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Dispersion of ink through papers

D. P. De Silva and T. R. Ariyaratne
Department of Physics, University of Colombo, Colombo 3

ABSTRACT

This study examines dispersion of printing ink drops on different types of papers with reference to ink-jet printing. Simultaneous spreading and radial penetration have been considered as a combined process and vertical penetration was not studied separately because of the complexity. Two studies of how printing ink interacts with thin commercial papers are presented.

The first study examines dispersion (diffusion) of printing ink through different types of papers at environmental humidity level. These profiles were found to depend on the GSM value of papers and the interfacial properties of the ink and the paper with which it interacts. Diffusion coefficients that are calculated for the halfsheets of GSM value 48.93, photocopy papers of GSM value 80.00 and different types of duplication papers of GSM values 58.25 and 60.25 are found to be 0.6, 0.7, 1.1, and 1.6 respectively.

The second study consists of an investigation of the dispersion of printing ink through a selected type of photocopy paper at four different relative humidity levels. It shows that the dispersion of printing ink through papers and drying time both has an exponential relationship on the relative humidity level and the moisture content of the papers. Results indicate the quality of ink-jet printing can be improved by carrying out the printing process at low humidity environments while storing the papers at low humidity environments.

1. INTRODUCTION

Phenomena associated with the dispersion of ink through papers, can be seen in many industrial applications. Spray painting, inkjet printing and news paper industry are just a few examples to mention. In the field of graphics, the term ‘ink diffusion’ [1] has been traditionally used to describe ink dispersion in absorbent paper. However, in physics, ‘diffusion’ refers to the random movement of particles towards the less concentrated regions from high concentrated regions. It is mathematically described by Fick’s law. In effect, diffusion simply averages out any spatial difference in the concentration, making the concentration approach a constant with time. In reality, the actual process of ink dispersion is a complex interplay between paper, water and ink constituents [2]. Ink dispersion can be viewed as a two-part process [2]: The percolation of water flow of water through the paper fibers in low speed due to water pressure and capillary attractions, and the movement of pigments within the water. The later is mainly caused by the spatial difference in water velocity and the hindrance by paper fibers. The pigment diffusion only plays a minimal role in this process.

Ink-jet printing is a technology where text, black and white illustrations, and color images are created by placing the microscopic colored dots on a porous ink-receiving layer. In order to achieve this, a dye or pigment is placed in a carrier fluid and ejected at high-speed (~10 m/s) from nozzles on a moving print head. The ink leaves the nozzles in the form of pico liter droplets and impacts the receiving layer after a brief period of flight (~100µs). Depending on the chemistry and morphology of the print medium, i.e., the substrate, the ink may form non-wetting droplets on the surface or may spread and penetrate into the receiving layer. During this time, the dye binds to the substrate and the carrier fluid evaporates. In order to facilitate the absorption of ink into the substrate the ink is mixed with surfactant liquids. The spreading of surfactant-laden drops on thin permeable media is a fundamental aspect of ink-jet printing. Here, two events dominate the interaction between drop and receiving Layer [1],

1. Spreading on the surface of the medium (surface wetting)
2. Bi-directional penetration into the underlying substrate (radial and vertical directions)

There are three main factors that influence the dispersion of ink through papers
1. Paper properties such as structure and the surface properties (Coatings)
2. Ink fluid properties, such as surface tension and viscosity
3. Humidity level, Inkjet printouts vary considerably in their sensitivity to high relative humidity environments

The objectives of this work are to investigate dispersion of printing ink (Used in ink-jet printers) through different types of papers, at environmental humidity level, and to the investigate dispersion of printing ink through photocopy papers (80GSM) at different humidity levels

2. MATERIALS EQUIPMENTS & METHODOLOGY

Eight types of commercially available papers and one type of printing ink were used for the investigation. Experiments were carried out only to examine the simultaneous spreading and radial penetration characteristics along the surface of the paper. Characteristics of vertical penetration of ink were not studied as it was found to be very complex. All experiments were carried out with ink drops of constant (0.02 cm^3) volume. A special dropper was constructed for this purpose. A test was carried out to check the accuracy and the repeatability in the formation of identical droplets by the dropper. To observe and obtain the measurements on the dispersion of ink droplets placed on papers digital video camera with a frame rate of 25 frames per second and 1 Mpixel resolution was used.

