XAAR

Pushing the boundaries of inkjet technology with high viscosity printing

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Ultra High Viscosity TECHNOLOGY

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Introduction

Inkjet printing's adoption into new markets, processes and applications has been fundamental to the technology since its very inception.

The combination of a digitally based process and increasing capabilities in frequency (thereby speed), print resolution – and most importantly for success in many new industrial applications – reliability, have made it a key enabler for many innovators and developers.

However, inkjet has also had its limitations, so a variety of coating, decorating and manufacturing methods based on other printing or deposition techniques have been used to overcome these. Consequently, some innovative applications have led to inkjet technology being overlooked in the development of new processes and ways of working.

One such limitation is that of fluid and ink viscosity.

Traditionally, inkjet has only been considered when using low viscosity fluids – but this is now changing. The capability to handle a much wider range of fluids at viscosities of up to 100 centipoises (cP), is increasing the relevance and practicability of inkjet technology across a variety of new printing, coating, advanced (functional fluids) and additive manufacturing applications. It is rapidly becoming ***the*** manufacturing technology for additive manufacturing and 3D printing, as well as for personalisation, coating and other innovative print and manufacturing processes.

This white paper looks at the historical background to the limitation of inkjet technology's use and highlights how the latest printhead innovations, such as Xaar's Ultra High Viscosity Technology, are changing the landscape of jettable fluids.

What is viscosity and how does it impact inkjet?

Viscosity is a measure of a fluid's resistance to flow, and it describes the internal friction of a moving fluid. A fluid with high viscosity resists motion due to its molecular makeup, which generates a lot of internal friction, whereas a fluid with low viscosity flows easily because its molecular makeup causes very little friction when in motion. Viscosity is also influenced by a variety of factors including temperature, the base viscosity of materials and particle loading.

Traditionally, industrial inkjet printing applications have had a recommended nominal jetting viscosity of up to 10-12cP affected by printhead architecture, flow rates, temperature and fluid handling capabilities.

The development of Xaar's TF Technology helped enable the transition of inkjet into the industrial ceramics market, where fluids loaded with more particles pushed the base viscosity higher. However, it is only with the further development of new enabling technology and the latest printheads that this has changed more significantly. The stabilisation of increased particle concentrations and densities, and the ability to explore higher viscosities in applications such as 3D photopolymer jetting and beyond, have now become viable.

The importance of high viscosity

But why is printing more viscous fluids important, or indeed needed? In answer, the ability to print high viscosity fluids significantly extends the range of materials that can be printed using drop-on-demand inkjet, and therefore enhances its relevance as a technology of choice for many different applications.

Modifying ink formulations, for example, provides additional functionality in many existing uses. By increasing particle loading or using larger particles, a wider colour gamut and greater opacity can be achieved in a single pass, alongside helping to reduce ink usage and save energy.

Consequently, colours are more vibrant and whites and blacks are stronger. This unbeatable capability to print high opacity, especially whites, in a single pass is extremely useful for delivering impact on many labels and direct-to-shape packaging applications.

In addition, jetting fluids or inks in a single pass, presents opportunities for label and packaging printers to deliver new and exciting finishes for clients across a wider variety of packaging materials, with a high degree of efficiency and productivity.

Energy is also saved because UV fluids, which previously required heating to 45°C before jetting, can now be laid down at room temperature. Overall, less fluid is required as well, making the process even more sustainable.

High-build varnish embellishments can also be achieved more easily, to add texture, visual impact, and functionality (such as ink that resists cracking on flexible surfaces) to labels and packaging or direct to the primary packaging or product itself, such as glass bottles where effects need to survive handling and cleaning cycles. From braille and tactile warning triangles on labels, to the latest haptic and embossed effects for a high-end look and real shelf presence for glass, rigid and flexible packaging, so much more can be achieved.

In 3D and additive manufacturing applications, the printing of high molecular weight polymers can enable a range of functional benefits such as more robust, resilient and flexible printed parts.

