INK-JET PRINTING FOR THE DECORATION OF CERAMIC TILES: TECHNOLOGY AND OPPORTUNITIES

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ABSTRACT

Ink-jet printing is widely used for small-scale (home and small office) graphical and text printing. It is also now being increasingly applied to commercial printing and certain features make it particularly attractive for printing in a manufacturing environment. Over the past ten years, the possibilities of ink-jet printing for the decoration of ceramic tiles have been explored and significant advances have occurred in the underlying technologies of printhead design and ink formulation. Several commercial printing systems, both for in-line and off-line use, are now on the market. This paper reviews the basic principles of ink-jet printing, and discusses the features of the process which make it suitable for decorating ceramic tiles in an industrial context. We consider the current level of development of ink-jet printing for this application and briefly consider possible future opportunities.

1. INTRODUCTION

The past few years have seen an explosion in the number of companies offering new printers based on inkjet printing technology for the decoration of ceramic tiles. In the year 2008 alone, five companies launched new in-line printers, while three others launched off-line machines. Indeed, 2008 has been termed 'the year of the digital revolution for the ceramic sector' (CeramicWorldWeb, January 2009). The very rapid expansion of this technology which has occurred over the past decade is shown clearly in figure 1, which plots the number of companies offering in-line ink-jet tile printers.

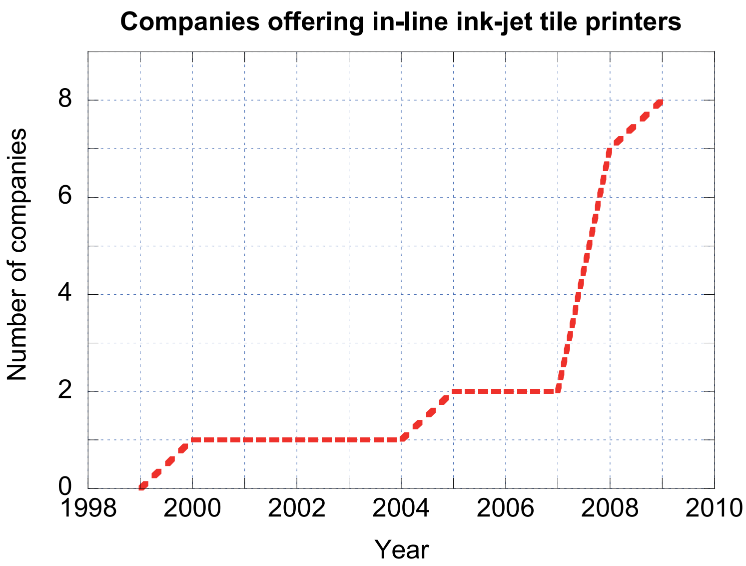

Figure 1. Numbers of companies offering commercial in-line ceramic tile printers based on ink-jet technology (data from table 1 below).

It seems highly likely that despite the current worldwide economic difficulties and their effects on the architectural ceramics industry, this new technology is here to stay, and that once ceramic production starts to recover there will be renewed interest in investment in this method of tile decoration. It is the purpose of this paper to explain what ink-jet printing can do, and to show why it has features which can contribute value and flexibility to manufacturers and users of ceramic tiles. We will review the basic principles of ink-jet printing, and discuss the features of the process which make it suitable for printing on to ceramics. We will consider the current level of development of ink-jet printing for ceramic tile applications and briefly consider some more speculative possible future opportunities for the application of this technology.

The basic principles of conventional printing have remained the same for hundreds of years: the many different processes which we take for granted all involve the repeated reproduction of the same image or text many times. Usually, this is achieved by transferring a pattern of liquid or semi-liquid ink from some master pattern through direct contact with the paper or other substrate. Changes to the printed pattern can only be achieved by changing the master pattern, which involves making physical, mechanical changes within the printing machine.

The conventional printing processes used for ceramic tile printing are essentially the same processes which have been developed for the printing of paper, card and textiles: flat screen printing during the 1960s, rotary screen printing in the 1970s, and flexographic and intaglio printing in the 1990s (De Carlo 2003). In contrast to these methods, ink-jet printing provides a fundamentally different process. The creation and deposition of each small droplet of ink is carried out under digital control, so that each pattern printed in a sequence can just as readily be different from the others as it can be the same. This method is widely used for small-scale (home and small office) graphical and text printing. It is now being increasingly applied to commercial printing on to paper and card, and the process also offers a wide range of possibilities for the deposition of materials in manufacturing processes. Several factors make it particularly attractive for these applications (Hutchings 2009).

First, it is a digital process. The location of each droplet of material can be predetermined on an x-y grid, and if necessary can in principle be changed in real time, for example to adjust for distortion or misalignment of the substrate. Because it is a digital process, each product in a sequence can easily be made different from every other, in small or even in major ways; bespoke products are generated just as readily as multiple replicas of the same design. Since the pattern to be printed is held as digital data, there may be significant cost savings over processes which involve the use of a physical mask or template.

Second, it is a non-contact method; the only forces which are applied to the substrate result from the impact of very small liquid drops. Thus fragile substrates can be processed which would be difficult or even impossible to handle in more conventional printing methods. Non-flat substrates can be printed, since the process can be operated with a stand-off distance of at least 1 mm, and in some cases much more.

