Recent developments in moving nozzle inkjet printhead technology

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Abstract

The developments seen in inkjet printing over the past two decades have resulted in the adoption of the technology in significant, previously untapped, markets. Applications such as ceramic tile decoration, printed electronics and additive manufacturing have all been transformed by the increased reliability, speed and range of materials that can be deposited, delivering huge commercial upsides to the end users. [1]

Nevertheless, there is still significant room for further technical developments to drive inkjet technology into new markets. Incremental changes to the performance of established technologies could deliver this vision given sufficient time and investment, but there is plenty of opportunity for a new, disruptive approach to drive the industry forwards.

The Technology Partnership plc (TTP) has been developing a portfolio of droplet generating technologies for a number of applications, one embodiment of which is an industrial inkjet printhead. The ejection mechanism is based on a 'moving nozzle' approach, which is characterized by driving a nozzle plate at ultrasonic frequencies in order to generate the fluidic pressure required to generate the droplet.

This paper provides an update on the anticipated benefits of the technology, applications where we believe it could deliver significant commercial advantages and the current status of development.

Details

The Technology Partnership plc (TTP) is Europe's leading product and technology development company. We have been developing novel droplet generating technologies for over 25 years, building a portfolio of commercialized products and technologies directed at a wide range of applications. One particular technology is based on a 'moving nozzle' approach, which is characterized by vibrating a nozzle plate at ultrasonic frequencies in order to generate the fluidic pressure required to generate a droplet. Pressure is created in the fluid behind the nozzle as the nozzle plate is accelerated into the bulk fluid due to the fluid's largely incompressible nature. Surface tension holds the fluid in the nozzle at other times. A schematic of this ejection process is shown in Figure 1. Typically, the amplitude of motion is ~1 µm and the oscillation occurs at 10-100 kHz.

A defining characteristic of this technology is that it removes the requirement for tiny chambers behind the nozzle to constrain the pressure generated in order to drive droplet generation. This yields a planar head architecture, which can be as simple as a piezoelectric actuator bonded to a nozzle plate. Behind the nozzle plate, the fluidic reservoir can be completely open.

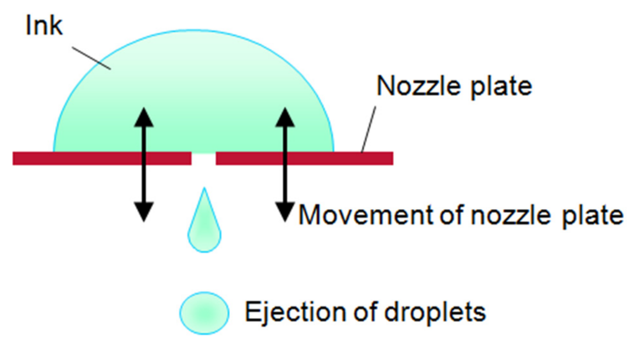

Figure 1: *a schematic showing the basic ejection mechanism of TTP's moving nozzle technology.*

The architecture of the head can be readily tailored to different applications; for example, one can choose to have a different number of nozzles per independent actuator. Multiple nozzles per actuator can yield sprays or aerosols when the drive waveform is applied continuously. Alternatively, a single nozzle per actuator yields a dispensing head or an inkjet printhead when a modulated drive waveform is used in order to produce single droplets on demand.

Figure 2: *the eFlow produced by Pari GmbH.*

Further, different geometries can be designed depending on the requirements of the application. Typically circular devices are used for aerosol production and linear arrays of nozzles are used for industrial coating heads and inkjet printheads.

Several technical features are enabled by this ejection process. Firstly, when operating in spray mode, a relatively narrow droplet size distribution is produced. This feature enabled the first commercial application of the technology: the eFlow nebulizer by Pari GmbH [2]. This device was designed to create droplets around 5 µm in diameter, which are ideally sized to maximize the efficiency by which drugs are delivered into the patient's lungs. A version of the eFlow is shown in Figure 2.

A more recent product has also taken advantage of this feature: the Büchi B-90 laboratory spray drier.

A second important feature of devices incorporating the moving nozzle ejection mechanism is the ability to eject a very wide range of fluids. The heads can eject fluids that have a wide range of surface tensions; can eject particles up to at least 50µm in diameter, can handle highly shear-thinning rheologies; and can tolerate rapidly sedimenting dispersions.

