Inkjet printing dynamics - influence on ink distribution in paper and print quality.

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Abstract

Inkjet technology is becoming established as a production method and emerges as a printing technology for printing functionalities on various media. The development has encouraged intensified research in the fields of inkjet technology and paper media. The work presented here is part of a research program that attempts to bridge the gap between the two disciplines. The overall objective is to control and improve the print quality and print functionality by observing and controlling the dynamic processes that occur in paper media in the inkjet printing process. Detailed information about the dynamic processes is however not available with the experimental methods present today, and improvements of experimental techniques is consequently a prerequisite for a better understanding. Therefore, inkjet printing machines were built and tested. The printers allow for inkjet printing with various types of inks and print heads at freely chosen paper feeding speed. Methods to study the inkjet printing process in-situ by use of camera and high-speed video camera were developed. It is shown that the in-situ methods capture spreading and absorption processes of inkjet droplets on still-standing paper and paper fed at high speed. The in-situ measurements and analysis are discussed in terms of relevant print quality parameters.

1. Introduction

Spreading and absorption of inkjet droplets in paper media in the inkjet printing process is of great importance to the final print quality. For several reasons, however, our understanding of the dynamics of inkjet printing on paper media is limited. One reason is the complexity of both the ink and the paper media; another reason is the lack of experimental equipment to follow, in-situ, both the spreading and absorption of the inkjet droplet in the inkjet printing process. Studies have been performed on spreading of comparatively large, well-defined droplets without initial velocity, on non-absorbing smooth surfaces [1,2], as well as on well-defined, structured surfaces [3-5]. Studies of inkjet droplet dynamics on paper under realistic printing conditions have been demonstrated [6-8] and recently it was shown that competing absorption mechanisms can be separated by careful in-situ studies of inkjet printing on paper [9-11]. However, for a full understanding of the spreading and absorption processes, a refinement of experimental techniques and measurements combined with theoretical analysis are necessary. A thorough description of research in the field is given in reference [12].

In this paper, the establishment of inkjet printing equipment and an experimental technique for in-situ studies of spreading of ink jet droplets on paper in the ink jet printing process are reported. The inkjet printing equipment simulates RISO HC 5000 / 5500, which are inkjet printing systems for oil-based ink having a maximum paper feeding speed of 2 A4 s^{-1}. The measurements were performed on well-characterized commercial papers and followed by spectroscopy measurements and print quality analysis. Selected measurements and results are reported.

2. Materials and Methods

Paper: commercially available inkjet paper, copy paper and base paper were used in the study. The inkjet paper had a coating layer containing silica, whereas the copy paper and the base paper were uncoated. The copy paper contained internal sizing agents, and had been surface sized, whereas the base paper lacked sizing agents, and had not been surface sized.

Printing system: Two inkjet printing systems were built: an xyz-table, shown in Figure 1, which allows for paper feeding speeds up to 0.66 m s^{-1}, and a production speed ink jet system, which allows paper feeding speeds up to 10 m s^{-1}. The latter system is a belt rig described in detail elsewhere [13]. 80 pl inkjet ink droplets were ejected with a XJ-126 (Xaar) print head at an initial droplet velocity of 6 m s^{-1} at a paper feeding speed of 0.23 m s^{-1} under realistic printing conditions. Inkjet printing was performed with pigmented, oil-based ink having carbon black as pigment (Ink black Toyo XS; Xaar- IK86104). Ink jet printing was also carried through in the commercial inkjet printer RISO HC 5000 (pigmented oil-based ink, Toshiba TEC print head, multi drop system 6-42 pl).

