

INKJET PRINTING TECHNOLOGY FOR CERAMIC TILE DECORATION

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ABSTRACT

Inkjet decoration technology has revolutionised the ceramic sector. Inkjet printers have been massively implemented, worldwide, for tile decoration and their use is currently extending to the obtainment of surface effects (gloss, matt, chameleonic...) and to the application of glazes. However, knowledge of different aspects of the technology is required in order to be able to achieve optimum results.

This paper describes the foundations of the technologies involved in inkjet decoration. These include the printing systems and the images themselves, which both require specific management to achieve the sought-after result. Printhead operation and the most noteworthy aspects of drop and dot formation, in which ink properties play a critical role, are also briefly set out. Finally, basic printer components are described.

1. INTRODUCTION

Ceramic tile decorating techniques have evolved considerably in recent years owing to the need to launch products with new aesthetic finishes, to environmental constraints, and to economic factors.

Initially, the most widespread techniques for decorating ceramic tiles were flat screen printing, which commenced in the 1960s, and rotary screen printing, which emerged in the 1970s. This technique was relatively simple and cheap, though image quality was low and it did not have the necessary robustness for an industrial product (sticking, colour differences, etc.) [1].

Subsequently, in the 1990s, rotogravure decoration improved print quality and increased productivity [2]. A disadvantage was the high price of the silicone rollers, which required a high number of prints in order to make the design profitable. The 1990s also witnessed the appearance of flexography in ceramic decoration [3], though it was used to a much smaller extent.

Inkjet printing systems are very recent and they were developed towards the end of the 1980s for office automation applications. The first studies on the possible use of inkjet printing for ceramic decoration date back to the 1980s, when W. Roberts [4] from British Ceram Research proposed a continuous inkjet system using nozzles with sizes between 20 and 100 μm . Although the idea of introducing this technology in ceramic tile decoration became increasingly stronger, implementation still demanded considerable research into the inks, printheads, and printers.

The first industrial printer was presented by the Kerajet company at the Cevisama international trade fair in 2000 [5]. The first inks for this machine were patented by Ferro that year [6]. That patent describes a set of four inks (CMYK) for colour printing, each of which included one or more soluble complexes of transition metals. The presentation of the machine caused a great stir. However, the high price of the inks and the machines, the limited colour space obtained, and the dependence on the glaze used acted as barriers to the rapid spread of this technology.

The parallel development of new printheads and pigmented inks may be considered key elements in the development of this technology, though there were many other issues that also needed to be resolved in order to turn it into an industrial reality. These issues included the tile transport system, ink supply system, data feed, related control systems, and the integration of the assembly into an industrial production environment:

- Non-contact printing, which reduces unfired product losses
- Decoration to the edge.
- Decoration of profiles, reliefs, and embossings.
- High image resolution.



Figure 1. First Kerajet model in 2000
(source SECV).

- On-line control and correction of the design, which reduces colour differences.
- Boundless (random) variations of designs.
- Immediate changeovers of models.
- Simplification of ink management. Smaller production inventories and ink stores.
- Elimination of printing media.
- Process economy, in both small and large lots.
- Simple customisation of the product.
- Shorter product development time.
- Less manpower.

In this context, inkjet printing technology was a milestone because it enabled the three dimensions of businesses to be simultaneously addressed [7]. It allowed the sales strategy to be based on product differentiation, the process to be optimised and manufacturing costs to be reduced, and relational marketing to be enhanced.

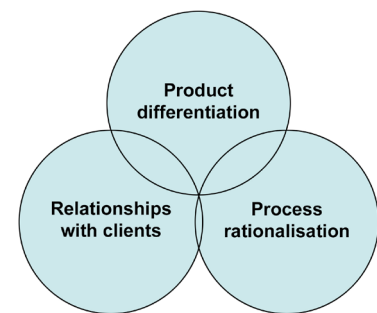


Figure 2. Dimensions of businesses.

Since the first ceramic printing machine appeared in the year 2000, other improved machines have come onto the market. At present, more than thirteen different machines are available on the market for ceramic printing.

