"FULL DIGITAL" ADVANTAGES AND DISADVANTAGES OF THE TECHNOLOGY TECHNICAL-ECONOMIC VIABILITY OF THE PROCESS

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1. ABSTRACT

Since the introduction of the first digital printer, back in 2000, ceramic inkjet decoration has developed at a dizzying speed. On reviewing the historical milestones of this technology, the following may be highlighted:

- 2000: presentation of the first industrial prototype
- 2005: appearance of the first pigment inks
- 2008: first recirculation printheads
- 2012: appearance of the first digital effects
- 2014: appearance of the first high-discharge printheads
- 2015: first Full Digital installations (only for large sizes)

The success of the ceramic sector's very rapid adaptation of this technology and its development have not only been due to the possibility of achieving greater print quality or a broader graphic variety in the same manufactured product compared to that obtained by the rotary technology that preceded it, but mainly to the reduction in operating costs, such as:

- Reduction in the cost of consumables (rollers)
- Increase in first quality due to defects in the decoration process
- Decrease in unfired tile losses due to non-contact technology
- Much shorter modelling development times, dispatch of samples to customers and reproducibility of the developed product
- Single tone for manufactured products
- Stock reduction (need for lower working capital)
- Elimination of screen printing preparation and corresponding controls
- Lower material losses due to absence of surplus screen printing material in each production order
- Elimination of airbrushing by simulating this digitally
- …etc.

With all this industrial baggage as far as inkjet technology is concerned, the question is: Why is it taking so long for this technology to expand to other parts of the decorating process?

There are two main reasons why this technology has not yet reached other fields of ceramic decoration:

- Firstly, due to technical problems with the printheads.
- Currently, economic barriers (return on investment) together with possible emissions from the kiln stack.

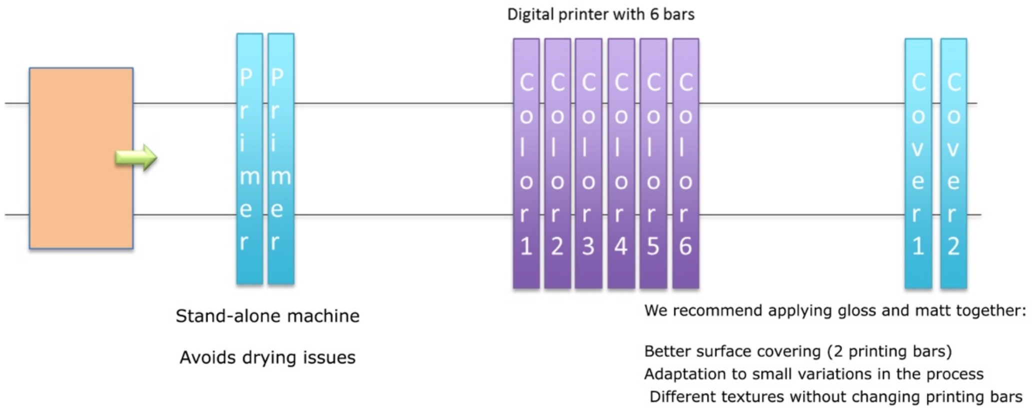
At this point, the issue of emissions again raises the question of whether to go for water-based products or to continue using oil-based products.

The following points are discussed in this paper:

1) Advantages of Full Digital vs. traditional
2) Water-based or oil-based Full Digital?
3) Conclusions

2. ADVANTAGES OF FULL DIGITAL VS. TRADITIONAL

Outline of a Full Digital line:



ADVANTAGES

Lower water content	•Formulations with a higher solids content •Lower grammage than in traditional application
More homogeneous glaze application	•The whole width of the piece is glazed using fixed printheads heads •Compared to mobile airless spraying which does not achieve a homogeneous application, especially on large sizes •Airless application: drops, lumps and need for cleaning stops
More decoration possibilities	•Selective glazing depending on design •Allows different textures within a single piece
Lower labour costs	•One person less for every two decoration lines
Lower material losses in the line	•Traditional airless application is estimated to produce 30% material losses •Plus the cost of subsequent treatment of these wastes

The above table leads to the following improvements:

- **Better flatness of pieces**
  - Mainly for large sizes and slim pieces
- **Lower manufacturing costs**
  - Increased percentage of first quality
  - Lower labour costs
  - Lower material losses in the line
- **Added value**
  - Selective glazing, which enables development of new products