Jetting higher viscosity fluids also delivers improved edge definition on non-porous substrates because of reduced drop spread (known as dot gain in analogue printing) before the print is fixed. In addition, new types of materials can be inkjet printed including adhesives, paints and photoresists. This opens up a further new range of applications for inkjet, including bio-medical, automotive, printed circuits, electronics applications and braille printing solutions.

Inkjet is a digital technology that opens the door to new applications within existing and new markets, and through improvements in handling fluids and inks with greater viscosity, it has a significant role to play in the printing and manufacturing processes of not just tomorrow, but today.

Xaar, delivering the capability for high viscosity printing

Xaar has demonstrated jetting at much higher viscosities than other manufacturers in commercial applications and central to this capability is its printhead architecture, and hybrid side shooter design. The open, simple sub-manifold structure directly supplies ink channels and the double-ended acoustic design focusses pressure waves on the nozzle. The flow restriction is also only governed by short channels, reducing the resistance to flow and ensuring the nozzle is primed, making it well suited for high viscosity printing when compared to more convoluted fluid paths.

Any fluid ejected from a printhead always needs to be replenished and if the fluid path is restrictive or indirect, with lots of bends and convolutions, then this refill can be slow, and in the worst case, result in starvation. With an open printhead structure, the channel refill is less impeded meaning starvation is less likely.

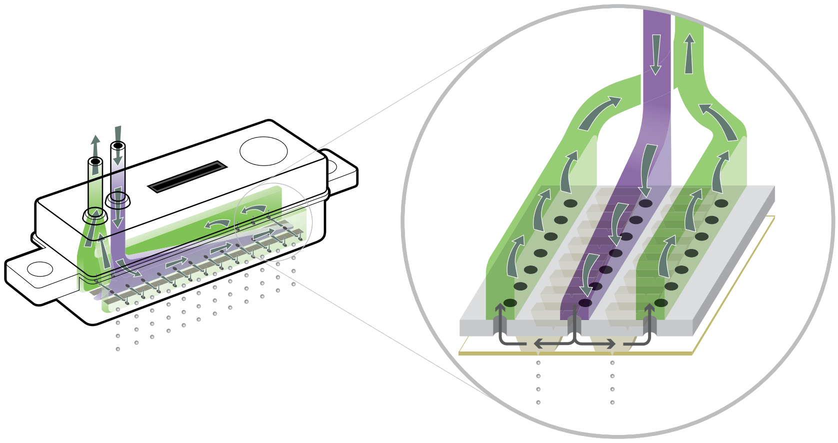


Figure 1:
The fluid flow through Xaar's Hydrid Sideshooter Architecture. Purple indicates the incoming fluid and green the outgoing fluid either side of the nozzle.

With the launch of the Xaar 1001 printhead in 2007, featuring TF Technology, it was possible for the first time to reliably jet highly-pigmented inks, presenting exciting new applications – ceramic tile printing, for example – with the opportunity to employ digital inkjet printing.

TF Technology continuously recirculates the ink through the complete fluid path, right up to the nozzle inlet and – very importantly – immediately past the back of the nozzle at very high flow rates. This constant movement removes debris and bubbles from the actuator, making jetting more reliable and enabling nozzles to 'self-recover' from blockages.