Third, a wide range of materials can be deposited; the only limitation is that at the point of printing, the material is in liquid form with its physical properties (mainly viscosity and surface tension) lying in an appropriate range. Pigments, dyes, glass frits and metallic particles are readily printed from suspensions, as well as a wide range of other materials which can be used to perform optical and electronic functions.

The advantages of ink-jet printing for decorating ceramic tiles draw on all three of these factors. Specifically, the following benefits have been claimed in comparison with conventional printing methods (Harvey and Sainz 2000, Burzacchini and Zannini 2009):

- digital image definition and the flexibility of the process mean that each tile can be different if required, allowing more realistic representation of natural material such as stone, and also the possibility of printing one-off products such as murals or unique floors;
- different patterns of tile can be processed in sequence or even together;
- high image definition can be achieved;
- overall production times for prototypes and new products are shortened;
- customization, through small changes to a basic design, is straightforward;
- storage of designs in the form of digital data is simple and very low cost;
- edge-to-edge printing allows uninterrupted patterns across tile boundaries;
- profiled tiles can be decorated automatically, avoiding costly manual handling;
- set-up times are significantly lower than for conventional printing methods;
- changes to image size can readily be made to accommodate different tile sizes;
- process colour capability is achieved with a small range of inks, typically the standard four colours (CMYK) used in conventional printing: cyan, magenta, yellow and black;
- there is more efficient use of inks, and so less wastage;
- machine footprints are smaller than for conventional processes.

The aim of this review is to explore the principles of ink-jet printing, and see how it is being used for ceramic tile decoration. We shall review the printer technologies in current use, and comment on possible future developments for innovative applications.

2. PRINCIPLES OF INK-JET PRINTING

Two different methods are commonly used to generate drops in ink-jet printing, termed continuous ink-jet (CIJ) and drop-on-demand (DOD) (Martin et al. 2008). These are illustrated in figure 2. In CIJ (figure 2a) a continuous jet of ink is emitted from a nozzle and breaks up into a stream of spherical ink drops. The break-up is caused by surface tension forces which make a cylindrical jet unstable (the Plateau-Rayleigh instability), but it is also controlled by applying a well-defined vibration to the stream. Each of the drops is then individually electrically charged by induction from a nearby electrode, and steered (deflected) by electrostatic forces to write spots on the substrate. By varying the level of the induced charge the deflection experienced by the drop, and hence its final position on the substrate, can be controlled. Drops that are not charged in this way are fed into a gutter and recycled. Simple CIJ systems use single nozzles, but some systems also exist with multiple nozzles. CIJ printing is a well-established process which is widely used in industry, for example for printing date and batch codes, and is to be found in the ceramics industry for labelling of packaging, and in some cases to print identification codes on to the edges of tiles. It is not, however, used for tile decoration.

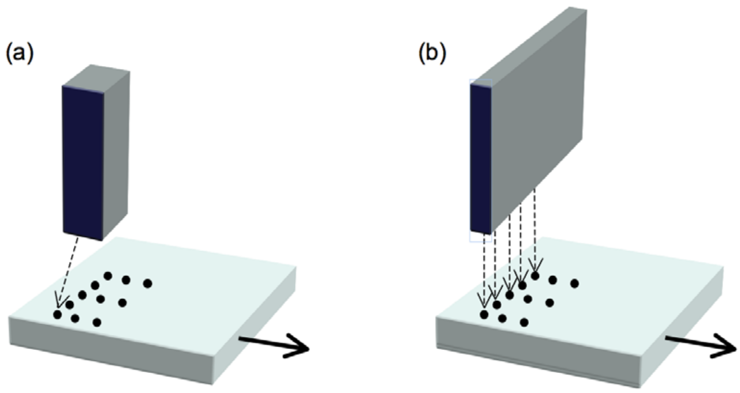

Figure 2. Illustration of the principles of operation of (a) continuous ink-jet (CIJ) printing, and (b) drop-on-demand (DOD) ink-jet printing. In each case ink drops are emitted from a printhead: in CIJ they are individually steered on to the substrate from a single nozzle, while in DOD they are emitted from an array of nozzles in response to digital signals.

In the DOD method an individual nozzle, usually within an array containing a large number of nozzles, is individually addressed to eject a single drop of ink on demand by inducing a transient pressure pulse in an ink chamber behind the nozzle. The drop then travels in a straight line from the nozzle to form a deposit on the substrate. All current printers which use ink-jet technology to decorate ceramic tiles (except one which will be discussed later) use the DOD principle, and we shall focus on this method here.

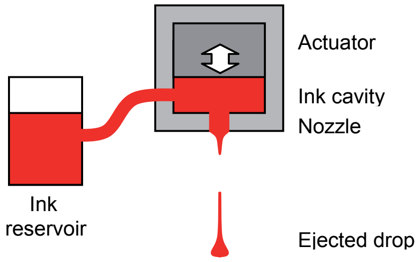

Figure 3. Schematic illustration of the principle of operation of a drop-on-demand (DOD) printhead.

Figure 4. Example of a modern industrial piezoelectric DOD printhead, with 1000 nozzles and a printing width of 70 mm (Xaar plc, UK).