In-situ studies of droplet spreading on paper in the inkjet rig configuration: the print head was tilted 50° from vertical direction and single droplets were ejected on still-standing paper. The spreading of inkjet ink droplets on paper was filmed from above at 800 frames per second with a Redlake Motionscope M1 high-speed video camera equipped with a long-distance objective (Nikon; NA 0.40, 20x magnification, working distance 20 mm). The spreading of inkjet droplets jetted from the same print head nozzle in series of at least ten different spots on each paper was recorded in order to receive statistical information. The video sequences were saved as tif-files in a computer and the dot area and the dot roundness were evaluated in Matlab using own written software. The dot area is given in pixels (of the camera sensor) and

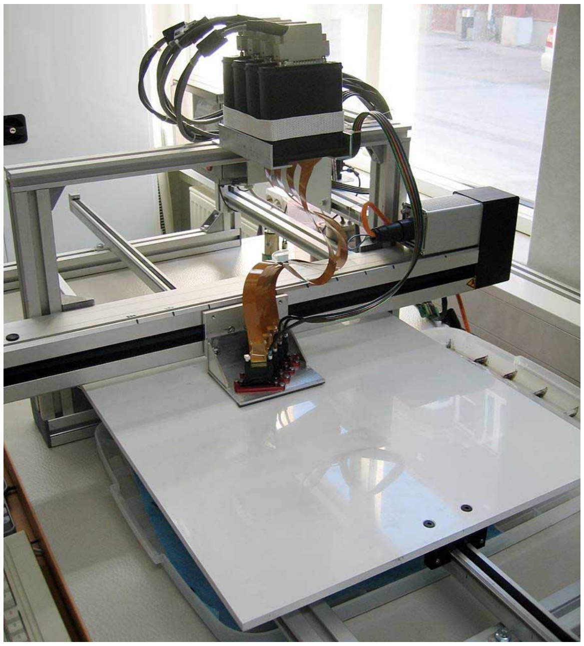

Figure 1. Inkjet printing system: xyz-table.

the dot roundness is defined as the part of the dot that lies within a circle that has the same area and the same "center of mass" as the dot.

Photograps from the side on a moving paper web were taken by a Canon 20 Da with a bellows extension and a reversed Nikkor f=50/1.8 lens, yielding a magnification of about 3.5.

Paper properties: several paper properties were determined by standardized paper characterisation methods, and a few are referred to in passing in the next section. The methods are described in detail in ref [14].

Print quality evaluation: images were scanned with an Epson GT 30000 and an Epson 10000 XL, and the linewidth, the raggedness, the perimeter and the blurriness were analyzed in Matlab using own written software. The blurriness was defined as the width corresponding to 30%-70% print density. The print density and the print-through were measured with an Elrepho spectrophotometer.

3. Results and Discussion

Fixation of ink pigments at the paper surface by additives in the ink or the paper improves important print quality parameters (e.g colour gamut, print density) but may slow down the drying of the ink and cause unwanted ink spreading on the surface, leading to print quality defects such as colour bleeding. In inkjet papers this has typically been solved by coating the paper with an absorptive coating layer containing micro pores which keeps the colorants at the surface and lets the solvent pass through, yielding a print with high print density and low print-through. In the case of oil-based ink, evaporation of liquid can be neglected and the absorption properties of the ink and the paper are then even more critical, since the paper has to absorb all the liquid in the printing process. In this study, the print quality and the inkjet printing dynamics on three papers with very different surface treatment and properties were studied. It can be expected that both the print quality and the dynamic processes (spreading and absorption) are affected by the varying paper properties of the three papers. Test patterns were printed on the papers in both commercial equipment and in the xyz-table set-up, and print quality parameters like print density, print-through, and line quality were determined. The print density and print-through were higher in samples printed in the xyz-table set-up, which can be explained by the larger ink droplets ejected with the xyz-table printer set-up than with the commercial equipment. Print quality evaluation of samples printed in the commercial equipment and in the xyz-table set-up showed similar tendencies for various papers (data not shown). It was found that the print quality was higher on the inkjet paper, as compared to copy paper and base paper, whereas no significant differences in measured print quality parameters were found between the two latter papers. Three scanned images of 0.4 mm lines printed on the three papers in a commercial printer are shown in Figure 2. In the case of the inkjet paper sample, (Figure 2, upper line), the line width is narrower (by about 5-10 %), the raggedness is about half, and the blurriness is smaller (by about 20 %) than on copy paper and base paper, as evaluated by a print quality analysis program. The higher print density of the print on inkjet paper (~1) than on copy paper and base paper (~0.7) may also be perceived in Figure 2.