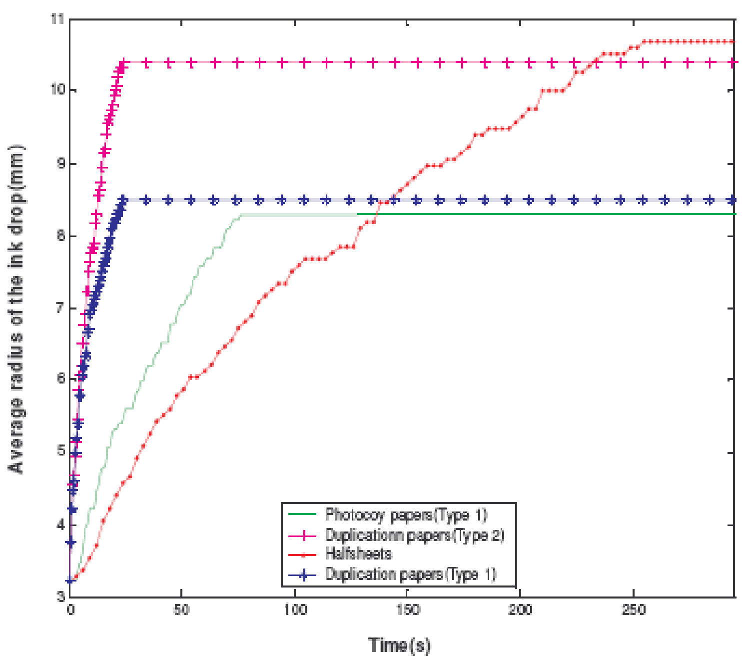
A printing ink droplet was placed on each of the selected eight different types of papers using the dropper and the dispersion of those droplets were recorded separately by the video camera. The distance between camera lens and paper was kept constant at 30 mm. In order to investigate the dispersion of ink through papers at different humidity levels, first the papers were dried in humidity control chamber. An electronic balance was placed inside the low humidity chamber and nine photocopy papers were stored up on the balance. Then required humidity level was setup at the chamber, and the variation of the mass of papers was measured with time. Once the papers had attained the equilibrium moisture level corresponding to the humidity level inside the chamber, an ink droplet was placed on one of the papers and its dispersion was recorded with the video camera. This experiment was repeated for four different relative humidity levels (30%, 40%, 50%, 60%, and the environmental humidity level which was 76%).

After recording the video clips on ink dispersion a DV card (Digital video card IEEE1394, 4 pin) was used to capture video clips into computer. Captured video clips were subsequently divided into frames by using the **Adobe premium pro 1.5** software**,** and the average value of the radius of the droplet at different times was calculated using the matlab software.

3. DATA ANALYSIS & DISCUSSION

3.1 Dispersion of printing ink through different types of papers at the environmental humidity level

The Figure 1 shows dispersion of printing ink through four different types of papers at environmental humidity (76.5%) and room temperature (31^{0}C) with time.



According to the results minimum spreading was observed for photocopy papers type 1 and the duplication paper type 2 shows spreading very much closer to the photocopy papers type 1 with considerably low drying time. It implies that the duplication papers type 2 also performs well for printing ink with low spreading and low drying time. However, performance of half sheets for printing ink shows maximum spreading with maximum drying time for printing ink.

Figure 1: Variation of the average radius (R) of the ink drop on the paper with time through four different types of papers at environmental RH

Table 1 is prepared by considering the results obtained from Figure 1.

Table 1: GSM values of four types of papers and corresponding, R(max) (maximum dispersion) , and T(max) (Drying time) values for a ink drop with volume 0.02cm^3.

Type of paper	**GSM**	**R(max)mm Maximum dispersion of ink**
Halfsheets	48.93	10.8 ± 0.1
Duplication paper type1	58.25	10.4 ± 0.1
Duplication paper type2	60.25	8.4 ± 0.1
Photocopy papers type 1	80.00	8.2 ± 0.1

According to the Figure 2, there is a trend that the R(max) decreases with the increasing GSM values. Reason for that the, thickness of a paper increases with the increasing of the GSM value, and therefore extensive vertical penetration also occur simultaneously with the radial penetration. However, duplication papers type 2 presents spreading very much less than duplication papers type1 though both have nearly equal GSM values. It implies that the spreading property will not only get affected with the GSM value of the paper, but also varies with the structure of the papers. Structure of papers depends on the pulp that is used to create the paper and also the coating structures used by the manufactures. Paper pulp is produced by using number of raw materials. They are waste papers, hay, and molasses of sugar cane.