In DOD printing the liquid is ejected from a cavity in the printhead in response to a trigger signal, as shown schematically in figure 3, through the generation of a pressure pulse by an actuator. There are two common types of actuator. The thermal DOD (or bubble-jet) method is widely used in home and small-office printers; rapid transient heating of the ink by a small electrical heating element located in the ink cavity close to the nozzle creates a short-lived bubble of vapour which drives a jet of ink out of the nozzle. The bubble then collapses, drawing ink from the reservoir to refill the cavity, and the process can be repeated. Most industrial ink-jet systems, however, use a different method, in which a piezoelectric element changes the internal volume of the cavity on the application of an electric field, and generates pressure waves which in turn eject ink from the nozzle and then refill the cavity. Since thermal DOD involves the vaporisation of a small volume of the ink, this places significant restrictions on the materials which can be jetted by this method; they must be relatively volatile, or at least have a volatile component. There are no such restrictions for the piezoelectric DOD method.

Printheads for both methods of DOD printing typically contain hundreds of separate nozzles, fed from a single ink manifold but each individually addressable. figure 4 shows a typical modern industrial piezoeolectric DOD printhead, with 1000 nozzles spread over a width of 70 mm, each of which is individually addressable.

The separation of the nozzles in the head (in this case 70 µm) defines the 'native' resolution which will be achieved in a single printing pass, although this can be increased in various ways, for example by printing with the head at an angle to the print direction, or by using more than one head mounted in parallel. Multi-pass printing which is discussed below can also be used to increase resolution. The resolution of the printing process is usually stated in 'dots per inch' (where 1 dpi = 1 printed drop per 25.4 mm).

The printhead ejects a small volume of liquid which emerges as a short jet. Once the jet leaves the nozzle, surface tension forces cause it to form a main drop followed by a fluid ligament which may then collapse into one or more smaller satellite drops. These satellites may then combine with the main drop, or remain separate, as shown in the example in figure 5. In an ideal system the ink will have formed a single drop by the point at which it strikes the substrate, typically at a stand-off distance of about 1 mm, but this is sometimes not achieved. Generally, a larger stand-off distance will provide more time for a spherical drop to form, but at the expense of a lower drop speed and less precision in the exact position at which it hits the surface.

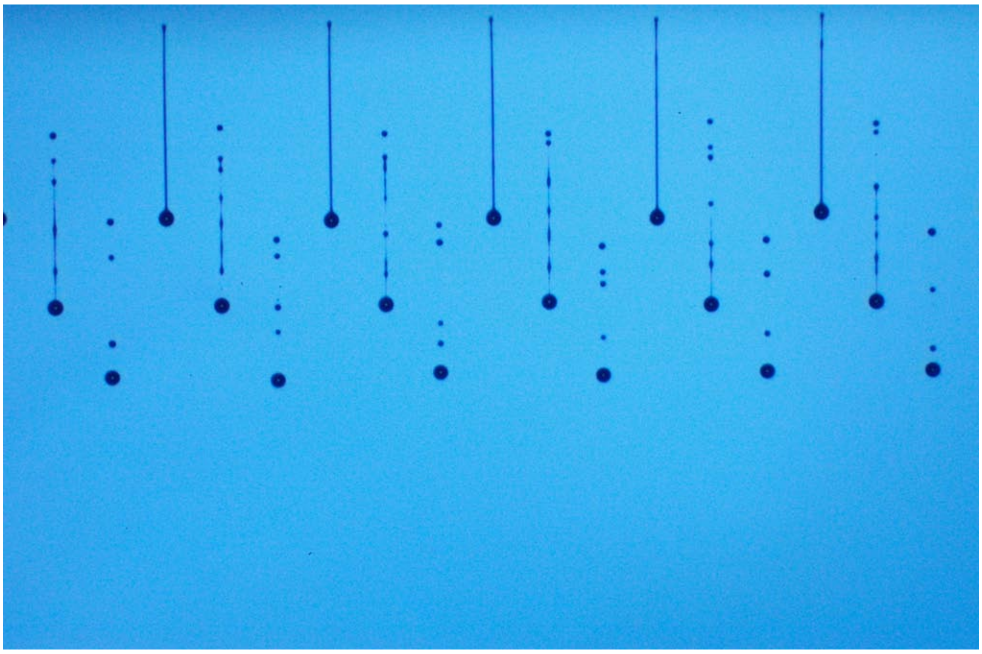

Figure 5. High speed flash image showing jets formed from a row of nozzles (beyond the top of the image) at three different time intervals after ejection. The drops in the upper row have long ligaments which form 'tails' behind the main spherical drops. The second and third rows show drops at later stages of evolution; in this case the ligament breaks up into very small satellite drops.

The diameter of the drop, which ultimately limits the resolution of the printing process, is similar to the diameter of the nozzle. Typically this is about 50 µm, corresponding to a drop volume of some 60 pL (picolitres), although industrial printheads are available which produce drops as small as 1 pL (~10 µm diameter). By using a small nozzle and a complex drive waveform some second-generation systems ('grey-scale' heads) can produce a stream of sub-drops which then merge into a single drop with controllable size before it strikes the substrate. Figure 6 shows the difference between a so-called 'binary' printhead (a) in which a single size of drop is emitted in response to the drive signal, and a 'grey-scale' head in which one or more small sub-drops are generated by applying an appropriate drive signal: these then merge to give a single final drop of controllable size (b-d). In this type of head the size of each drop from each nozzle can be individually controlled during printing, which, in comparison with a binary head, allows higher image quality to be achieved for the same native nozzle pitch (Knight 2009).