DISADVANTAGES

- **Greater initial investment**
  - Need for two stand-alone machines for the application of primer and coating
  - Compared to airless chambers which customers already have at their facilities
- **Difficult to obtain superwhite tones**
  - On applying lower grammage, opacity is lower
  - On applying the digital coating, a little more opacity is lost
- **Greater cost of consumables**
  - The unit price (€/kg) is higher with digital application
- **Greater TOC emissions**
  - The total amount of carbon at the stack outlet is higher on applying oil-based materials
  - Due solely to the greater quantity of material applied and NOT to the chemical nature

1.1. ECONOMIC ASSESSMENT

The following **quantifies** the pros and cons of whether Full Digital is beneficial from an economic point of view:

PREMISES:

Cost difference between first and second quality (€): 7 *

Number of losses using an airless application (%): 30

Cost of managing line glaze losses (€/T): 16

Total corporate cost of a line operator (€/year): 30,000

Maintenance cost of stand-alone machines (€/year): 20,000

Production line output (m2/year): 1,500,000

Traditional "smaltobbio": 65% solids content at a cost of 0.40€/kg dry material

Traditional coating: 50% solids content at a cost of 0.65€/kg dry material

Increase of 0.1 €/kg cost for "smaltobbio" and coating owing to grinding costs

*If applied to large sizes, there is no second-quality market, thus increasing the cost

These data yield the following synopsis table:

	Traditional		Full Digital		Balance
	Gr/m2 (liq.)	€/Kg	Gr/m2	€/Kg	Total (€/m2)
Consumable (Esmalgobio)	550	0,36	25	10	+0,052
Consumable (Salatura)	250	0,43	25	10	+0,143
Digital Maintenance cost					+0,013
Waste(both applications)	240	0,38	0	0	-0,107
Planarity* (1 point 1st class improvement)					-0,080
Glaze applic. (2 points 1st class improvement)					-0,160
Labor costs (0,5 person per line)					-0,010
Total balance					-0,149
Net amount per year (1.500.000 m2)					223.500

The table shows there is a saving of €223,000 per year. Therefore, from an economic point of view, this technology makes a lot of sense.

In terms of investment, it is estimated that two stand-alone machines with two printing bars each may cost about €280,000 depending on the manufacturer and type of printhead.

Nevertheless, the most important fact is that in just over a year, there is a return on investment. This is a relatively short period, WITHOUT considering the hyper-amortization assistance governments are offering for Industry 4.0, which would further reduce ROI time.

1.2. WHITENESS:

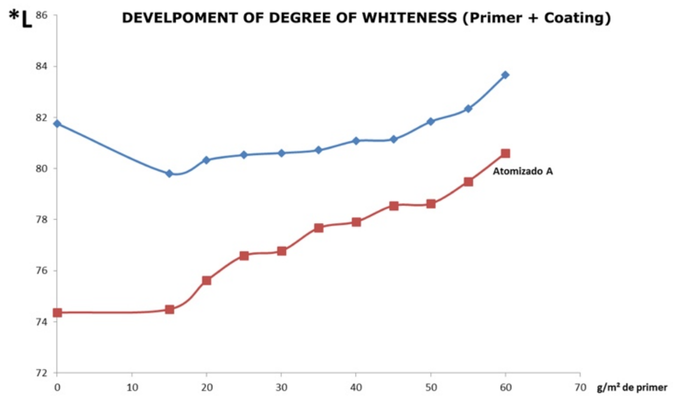
This aspect has been analysed with two spray-dried powders of different whiteness:

Spray-dried material A: less white for use with glazed porcelain tile

L: 74.36 a: 3.17 b: 13.37

Spray-dried material B: whiter for use with coloured technical porcelain tile

L: 81.76 a: 3.04 b: 12.41



In the graph it may be observed that starting with whiter spray-dried material, higher L values are obtained.

As more primer is applied, the degree of opacification is greater.

The problem lies in the fact that the greater the amount of material applied, the greater is the amount of organic matter contributed to the piece, with possibly ensuing consequences in terms of surface defects and kiln stack emissions.

3. WATER-BASED OR OIL-BASED FULL DIGITAL?

This question is NOT easy to answer and there are surely many different opinions and justifications for each position.