Ceramic tile decoration using inkjet technology is growing at breakneck speed. According to a survey conducted by the Ceramic World Review [8] at seven manufacturers of digital printing machines for ceramics, 538 machines had been installed worldwide in 2010. In 2011, 516 machines were installed, and more than 368 machines were expected to be installed in the first semester of 2012.

At present, digital decoration systems are being used in 41 countries, compared to 24 countries in which they were being used in April 2012. Spain is where this technology began, and Spain continues to have the most installed machines. From January 2011 to the end of June 2012, 155 machines were installed. In the same period, Italy, which has the second largest number of installed machines, practically doubled the number of machines, which went from 141 to 266.

Inkjet printing technology is prevailing worldwide. At the end of 2010, Spain and Italy accounted for 76% of all inkjet machines installed worldwide (410 out of a total of 538 machines); however, in June 2012 this percentage had dropped to 48% (690 out of a total of 1422 machines). At the end of 2010, China, India, and Brazil had a relatively small number of installed machines, but this figure has grown considerably and they are now the third, fourth, and fifth country, respectively, in number of installed machines, behind Spain and Italy. The ceramic digital decoration technology is also expanding rapidly in Turkey, Iran, Mexico, Vietnam, Indonesia, Tunisia, Algeria, Egypt, and Saudi Arabia.

3. IMAGE MANAGEMENT

There has been a growing trend in recent years to simplify printing. This began with the printing of the photolithos used in making screen printing screens, continued with the direct obtainment of these screens and engraving of the silicone rollers, and it has ended with the digital systems for direct printing on ceramic tiles. However, the obtainment of acceptable printed results requires previous adjustment of the systems used and control of the processes to which the image is subjected before printing.

To prepare the system, each element must be calibrated (linearisation, ink limit) and characterised (profiling) [9].

The calibration of the input and output devices (camera, scanner, monitor, printers) enables their range of response to be optimised. In the case of the input electronic devices, the detectors are calibrated by the manufacturer, while the monitor can be calibrated by the user. In the case of the printers, calibration requires two adjustments: linearisation and the determination of the maximum ink limit.

The relationship between the quantity of ink and the resulting colour is not direct. Sometimes, as a result of pigment dissolution in the glaze, no colour is obtained until a certain quantity of pigment has been reached (e.g. yellow). At the other end of this range, there are pigments (e.g. blue) that provide maximum saturation (100%) with a smaller quantity than the quantity the system can apply. In addition, in the intermediate range, the response is frequently not linear, which adversely affects the image colour balance. Consequently, it is essential to linearise the colour response of the printers in relation to the input signal.

Excess ink produces different problems, such as dot blurring, longer drying times, and higher costs. When a profile is generated, the appropriate quantity of black and ink limit must be used. In ceramics, the ink limit can vary with the characteristics of the glaze, the ink, and working conditions, though it is usually about 250%, the attainable maximum ink limit being 400% when four inks are used. When a colour profile is created that allows the colours of the image to be converted, the total ink limit that is deemed appropriate can be defined, and the image is recalculated on that basis. If a total ink limit of 300% is indicated for example, no part of the image will contain more than 300% ink. This limit can be controlled by techniques such as UGR (Under Colour Removal) or, preferably, GCR (Grey Colour Removal). In GCR, the neutral or grey component of the image,

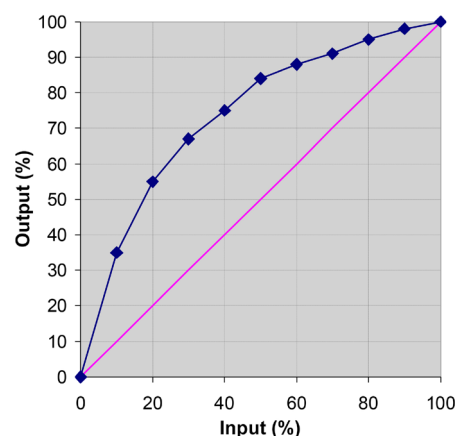


Figure 3. Output/input relationship of a non-linearised blue ink.

