Wicking process of penetrants and inkjet inks on printing media

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Abstract

In this study, the dynamics of liquid capillary wicking (known as absorption, penetration, or imbibition) is discussed for a penetrant of an inkjet ink and commercial magenta inks. Different concentrations of penetrants on various printing media were tested, as well as magenta inks from HP and Canon. Penetrants are very efficient to wick inks on printing media and to reach maximum wicking area fast. The wicking areas of the penetrant solutions on test substrates are much lager than DI water. Since commercial ink contains 2 - 5% of penetrants, maximum areas of inks are larger than water and smaller than penetrant solutions. Alkylene glycol type penetrants such as Diethylene glycol monobutyl ether (DEGMBE), Diethylene glycol diethyl ether (DEGDEE) are to show large maximum wicking area and fast wicking rate. Alcohol type penetrants including Ethyl alcohol (EtOH) and Isopropyl alcohol (IPA) indicate fast drying rate at 100 and 50% concentration; however, drying rate of both alcohol type and alkylene glycol type penetrants at low concentrations are close to drying rate of water. Alkylene glycol type penetrants show less effects of concentration on wicking ratio, while concentrations of alcohol type penetrants greatly affects to absorption.

Introduction

Inkjet printing becomes a leading technology for desktop digital color printing. Good image qualities can be achieved by various factors including printing media such as plain copy paper and coated photo paper and ink components such as penetrant and surfactant [1-3]. Most of plain copy papers consist of pulp, resin, and filler with micro porous capillary and hydrophobic surface. Photo papers on the market are nonabsorbing substrates coated with either PVA or Alumina sol as absorbing or micro porous layers. The penetrants used in commercial inks are alkylene glycol type such as Diethylene glycol monobutyl ether (DEGMBE), Diethylene glycol diethyl ether (DEGDEE) and alcohol type such as Ethyl alcohol (EtOH) and Isopropyl alcohol (IPA).

The dynamics of liquid capillary wicking (known as absorption, penetration, or imbibition) are one of printing processes. The fundamental rules relating to physical chemistry determining the dynamics can be varied for different ink components and inks. Inkjet printing processes consist of ink drop formation, drop impaction, wicking, and evaporation. Liquid inks are ejected by thermal bubbles or mechanical movement in an inkjet head and form droplets by surface tension with free surface. When ink drops impact on printing media, drop/substrate interaction can be described as non-equilibrium, which can be separated into the two stages. First stage is before impact, and the energy of the impacting drop consists of kinetic energy, surface energy, and potential energy. In second stage, the impacting drop spreads over the surface. The spreading rate is initially rapid and then decreases to a very low rate. For a period of time, the spreading diameter is almost constant (pseudo-equilibrium). Then the next stage begins where spontaneous wicking occurs. The wicking speed depends on interaction between the substrate and the ink. The active ingredient of the ink for the wicking is the penetrant. After absorption, the liquid is evaporated leading to the final equilibrium condition. The wicking processes are more important to improve printing speed than spreading and evaporation processes. Whole spreading time is extremely short and evaporation takes longer time than wicking process; however, the processes of evaporation are occurred in capillaries of the media, so drying in capillary may not affect to image quality. Since visualization of wicking processes for few pico-liter sized droplets is not easy, comparison of scale-up experiment and tests with small droplets for impacting are done in previous researches [4, 5]; however, those tests for wicking processes are not achieved.

The objectives of this study are 1) to understand the effects of ink penetrants on wicking and evaporation processes on printing media and 2) to understand how ink composition affects to inkjet ink wicking and evaporation performance. The experiments were conducted to evaluate the effects of various penetrants and commercial inks on capillary wicking and drying in the capillary. Most of penetrants have low surface tension, which improves adsorption and wicking rate; therefore, the imbibed area of an ink containing penetrant is much larger than the area of an ink without penetrant.