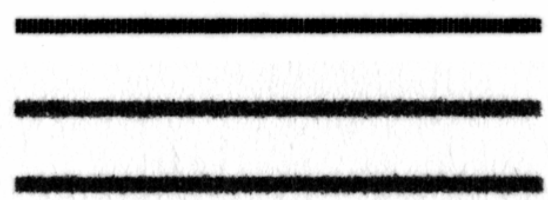

Figure 2. Lines printed on, from top to bottom, inkjet paper, copy paper and base paper, in RISO HC 5000. Line thickness is about 0.4 mm.

In-situ studies of the dynamics of inkjet droplets on the papers was carried through with a high-speed camera in order to collect information about the reasons for the variations in print quality of the samples. Representative photographs are shown in Figure 3. The spreading of inkjet droplets is limited and ceases rapidly on inkjet paper, as compared to copy paper and base paper (Figure 3 and 4). The dot quality, evaluated as dot roundness, is furthermore higher on the inkjet paper (Figure 5). It may be argued, based on Figures 3-5, as well as on measurements on pilot papers [14], that the dot quality decreases during spreading, and that the reason for the comparatively high dot quality on inkjet paper is the limited and comparatively rapid ending of the spreading process, in combination with the low surface roughness of the inkjet paper. The error bars representing the standard deviation of experimental data of ink droplets on inkjet paper in Figures 4 and 5 are comparatively small and

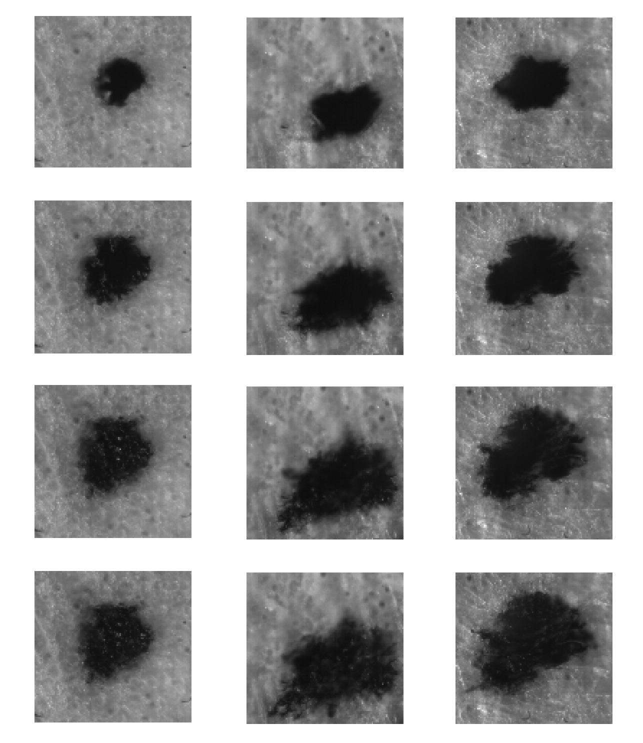

Figure 3. Representative pictures of spreading of inkjetted droplets on inkjet paper (left column) copy paper (middle column) and base paper (right column), after times, from top to bottom, 0, 5, 20 and 100 ms.