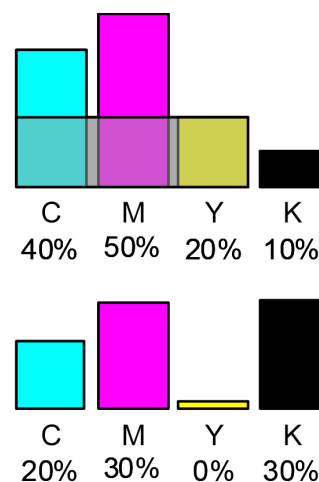


Figure 4. Example of GCR conversion with 40% ink reduction.

which could be obtained by a CMY mixture, is entirely or partly replaced with black ink (K), with the ensuing reduction in ink deposition. This correction can be made in the entire image; however, when colours are replaced with the black ink, the dark tones in the image can lose shades of colour. To avoid this, a little colour can be added to the dark tones (Under Colour Addition).

The colour profiles perform the necessary transformations to convert the colours of the colour space of a (source) device to the colour space of a (target) device, so that the colour remains unchanged. In complex systems with more than one input and output device or when different materials are used, a profile connection space is required (PCS). In the case of ceramics, the source colour space is much larger than the target colour space, so that working colour spaces are being developed specifically for ceramics. In all cases, the colour management architecture must allow colour transmission between physical systems, applications and operating systems [9].

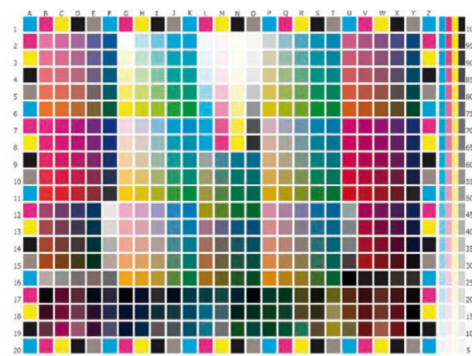


Figure 5. Example of a table for obtaining profiles.

A suitable **workflow** in design and development shall include the following phases.

The first phase is image acquisition. The better the image, the easier will the later work be. In view of the problems produced by the scanners, the use of digital cameras has prevailed at present. These can provide appropriate resolution and colour depth, adapt to models that display profiling, and are also reasonably priced. However, use requires having an experienced person with a good understanding of lighting. It is advisable for the images to be acquired with the same size as that to be used and with high colour depth (> 8 bits), which minimises errors in editing and conversion processes.

The image then needs to be manipulated to adapt it to the ceramic design. These modifications must be done in the working colour space (typically Adobe RGB) and they include highly varying operations, such as changes in size and adjustment of intensity levels, gloss, noise, contours, and other overall adjustments. All these adjustments are performed with a monitor, so that it is essential that this should be properly calibrated and profiled, in addition to having appropriate environmental lighting conditions.

The printing colour space is much smaller than the space perceived by the human eye or by the input devices, so that the images must be corrected to the actually printable colour space. There are four colour correction intents, the three most widely used intents being: **relative colorimetric**, absolute colorimetric, and **perceptual**. All are intended to manage the parts of the image that have colours that cannot be printed, though some also correct the image in its entirety. Depending on the selected intent, the black dot may require a specific conversion to maintain its neutrality and brightness [10]. The most appropriate correction depends on the image, so that at present the designer must choose the most appropriate one.

Then follow a trial print, the eventually needed corrections, and finally printing of the lot.

4. PRINTHEADS

The inkjet printheads used in ceramic decoration generate drops on demand by means of a piezoelectric actuator. The main piezoelectric printhead manufacturers for the ceramic market are Xaar, Fujifilm Dimatix, Toshiba, and Seiko II. Other manufacturers, such as Sharp, Domino, Brother, Videojet, Epson, Ricoh, Trident, Kyocera, HP, Panasonic, Samsung, Konica Minolta, Xerox, PicoJet, and Microfab, focus on other industrial sectors.