Experimental

Materials

Investigations of the wicking and drying phenomena were carried out using four penetrants with different concentrations and two commercial inks. Penetrants and inkjet inks for experimental tests include Diethylene glycol butyl ether (DEGMBE; Junsei Chemical co. LTD), Diethylene glycol diethyl ether (DEGDEE; Kanto Chemical Co., Inc), Ethyl alcohol (EtOH; Samchun pure chemical Co., Ltd), Isopropyl alcohol (IPA; Kanto Chemical Co., Inc), HP 02 magenta ink, and Canon 6 magenta ink, which properties are shown in Table 1. Two copy paper and two premium photo papers were used. Figure 1 shows morphologies of Premium^{TM} copy (Samsung; Samsung co., Ltd), Business Multipurpose 4200 (Xerox; Xerox co., Ltd), Premium glossy photo paper (Epson; Epson co., Ltd), and Premium plus photo paper (HP; Hewlett-Packard Development Company, L.P.). In Figure 1 (a) and (b), surface morphologies of general copy paper are shown. Pulp fiber with resins is randomly entangled on the surface. Main components of plain paper are pulp, resin, and filler. Figure 1(c) and (d) show surfaces of photo papers. The surfaces are smoother than both Samsung and Xerox copy papers and few pores are found. Epson and HP photo paper coated with Alumina sol and PVA, respectively. The current paper was intended to report effects of wicking properties.

Table 1: Physical properties of test liquids

Liquids	Viscosity (cP)	Surface Tension (mN/m)
DI Water	1	72.8
Ethanol	1.5	23.3
IPA	1.9	21.7
DEGDEE	1.3	26.7
DEGMBE	5.2	29.1
HP 02 Magenta	2.6	29.4
CN 6 Magenta	2.3	34.7

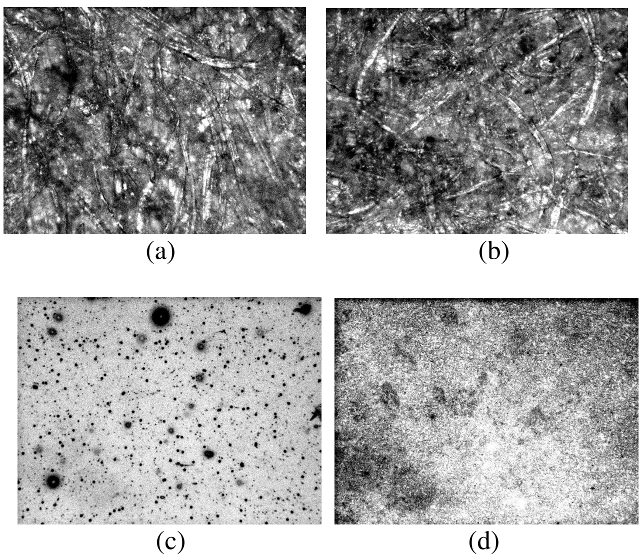


***Figure 1**. Surface morphologies of four different printing media (a) Samsung, (b) Xerox, (c) HP, and (d) Epson*

Measurement of the viscosity and surface tension of the liquids

The attractive forces between water molecules create surface tension on the liquid surface. Wilhelm plate method was used to measure the surface tension. A du Nouy tensiometer, a surface tension torsion balance (KRÜSS GmbH), was employed. Five measurements for each liquid sample were carried of which the average was taken as the surface tension of the liquid sample.

A Brookfield model DV-II+ viscometer (Brookfield Viscometers Ltd.) was used for measuring the viscosities of the liquids. Viscosities and surface tensions of test liquids are shown in Table 1.

Evaluation of the ratio and area of wicking

The wicking ratio of liquid on a paper was determined by measuring the residual volume over a period of time. A modified contact angle analyzer, FTÅ200 (First Ten Ångstroms), shown in Figure 2 was used for wicking tests. A syringe with range of 0.1 to 5 μl was used to apply test liquid on various papers. After test liquid was applied, a strobe and a CCD camera were triggered to capture the wicking processes. The captured images were used to calculate residual volume based on contact angle and the diameter of base contact area. The wicking areas were measured on four different types of the papers after each test liquid disappeared on the top of the surface. The wicking tests were reported with the surface area against the applied volume.

Determination of the rate of drying

Two drying tests were conducted to measure drying time of various test liquids on an aluminum plate. Halogen Moisture analyzer (Mettler-Toledo International Inc.) was used to get drying rate against time. A drying test called "Bulk drying test" was conducted with applying 4g of liquid samples on the plate and drying at 70^oC. The purpose of the test is to evaluate drying rate of a liquid sample with infinite curvature. This test results were compared with drying rates of a test liquid wetting on printing media. The drying test using wetted paper is called as "capillary drying test." The sample liquid or wetted paper was placed on an aluminum plate and heated by halogen lamp located the top of the plate and recorded losing weight with time.

