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Investigating the Effect of Pigment and Solvent Components on the Physical Properties of Digital Ink for the Decoration of Ceramic Tiles

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ABSTRACT

The inkjet printing machine was initially used on ceramic parts as a small device in designing and advertising offices limitedly. In recent years, this device has been applied professionally to create high-quality patterns in the industry. In this method, liquid ceramic ink is sprayed on the specified parts by piezoelectric nozzles and after drying and discharging, the organic matter is baked at a different temperature. The ink of the digital print consists of two parts of the pigment and solvent. In this article, the effect of pigment and solvent additives has been investigated as the main factors affecting the physical properties of digital ink. The results of this study indicate that pigment is known as the main component of the physical properties of digital ink. The amount of pigment in ink can have a definite effect on density, viscosity, and surface tension while its effect on surface tension is lower than other properties.

1. INTRODUCTION

The inkjet printers are widely used on a small scale (home and office) for the purpose of printing and graphical applications. These printers are now commercially available in their manufacturing environments due to their special features to perform in industrial applications. Over the past ten years, the ability of these printers have been discovered for decoration on tile and ceramic products and there have been significant advances in printed design and ink formation [1,2]. In 2008, several new printer manufacturers introduced the technologies for the decoration on ceramic tile products as digital inkjet printers. That's why this year was called the Year of the Digital Printing Industry Revolution in the field of ceramic tile. The rapid expansion of this technology over the past decade has been linked through the cooperation of many companies offering these printing lines [3]. Currently, there are two main kinds of ink-jet printers including continuous and impulse or drop on demand (DOD). In the continuous printer, the ink is driven by a spray agent from the nozzle and flows into spherical droplets. This flow is well controlled by defined vibrations. Each of the droplets, individually induced by an electrical charge from an electrode near the body, creates electrostatic stains on the substrate, which can be controlled by changing the charged surface of the final position on the substrate. The non-drained substance returns to the system [4,5]. Continuous ink-jet (CIJ) printers are widely used in various industries. For example, this system is used to apply product identifier information, such as production date, expire date, batch number, etc. [6]. In the drop on demand method, a large number of nozzles are transversely placed. The drop of ink from these nozzles is addressed separately and transmitted by a transient pressure pulse on the ink chamber at the back of the nozzle. Then, the drops are removed and transferred directly onto the substrate. The DOD printers are the major inkjet printers used in ceramic tile industries. In DOD printers, the fluid is thrown out of the hole in the printer head by a signal from the device. In the new generation of this technology, this action is triggered through the pulse pressure. There are currently two types of triggers. Thermal heads are applied for home and office use. In this type of head,

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rapid heating is carried out by an electrical thermal element inside the nozzle hole. This heat creates a short-lived steam bubble, which causes the ink to come out of the nozzle. Most of the printers in the market are applying piezoelectric and thermal type technologies [7,8]. The most common systems for industrial inkjet printing are those using the piezoelectric element. In this type of head, the internal volume of the cavity is changed with the application of electric current and the ink is removed from the nozzle hole and then, recharged. There is a limit to the choice of the raw materials consumed by these inks as the thermal head mechanism is the evaporation of a small part of the ink and the formation of steam,. Therefore, the ink should consist of a volatile component or components to create steam. On the other side, there is no limit on the piezoelectric method. Thermal and piezoelectric heads typically contain hundreds of separate nozzles with a single feeding container and each of the nozzles has its unique addressing system. The diameter of the nozzles is typically about 50μm with a capacity of about 60pl. the flow of droplets can be controlled from formation to bed-handling using a small nozzle and a complex drive that is available in second-generation systems [9-11]. The digital printing technology used for tile decorating is very similar to that used in paper printers. This means that the technology uses three main colors called the CMY system. The CMY system represents three main colors with the name of Cyan, Magenta, and Yellow. Black color can also be obtained from the original three-color combination, but it is preferred to add black color to this three-dimensional system due to the high price of these three colors. Therefore, the CMYK quadrilateral system is used in digital tile printing technology where K represents the black color. All the desired colors can be obtained from the combination of four colors (cyan, magenta, yellow, and black) [12, 13]. Nanoceramic pigments of the quadrilateral color system (CMYK), which are solved in an organic solvent are used to produce digital ink. This organic solvent includes all kinds of additives, such as binders and suspenders, and so on. The most important features of these nanoscale pigments are their small size and their chemical and thermal stability at the temperature of the fired tile. Moreover, the used inks should have proper rheological and surface tension properties [14,15]. The ceramic pigment in these inks should be properly dispersed and should not be agglomerated over time. Generally, ceramic inks contain various components such as solvent, ceramic pigments with nanoscale and submicron dimensions, reduced surface tension factor, and dispersing agents [16,17]. The production of ceramic inks consists of two steps including the production of ceramic pigments in the quadrilateral color system (CMYK), which should be nano and sub-micron sized to prevent the nozzles from clogging and applying the stability and dispersion of the ink [18-20]. In this paper, a new formulation of digital ink for production of beige color is presented, which is known as one of the most used digital inks for tile decoration. For this purpose, the inorganic pigment was synthesized and mixed with the organic solvent. Designing an experiment based on the Taguchi method was applied to predict the optimum amount of each component of the organic solvent.