The printhead architecture for producing the drop pulse pressure in the nozzle varies considerably, but all have certain common physical principles [12].

The piezoelectric actuator deforms under the action of an electric field, generating overpressure in the adjacent fluid. This overpressure is transmitted as a sound wave in the fluid contained in the printhead channel. The transmission of this wave is influenced by ink density and viscosity, as well as by the geometry and mechanical behaviour of the channel walls.

When the fluid overpressure reaches the nozzle, ink is ejected and drops form in which the initial energy is converted to other types of energy, such as kinetic, surface, and thermal energy.

The piezoelectric rate of response is very high. However, to control drop formation the pressure wave must be suitably generated and transmitted in the printhead. For each printhead, there are resonance frequencies in which constructive interferences occur between the arising pressure waves, whereas in other frequencies the interferences are destructive and must be avoided. On the other hand, the intensity and shape of the electric wave used in exciting the piezoelectric element determine the intensity and shape of the pressure wave in the printhead nozzle. The design of the wave shape used to excite a printhead enables the firing rate, drop volume, and satellite drop formation to be controlled; however, the existence of numerous interconnected variables advise against this work being done by the end-user.

Many current printheads can work in two ways: with either a constant or a variable drop size. In the former case, the images are poorer quality, but the firing frequency is higher, providing greater productivity. In the latter case, smaller drops are generated, which can join to form larger drops. The images obtained are much more natural, but the firing frequency is lower.

In all cases, the printheads have a heating system in order to be able to use inks that are more concentrated and to maintain an appropriate firing viscosity.

The main characteristics of some printheads used in ceramics are shown in the following table.

	XAAR 1001 GS12	DIMATIX Durst	TOSHIBA CF-1L
Compatible liquids	Oil/solvent	Oil/solvent/water	Oil/solvent
Maximum viscosity (cP)	22	20	18
Native resolution (dpi)	360	220/360	300
Primary drop size (pL)	12	30	12
Maximum drop size (pL)	84	90	84
Length (mm)	70.5	64.77	53.7
Scales of grey (N)	8	4	8
Frequency (kHz)	6-14	12-33	6-14

Table 1. Characteristics of the main printheads used in ceramics.

Inkjet printheads also have other characteristics of interest that affect print quality. The straightness of the firing paths depends on the precision with which the nozzle plate has been made and on its maintenance. If the drop trajectories do not remain parallel, some dots will be superimposed and the images will have systematic defects, depending on the printhead used. Equally important is the maximum firing distance, which is closely linked to the firing rate and the drop volume used.

5. INKS

5.1 PROCESS DYNAMICS

5.1.1 Drop formation

Once the pressure front has been generated in the printhead nozzle, a rate profile is created and drop formation begins. This phenomenon is governed by the continuity equation (mass conservation) and the equation of motion (Navier-Stokes) [12].

Analysis of the process indicates that ejection is controlled by the balance between the forces of inertia, viscous forces, and surface forces. Initially, a part of the energy generated by the piezoelectric element is converted to kinetic energy in the printhead nozzle. Viscosity consumes part of the kinetic energy and dissipates it in the form of heat. Similarly, the generation of new surfaces during drop formation also consumes energy that comes from the initial kinetic energy. Consequently, viscosity and surface tension both oppose drop formation and, when they increase, slower jets are generated.

The balance between the energy of inertia, on the one hand, and the viscous and surface energy, on the other hand, are given by the Reynolds ($Re = \rho D / \mu$)¹ and Weber ($We = \rho v^2 D / \sigma$) dimensionless numbers, respectively.

On the other hand, the relationship between viscous and surface energy ($Ca = \mu v / \sigma$) determines the break-off time of the drop tail. The driving force for tail break-off is determined by surface tension, while strength is determined by viscosity.

The numerical analysis of these phenomena allows the process to be quantified and predictions to be made, provided that the system is appropriately calibrated.

