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ENVIRONMENTALLY FRIENDLY WATER-BASED INKJET INK PRODUCTION AND DETERMINING PRINTABILITY

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Abstract: *Inkjet printing system, one of the digital printing systems, has a more widespread market day by day due to its low operating costs and allowing variable data printing. Bio-based inks, in which natural polymers are used and whose solvent is water, are attracting more and more attention both in the food industry and other industries, in order to reduce the decrease in oil resources and possible harm to environmental and human health. Polymers that can be used in naturally sourced inks include cellulose, starch, polylactic acid, polyvinyl alcohol, and cellulose derivatives. In this study, water-based ink was prepared with magenta pigment as a colorant and hydroxyethyl cellulose, a natural polymer as a binder, and printed with thermal inkjet, and its printability properties were examined. For this purpose, the study started with the preparation of ink. In ink production, first, a binder was prepared with hydroxyethyl cellulose and water. 6.5% magenta pigment was added into the prepared binder. The viscosity of the ink was adjusted to 9 cP using pure water. Since the colorant used is water-soluble, there is no need for a surfactant. Surface tension was adjusted to 31 mN/m with 3 drops of BYK 348. Test prints were made with the obtained ink using the BENTSAI BT-HH6105B1 Portable Handheld Mobile inkjet printing machine. The most stable prints were obtained at 1 m/s speed, 300 dpi resolution and 11 volt printing parameters. The color measurements of the obtained prints were measured with an X-Rite spectrophotometer and their gloss was measured BYK Gardner gloss meter. As a result, it was determined that stable ink with good printability parameters was produced in thermal inkjet.*

Key words: inkjet ink, printability, natural ink, water-based ink, thermal inkjet

1. INTRODUCTION

Inkjet printing is a printing method that creates an image by rapidly directing small droplets or particles onto a substrate surface. There are two distinct methods of creating and transferring droplets; continuous inkjet and drop on demand inkjet. Continuous inkjet is a continuous jet of ink that is forced out of a small nozzle under pressure. Under these conditions, a jet of liquid tends to break up into a stream of droplets of a size and frequency determined primarily by the surface tension of the liquid (Leach, 2012). Since inkjet is a versatile technology and the range of inks is so wide, almost any surface can be printed on; however, paper is more commonly used as the most widely used substrate in the graphics and printing industry. Most inkjet inks are highly surface-active and penetrating. The quality of the print depends on both the ink properties (surface tension and viscosity) and, to a large extent, the absorption properties of the substrate (surface tension, roughness, and porosity) (Svanholm, 2007). It is used for industrial applications where it is ideal for printing information such as batch numbers and date marks on products with rough or uneven surfaces, especially in mass production. Continuous inkjet is increasingly popular for on-line naming and addressing printing on high-speed presses. It is called by this name because the droplets are continuously produced regardless of the printed or unprinted area and the droplets in the areas that should not be printed are returned to the ink tank. The production of droplets is based on the principle of stimulating the spray liquid by destabilization (mixing) in a controlled manner. In continuous ink jet systems, as mentioned above, the jetting is made unstable, and the ink moves in controlled droplets with the vibration movement. The structure, physical and chemical properties of the ink are very important for the droplets to be consistent as desired and then for the required charging process. In DOD inkjet systems, ink droplets are produced only for the areas that need to be printed, and again these droplets move with a pressure ejection mechanism. This mechanism is the characteristic feature of DOD systems. It has a very wide area of use regardless of outdoor or indoor and has the ability to work with different printing materials. The most prominent drop on demand technologies are thermal inkjet and piezo inkjet printing. In piezo inkjet, the ink drop is created by mechanically deforming the jet chamber and is ejected from the nozzle; this action is caused by an electronic signal and the piezoelectric properties of the ink chamber (Cao et al., 2024).

Thermal inkjet printers are one of the most widely used technologies in desktop printers and are widespread in the industry. In this technology, droplets are formed by rapidly heating and localized evaporation of a resistive element in a small area containing the ink (Figure 1). The temperature of the resistive element rises to 350-400°C, causing a thin film of ink on the heater to evaporate. This evaporation rapidly forms a bubble and causes a pressure pulse that forces a drop of ink through the nozzle. The ejection of the drop then leaves a void in the chamber, which is then filled with reserve fluid in preparation for the formation of the next drop.