On surface tension: Fluids with carriers ranging from MEK through to water can all be ejected, often from the same design of ejection head with similar ejection dynamics.

On rheology: the only viscosity-limited process in the ejection mechanism is the movement of the fluid through the nozzle. This occurs at a shear rate of 10^5-10^6 s^{-1} and requires the viscosity to be less than 100 mPa.s at this shear rate for the fluid to be sprayed. To achieve drop-on-demand ejection the limit is closer to 20 mPa.s at 10^5 s^{-1}.

As an example, the rheology of a fluid that was ejected in spray mode is shown in Figure 3. The highly shear-thinning rheology exhibits a leveling off below 100 mPa.s, satisfying the condition for spraying.

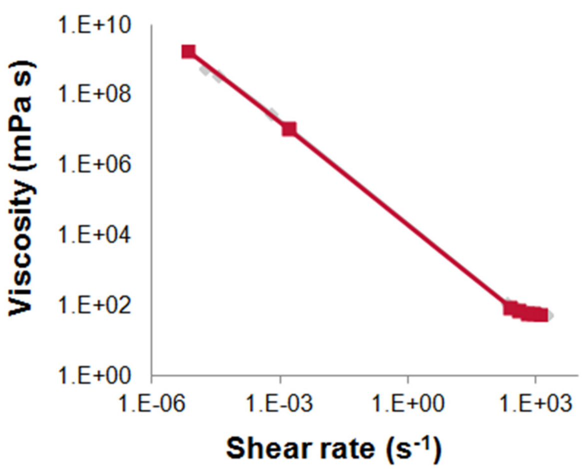

Figure 3: *rheology of an example fluid that TTP's TouchSpray can eject.*

On particle size: fluids containing large particles with sizes up to 50 µm (D_{100}) have been demonstrated to date. (Note that there is no reason to believe that this is a fundamental upper limit.) Such particles are often heavily sedimenting and, due to the open architecture of the devices, this can be readily countered by continuously recirculating the fluid through the head directly at the nozzle. We have also developed recirculating fluid supply systems specifically to handle such heavily sedimenting fluids.

As a result of the ability to eject fluids with these wide range of properties, we have shown the ability to eject metallic flakes; large decorative pigments; glass frit and ceramic glaze; adhesives; paints; varnishes; polyurethanes (including two-part polyurethanes); flexo and gravure inks; and even live cells. We have also demonstrated the ejection of standard fluids from a variety of industries, sometimes with only minimal modification.

Such capability, when placed in the context of industrial inkjet printing, yields a highly differentiated offering, which could enhance the penetration of inkjet into current markets and open up new opportunities. Some examples are listed below.

- *Additive manufacturing:* 3D printing is already a hugely important application for many industries, but the range of materials that can be ejected is very limited, largely restricting applications to prototyping. Moving nozzle technology could enable the ability to eject engineering materials, greatly expanding the role of inkjet as a manufacturing tool.
- *Life sciences*: the ability to print living cells and other biological fluids that have complex rheologies means that materials with improved biocompatibility and biointegration can be ejected. Faster, cheaper and more accurate diagnostic techniques can be developed.
- *Two-part polyurethanes and other polymers/adhesives*: these materials can be very viscous and hence the materials are rarely compatible with inkjet printing. Highly controlled printing of these adhesives would reduce manufacturing costs and improve quality across a wide range of products.
- *Automotive and aviation paint*: decorative details are currently applied manually using decals and masking. In the short term, digital printing enables an economic alternative for painting two-tone cars and, in the longer term, full digital decoration, e.g. for fleet vehicles.
- *Security printing*: large pigments, for example overt pigments and taggants, have applications in currency and passports. Although these inks are commonly deposited by analogue printing techniques, digital deposition means that every image can be encoded with information and hence will increase security for authentication.
- *Ceramic tile and glass decoration*: tile/glass manufacturers would like to combine screen-printing pigments/frits with digital deposition. The large particle size of the pigments/frits leads to higher quality images whilst digital deposition allows tile-by-tile variation and, since non contact, thinner tiles leading to lower costs throughout the supply chain.
- *Coding and marking*: this is one of the best-known existing applications for inkjet. Continuous inkjet heads use acetone or MEK inks to enable fast drying on any substrate, but the print quality is relatively poor. Current industrial inkjet offers a possible route to higher print quality, but the reliability is poor. A moving-nozzle printhead enables the possibility of higher quality printing with industry standard inks.