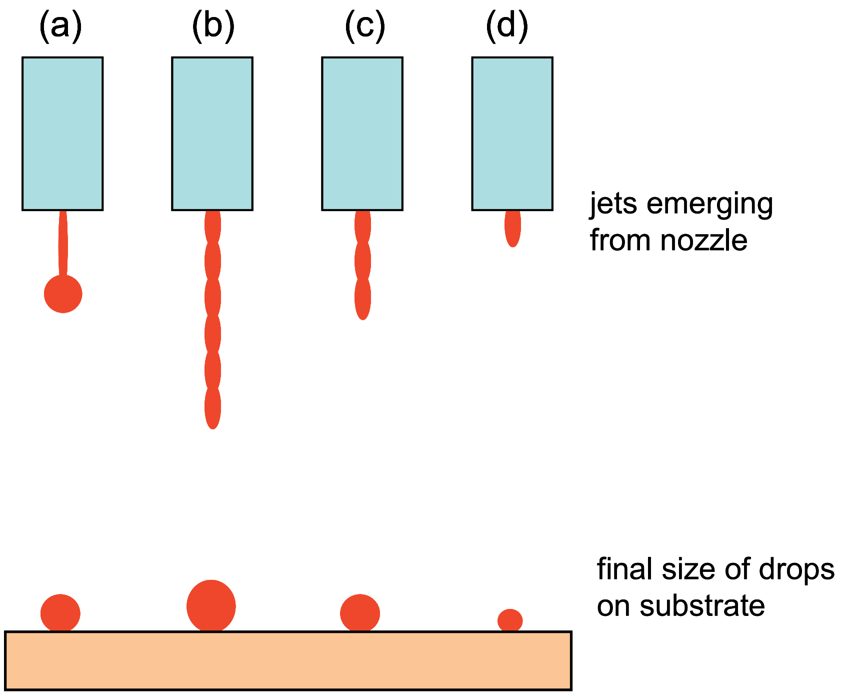

Figure 6. The principles of operation of (a) a binary printhead which delivers a single drop size, and (b-d) a grey-scale printhead in which by combining a number of sub-drops, the final size of the drop can be changed.

Drop speeds in DOD printing are typically 5 to 10 m/s. The process of jet ejection and drop formation involves the sequential, discrete steps of fluid ejection and cavity replenishment, and the maximum frequency of operation is governed by the timescale of these events. In a typical DOD system this results in a minimum drop spacing along the stream ejected from a single nozzle which is some 10 to 20 times the drop diameter.

3. IN-LINE PRINTING OF CERAMIC TILES

In principle, the process by which ink-jet printing can be used to decorate ceramic tiles is straightforward. In order to integrate ink-jet printing efficiently into a tile production line, a single-pass process is required, in which the tiles pass in a continuous flow through the printing machine. In that single pass, the printer must deposit accurately and reliably the correct intensities of colour over the whole surface to be decorated. Figure 7 shows schematically the components of a typical system for four-colour, single-pass printing.

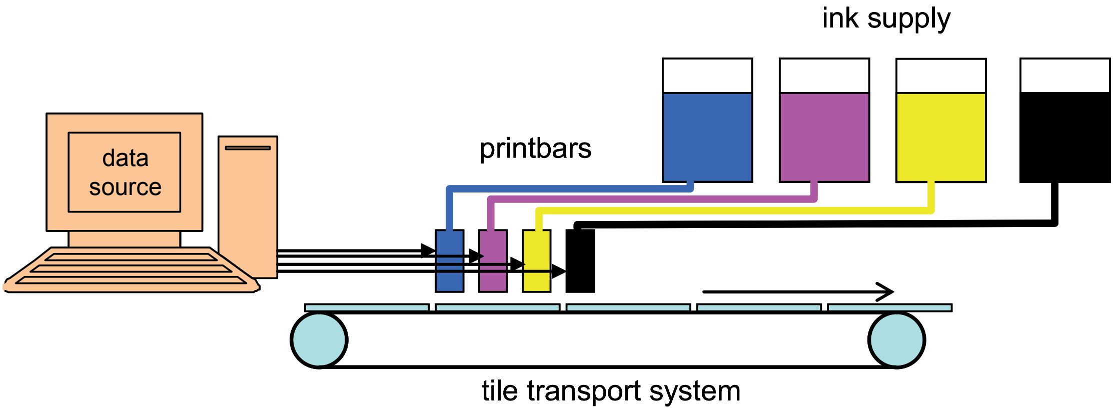

Figure 7. Schematic diagram of an in-line, single-pass four-colour ink-jet tile printer.

For each colour, printheads are assembled into an array (known as a printbar) which presents a continuous row of nozzles across the width of the tile: for typical tile and printhead widths this may involve ten or more printheads. The printheads are usually staggered as shown in figure 8.