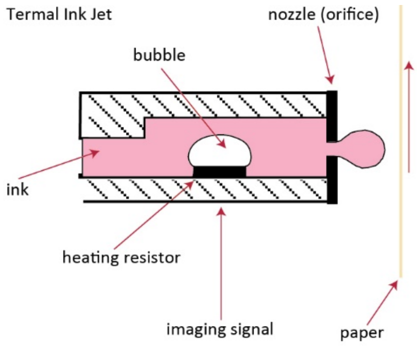

Figure 1: Drop on demand - Thermal ink jet ink system schematic view (Kipphan, 2001)

Thermal inkjet has the potential advantage of producing high nozzle density and very small drop sizes. In this way, more compact devices can be produced and print head costs are more affordable. This advantage is also reflected in unit product costs. On the other hand, the liquids that can be used in ink production are limited compared to other systems. Because the liquid to be used in this system must be more resistant to environmental conditions and temperatures. If the ink is not well designed, environmental factors and unwanted temperatures can cause unwanted situations in the ink tank. This leads to changes in properties such as conductivity and surface energy, efficiency decreases, and the print head can be short-lived. For example, if the functionality of the liquid is damaged due to high temperatures (as in some sensitive liquids and polymers), high temperatures can also cause problems.

Thermal ink jet has different shooters depending on the configuration, one of them is called a roof shooter which has a hole on the top of the heater and is placed behind the heater nozzle, the other is known as a side shooter which has a hole on the side near the heater and is placed together with the heater nozzle. In another configuration, the heater is suspended in the ink chamber (Le, 1998). Most industries manufacture and use roof shooter thermal ink jet (Simske, 2017). The biggest problem with thermal ink jet printhead is its short life due to electromigration of the heater, damage due to bubble cavitation and cracks due to thermal stress (Lim et al., 2005). The life can be increased by increasing the thickness and shape of the heater (Bar-Levav, Witman, & Einat, 2020). Another problem is cogging, a phenomenon in which ink particles accumulate on the heater surface during thermal ink jet operation, affecting the formation of bubbles and droplets. Adding anions to the ink can prevent this phenomenon (Shah et al., 2021).

In inkjet systems, the ink colorant must be immobilized quickly on the substrate surface and separated from the ink carrier. If the ink is absorbed too quickly by the substrate, it can cause a decrease in optical density and therefore a decrease in color intensity in the print. On the other hand, if the ink is not absorbed quickly enough, it can cause color bleeding, edge irregularities and distortions in lines. Therefore, the transfer and placement of the ink on the substrate must be at an optimum level (Svanholm, 2007).

The use of water-based ink in inkjet printing systems is not new. However, solvent-based systems have been widely used for a long time. Today, water-based systems are again coming to the fore with environmental factors, health and legislation. Low toxicity value and the absence of volatile organic compounds are the most important preference criteria. However, compared to solvent systems, drying occurs more slowly in rough-surfaced printing materials, and light fastness values are also low. With these features, it is recommended to be used in indoor printing or lamination can be preferred for protective purposes after printing. However, this also increases the printing cost.

Water-based inks are called by this name because they use water as a carrier, and in some cases, different solvents (that do not produce ozone) can be used. The water ratio in the ink formulation varies between 75-90%. These inks, which have water or a similar carrier, stand out with their lower cost and environmental friendliness compared to their counterparts. In addition to these advantages, they settle more slowly on some substrates, some surfaces may have adhesion problems and drying problems may