5.1.2 Dot formation

The dot formation process from a drop that impinges on a substrate can be divided into two phases: impact, with a microsecond time scale, and levelling, with a second time scale. The variables that determine these processes are drop size, speed, and angle of impact; ink surface tension and viscosity; and surface properties such as surface energy, roughness, and porosity [13].

When a spherical drop impinges on a surface, it deforms and spreads on the surface. The magnitude of the spread depends on the relationship between the driving force (inertia) and the existing counter-forces (mainly viscosity and surface tension). The relationship between kinetic energy and surface energy is given by the Weber number (We), while the relationship between kinetic energy and viscous strength is given by the Reynolds number (Re). Depending on these relationships, the greater the drop size, speed, and density (solids content), the greater will its spread be, while the greater the viscosity and surface tension, the smaller will the spread be.

The roughness of the surface can constrain drop spread owing to retention of part of the ink in the valleys. In addition, the contact angle can encourage or counteract drop spread, depending on its value.

The rate of tile advance down the line is relatively low (<1 m/s) in relation to the drop impact rate (6 m/s), so that the impact angle is close to 90° and, consequently, the dot does not deform.

In the levelling phase, the surface tension attempts to minimise the surface generated in the impact phase, which tends to make the dot uniform. As occurred in the impact phase, the contact angle between the ink and the substrate can contribute to the resulting spread.

Dot consolidation takes place concurrently to these phases, whether by a chemical curing process, substrate suction, or evaporation of the vehicle. In every case, the time scale can be of the same order of magnitude as that of the levelling phase, which can limit levelling development, as the ink stops being liquid [14][15].

¹ Symbols used: Reynolds number (Re), Weber number (We), Capillary number (Ca), density (ρ), velocity (v), characteristic length (D), viscosity (μ), and surface tension (σ).

In the case of the ceramic inks that are customarily used, the vehicles are not reactive, so that they do not polymerise; in addition, the vapour pressures are very low, which rules out drying by evaporation. Therefore, the only dot consolidation mechanism is substrate suction.

The suction rate of dry porous solids is very high in the initial moments, producing rapid consolidation of the drops. However, the nature of the vehicle used and the moisture and temperature conditions of the ceramic substrate can greatly affect suction and, hence, dot spread [16].

5.2 REQUIREMENTS

5.2.1 Chemical compatibility

During use, the inks will be in prolonged contact with numerous materials of both the actual printhead and the rest of the machine, so that it is essential to verify their chemical compatibility.

Compatibility must be verified with the formulated ink, because even though this mainly depends on the nature of the vehicle and on the additives used, it also depends on their concentrations and on the interactions that can take place between them.

The specific materials to be tested with the ink depend on each printhead and/or machine manufacturer, though common materials include polyethylene, polypropylene, nylon, and silicone.

Incompatibility is determined by prolonged contact between the tested materials over several months. In plastic materials, this is mainly evidenced by a variation in weight or a change in their physical properties (e.g. hardness, flexibility, etc.). Adhesives can stop working. Metal parts can undergo corrosion processes.

Chemical compatibility with the cleaning liquids must also be verified. These are usually more aggressive, though their contact with the pieces is brief.

5.2.2 Physical properties

The physical properties determining ink behaviour follow [17].

5.2.2.1 Viscosity

Viscosity directly influences the dynamics of drop and dot formation processes, owing to flow resistance. Viscosity, at the firing temperature, is usually between 15 and 25 mPa·s. Traditionally the view was held that ink behaviour needed to be Newtonian; however, at present it is assumed that a slightly shear-thinning behaviour is also acceptable and can increase ink stability with relation to sedimentation. Viscosity must be measured in rheometers that allow viscosity determination at different shear rates.

5.2.2.2 Surface tension

Surface tension also significantly influences the dynamics of drop and dot formation processes because of the resistance it offers to the generation of new surfaces. Surface tension is usually between 25 and 35 mN/m. The organic vehicles used in the inks easily provide these values, although surfactants or mixtures of liquids can also be used. Surface tension is usually determined with tensiometers, using a Wilhelmy plate.