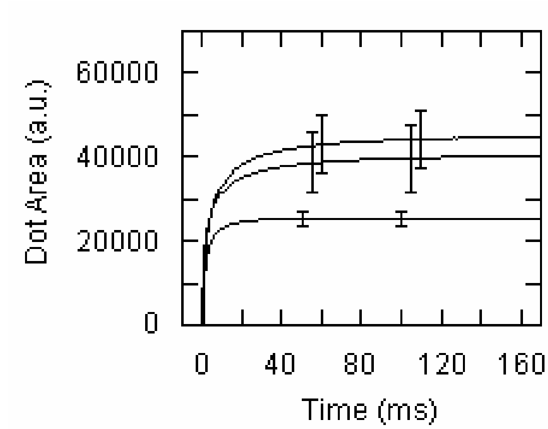

Figure 4. Dot area on, from bottom to top, inkjet paper, copy paper and base paper as function of time. The error bars represent the standard deviation.

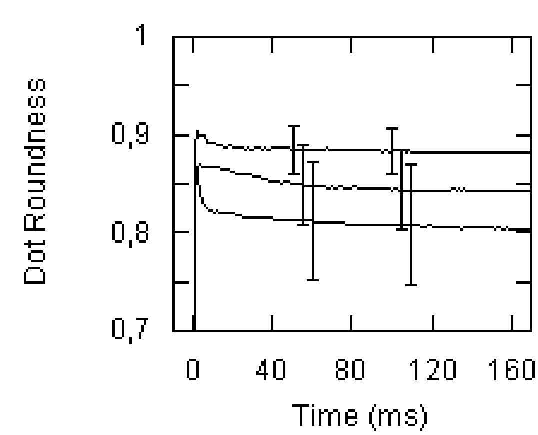

Figure 5. Dot roundness on, from top to bottom, inkjet paper, copy paper and base paper as function of time. The error bars represent the standard deviation.

Figure 6. Inkjet ink droplets on copy paper during printing. The paper is moving from right to left at a paper feeding speed of 0.2 m s^{-1}. An ink droplet is jetted every 1.2 ms. The rightmost droplet has just reached the paper as the picture was taken. Satellite droplets can be seen in the upper part of the picture.

indicate that the surface of the inkjet paper is spatially more homogenous than the surface of the copy paper and the base paper. The measurements of spreading and dot quality as a function of time depicted in Figures 3-5, explain the higher line quality of the inkjet paper sample shown in Figure 2.

The surface energy of the copy paper is lower than that of the inkjet paper and the base paper. When comparing the base paper with the copy paper, this difference does however not seem to largely affect the spreading process (Figures 3-5). One possible reason may be the low surface tension of the oil-based ink, which should lead to rapid wetting of the surface. Contact angle measurements of droplets of diiodmethane on the three papers show that the absorption of diiodmethane is fastest in the inkjet paper and slowest in the copy paper (data not shown). The absorption data, combined with the print quality analysis and Figures 3-5 indicate that the inkjet paper effectively absorbs the liquid, leaving the pigments in the coating layer at the surface, whereas the ink pigments penetrate the base paper to a larger extent, possibly due to the lack of both coating layer and sizing agents. The absorption of inkjet droplets is however different from the absorption studied with contact angle measurements on comparatively large (diiodmethane) droplets with no, or small, initial velocity. Figure 6 shows the shape and absorption of inkjet ink droplets on copy paper at a paper feeding speed of 0.2 m s^{-1}. The rightmost droplet had just reached the paper as the picture was taken, and the flattened droplet in the middle of Figure 6 reached the paper 2-3 ms before that. The fast spreading and absorption illustrated in Figure 6 is due to the high momentum of the droplet and the smaller amount of liquid as compared to contact angle measurements. Detailed contact angle measurements of inkjet droplets on the papers and modelling may yield information about absorption mechanisms and how these are affected by the high velocity of the inkjet droplet. Initial confocal fluoresecence spectroscopy measurements and confocal Raman spectroscopy measurements have been performed on selected samples in order to evaluate the power of these methods.

In conclusion, inkjet printing rigs were built and equipped with a high-speed camera. Inkjet printing was performed on three different papers, and inkjet printing on paper was studied in-situ. Important print quality parameters could be explained in terms of the dynamics of the inkjet droplets during printing on the various papers. The method does however not give explicit information about the chemical bindings and physical interactions between ink and paper. This will be the aim of future work.

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