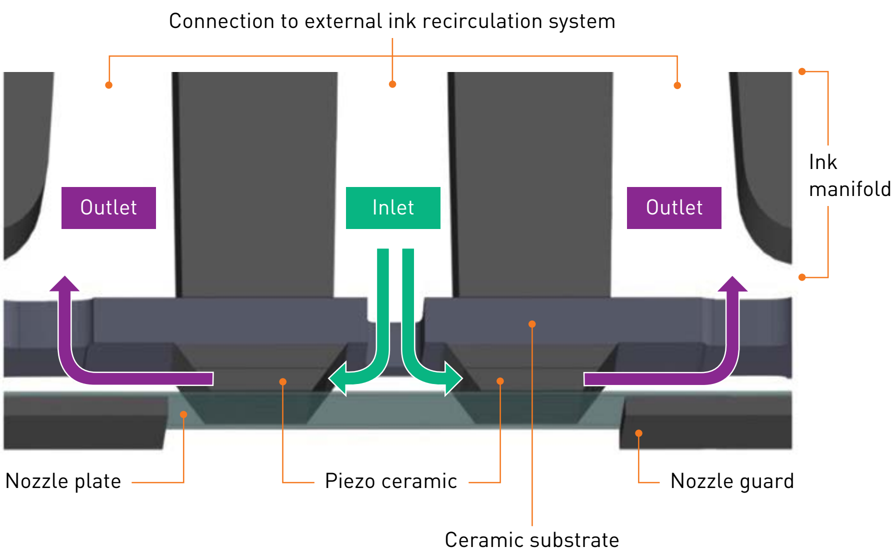


Figure 2:
Schematic of Xaar's TF Technology showing the path of fluid into the piezoceramic channels, directly behind the nozzles, and out again.

TF Technology also ensures fluid is supplied to nozzles at a constant temperature due to its constant recirculation, which removes any viscosity variation caused by changes in ambient temperature and ensures ink solids and gas content become more uniform across the whole printhead nozzle array. This is all the more important for high viscosity applications which may operate on a steeper part of the viscosity-temperature curve and hence any variation would be greater.

It is this combination of TF Technology with Xaar's printhead architecture which allows a continuous and low restriction supply of ink to the nozzle channel and thereby enables high viscosity printing.

TF Technology has additionally enabled Xaar to develop High Laydown Technology, a unique high-productivity single cycle printing mode for Xaar's printheads which has further increased viscosity capability.

High Laydown Technology is achieved by employing a new print mode with existing printheads, and results in larger printed drops at much higher printing frequencies, delivering a massive increase in throughput for high volume applications. For example, with an ejection rate of up to 165 ml/min per printhead, the Xaar 1003 GS12 printhead can fill a Starbucks Grande cup in as little as 3 minutes! And to go even further, the Xaar 2002 printhead can halve that time.

This capability is asking questions of what is possible with inkjet, and Xaar has already demonstrated jetting at much higher viscosities up to 100cP. Handling fluids at this viscosity does of course bring its own engineering challenges, and the need to handle them differently is also a key learning process.

Heating a fluid is one way to drop its viscosity. However, although this is a useful technique to enable printing of more viscous fluids, Xaar's Ultra High Viscosity Technology reduces the requirement to heat the fluid quite as much, meaning higher viscosity fluids can still be effectively jetted and with a reduced energy footprint.

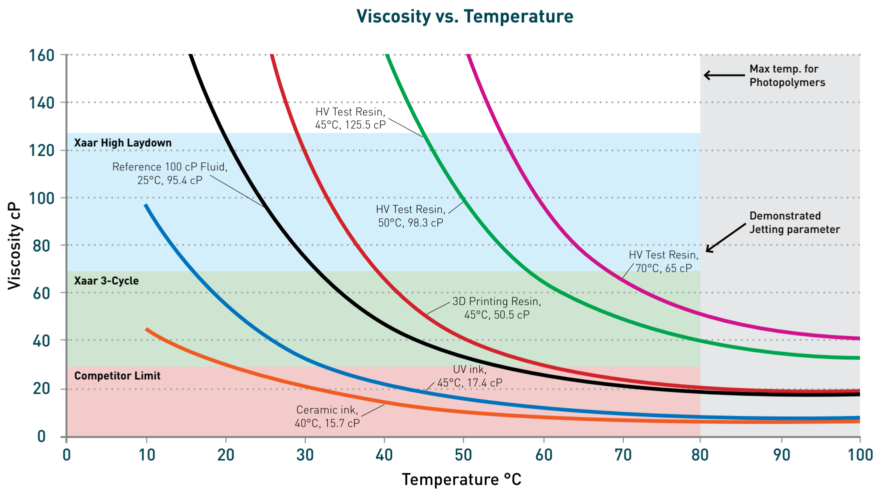


Figure 3:
The viscosity vs. temperature for some example fluids, annotated with specific successful jetting results. The colour bands show the viscosity ranges possible with competitor printheads (red), Xaar's 3-Cycle technology (green) and Xaar's High Laydown Technology (blue). Of note is that fluids that are heated to achieve jettable viscosities either do not need to be heated at all (such as the ceramic ink that could be jetted at 10 °C with Xaar's 3-cycle technology in green section vs. heated to 43 °C in red section) or have extremely high viscosity at low temperature if they are heated and jetted using Xaar's Ultra High Viscosity Technology (green or blue sections).