5.2.2.3 Density

Density is another key property in the dynamics of drop and dot formation processes, owing to the forces of inertia and printhead acoustics. For a given ink, density is directly related to solids content. Density values usually range from 1.2 to 1.4 g/cm³. The simplest way of measuring density is with a pycnometer, though there are also other instrumental methods.

5.2.2.4 Particle size

In order to avoid nozzle clogging, it is usually held that ink particle size must be, at least, 20 times smaller than the nozzle diameter. Consequently, with the printheads that are customarily used, the particle size of the solids used in the inks must be smaller than 1 µm. In order to assure this limit, the inks are filtered in ink fabrication. Particle size also influences ink stability and colour development so that particle size measurement is a control parameter of the utmost importance. There are two main techniques for measuring particle size distribution: laser diffraction and dynamic light scattering.

5.2.2.5 Volatility

The vehicle used in ink manufacture should not evaporate on the nozzle plate, as ink drying would lead to the deposition of solids that would clog the nozzles. Liquids with a very low volatility are therefore usually chosen, or materials are added to control evaporation. Volatility is usually measured in relative terms, under constant conditions, by comparison with known materials.

5.2.3 Stability

Inks must be stable in order to provide consistent results and avoid printing breaks. The two phenomena that must be avoided are particle sedimentation and aggregation.

Particle sedimentation velocity (v) can be represented by Stokes' law. According to this law, the lower the viscosity (η) of the suspending liquid and the higher the difference in particle densities (ρ) and size (D), the greater will the sedimentation velocity be. However, this behaviour is only observed in very diluted suspensions, $\phi < 0.03$ (in which particles can settle without interacting with other particles), and relatively coarse particles (in which the Brownian forces are negligible), provided that the sedimentation velocity is low, $Re_p < 1$.

$$v = \frac{g \cdot (\rho_p - \rho_l) \cdot D^2}{18\eta}$$

In the case of relatively concentrated suspensions ($\phi > 0.1$) such as printing inks, the average inter-particle distance is small, of the same order as or smaller than the size of the particles, so that the sedimentation of each particle is hindered by the others. In addition, in their descent, the particles displace an equivalent volume of liquid, which will rise in the opposite direction, so that the relative rate of particle motion, and hence the friction force, is greater. This effect leads to a decrease in sedimentation velocity when the solids volume fraction (ϕ) is increased. This phenomenon can be quantified by power laws or by using the physical parameters of the suspension (instead of those of the liquid) in the Stokes equation.

For even higher concentrations ($\phi > 0.3$), or when the particles build up on the bottom of the container, a relatively compact bed forms, the evolution of which with time depends on the particle aggregation state. The ranges of validity of these processes depend on the solids concentration and on the deflocculation of the system.

Reduction in particle **size** is the main way of avoiding sedimentation. Indeed, when the molecules of the suspending liquid collide with the smallest particles ($< 0.1\text{--}1\ \mu\text{m}$), they transfer part of their kinetic energy to those particles, thus preventing them from settling. In the case of bimodal suspensions, the smaller particles must support the larger.

The inks must also stabilise from a **colloidal** viewpoint. That is, the appropriate repulsion forces must be generated to keep the particles individualised. These repulsion forces can be of an electrostatic and/or steric nature. These forces are controlled by molecules that are adsorbed on the particle surface and/or regulate the electric charges in their proximity. If the suspension is not stabilised, particle aggregation raises the hydrodynamic size, which increases particle sedimentation velocity.

Ink stability is determined from the variation of ink properties with time, ink sedimentation being accelerated by means of a centrifugal force or by instrumental techniques based on light backscattering.

5.3 INK COMPOSITION

Inkjet printing technology is tremendously versatile, enabling a great variety of materials to be used, provided that the final physico-chemical properties are appropriate for the printhead involved. The inks used in ceramic decoration contain the following components:

- **Sólids.** These are in charge of the coloration or sought-after end effect after firing. The solids may be pigments, raw materials, or frits. Ink solids content is usually about 40% by weight.
- **Vehicle.** This is the liquid used to apply the solids on the ceramic surface. Glycols, oils, and esters have been used. Viscosity, surface tension, and vehicle volatility must be low.
- **Additives.** Their main function is the colloidal stabilisation of the particles, which determines ink rheological behaviour and stability. Additives can also be used to modify surface tension and to facilitate ink de-airing. There is a great variety of products, though most use a steric mechanism for particle stabilization.