occur. In industrial applications where these types of inks are used and durability is at the forefront, lamination is needed to strengthen and reinforce the surface, which can increase the cost.
Water-based inks are also used in flexographic printing systems for printing paper and board materials. Due to the absorbent nature of paper fibers, printing with water on these substrates has been easily achieved. Inks and solvents (including water) are partially absorbed into the substrate and partially evaporate into the surrounding air. However, placing a water-based solution on a film or foil is like putting water on a freshly waxed car: The water beads up and slides around the surface. The surface tension differences between the ink and the substrate - particularly emphasizing the difference between solvent and water-based inks - require the substrate surface tension to be modified to facilitate transfer and adhesion of water-based inks. In addition, components added to the film to give it certain properties can also migrate to the surface and prevent the inks from adhering. Inks need to be resistant to all external influences. Overcoming these obstacles is one of the biggest challenges facing packaging printers who choose to use water-based inks and coatings.
The average water-based inkjet printing ink components are as follows; pigment or dye as a colorant is 2-5%, surfactants or additives are also at the same rate of 2-5%, ethylene glycol or diethanolamine as a moisturizing agent is around 30% and the remaining 65% consists of water. Viscosity is in the range of 2-5 cp and surface tension is 30-40 dyne/cm (Svanholm, 2007). While colorants are more prominent in other printing systems, colorants in inkjet ink can be both pigment and dye. We can explain this situation by the ability to print on very different substrates with these systems. The difference between these two colorants is that the dye is completely dissolved in the carrier, while the pigment is found as very small particles homogeneously distributed in the carrier (Figure 2). Both colorants are widely used in industrial applications (Marie et al, 2013).

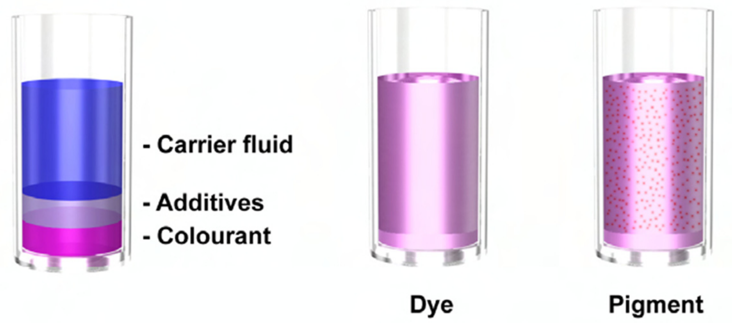

Figure 2: Inkjet ink colourants

For an ink formulation, the required rheological properties must first be provided. The ideal rheological properties required for an inkjet system are a (static) Newtonian ink viscosity between $\eta = 3$ and 40 mPa s (ideally 10 – 20 mPa s) and a surface tension in the range of $\sigma = 25 – 40$ mN/m (Reis, Ainsley, & Derby, 2005; Liu & Derby, 2019). Apart from these ink properties, the compatibility of the ink to be produced with the substrate is also important. The adhesion of the ink to the material, drying properties and color properties, conductivity, working stability, and fastness properties are also important for a good ink (Castrejón-Pita et al., 2021). In addition, spray performance depends on the nozzle, purity to prevent clogging, particle size, pH, and defoaming properties are also important (Tyler, 2005).
In the study, water-based inkjet digital printing ink formulations were prepared and produced for use in thermal inkjet printing. After obtaining the optimum ink, printing was carried out under optimum conditions on a hand-held inkjet printing machine and the suitability of the new ink for inkjet digital printing systems was determined.

2. METHODS

For the production of water-based inkjet ink, distilled water, surfactant to control viscosity, dye as colorant, buffer as pH regulator and defoamer if needed were used. Surfactant tergitol, dye Reactive Red 195, and buffer were purchased from Sigma-Aldrich (Germany). The viscosity of the produced water-based ink was measured with a viscometer and the surface tension was measured with a surface tension meter and the necessary additions were made and adjusted. The basic formulation of the produced ink is given in

Table 1. In addition, it was monitored with a dilatometer whether there was expansion in the dimensions of the produced ink depending on temperature and time.
In the first stage for ink production, dye was mixed with water, then surfactant was added. Homogenization was achieved by mixing at 600 rpm for 10 minutes. The pH of the resulting mixture was measured, and buffer was added to bring it to a weak basic condition suitable for printing. BYK 024 anti-foaming agent 1 drop was added to the formulation to eliminate the foam formed in the prepared ink. The long-term stabilization of the obtained ink was visually examined for 72 hours. The images of the dye used in the study and the prepared inks are given in Figure 3.