Results and discussion

This research primarily shows the effect of various penetrants on wicking time and volume and drying time in capillary. The studies were conducted with four penetrants and two inks as test liquids and four different treated papers as substrates. The results were discussed in terms of wicking and drying ratios. Inkjet printing speed depends on drying time as well as wicking time.

Maximum spreading area

Maximum area with applied volume of selected test liquids was assessed in this session. Sample substrate was prepared with dimension of 5cm X 5cm. Glue tape was placed backside of testing surfaces of paper. All glue tape for the experiments was collected in the same roll of tape for reducing errors associated with chemical reaction between paper and glue or paper and sample liquid. With applying tape, standard deviation of test results were significantly reduced, comparing with paper samples without applying the tape. The maximum spreading areas were recorded when the residual liquid on the substrate totally disappeared. The remaining residual liquid was checked with observer's bare eyes. Amount of sample liquids applied were 1, 2, 3, and 5 μl by micro syringe. To remove additional pressure by pressing syringe cylinder, the liquid drop was formed and pended at the end of the needle tip and applied to the Samsung copy paper slowly.

As shown in Figure 2, IPA, EtOH, DEGMBE, and DEGDEE as penetrants, spread larger area than two commercial inks and D. I. water with the same amount of liquid application,. Usually commercial inks comprise of at least one penetrant with 1 – 10 % of concentration. Thus, the curves of ink wicking areas locate between four penetrants and water. DEGDEE among four penetrants appears highest wicking area. Based on wettability coefficient [6], surface tension, contact angle of substrate and liquid are major factors. DEGDEE shows highest surface and lowest contact angle with Samsung copy paper among other tested liquid samples.

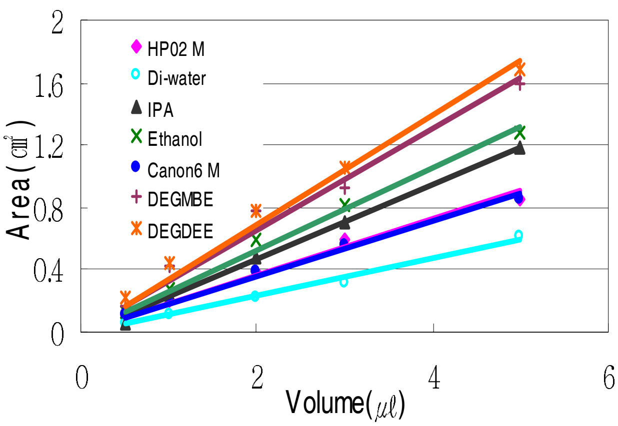


***Figure 2**. Maximum wicking area with given volumes of penetrants, commercial inks, and D.I. water on Samsung copy paper.*

Effect of different penetrants and commercial inks on wicking

To improve printing speed, penetrants with fast wicking rate are required. Two types of penetrants (alkylene glycol and alcohol) were used to find a fast wicking penetrant. Wicking rate based on residual volume ratio on the various papers was described in this session. Figure 3 shows picture of wicking taken from FTÅ200. A selected liquid in the syringe formed a drop at the end of the needle and placed on the top of the paper. The wicking processes were recorded with a certain period time programmed for each liquid. The programmed time becomes longer when absorption process of the liquid is slow. The FTÅ32 program calculated the residual volume of liquid based on contact diameter and contact angle between liquid and paper media.

Figure 4 shows effects of penetrants on wicking rate with Samsung copy paper. IPA, DEGMBE, EtOH, as penetrant and DI Water as reference were used. The trend lines were created with 22 data points on 105 seconds. The water was not absorbed on a copy paper which has hydrophobic properties. Most of penetrants including IPA, EtOH, DEGMBE wicked in 3 seconds while DEGDEE absorbed in about 1 second. Thus DEGDEE has best wicking rate with Samsung copy paper substrate. The same results were observed for Xerox, Epson and HP papers. Absorption rates of commercial inks (CN6 M and HP02 M) are about 0.17 volume/second which is between slops of water and penetrant. These results are expected because commercial inks usually comprise 2 – 5% of at least one penetrant. 100% of pure penetrants in Figure 4 were used to get wicking rate curves.

Effect of penetrant concentration on wicking

Since commercial inks include 2 – 5% of penetrants, study about the effect of penetrant concentration on wicking is important. The behavior of a penetrant in an ink can be predicted before designing inks. Figure 5 (a) shows wicking rate with various concentrations of DEGMBE. Curves for 50, 10, and 5% DEGMBE solutions show similar slops of wicking ratio. However, 100% pure DEGMBE liquid decreases dramatically with wicking time and absorbed all in 3 seconds. The rest shows that the concentration of DEGMBE solution does not affect to wicking rate.