2. EXPERIMENTAL PROCEDURES

2.1. Materials

The digital ink is composed of two main parts of the pigment and solvent. In the present paper, the beige pigment is selected as the most consumable pigment and synthesized. Zinc oxide, chromium oxide, iron oxide, and aluminum oxide were purchased from Merck and kaolin was purchased from Zettlitz Company. The ink solvent also consists of seven parts, which are listed in Table 1.

TABLE 1. Different Components of Digital Ink Solvent

No.	Code	Material Name	Company
1	HS1	Liquid Paraffin	Merck
2	HS2	Dioctyl Phthalate (DOP)	Merck
3	HS3	White Spirit	Sigma Alderich
4	HS4	Print Oil	Reef Industries
5	HS5	Long base alkyd resin	Reef Industries
6	HS6	Long base alkyd resin	Reef Industries
7	HS7	Methyl Myristate	Sigma Alderich

2.2. Pigment Synthesis Method

Figure 1 illustrates the process of beige pigment from alumina, zinc oxide, chromium oxide, and iron oxide. The raw materials based on the formula were milled and mixed in a fast mill with water for 15 minutes to obtain a uniform composition and same particle size. Then, the resulted homogeneous mixture was dried and sieved with 30 mesh sieve size.

In the next step, the obtained uniform powder is sintered in an electric furnace at 1300°C. The sintered pigment was milled again with a fast mill for 10 minutes and was sieved with 325 mesh sieve.

2.3. Digital Ink Production Procedure

Synthetic pigments and solvent compounds were mixed in a process for producing digital ink according to Figure 2.

According to Figure 2, the pigment was mixed ultrasonically with two kinds of resin and white spray for 30 minutes using an ultrasonic homogenizer to make the pigment completely spread in the resin to prepare the ink for digital printing. Then, the liquid paraffin and dioctyl phthalate are added to the resulting mixture and mixed for 15 minutes. Finally, the print oil and methyl myristate were added to the mixture and sonicated for 15 minutes.