To date, TTP has developed Vista Inkjet to a high level of laboratory demonstration. Specifically, this entails:

- a prototype printhead capable of printing a wide range of materials that can be readily tailored to a number of specifications. An example of an industrial inkjet printhead encapsulating TTP's moving nozzle technology is shown in Figure 4;
- creation of small-volume printhead assembly process with bespoke tooling, but based on scalable processes;
- drive electronics based on TTP Meteor, a product available on the market that enables platform-

independent drive electronics for a variety of commercial printheads;
- novel fluid supply systems capable of handling a wide range of inks, in particular those containing heavily sedimenting particles;
- test-bed print stations to enable the further development of the technology and to allow the creation of samples.

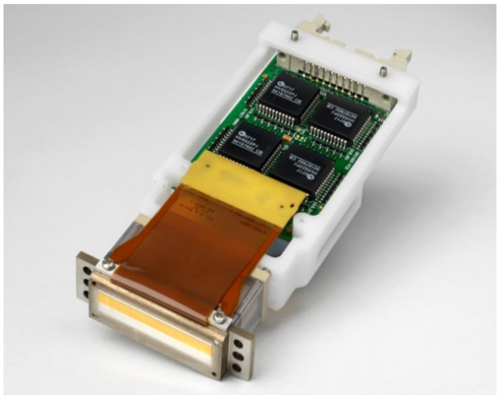

Figure 4: *a laboratory prototype of an industrial inkjet printhead with TTP's moving nozzle technology, including drive electronics.*

As a result of this development and the unique capabilities of the technology, we have been able to demonstrate the applicability of TTP's technology to all the applications described above and more. A small number of samples demonstrating this can be viewed in Figure 5.

Of critical importance to any industrial inkjet is reliability. A further advantage of moving nozzle technology is the inbuilt ultrasonic cleaner that is effectively embedded in the technology. If a rogue piece of dirt gets stuck in the nozzle, it frequently gets cleared due to the normal action of the printhead in operation. This is a powerful contribution to reliability in addition to the ability to continuously recirculate – and potentially filter – the inks in use.

Summary

Moving nozzle droplet generating technology of the type invented by TTP was first described as a circular device over 20 years ago.[3] Over recent years, TTP has modified the device architecture to provide a linear array of independently addressable nozzles: an inkjet printhead. The main advantages that have been demonstrated are the ability to eject a wider range of materials with the promise of increased reliability in a production environment.

Applications being actively pursued by TTP and its partners include digital deposition and printing of high-value and functional materials; biological materials, including cells; large security pigments; coding and marking; paints and varnishes including automotive paints; large glass frit and complex inorganic pigments for glass and ceramic tile decoration; textile decoration; and large metallic flakes for electronic and decorative uses. It is ideally suited to applications where digital printing is desired, but where off-the-shelf technologies cannot print the desired materials.

TTP has developed the technology to a high level of demonstration for a number of applications and we are now well-placed to address the next steps towards commercialisation.

Figure 5: *samples printed using TTP's moving nozzle industrial inkjet technology. Top left: ceramic pigments and glass frit on glass, the solids are those used in standard screen printing pastes. Top right: standard two-part aviation paint on metal sheet. Bottom left: 11 μm (D_{50}) aluminum flakes on red card. Bottom right: flexo ink on textile.*

References

[1] J. R. Castreon-Pita et al., Atomisation and Sprays, 23 (6), 541-565 (2013).

[2] http://www.pari.de/de-en/products/lower-airways/eflow-rapid-nebuliser-system/on

[3] EP 0,615,470 B1.

Author Biography

Dr. Peter Brown has been with TTP for 13 years and is an experienced leader of technical and business development activities with a focus on industrial digital printing and spray coating. Peter obtained his PhD from the University of Cambridge on the optoelectronics of semiconducting polymers and joined TTP's Printing Technology Division in 2002. Now embedded in the Applied Sciences group, his main interests lie in developing novel technical solutions to a wide range of industrial and commercial challenges.