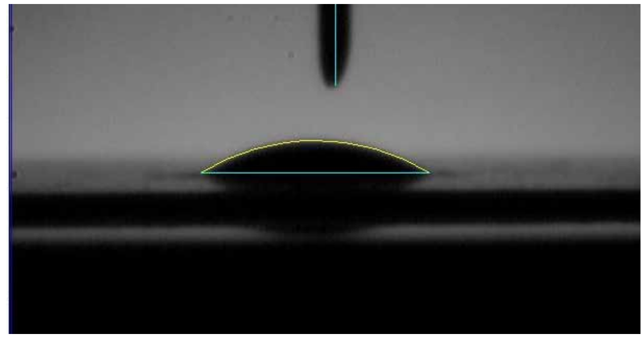


***Figure 3**. Image of a wicking drop on Samsung copy paper using the FTA32 program*

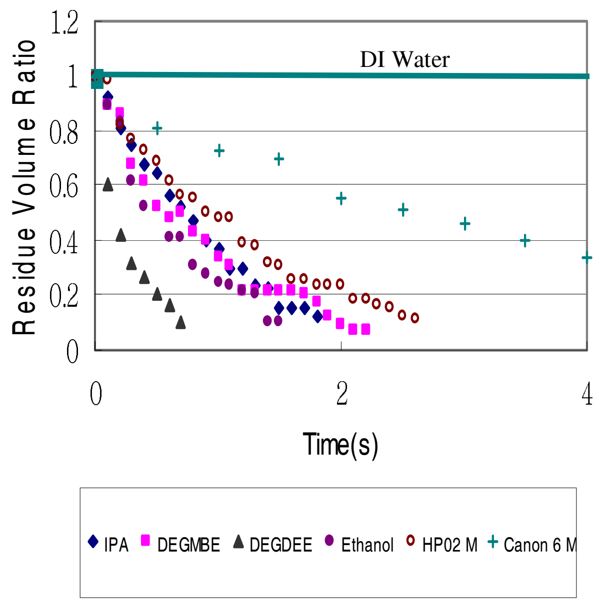


***Figure 4**. Wicking ratios of various penetrants on Samsung copy paper*

Figure 5 (b) shows wicking rate with different concentrations of IPA. Wicking behavior of IPA is quite different with that of DEGMBE. 100% IPA totally wicked in 3 seconds while 5% IPA solution wicking rate is close to water. The wicking rates of IPA solutions gradually decrease with decreasing concentration of IPA. Thus, wicking rate of IPA solution depends on the alcohol concentrations. When concentration is less than 50%, absorption rate is too low to use as a penetrant.

Figure 5 (c) shows wicking of commercial inks with different concentrations. Four inks tested were HP02 M, CN6 M, 50% diluted HP02 M, and 50% diluted HP02 M. The diluted solutions of commercial inks show almost the same wicking rate with original inks. The wicking processes are very similar to that of alkylene glycol type penetrants.