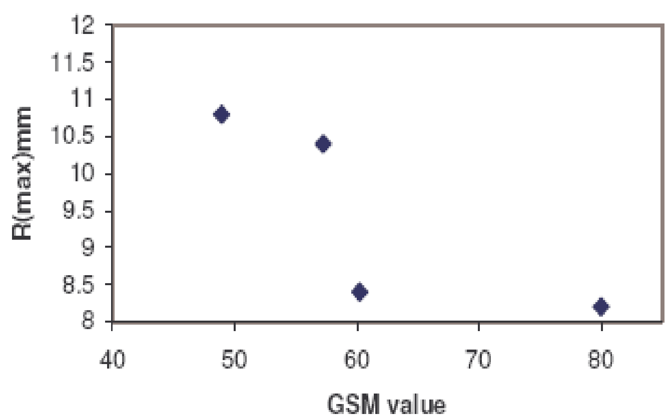


Figure 2: Variation of R(max) with GSM value the papers

Different types of papers are produced by varying the concentration of the predefined row materials that are used for the pulp creation and also by applying different coating structures. It yields papers with different surface properties. When a liquid interacts with a non-porous solid, the equilibrium shape of the droplet is dictated by the interfacial properties (contact angle between ink fluid and paper) of the liquid and the solid. Addition of surfactants can also modify the balance of interfacial energies. These physical and chemical properties will determine the initial radius of the patch produce by the droplet on the paper and its contact angles with the surface of the papers, giving rise different rates of spreading.

Table 2 is prepared according to the results obtained from plots which were prepared by curve fitting for the equation $R = k*t^{1/2} + r_{0,}$ [1] for four curves shown in the Figure 1. Here R is ink dispersion radius, t is the dispersion time, k is diffusion coefficient and r_0 is initial radius of the droplet.

Table 2: k (diffusion coefficient), r_0 (Initial radius of the droplet), and T(max) (Drying time) values of four types of papers for a ink droplet with volume $0.02cm^3$

Type of paper	**k value**	***r_0 (initial radius)mm***	***T(max)s***
Halfsheets	0.6	1.6	255.0±1.5
Photocopy papers type 1	0.7	1.7	75.0 ±0.5
Duplication paper type 2	1.1	1.9	25.0 ±0.2
Duplication paper type 1	1.6	2.7	25.0 ±0.2

According to the table, the initial radius of the droplet, as it touches the surface of the paper, is higher for duplication papers indicating fast spreading. On the other hand half sheets produce smaller droplets at the beginning indicating slow spreading.

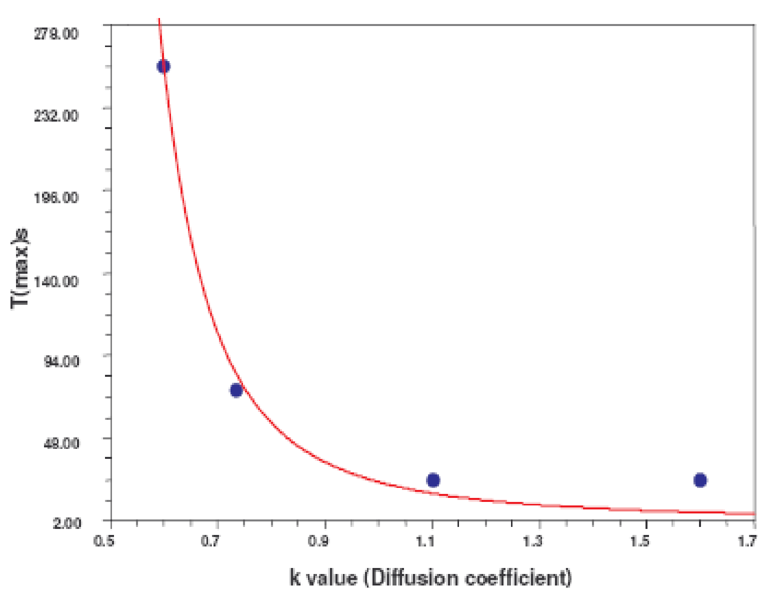


Figure 3 shows the variation of the time (T_{max}) taken by an ink patch dry up with the diffusion coefficient k for papers. According to the Figure 3, there is an exponential relationship of the form [$pe^{(q/x)}$] between the drying time (T(max)) and k value (Diffusion coefficient). Curve fits with the obtained data according to the semi empherical formula