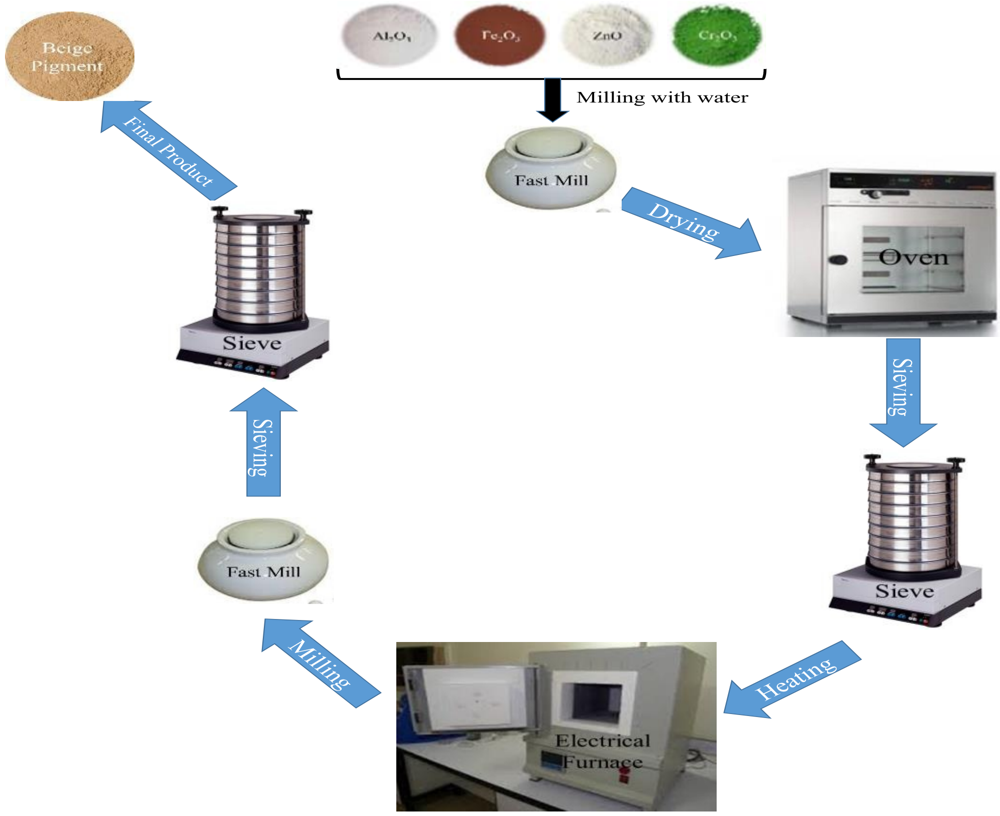

Figure 1. The process of pigment production from metal oxides

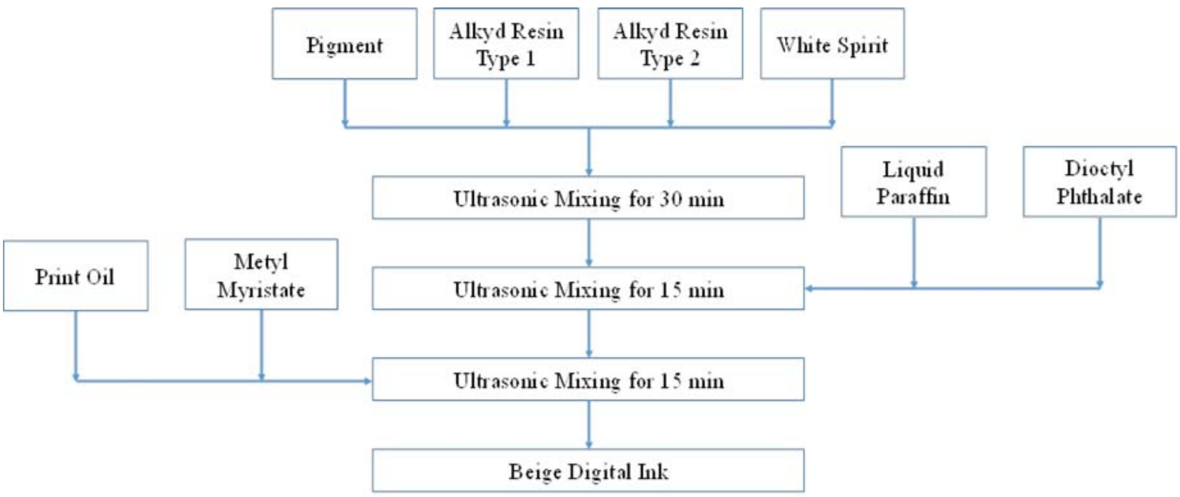

Figure 2. The beige digital ink production method

2.4. Experimental Design

An experimental design has been used to achieve digital ink with optimal amounts of solvent components. This work decreased the number of experiments needed for achieving optimal conditions. In this section, the amount of some components in the solvent, as well as the pigment used for the preparation of digital ink, will be discussed. As mentioned before, most of the digital ink solvent consists of paraffin, white spirit, and resin. While other materials that have an additive role can have a more significant impact on increasing shelf life and