Table 1: Water-based ink formulation

Contents	Ratio (%)
Water	90
Surfactant	3
Dyes	6.5
Buffer	0.5
Total	100

Figure 3: Dye and prepared inks used in the study

Prints were made on 80 g/m^2 office papers using water-based inks. Bentsai bt-hh6105b2 thermal inkjet digital printer (Figure 4) was used as the printing machine. Technical specifications of the paper used in the study are given in the Table 2. Then, the spectrophotometric properties of the papers were determined using CIEL*a*b* color values by using an X-Rite eXact spectrophotometer according to the ISO 13655:2017 standard. The difference between the colors of the different prints was calculated according to the CIE ΔE 2000 color-difference formula ISO 11664-6:2014. Calculations were performed by calculating the average of five measurements.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}} \quad (1)$$

Figure 4: Bentsai bt handheld thermal inkjet digital printing machine

Table 2: Technical properties of the paper used in the study

Properties	Standard	Office paper
Grammage (g/m^2)	ISO 536	80
Thickness (µm)	TAPPI T411	188
Whiteness (D65/10) (%)	ASTM E313	95
Gloss (75°)	ISO 8254-1 Part-1	5.8
Yellowness	ASTM E313	0.06

3. RESULTS AND DISCUSSION

As a result of printing experiments with inks having different viscosity values, it was determined that the ideal ink viscosity was 9-11 cps 25°C. The ideal surface tension in this viscosity range was measured as 30-31 dyn/cm. Surface tension was adjusted to 31 mN/m with 3 drops of BYK 348. In addition, expansion depending on temperature and time was monitored with a dilatometer and no expansion occurred in the ink.

The water-based inks produced were used with Bentsai bt-hh6105b2 thermal inkjet digital printer prints. The prints were made with 11 volts, dual nozzle, 256 dots, 300 dpi resolution, 1m/s speed and 35° angle. The printed text sample is shown in Figure 5. The average values of CIEL*a*b* color measurements performed with the spectrophotometer are L*52, a*54, b*7. The difference between the color obtained according to the CIE ΔE 2000 color-difference formula and the standard color is around ΔE_{00} 2.5.

Figure 5: Printing sample with prepared ink

The long-term stabilization of the obtained ink was visually examined for 72 hours, and no changes were observed in the inks (Figure 6).

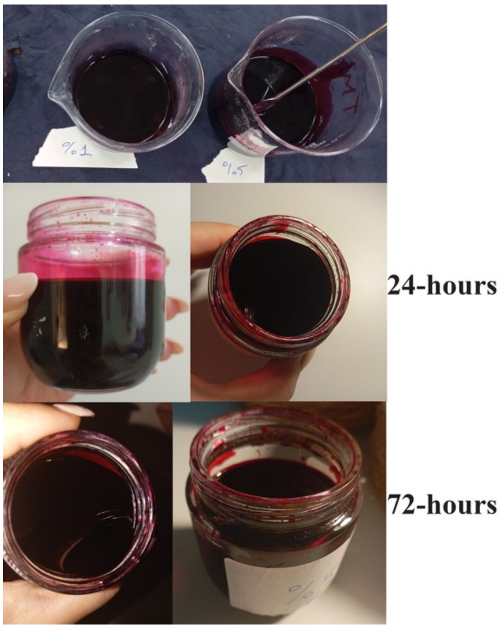

Figure 6: Visual control of the stabilization of prepared inks for up to 72 hours

4. CONCLUSIONS

In the study, after various tests, magenta color thermal inkjet printing ink with a viscosity range of 10-14 cps 25°C and a surface tension of 30-35 dyn/cm was produced. There was no expansion in the produced ink depending on temperature and time. Its stabilization was monitored for a long time, and it was seen that there was no problem. The ink was currently examined by printing on only one type of paper. Tests will be made on other process colors and different substrates.

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