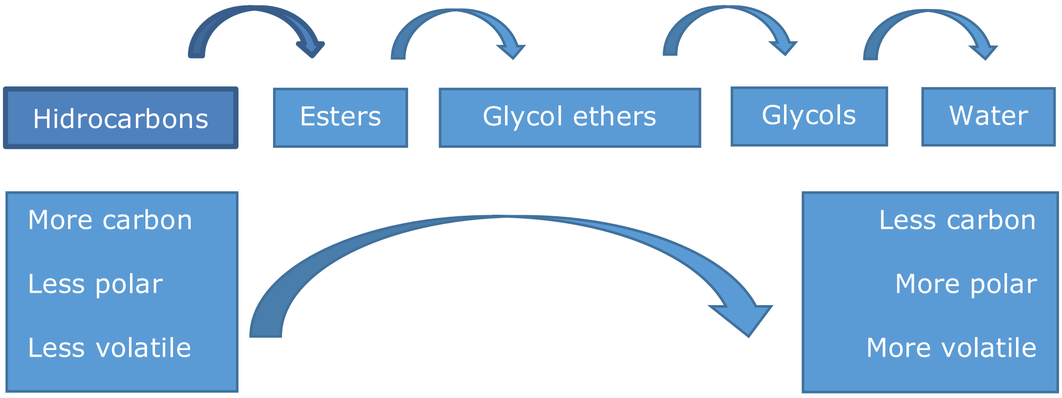
It has therefore been attempted to quantify the drivers that will provide the values to answer the question.

In this case, the following indicators have been used:

- 3.1. Compliance with emission regulations:
  - 3.1.1 Volatile Organic Compounds (VOCs)
  - 3.1.2. Total Organic Carbon (TOC)
  - 3.1.2. Emission of hazardous molecules (Aldehydes and Ketones)
- 3.2. Performance of products in printers
- 3.3. Odour of kiln stack exhaust gases

3.1. COMPLIANCE WITH EMISSION REGULATIONS:

Analysis of the chemistry available today provides the following gradation:



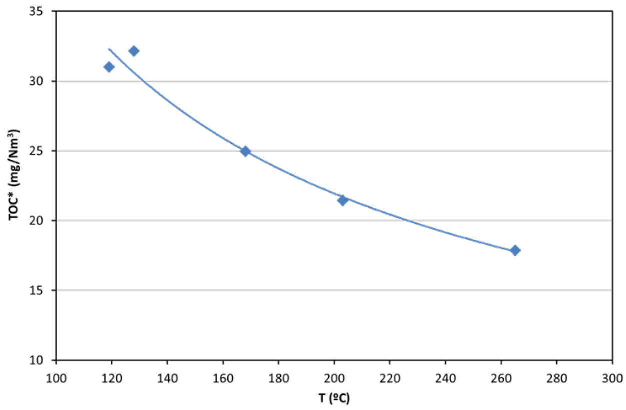
VOCs depend directly on the formulation used. The more volatile the materials (lower evaporation temperature), the more risk there is of generating VOCs in the glazing line, with the consequent danger for line operators.

In this regard, water-based formulations are penalized compared to oil-based formulations where hydrocarbons and esters can be found with a higher evaporation temperature than that of most glycols accompanying water-based formulations.

This is not so clear in the case of TOC. Tests were carried out at our pilot plant:

After several trials with different formulations containing significantly different amounts of carbon, very similar TOC values were observed.

However, on firing the same material according to different curves, a substantial improvement of TOC at the stack outlet was observed. In this case, the temperature in the preheating zone was modified.



That is, on favouring the carbon compound oxidative chain, total organic carbon was reduced:

$CH_3—CH_3 \xrightarrow{(O)} CH_3—CH_2OH \rightarrow CH_3—CH{=}O \rightarrow$

Ethane hydrocarbon (oven gas) | Ethanol alcohol (sugar cane alcohol) | Acetaldehyde aldehyde

$CH_3COOH \rightarrow CO_2$

Acetic acid Ethanoic acid (vinegar acid) | Carbon dioxide

If, on the contrary, oxidation is NOT complete, substances such as aldehydes or organic acids are generated, which increase the amount of TOC.

At the process level there is more room for improvement than merely treating the chemical aspect. Therefore, typical post-combustion solutions, or gas recirculation to high temperature kiln zones, seem to be the most effective solutions.

3.2. PERFORMANCE OF PRODUCTS IN PRINTERS

A comparison was carried out at laboratory level with two **colour inks** formulated with an equal solids content, one being oil-based and the other water-based.

3.2.1 VOLTAGE OPERATING WINDOW

Very similar values with almost identical operating ranges.

3.2.2 DOT GAIN

Due to a higher drying speed, water-based formulations have a lower dot gain and therefore greater sharpness of printed images.

3.2.3 COLORIMETRY

At the same grammage, for all the technologies, colorimetry was identical.

3.2.4 SHOT STABILITY

Water condensation was simulated in the nozzle plate to reproduce industrial printing conditions over time. In this test, the water-based formulation offered better performance with regard to lines than the oil-based formulation.