performance of digital ink. In this paper, four of the seven ink-forming substances under conventional digital ink formulations are considered constant as follows: Liquid Paraffin 20%, white spirit 30%, alkyd resin type 1 2% and alkyd resin type 2 6% to remove several experiments.
Finally, attempts have been made to determine the amount of additive substance. An experimental design was also used to determine the optimal amount of these compounds. In this design, four factors including dioctyl phthalate, print oil, methyl myristate, and pigment amounts were identified as the main factors. For each factor, four levels of composition were considered, as shown in Table 2.

TABLE 2. List of factors and levels used in the design of the experiment

Factor	Level 1	Level 2	Level 3	Level 4
HS2	1	2	3	4
HS4	4	5	6	7
HS7	2	3	4	5
Pigment	20	25	30	35

The Minitab 16 software and Taguchi experimental design were used in this study. According to the number of factors and levels, the software proposed the L16 model, which has 16 experiments. According to the proposed model, 16 formulations were prepared for the production of digital ink. Table 3 summarizes the composition of the percentage of different samples.

3. RESULTS AND DISCUSSION

The dimensionless Ohnesorge number is a well-known criterion to evaluate the quality of prepared ink, which is calculated as follows:

$$Oh = \frac{\mu}{\sqrt{\rho \gamma R}} \tag{1}$$

Where Oh, μ, ρ, γ, and R are abbreviations for Ohnesorge number, viscosity, density, surface tension, and pigment diameter, respectively. The calculated value of the Ohnesorge number for each ink is listed in Table 4.
In the present applied design of experiments, the objective function is the Ohnesorge dimensionless number. The Ohnesorge number should be close to the industrial digital ink one to have the proper ink for spray from the printer nozzles. The Ohnesorge number of industrial digital ink is equal to 0.622.
Therefore, it is attempted to select a kind of ink that with the closeness of the Ohnesorge dimensionless number to the industrial sample by selecting the suitable objective function for the design of experiment to ensure that the ink is not disintegrated, sprayed properly, and the ink is evenly colored by the printer.

TABLE 3. Suggested experiments by Taguchi experimental design

Prepared Ink	HS 1 %	HS 2 %	HS 3 %	HS 4 %	HS 5 %	HS 6 %	HS 7 %	Pigment (%)
Ink 1	25	1	38	4	3	8	2	20
Ink 2	23	1	34	5	2	7	3	25
Ink 3	20	1	31	6	2	6	4	30
Ink 4	18	1	27	7	2	5	5	35
Ink 5	21	2	32	4	2	6	3	30
Ink 6	19	2	29	5	2	6	2	35
Ink 7	23	2	35	6	2	7	5	20
Ink 8	21	2	32	7	2	6	4	25
Ink 9	19	3	28	4	2	6	4	35
Ink 10	20	3	29	5	2	6	5	30
Ink 11	22	3	33	6	2	7	2	25
Ink 12	23	3	35	7	2	7	3	20
Ink 13	21	4	32	4	2	6	5	25
Ink 14	23	4	35	5	2	7	4	20
Ink 15	18	4	27	6	2	5	3	35
Ink 16	20	4	29	7	2	6	2	30

TABLE 4. Calculated values of physical properties of prepared inks

Prepared Ink	Density (g/L)	Viscosity (Pa.s)	Surface Tension (N/m)	Ohnesorge Number (Oh)
Ink 1	1006	20.8	23.1	0.610
Ink 2	1047	25.2	24.2	0.708
Ink 3	1098	27.5	24.6	0.748
Ink 4	1120	35.7	28.7	0.890
Ink 5	1012	21.9	23.4	0.636
Ink 6	1105	33.6	24.6	0.911
Ink 7	1095	26.3	24.5	0.718
Ink 8	1054	25.5	24.3	0.713
Ink 9	1108	34.4	24.7	0.930
Ink 10	1103	32.9	24.1	0.902
Ink 11	1049	25.3	24.4	0.707
Ink 12	1015	22.5	23.5	0.652
Ink 13	1056	25.8	24.5	0.717
Ink 14	1011	22.4	23.2	0.654
Ink 15	1118	34.2	28.2	0.861
Ink 16	1102	32.3	24.2	0.885