6. PRINTERS

Although the main part of the printers is its array of printheads, other components also directly affect printer performance, such as the ink recirculation circuit, control electronics, user interface, and mechanical structure on which the entire assembly is mounted [18].

6.1 INK RECIRCULATION CIRCUIT

The ink consumed by the printheads needs to be continuously replenished from the storage containers to maintain the ink level and prevent air from entering. This volume flow is very small and variable, so that a larger, constant volume flow is used that is pumped through a readily controllable recirculation circuit in which, in addition, other necessary operations are performed.

Filtration of the ink coming from the storage containers is an operation that prevents large particles and aggregates from entering the printheads, which would impede proper operation. Filter pore size is usually between 10 and 25 μm .

Ink **temperature** in the printhead must be controlled to assure appropriate viscosity in printing. The ink can be preheated in the recirculation circuit, while fine control is performed in the printhead.

Ink can be readily **recirculated** outside the printhead, and this allows overall conditioning of the ink; however, it is not very effective in preventing nozzle clogging. In contrast, ink recirculation inside the printhead has the following advantages (Durst and Xaar):

- It minimises the risk of ink sedimentation, owing to the pull generated by the flow.
- It minimises particle agglomeration, owing to the shear, increasing ink stability.
- It allows the use of more viscous inks and slightly shear-thinning behaviour.
- It favours de-airing, as the bubbles generated inside the printheads are pulled away.
- It eliminates the need for purges.

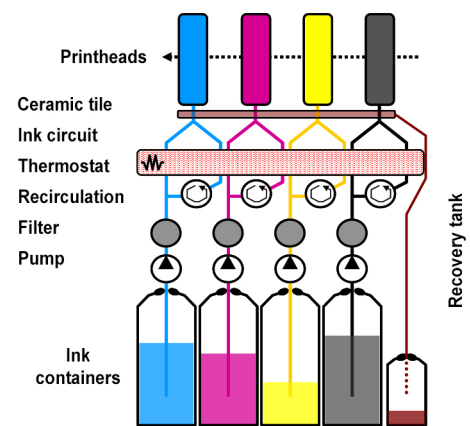


Figure 6. Ink circuit.

As a result, current machines usually have a **double recirculation** system, in which the ink is kept in continuous movement inside the printheads and in the storage containers, using the benefits of both systems.

6.2 PRINthead BARS

In single-pass printers, the individual printheads need to be arranged in **bars** to encompass the printing width. There are two basic configurations: transverse and oblique (Figure 7). In the oblique configuration, the printing resolution is greater than the native resolution of the printheads (depending on the installation angle), and the number of printheads used is greater. The users of this configuration [11] assure that interlacing of the printing dots between the different printheads enhances uniformity and reduces the risk of printing defects (lines). Printing width has grown (at present 1152 mm). With a view to optimising printing width, some printers allow parallel tile feed from two lines. This approach considerably raises productivity and reduces expenses.

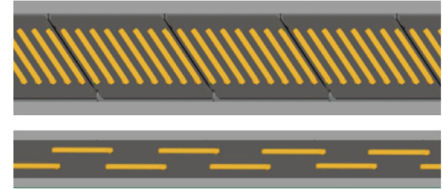


Figure 7. Printhead arrangement.

Each printing bar uses one type of ink, so that the machines use as many bars as there are materials to be printed. Three bars were initially used, one per colour; however, ceramic tile decoration is becoming increasingly complex and the number of bars is growing. Sometimes the same ink is also printed with two bars, in order to increase machine productivity. At present, up to 12 bars can be used, devoted both to coloured inks and to obtaining special effects. Depending on the decorating intention and the ink used, each bar can be equipped with a different type of printhead. In particular, the obtainment of effects requires the use of printheads with a greater discharge than those used with pigmented inks.