3.2.5 OPEN TIME

It was observed that after three hours of system shut-down, upon restarting printing, the water-based formulation led to many clogged nozzles while the oil-based formulation maintained its initial quality.

At the **digital glaze** level, on working with larger drop sizes and discharges that covered the entire surface, shot stability was shown to be greater than in the case of colour inks.

Additionally, applying glazes with two printing bars provided greater assurance for the absence of defects caused by possibly clogged injectors or problems with drop deviation.

3.3. ODOUR OF KILN STACK EXHAUST GASES

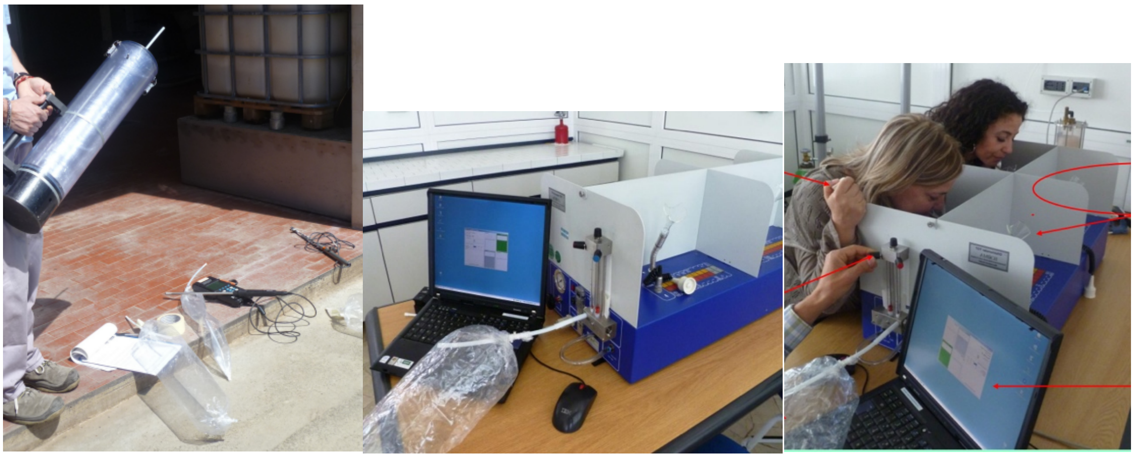
Several formulations were tested at our facilities to determine which could have an olfactometric value not perceptible to humans.

This was done by applying Technical Standard UNI EN 13725: 2004, using a dynamic olfactometry system with human examiners.

The units of measure are:

EROM (European Reference Odour Mass): Mass of a substance that, evaporated in 1 m^3 neutral gas under standard conditions, causes a physiological response (perception of smell)

OU_E (European Odour Unit): quantity of a substance that produces odour that, evaporated in 1 m^3 neutral gas under standard conditions, causes a physiological response equivalent to that caused by an EROM evaporated in 1 m^3 neutral gas under standard conditions.



All formulations tested in our kiln exhibited values above 12,000 OU_E.

Only one displayed values of approximately 6,000 OU_E.

Water-based formulations and glycols had values of approximately 500 OU_E.

Values below 3.000 OU_E are considered suitable for humans.

4. CONCLUSIONS

Full Digital technology improves manufacturing costs particularly for large sizes starting at slabs 60 cm in width where current glaze application techniques tend to be less stable.

The added costs of consumables and initial investment are mitigated primarily by improvements in quality, elimination of losses in consumables and savings in labour costs. Initial investment is recovered in just over a year.

Currently, weak points are the achievement of whites with high "L" values, and emissions and odours on using oil-based digital glazes.

For large sizes, Full Digital technology is essential for thicknesses between three and six millimetres.

The problem regarding odours arises from the amount of organic matter applied to the piece on using primers and oil-based final coatings. With the 50g applied on average using these two applications, the kiln is unable to oxidise all this material, generating carbon compounds that may result in unpleasant odours.

Water-based colour inks have not yet achieved the performance level of oil-based products in terms of drying times on the injector plate, which causes greater problems for shot stability with increased cleaning cycles to minimize the impact of defects produced by lines in the graphic.

Therefore, substitution of primers and final coatings for water-based materials is essential. Substitution of these two applications eliminates the problem of kiln stack odours. It is NOT necessary to substitute the inks to solve it, as the quantities applied are so low in comparison with those of the glazes and coatings that the current priority focuses on the last two.

Although water-based chemistry can help to greatly improve this issue, environmental regulations will become increasingly stringent. It is therefore necessary to also work on the machinery (mainly kilns) and the process in order to continue improving in this regard.