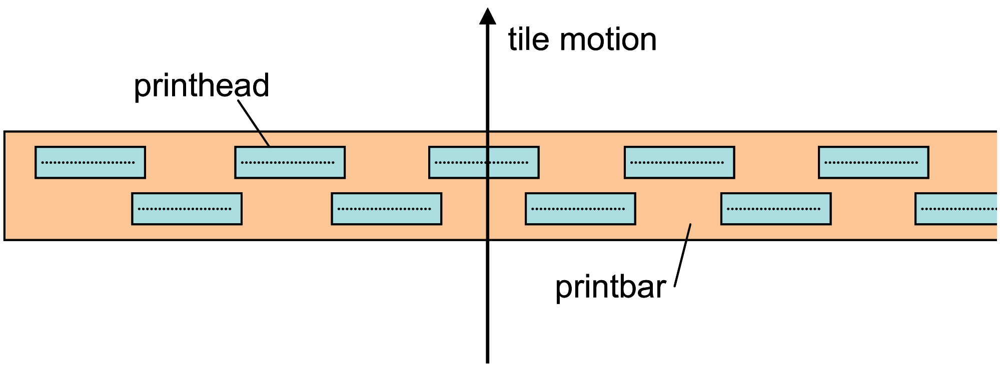

Figure 8. Diagram showing how ten separate printheads can be assembled to form a single long printbar. For in-line printing one printbar is used for each colour.

The printbars are mounted above the tile transport system, and the digitally-defined print image is generated by driving the printheads, fed with ink, with appropriate signals which are synchronised with the continuous motion of the tiles under the printbar. The key elements of the printer thus consist of the printheads, the tile transport system, the ink supply system, the data feed and associated control systems. However, the design and optimisation of these components, and their integration into a robust, reliable and precise machine capable of operating continuously with minimal maintenance in a ceramic production environment, involves significant engineering challenges. There are probably many commercial and economic reasons for the recent rapid growth in the availability of in-line inkjet printers for ceramic tiles, but there are also technical reasons.

The computational requirements of in-line printing are substantial. Data signals need to be sent to every nozzle, in real time, so that for example to print at a resolution of 360 dpi on a tile 70 cm wide at a production speed of 35 m/min, more than 80 million signals must be transmitted per second to each printbar: a four-colour process would require four times this figure. These signals must be accurately synchronized with each other and with the tile transport system, which is required to move the tiles smoothly and at a constant speed under the printbars since irregularities in tile motion will lead to defects in colour and pattern registration. The demands on the printheads are severe. Their manufacture involves precision micro-manufacturing, for example to produce the very small and precise nozzles with accuracy and reproducibility, yet they must be able to operate in a heavy industrial environment with minimal maintenance for long periods. Inks for ceramic decoration must be specially developed, with particular properties as discussed below. All these components of the system must be compatible in order to deliver a robust manufacturing process, and it is only recently that advances in computing power, printhead design and ink development been achieved and integrated for this purpose. It is significant that the challenges of in-line printing are not confined to the ceramic industry. A similar explosion in the recent availability of commercial single-pass printing systems, as a result of technical developments, has occurred in other printing markets as well (Baker and Chrusciel 2008, Alexander 2008), although it can be argued that compared with printing on to continuous paper or polymer webs, ceramic tile printing poses additional challenges in terms of the industrial environment, ink formulations and substrate handling.

4. INKS FOR CERAMIC DECORATION

The inks used for ceramic tile decoration must satisfy at least two important criteria. First, they must have the correct rheological and other properties to be usable in this process i.e. they must be printable; second, they must produce the desired final colours after application to the tile and its further processing.

Our understanding is still developing of the complex influences of the rheological properties of a liquid on its ability to form well-defined droplets during ink-jet printing, with few or no satellite drops. For a simple liquid with a viscosity which is independent of shear rate or shear history (a Newtonian liquid), the important properties are its viscosity and surface tension. Drop-on-demand ink-jet printheads usually require an ink with a viscosity, at the printing temperature, in the range from 8 to 25 mPa s, although some heads can print inks with viscosities as high as 100 mPa s. For comparison, the viscosity of water at room temperature is about 1 mPa s (= 1 centipoise). The printhead and ink temperatures are usually controlled in the printer to maintain stable and accurate viscosity values.

The combined effects of viscosity and surface tension on the ink's printability can be expressed through the value of the Ohnesorge number (Oh), where Oh = $\eta/(\rho\sigma D)^{1/2}$. Here η, ρ and σ are the viscosity, density and surface tension of the fluid respectively, and D is the nozzle (or drop) diameter. The Ohnesorge number describes the relative importance of viscous and surface forces on the fluid. DOD printing of a fluid is practical only if the value of Oh lies within a range between about 0.1 and 1. For Oh > 1 viscous dissipation in the fluid prevents jet formation, while for Oh < 0.1 multiple drops form, rather than a single well-defined drop. The criteria for the printability of a Newtonian fluid thus involve its viscosity, and also the density and surface tension, through their influence on the Ohnesorge number. Additional conditions apply to inks which are non-Newtonian: the presence of polymers, or even solid particles, for example, can cause the ink to behave viscoelastically, which may affect the ease with which the ink is ejected from the nozzle, and also the way in which the jet then collapses to form one or more drops.