The influence of each factor on the Ohnesorge number was depicted in Figure 3.
Based on the experimental design results shown in Figure 5, it is clear that the pigment amount has the greatest impact on the quality of the prepared ink. Subsequently, HS2, HS4, and HS7 samples have the greatest impact on the physical properties of the produced ink. Furthermore, the optimal amount of the determined factors in the experimental design was found.

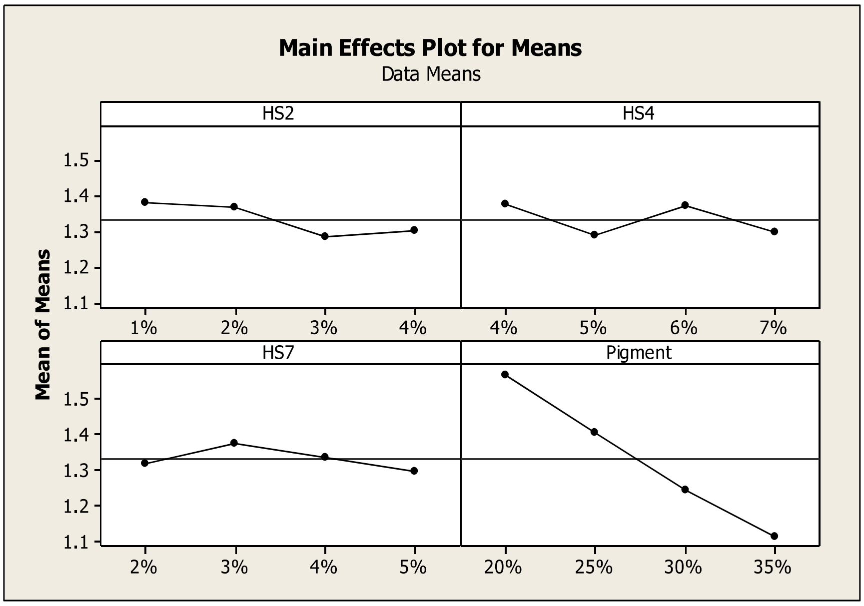

Figure 3. The influence of factors on the objective function

Thus, the optimal values of HS2, HS4, HS7, and pigment are equal to 2, 4, 3, and 30% of that used in the composition of the sample No. 5. Studies have been carried out to determine the role of each of the HS2, HS4, HS7, and pigment specimens on the main parameters of digital ink (such as density, viscosity, and surface tension) and their results are investigated. In Figure 4, the effect of the main factors on the density of digital ink has been investigated.

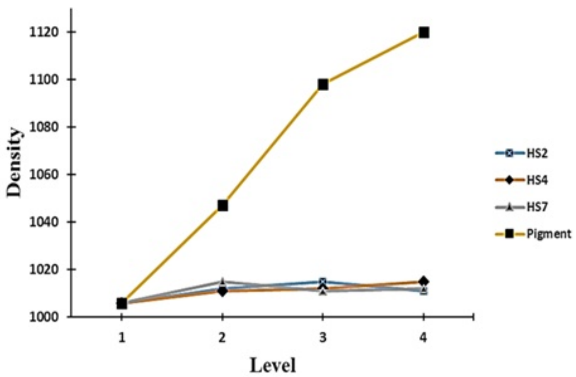

Figure 4. The effect of different factors on digital ink density

It can be observed that the amount of pigment is the major factor influencing the density of digital ink. This is due to the close density of the solvent components of the digital ink as their change has no significant effect on the density of digital ink. Moreover, it should be noted that the increase of each of these samples generally results in a partial increase in the density. The effect of pigment, HS2, HS4, and HS7 amounts on the viscosity of prepared digital ink is also shown in Figure 5.