Printing **speed** depends directly on the firing frequency of the printheads and on the targeted resolution:

$$velocidad \left(\frac{m}{min} \right) = freq. \left(\frac{gota}{s} \right) \times 1 \left(\frac{punto}{gota} \right) \times 60 \left(\frac{s}{min} \right) \times \frac{1}{resol.} \left(\frac{pulgada}{punto} \right) \times 0.0254 \left(\frac{metro}{pulgada} \right)$$

Consequently, if the resolution and the firing frequency are fixed, there can only be one printing speed. On the other hand, if the printing is altered without changing the firing frequency, the printing resolution will change in the direction of advance (Figure 8). Taking into account this relationship between printing speed and resolution, many manufacturers provide indications on the recommended speed with their printheads, in order to obtain a given resolution.

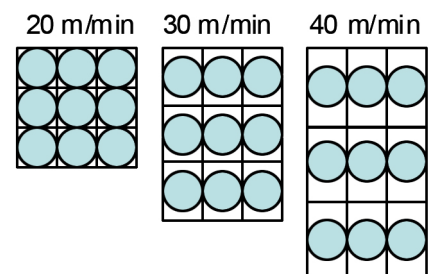


Figure 8. Influence of the speed of advance on inter-dot spacing.

Printing speed can also be limited by an insufficient ink input into the printhead channel. This problem has been partly solved by graphic designers, limiting the maximum quantity of ink in certain areas of the image, and doubling the number of bars.

On the other hand, the printers contain printhead **cleaning protocols** during printhead use, which limit their productivity to a certain degree. The need for these

phases is mainly determined by the ink build-up on the nozzle plate.

The **mechanics** that support the whole system must be sufficiently robust and precise to avoid vibrations and facilitate the necessary adjustments.

6.3 ELECTRONICS AND SOFTWARE

Printers handle millions of data items per second to control the printhead bars, ink circuit, pneumatic circuit, transport system, etc. This requires very powerful and precise electronic architecture. A master computer is normally used, on which other slaves depend (FPGA) that directly control bar operation.

Although images work in pixels per inch, printing must convert the files to physical drops/dots, as the printheads need to be instructed to either fire or not, and with what drop size. This is done by RIP (Raster Image Processing), integrated in the printer. Although there are many techniques for performing this operation, the simplest technique is as follows. Define a grid, determined by the distance between the printhead nozzles, in the direction transverse to advance, and by the ratio of speed to firing frequency, in the direction of advance. If a binary printhead is used (with a constant drop size), a grid of 2x2 will only allow four levels of grey (N) to be obtained, depending on the number of cells filled. Obtaining 256 levels would require defining a filling grid of 16x16, with the ensuing loss of image quality. If a variable-drop printhead is used, four sizes allows 256 levels to be obtained in a 2x2 grid because, in addition to the progressive filling of the cells, dot size is available. The effect on image quality is of such importance that only printheads of the latter type are used at present.

In addition, the printers allow the image to be previewed and adjusted to the printing conditions. They also incorporate graphic tools to obtain certain effects (mosaic, shifts, colour adjustments...) without needing to modify the original files.

7. CONCLUSIONS

Inkjet printing technology has developed greatly from its beginnings, leading to massive industrial implementation in ceramic tile manufacture. At present, the technology is not just restricted to decoration but enables obtainment of multiple ceramic effects, profiles or embossings, and glaze applications. In the near future, research into this technology will widen the spectrum of materials that can be used to obtain new functional applications and, possibly, to transform the tile manufacturing process itself and to develop new business models.

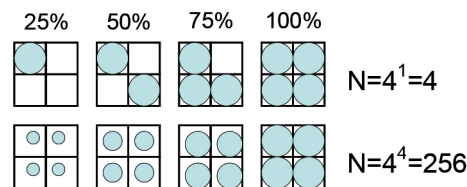


Figure 9. Levels of grey (N) available in a 2x2 grid with constant and variable drop size.

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