piezoelectric actuators extends substantially from the first end of the chamber to the second end of the chamber.

20. Apparatus according to any one of claims 16 to 19, wherein said chamber walls comprise piezoelectric material, each of said piezoelectric actuators comprising a corresponding one of said chamber walls.

21. Apparatus according to any preceding claim, wherein the longitudinal axes of said fluid chambers are parallel to a channel extension direction and preferably wherein said channel extension direction is perpendicular to said array direction.

22. Apparatus according to any preceding claim, wherein each of said orifices is tapered so that the area of the nozzle outlet is less than the area of the nozzle inlet.

23. Method for depositing droplets of fluid comprising the steps of:  
providing an apparatus according to any one of the preceding claims;  
operating said apparatus so as to provide said through-flow and said ejection-flow.



**Application No:** GB1214348.3  
**Claims searched:** 1-6 and 15-23

**Examiner:** Mr Marc Collins  
**Date of search:** 10 December 2012

**Patents Act 1977: Search Report under Section 17**

**Documents considered to be relevant:**

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	1-6, 15-23	WO 00/38928 A1 (XAAR TECHNOLOGY LTD.) See whole document especially abstract and figures 1-5.
Y	1-6, 15-23	WO 01/12442 A2 (XAAR TECHNOLOGY LTD.) See whole document especially figures.
Y	1-6, 15-23	EP 0792744 A2 (HEWLETT PACKARD CO.) See whole document especially figure 7B and 9.
Y	1-6, 15-23	US 2002/140774 A1 (MIKI et al.) See whole document especially figures 2A and 2B.
Y	1-6, 15-23	US 2007/268335 A1 (SILVERBROOK RESEARCH PTY LTD) See whole document especially figure 2.
Y	1-6, 15-23	WO 2007/041747 A1 (SILVERBROOK RESEARCH PTY LTD) See whole document especially abstract and figures.

**Categories:**

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

**Field of Search:**

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>X</sup> :

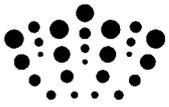
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Worldwide search of patent documents classified in the following areas of the IPC

B41J
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The following online and other databases have been used in the preparation of this search report

EPODOC, WPI
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**International Classification:**

<b>Subclass</b>	<b>Subgroup</b>	<b>Valid From</b>
B41J	0002/14	01/01/2006



**Application No:** GB1214348.3  
**Claims searched:** 7, 10-12 and 15-23

**Examiner:** Mr Marc Collins  
**Date of search:** 27 June 2013

**Patents Act 1977  
Further Search Report under Section 17**

**Documents considered to be relevant:**

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	7, 10-12 and 15-23	WO 00/38928 A1 (XAAR TECHNOLOGY LTD.) See whole document especially abstract and figures 1-5.
Y	7, 10-12 and 15-23	WO 01/12442 A2 (XAAR TECHNOLOGY LTD.) See whole document especially figures.
Y	7, 10-12 and 15-23	JP 55081173 A (CANON) 18.06.80. See EPO abstract and figures.
Y	7, 10-12 and 15-23	US 4707705 A (HARA et al.) See whole document especially column 14, lines 41-48 and figures 16-19.

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&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

**Field of Search:**

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>X</sup> :

Worldwide search of patent documents classified in the following areas of the IPC

B41J

The following online and other databases have been used in the preparation of this search report

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**International Classification:**

Subclass	Subgroup	Valid From
B41J	0002/14	01/01/2006



**Application No:** GB1214348.3  
**Claims searched:** 9-11 and 14-23

**Examiner:** Mr Marc Collins  
**Date of search:** 27 June 2013

**Patents Act 1977**  
**Further Search Report under Section 17**

**Documents considered to be relevant:**

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	9-11 and 14-23	WO 00/38928 A1 (XAAR TECHNOLOGY LTD.) See whole document especially abstract and figures 1-5.
Y	9-11 and 14-23	WO 01/12442 A2 (XAAR TECHNOLOGY LTD.) See whole document especially figures.
Y	9-11 and 14-23	EP 0792744 A2 (HEWLETT PACKARD COMPANY) See whole document especially column 6, lines 25-27.
Y	9-11 and 14-23	US 2004/201648 A1 (SEKIYA) See whole document especially paragraphs [0269], [0280] and [0289].
Y	9-11 and 14-23	JP 55081173 A (CANON) 18.06.80. See EPO abstract.
Y	9-11 and 14-23	US 2010/265296 A1 (KLADIAS et al.) See whole document especially paragraph [0006].

**Categories:**

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&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

**Field of Search:**

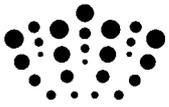
Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>X</sup> :

Worldwide search of patent documents classified in the following areas of the IPC

B41J

The following online and other databases have been used in the preparation of this search report

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**International Classification:**

<b>Subclass</b>	<b>Subgroup</b>	<b>Valid From</b>
B41J	0002/14	01/01/2006



**Application No:** GB1214348.3

**Examiner:** Mr Marc Collins

**Claims searched:** 8, 10-11, 13 and 15-23

**Date of search:** 27 June 2013

**Patents Act 1977**  
**Further Search Report under Section 17**

**Documents considered to be relevant:**

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	8, 10-11, 13 and 15-23	WO 00/38928 A1 (XAAR TECHNOLOGY LTD.) See whole document especially abstract and figures 1-5.
Y	8, 10-11, 13 and 15-23	WO 01/12442 A2 (XAAR TECHNOLOGY LTD.) See whole document especially figures.
Y	8, 10-11, 13 and 15-23	US 2005/285910 A1 (SEKIGUCHI) See whole document especially figures 5-6.
Y	8, 10-11, 13 and 15-23	GB 2166087 A (CANON) See whole document especially page 3, line 1 to page 4, line 1 and figure 6.

**Categories:**

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

**Field of Search:**

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC<sup>X</sup> :

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Worldwide search of patent documents classified in the following areas of the IPC

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The following online and other databases have been used in the preparation of this search report

EPODOC, WPI
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**International Classification:**

Subclass	Subgroup	Valid From
B41J	0002/14	01/01/2006