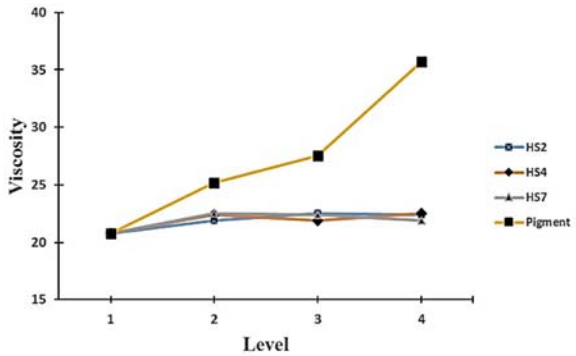

Figure 5. The effect of different factors on the viscosity amount of digital ink

Like density, the effect of amount of pigment on viscosity is more than other factors, and its change from 20 to 35% has increased viscosity as much as 41%. However, the increase in other factors does not have a significant effect on the viscosity of digital ink, which is also due to the similar viscosity of the material that causes changing in their amount to not have a definite effect on the viscosity of the final ink.

According to Figure 6, surface tension is also closely related to the amount of pigment as the other properties of digital ink. However, increasing the amount of HS2, HS4, and HS7 samples does not have much effect on surface tension. On the other hand, it is observed that the effect of the amount of pigment on the surface tension is less than its effect on density and viscosity so that its increase from level 3 to level 4 has a significant increase in surface tension.

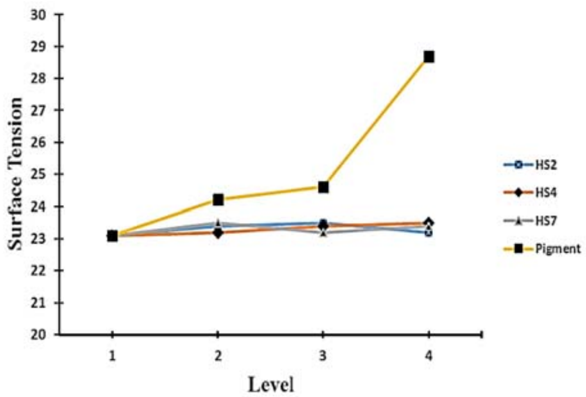

Figure 6. The effect of the amount of different factors on the surface tension of digital ink

TABLE 5. Comparison of the properties of industrial and synthetic digital ink samples

Sample Name	Density (g/L)	Viscosity (Pa.s)	Surface Tension (N/m)	Ohnesorge Number (Oh)
Industrial Ink	0.622	28	23.5	1020
Ink 5	0.636	23.4	21.9	1012

It is observed that the Ohsenorge dimensionless number of ink number 5 is almost close to the industrial sample. Therefore, it can be concluded that the ink has a good function in terms of rheological properties for proper spraying by the printer. The industrial and synthetic digital ink was sprayed on raw ceramic tile and heated at 1100°C in a furnace. The resulted beige colored tile is illustrated in Figure 7.

Figure 7. Comparison of synthetic and industrial ink after printing and heating on raw ceramic tile

As shown in Figure 7, the used ink is well spread by the printer on ceramic tile. Also, no ash or defect in coated paint is observed due to heat treatment. These results indicate the right choice of materials and the incorporation of the correct percentage of ink components.

4. CONCLUSION

In this paper, the effect of additives and pigments was investigated on the physical properties of digital ink. The experimental design was used to determine the effect of these factors. The results of this study indicated that the pigment parameter had the greatest impact on the quality of the produced ink. Subsequently, HS2, HS4, and HS7 components had the greatest impact on the physical properties of the produced ink. Also, the optimal values of the factors determined in the design of the experiment showed that the optimal values of HS2, HS4, HS7, and pigment were 2, 4, 3, and 30% of the percentages used in ink 5. It was also found that the important factor in changing the density, viscosity, and surface tension of digital ink as the three important parameters affecting its spatial properties in the device head is the change in the amount of pigment. Of course, the effect of the amount of pigment on the surface tension is less than its effect on density and viscosity.

5. ACKNOWLEDGEMENTS

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