The colours generated from an ink after printing on to a ceramic tile depend critically on the nature of the colouring agents present in the ink, and on their interactions with the tile body or glaze, which in turn depend on the process used (e.g. whether first, second or third-firing). Most inks contain either very finely ground inorganic pigments (which must be highly refractory to survive the firing temperature) or soluble metallic compounds which react with the glaze to generate the desired colour (Gardini et al. 2006, Burzacchini and Zannini 2009). The formulation of inks for this application is therefore especially challenging since not only must the correct final colour (hue and intensity) be achieved, but the physical properties (such as viscosity, surface tension, density and any viscoelastic behaviour) must also be optimized for ink-jet printing. As the viscosity of a dispersion of solid particle increases with solid content, there are limits to the amount of pigment loading which can be achieved. There are also constraints on the maximum sizes of the pigment particles, which must be sub-micrometre in size to avoid nozzle clogging, and there is also the need for long-term stability to avoid sedimentation (Allen 2008). Pigment particle size can also have important effects on colour. Improvements and developments in ink formulations have been the subject of intense research, and it is important to consider the inks for ceramic decoration as an essential component of the whole production system, since in order to achieve optimal results they must be matched not only to the printheads, but also to the tile constituents and the overall firing process.

5. COMMERCIAL INK-JET-BASED PRINTERS FOR CERAMIC TILES

We have seen above that there has been a recent rapid increase in the number of companies offering ink-jet technology for the decoration of ceramic tiles, and these are listed in table 1.

Spain and Italy have played a major role in nurturing this growing technology, with several printers emerging from these two countries since the year 2000.

5.1. In-line, single-pass printers.

The first commercial ink-jet-based methods of tile decoration had their origins in Castellón, Spain, in 1998 when the Ferro company started to explore the use of standard computer printers to produce monochrome (black and white) images on tiles, and then demonstrated the feasibility of four-colour printing. This work led to the first practical Kerajet printer which was shown at the Cevisama fair in 2000 (De Carlo 2003). Since then, the Ferro product line has evolved to the current Kerajet range of machines, now widely used in tile production, which use binary printheads from SII Printek for four-colour (CMYK) printing, with proprietary ceramic inks.

Launch year	Company	Country	Printheads	Inks	Printer name	Tile width; dpi; speed
In-line						
2000	Ferro	Spain, Italy	SII binary	Ferro KeramINK	KERAjet 350, 560	56 cm; 180 - 610 dpi; 10 - 50 m/min
2005	Durst Phototechnik	Austria, Italy	Fujifilm Dimatix binary		Gamma 60/70; 61/71 launched 2008	60 cm; 200-924 dpi; 1 - 64 m/min
2008	Cretaprint	Spain	Xaar greyscale	Itaca	Cretaprinter (Xennia OEM)	28 - 112 cm; 260 - 575 dpi; 15 - 35 m/min
2008	Jettable	Israel	Fujifilm Dimatix binary	Jettable	Glider 3000	70 cm; 360 - 720 dpi; to 60 m/min
2008	Newtech	Italy	Xaar greyscale		Keramagic 350, 700	70 cm; 360 dpi; to 25 m/min
2008	SACMI	Italy	Flatjet		DWD065	65 cm; 50 dpi; to 30 m/min
2008	System Ceramics	Italy	Fujifilm Dimatix binario		Rotodigit	100 - 600 dpi; 30 - 55 m/min
2009	Hope Ceramics	China	Xaar greyscale	Chimigraf	Hope Jet 600	70 cm; to 25 m/min
Off-line						
2008	Sertam	Italy	Fujifilm Dimatix binary	Sicer	Pink	80 x 120 cm máx.; to 720 dpi; multipass
2008	TSC	Italy	Binary	Sicer	Jet Digital Printer JDP08	180 - 545 dpi; multipass
2008	Jettable	Israel	Fujifilm Dimatix binary	Jettable	731/732	80 x 120 cm máx.; to 545 dpi; multipass

Table 1. Companies offering commercial ink-jet printers for ceramic tile decoration at the end of 2009 (sources: company web-sites).

Durst, a company involved in image processing since 1936 and based at facilities in Italy (South Tirol) and Austria, first offered a commercial digital tile decoration system using pigmented ceramic inks in 2005 and now claims more than 75 such printers in operation worldwide. The latest models (Gamma 60/61 and 70/71) feature three or four-colour (CMYK) printing for tile sizes up to 60 x 120 cm, and use Fujifilm Dimatix binary printheads. The system prints on to the same glazes as those used for more conventional decoration systems.

No fewer than five companies launched systems in 2008. System SpA (Italy) introduced Rotodigit, an ink-jet printing station using Fujifilm Dimatix binary heads which can be readily integrated into the more conventional rotary intaglio printing lines produced by the same company. Instead of printing the whole tile decoration by ink-jet methods, this allows details in one or more colours, for example, to be applied to supplement patterns produced by the conventional process which is based on ink transfer from patterned silicone rubber cylinders.

There is significant activity in ink-jet development in Israel, from which a new company, Jettable, has launched an on-line tile printer (Glider 3000) using Fujifilm Dimatix binary heads and a wide range of specially-developed inks, suitable for under-glaze (first and second firing) and also on-glaze (third firing) applications.