Xaar is working with a number of fluid partners to establish the viscosity capability of its printheads, and this has shown so far that a standard 3-cycle greyscale mode can print a viscosity of 65cP at 70°C. While using high laydown mode, viscosities of up to 125cP can be jetted. Ongoing research is continuing to push these levels even further. In fact we have recently jetted 100cP fluids in our laboratory using our 2002 GS6 printhead in 3-cycle mode (equivalent to over 1000cP at 23°C). This enables even higher viscosities at high resolution (720dpi).

By combining the increase in base viscosity with an (albeit reduced) increase in jetting temperature there is a greater impact on the viscosity limit of materials at room temperature. As an example, taking the jetting of a photopolymer of 65cP at 70°C as highlighted above, would actually be 1400cP at 20°C.

High viscosity fluids do however present some challenges on the ink system design, and in many ways need to be handled very differently to "standard" viscosity fluids. To achieve the same flow rate through the channels at higher viscosity, the differential pressure needs to be proportionally higher due to the increased flow resistance, however this means that any fluctuations in the pressure control system are also magnified.

Considering tolerance stacking of the supply and return pressures shows that ten per cent pressure variation from the pumps will still remain within the operating meniscus pressure window for a differential pressure of 150mbar for a standard viscosity fluid. In comparison, a high viscosity fluid requiring 500mbar differential pressure for the same flow rate, must maintain the pump control within two per cent to prevent the meniscus pressure from going out of range.

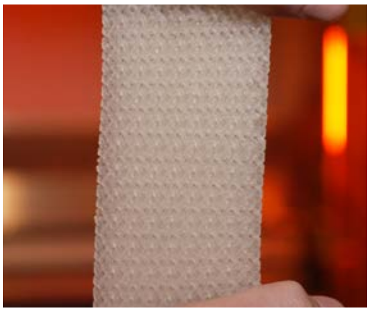
In addition to the control system, the pumps themselves need to be designed and selected to sufficiently handle the fluids being recirculated. For example, the design of the pump may need to be completely different for larger or increased loading of particles; diaphragm or membrane pumps can be damaged by large particles such as glass frits, while oligomeric fluids such as photopolymers may start to react and cure under the high shear of gear pumps, meaning the component selection is crucial.

Further consideration must also be made to the initial start-up conditions for the system. If the fluid viscosity is still high at elevated temperature, then it will be even higher at lower temperatures. For this reason, the system will need to be able to handle a 'cold start' to get the fluid moving and heated enough to recirculate at the desired flow rate.

Given the complexity of the issues, Xaar's dedicated team of experts are constantly working on new applications to support customers' use of this new technology. Understanding high viscosity and some of the challenges it presents for certain fluids such as dealing with particle loading effects and other properties, means the learning is continuous. Yet already the capability unleashed through Xaar technology is delivering significant benefits in print, coating, advanced and additive manufacturing applications.

The future for inkjet, associated industries and pioneers

Access to more materials unveils ever greater uses for digital inkjet printing. The greater flexibility in fluid formulation enables access to new functional group chemistries and new base solvents. For example, less penetrating acrylates for UV inks used in food packaging meeting the regulatory and safety demands or providing an increased range of refractive indexes for optical materials. Higher pigment loading due to potentially better suspension stability becomes an opportunity too, increasing the gamut of graphics for more instant visual impact and more efficient and sustainable printing.



Completely new markets which have not previously considered the use of inkjet technology have now become relevant, with everything from adhesives to electronics and paints potentially benefiting.