$k = 0.9678 \exp(3.1835/T_{max})$

Where k is diffusion coefficient and T_{max} is the drying time.

Figure 3: Variation of T(max) with k value (Diffusion coefficient) of the papers

3.2 Drying characteristics of photocopy papers 1 at different humidity levels

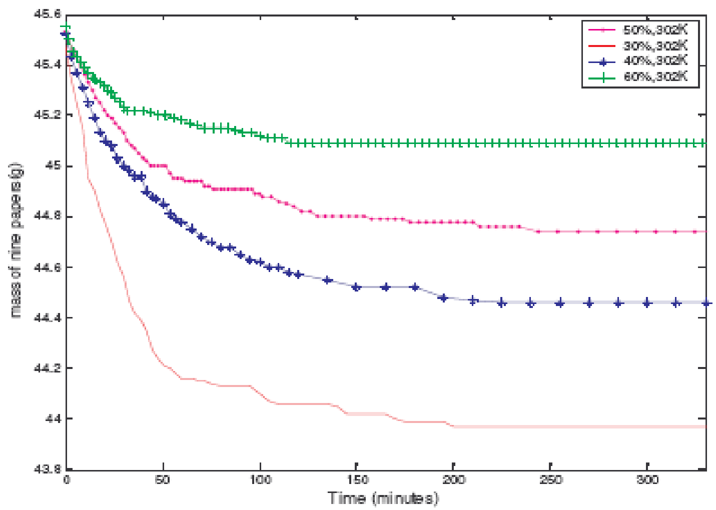
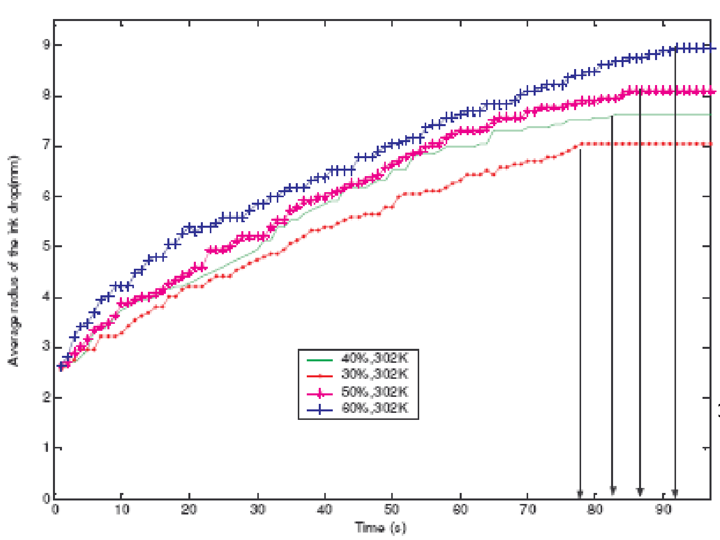


Figure 4 shows the drying characteristics (i.e. variation of mass of nine photocopy papers with time) at different humidity levels inside the chamber

Figure 4: Variation of Mass of nine Photocopy papers of GSM 80 kept at four different RH levels with time

3.3 Dispersion of printing ink through Photocopy of papers at different humidity levels

Variation of the average radius of an ink drop let placed on a photocopy paper which was initially dried at the given humidity level was measured with time. The Figure 5 shows variation of the average radius of dispersion of printing ink through Photocopy papers at four different humidity levels.



According to the above Figure 5 it is possible to conclude that the dispersion time as well as the dispersion radius of printing ink through photocopy papers decreases with decrease of relative humidity.