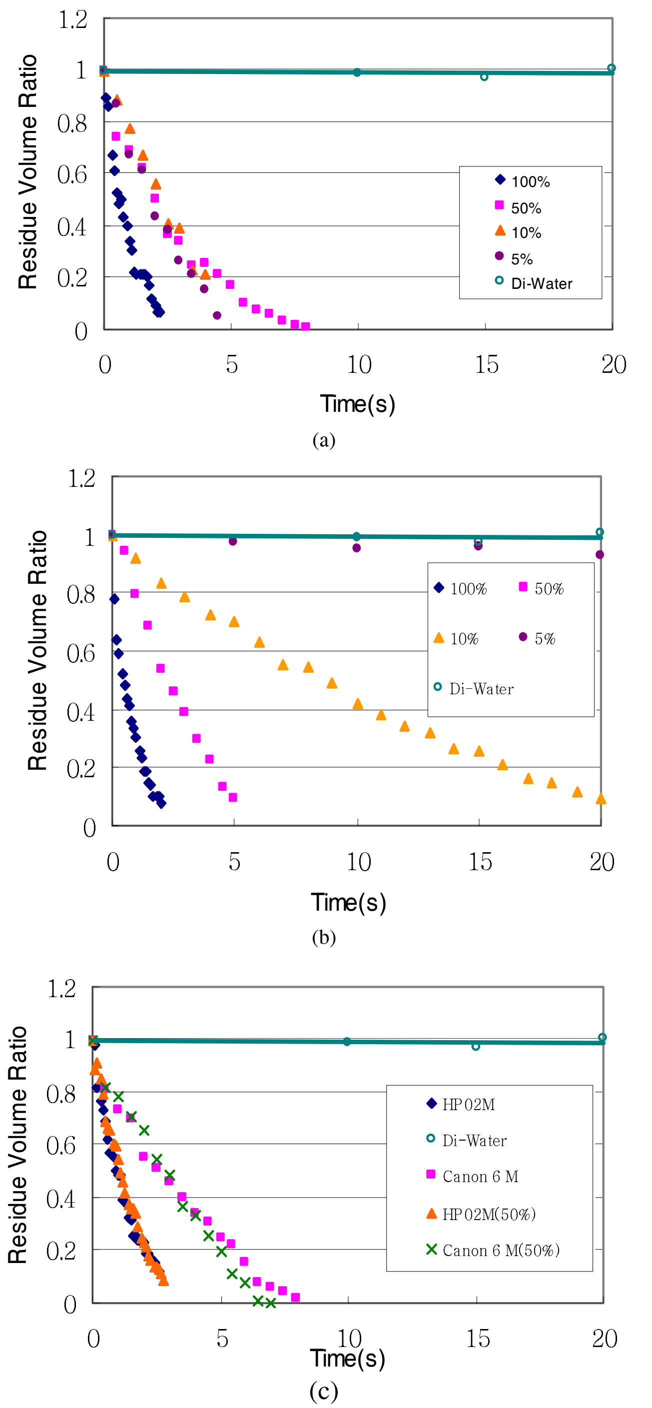


Figure 5*. Wicking ratios of different concentrations of penetrants and inks (a) DEGMBE, (b) IPA, and (c) commercial inks*

Effect of different penetrants and commercial inks on drying

Drying is an important factor affecting printing speed as well as wicking. In Figure 6, three penetrant (IPA, DEGMBE, EtOH), two inks (HP02 M, CN6 M), and DI water were tested in the halogen moisture analyzer. Accessed liquid on the sample surfaces were removed as much as possible. The conditions of the test were 70°C of experimental temperature and 0.1g of sample weight. Alcohol based penetrants such as IPA and EtOH are evaporated in around 30 seconds while slower drying is observed for an alkylene glycol type penetrant such as DEGMBE. The boiling temperatures of the two alcohols and DEGMBE are around 60°C and 250°C, respectively. The differences in temperatures can influence significantly on the drying rate. The drying rates of commercial inks were close to drying rate of the water until 1second and the slop of drying rates were significantly decreased and approached to equilibrium at 90%. Amount of unevaporated residue material was around 10% of a commercial ink, which is organic co-solvents.

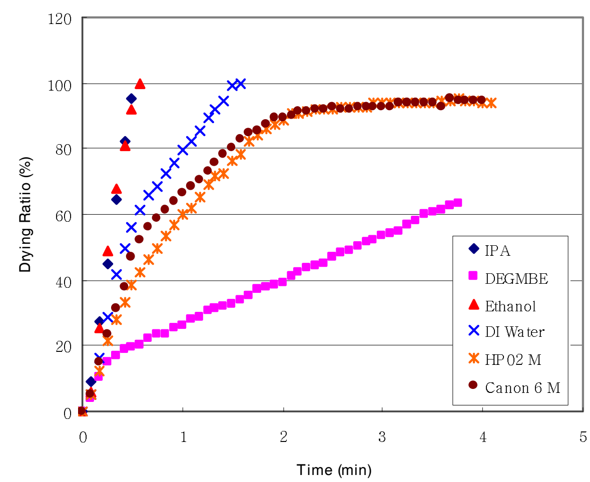


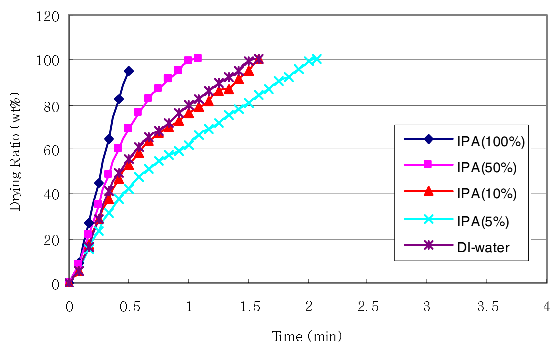
Figure 6*. Drying rate of various penetrants and commercial inks*