Additive manufacturing is a prime example of completely changing the way things are designed and made, and the use of inkjet and high viscosity capability delivers a very scalable process for new applications. Complex manifolds and shapes, previously unmakeable with traditional casting or machining, have now become a reality, and a world where electronics are functionality embedded within the structure being made, is just a part of the overall manufacturing process.

In addition, multiple materials can be jetted with negligible time increase per layer, and multiple mechanical properties can be changed in-situ by combining these materials, with no need for over-moulding.

These, alongside advantages such as customisation, short batch runs and manufacturing to demand, result in less waste throughout the whole manufacturing and distribution ecosystem, delivering the savings and sustainability that will become central to business.

Conclusion

Inkjet is still relatively young but is rapidly evolving into new markets and opportunities due to the capabilities driven by a portfolio of technologies. High Laydown Technology offers impressive throughput for high-build applications and Ultra High Viscosity Technology is truly pushing the boundaries of what's possible with inkjet while retaining high print resolutions for fine features.

These opportunities are many and varied.

In chemistry it ranges from offering access to new formulations while new optical, mechanical and other functional properties for printed parts and new applications previously rejected as not possible with inkjet all become apparent. In design and manufacturing applications a revolution in design is underway enabled by inkjet in additive manufacturing.

New added functionality is helping to deliver everything from haptics and braille for labels at high speed, and high impact lustres for ceramic tile printing in a single pass, through to embedding electronics in production parts.

And sustainability is at the heart of these technological developments, as inkjet delivers savings in energy use and minimises material waste through the highly precise jetting of fluids and inks across its many applications.

We are indeed now approaching a world where you can print anything you can imagine.

References

1. Handbook of Industrial Inkjet Printing, Editor Werner Zapka, Published by Wiley, 2018
2. Presentation to the IJC: An Analysis of Different Ink Recirculation Architectures and their Benefits. Angus Condie, Mark Crankshaw, Adam Strevens, Xaar plc, 5-6th October 2016
3. Xaar 2001+ Printhead Technology Delivers the Speed Needed for New Canon Digital Label Printer, What They Think, 20 June 2018
4. Print Quality vs. Print Resolution, Durst white paper http://viantrade.com/pdfs/EN-durst_whitepaper_final.pdf, 2014
5. www.Xaar.com/applications
6. High Speed Sintering for 3D printing applications Neil Hopkinson, Adam Ellis, Adam Strevens, Manolis Papastavrou and Torben Lange, Xaar plc, 2017
7. UV white inkjet inks for single-pass label applications Mark Ritchie, Xaar plc, 2016
8. Jetting Very High Viscosities With Piezo-Electric Drop-On-Demand Printheads For Increased Capability Of Photopolymer 3D Printing, Nick Jackson 1, Wolfgang Voit 2, Renzo Trip 2, Angus Condie 1, Xaar plc; 1 Cambridge, UK; 2 Stockholm, Sweden, 2019
9. Jetting Very High Viscosities with Piezo-Electric Drop-On-Demand Printheads for Photopolymer 3D Printing, Nick Jackson, Wolfgang Voit, Renzo Trip, Angus Condie, 2019
10. Presentation to IJC: Expanding the boundaries of piezo inkjet technology with very high viscosity jetting capabilities. Nick Jackson, November 2019
11. Inkjet printhead on a robotic arm, R. Trip, Xaar plc, R. Rätz, iPrint Center, O. Bürgy, iPrint Center, F. Bircher, iPrint Center, W. Zapka, Xaar plc, 2018
12. Presentation at InPrint Italy, Xaar Printhead Technology, Tomas Cerny, Xaar plc, 2018
13. Masters thesis: Detektion und characterisierung von verunreinigungen in Piezokeramischen Mikrokanälen, Stefan Sack, 2013
14. Ink Recirculation – Xaar TF Technology A Study of the Benefits, Mark Crankshaw, Mark Rulman, Hanifeh Zarezadeh, Maëlle Douaire, Angus Condie, 2016

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