In 2008 two companies launched machines based on the Xaar 1001 greyscale drop-on-demand printhead: Cretaprint from Spain and Newtech from Italy. The Cretaprinter (shown as an example in figure 9) uses a print engine developed by a UK company, Xennia, and has a very wide printbar, capable of single-pass printing with a total tile width of 112 cm. The Newtech Keramagic printers offer widths up to 700 mm, corresponding to a printbar containing ten printheads per colour. The same types of greyscale printheads are used by Hope Ceramics, based in China, which launched a machine in 2009 (Hope Jet 600), again with a printing width of 700 mm.

Figure 9. Example of a commercial in-line single-pass printer (Cretaprinter: image from Xaar plc).

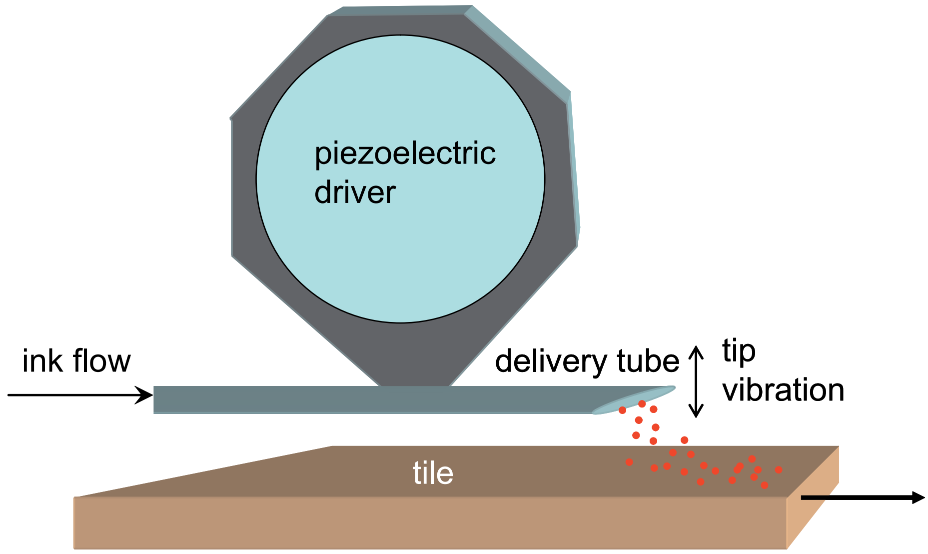

Figure 10. The principle of operation of the Flatjet printer, in which ink droplets are generated from the tip of a vibrating delivery tube.

In contrast, the Flatjet technology employed by Sacmi in the DWD065 printer, originally developed in Hungary, is fundamentally different from normal drop-on-demand inkjet printing (see figure 10). It uses much larger ink delivery tubes (500 µm internal diameter) which are individually vibrated by piezoelectric drivers mounted on to resonating metal plates. The ink emerges as a spray of fine droplets which form a diffuse patch of colour on the tile; the intensity of colour is controlled by the duration of the vibration signal sent to the delivery tube. The spacing between neighbouring tubes is typically 1/10 inch (2.54 mm), and an effective image resolution of 50 dpi is achieved by using five arrays of tubes. It is claimed that the technology produces images which are comparable, at normal viewing distances, with those from more conventional inkjet printing at higher resolutions, because despite the larger pixels the small ink droplets are spread more evenly over the substrate, giving more gradual changes in tone. The method allows a wide range of printing fluids to be used, for example containing solids with much larger particle sizes than those used in a drop-on-demand printhead.

5.2. Off-line, multi-pass printers

Although in-line printers are ideal for rapid production of standard-sized tiles, there are also applications where a more flexible, stand-alone printer can be very valuable. Examples include small production runs of flat tiles and specialised high value orders such as artworks and murals, as well as the decoration of complex shapes and contoured trims and edging tiles, which may involve large variations in surface height within the piece. For these cases, where rapid throughput is not an issue, multi-pass printing in the context of a third-firing process can be more suitable than the single-pass method used in in-line machines to print on to an unfired tile body. Multi-pass printing uses fewer printheads (usually only one per colour), which are moved relative to the substrate to cover the whole printed area several times, building up colour intensity and resolution in stages. This is the approach used in desktop ink-jet printers, and can also be cost-effective for specialized ceramic printing applications. The small number of printheads can make setting up the machine, and its operation, easier than managing a more complex in-line printing station. Although four-colour operation is normal, some machines can operate with more heads to allow a wider colour gamut to be achieved. As in the case of in-line printing, there was also rapid commercial development in this field in the year 2008, with three companies launching off-line ink-jet printers: Sertam (Pink), TSC (Jet Digital Printer) and Jettable (731 and 732).

6. POTENTIAL FOR FUTURE DEVELOPMENTS

It is clear from table 1 that with the exception of the Flatjet technology there are few major differences in specification (in terms of resolution and printing speed) between the ink-jet printers currently available. Whether single-pass in-line, or multi-pass off-line, they all use industrial printheads from a small number of suppliers, and the basic performance of the machines is determined by that of the printheads. There are differences in the ways in which the other major components of the printer, outlined in section 3, are designed and integrated, in the formulation of the inks, and in the software and hardware used to control the printer and to convert the desired print pattern into the data stream which is fed to the printheads. These factors together with the overall build quality will undoubtedly impact on the reliability of the printer, its ease of use, the quality of the output and the cost of operation, all of which ultimately influence the value of the machine to the user. As with any new technology, it is unlikely that the market will be able to sustain a large number of suppliers of different machines, some of which will inevitably achieve only a small market share, and some rationalisation is probable in the future.