Effect of penetrant concentration and commercial inks on drying

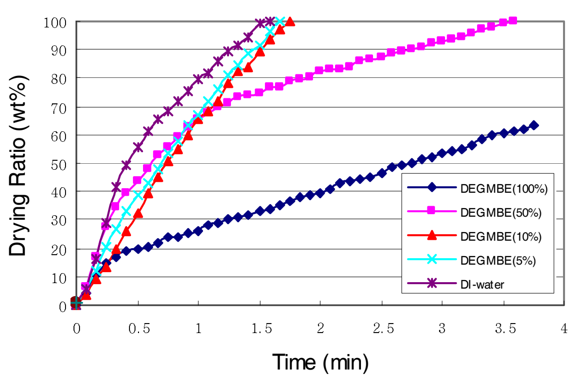
The normal concentration of penetrants is around 2 to 5 % in commercial inks. Pure penetrants and diluted penetrants show different drying rates in the capillaries of paper. Effect of concentrations of the penetrants on drying rate is studied in this session.

Figure 7 shows drying rate of various concentrations of penetrants (IPA and DEGMBE) and commercial inks (HP02 M and CN6 M) on Samsung copy paper. In the Figure 7 (a), effect of different concentrations of IPA on drying rates are compared with drying rate of water. High concentration of IPA solution significantly dries in around 50 seconds; however, drying rates for 5 and 10% IPA solutions are lower than that of water. The reason of lower drying rates may relate to interaction between water and IPA, which becomes stronger at 1 – 10% of concentrations.

Figure 7 (b) shows drying rate of DEGMGE solution with different concentrations. In the low concentrations such as 5 and 10% solutions, drying rates are close to pure water evaporation rate in the capillary. For DEGMBE solutions with higher concentration (50 and 100%), drying processes are comparable with the processes for alcohol based penetrants. Two separated curves can be observed for 100 and 50% DEGMBE solutions. The slops of initial curves are similar to the slop of water curve and then the slops are dramatically reduced. The slops of 100 and 50% DEGMBE solutions are changed after approximately 25 and 60 seconds, respectively. The ratios to change curves are around 15% higher than water concentration in the DEGMBE solution because paper contains moisture even at standard condition. After changing curves, the slops of 100 and 50% solutions are almost identical.



(a)



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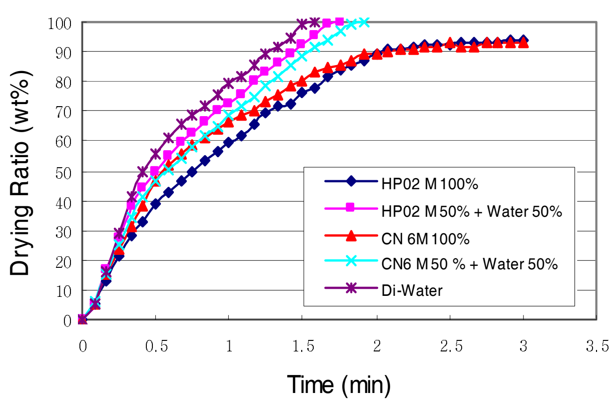

(c)

***Figure 7**. Drying rate of various concentrations of penetrants and commercial inks on Samsung copy paper. (a) IPA, (b) DEGMBE, and (c) the commercial inks*

In Figure 7 (c), the curves represent drying ratio of commercial inks with two different concentrations. Main differences of drying between original and diluted inks are equilibrium levels. Two diluted inks dried up to 100%, while original inks meet equilibrium at around 93% at approximately 2 minutes. This phenomenon may be occurred by drying the moisture contents in the paper. Drying rate of diluted ink evaporates faster than original inks, where the differences are less than 15%.

Conclusion

The dynamics of liquid capillary wicking and capillary drying of penetrants and commercial inks were studied. Printing speed usually depends on both wicking time and drying rate in the capillary of paper. Maximum wicking area of the penetrants is higher than both commercial inks and DI water. Alkylene glycol type penetrants such as DEGMBE and DEGDEE show larger maximum wicking area and the faster wicking rate than alcohol type penetrant such as EtOH and IPA. Pure IPA(100%) indicates better drying rate; however, both alcohol type and alkylene glycol type penetrants are close to drying rate of DI water for 5 – 10% concentrations.

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Author Biography

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