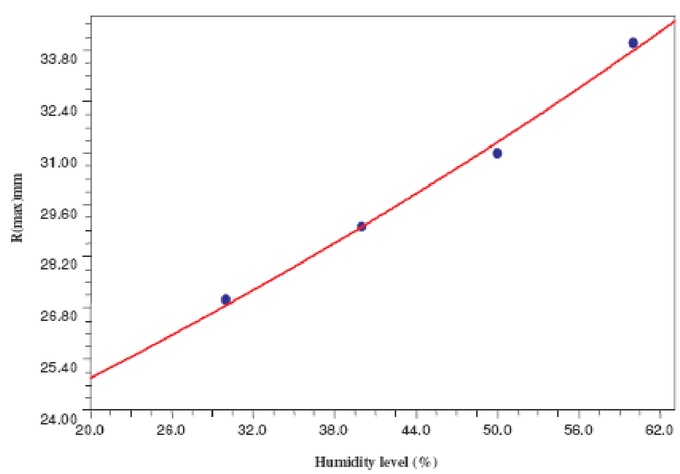
Figure 5: Dispersion of printing ink through Photocopy papers at four different RH levels

The table 3 was prepared by considering the results obtained from Figure 5.

Table 3: R (max) and T (max) values of a droplet with volume 0.02cm³ at four different humidity levels

Humidity level	**R(max)mm** **Maximum dispersion of ink**	**T(max)s** **Drying time**
30%	27±0.1	78±0.5
40%	29±0.1	82±0.5
50%	31±0.1	84±0.5
76%(Environmental)	34±0.1	90±0.5

Figure 6 shows the variation of R(max) with RH for a 0.02cm³ of droplet applied on a photocopy papers.



According to Figure 6 there is a week exponential relationship between the R(max) and RH. The curve fits with the obtained data according to the semi emphERical formula,

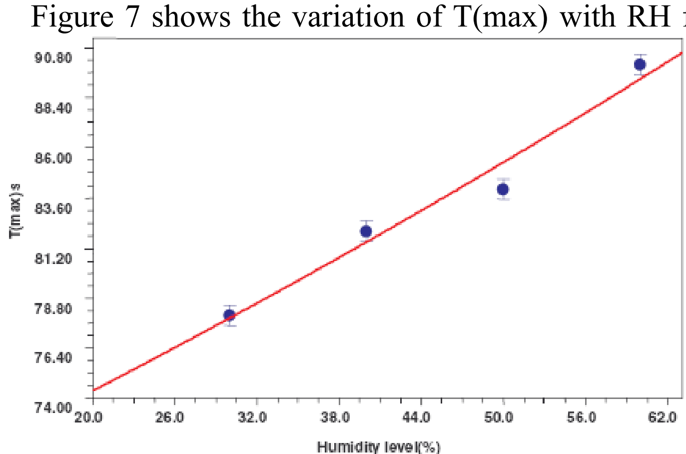
$r = 21.36 \exp(0.0076h)$, where r is maximum dispersion of an ink droplet of volume 0.02 cm³ on a photocopy paper and h is RH level. According to result, at 0% RH, R(max) has to be nearly equal to 21 mm.

Figure 6: Variation of R(max) with RH level

Figure 7 shows the variation of T(max) with RH for a of droplet of 0.02cm³ applied on a photocopy papers.

Figure 7 presents week exponential relationship between T(max) and RH. curve fits with the obtained data,

$T(max) = 67.88 \exp(0.00457h)$



gh papers

Where *T(max)* is drying time of a $0.02cm^3$ droplet applied on a photocopy papers and *h* is the RH. If it is possible to reduce the RH to 0% the expected T(max) has to be nearly equal to 68 s.

Figure 7: Variation of T(max) with RH level

4. CONCLUSION

According to the obtained results, there is a trend to increase the ink dispersion with increasing GSM value. Diffusion coefficients related to the spreading of ink through halfseets, photocopy papers type 1, duplication papers type 1 and duplication papers type 2 at environmental humidity level are equal to 0.6, 0.7, 1.1 and 1.6 respectively for a droplet of volume 0.02 cm^3. It indicate an exponential decrease with the drying time of the considered droplet

The dispersion times as well as the dispersion radius of an ink droplet on photocopy papers decrease with humidity. Moreover, according to the obtained results ink dispersion and drying time decreases exponentially with decreasing relative humidity.

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