Future technical developments are likely to result from improvements in both printhead and ink technologies. We may envisage further advances in pigment and ink chemistry, possibly increasingly involving nano-particles (Gardini et al. 2006), to achieve more intense colours with greater precision and stability and a wider colour gamut, delivered in more stable inks which can be printed over a wider range of conditions. There is a current drive within the commercial printing industry (for paper, card or polymer film substrates) towards higher resolution and higher printing speeds in single-pass processes, so that these can become more directly competitive with conventional processes such as offset and flexography. The in-line printing speeds offered by the current generation of tile printers (0.5 to ~1 m/s) are consistent with the limits of current commercial ink-jet printing for other applications, and it seems likely that as new printheads are developed for these applications they will also be rapidly adopted for ceramic decoration. However, the technical challenges involved should not be underestimated: to increase the printing speed will involve not only higher data processing and transfer rates, but also an increase in the drop generation frequency and drop velocity, which in turn imposes extra demands on the ink rheology. Advances in printing speeds by the enhancement of printhead performance will be achieved only when can be coupled with developments in ink formulation.

We have focused so far on the use of ink-jet printing for ceramic tile decoration by the deposition of coloured inks, but the process can also be used to deposit a much wider range of materials: ceramics, metals and polymers for many different applications (Hutchings 2009). There is considerable interest in adding functionality to ceramic tiles by the incorporation of novel, often electronic, features (Berto 2007). For example, tiles can be made which incorporate sensors for touch, pressure, or proximity – so that they can be used as switches or footstep detectors to control lights, open doors, count human traffic etc. Acoustic transducers could be introduced so that the tiles emit sounds in response to electrical signals. Electronically controllable light-emitting or reflecting layers could allow individual tiles, or areas within a tile, to act as switchable coloured pixels, allowing the creation of wall-sized displays integrated into the tiled area. Photovoltaic cells have been demonstrated, integrated into ceramic tiles, for electrical energy generation (Iencinella et al. 2009). Ink-jet printing has the potential to play a major role in all these and other functional enhancements of ceramic tiles: it has already proved its capability as an process for the deposition of conductive metallic tracks, for the fabrication of large-area displays based on light-emitting polymers (organic LEDs), and for the printing of polymer-based transistors. It forms one of the key technologies for the rapidly growing printed electronics industry. The integration of printed electronic and electrical components into ceramic tiles may provide significant future opportunities.

REFERENCES

[1] Alexander M. (2008) The Xaar guide to single pass printing, Technical White Paper, Xaar plc, UK.

[2] Allen H. (2008) Pigmentation of inks for emerging inkjet applications on glass, ceramics and metals, Actas 24th Int. Conf. on Digital Printing Technologies, NIP24, USA, 853-855.

[3] Baker R. and Chrusciel E. (2008) Single-pass digital production printing and deposition, SGIA Journal 1st quarter 2008, 31-34.

[4] Berto A.M. (2007) Ceramic tiles: above and beyond traditional applications, J. European Ceram. Soc., 27 1607-1613.

[5] Burzacchini B. and Zannini P. (2009), Digital ceramic decoration: development of non-impact inkjet decoration systems, in Digital decoration of ceramic tiles, ACIMAC, Italia, pp. 6-12 (disponible también en italiano: La decorazione digitale delle piastrelle ceramiche).

[6] De Carlo A. (2003) The digital revolution in tile decoration, Ceramic World Review 51 78-84.

[7] Gardini D. et al. (2006) Chemical-physical properties of nano-sized ceramic inks for ink-jet printing, Actas Qualicer 2006, P.BC 397-408.

[8] Harvey R.A. and Sainz J.G. (2000) Proc. 16th Int. Conf. on Digital Printing Technologies, NIP16, Society for Imaging Science and Technology, USA, 516-518.

[9] Hutchings I.M. (2009) Ink-jet printing in micro-manufacturing: opportunities and limitations, International Conferences on Multi-Material Micro Manufacture (4M)/ International Conferences on Micro Manufacturing (ICOMM), Karlsruhe, octubre de 2009, DOI: 10.1243/17547164C0012009006.

[10] Iencinella D., Centurioni E., Busana M.G. (2009) Thin-film solar cells on commercial ceramic tiles, Solar Energy Materials & Solar Cells 93 206–210.

[11] Knight E. (2009) Xaar: innovative inkjet technology for the ceramic tile industry, in Digital decoration of ceramic tiles, ACIMAC, Italia, pp. 70-73, (disponible también en italiano: La decorazione digitale delle piastrelle ceramiche). Véase también Knight E., The Xaar guide to digital print for the ceramic sector, White paper, Xaar plc, 2009.

[12] Martin G. D., Hoath S.D. and Hutchings I. M. (2008), 'Inkjet printing - the physics of manipulating liquid jets and drops, Journal of Physics: Conference Series 105 012001.