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Laser drying technology applied to improvement of density variation on offset-coated paper

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Abstract

High-speed inkjet printing system is growing in recent years. Laser-drying technology can dry inks in a very short time (~100ms). This technology has advantages of applicability for various paper types and suppressing paper deformation because heating is focused on an ink without heating a paper. Furthermore, this technology can control occurrence of density variation due to migration and flow of an ink on offset-coated paper by rapid drying. Exposure condition of laser was optimized using high speed camera and drying mechanism was discussed by comparing simulation and actual observations.

Introduction

Conventional inkjet (IJ) continuous feed printing systems, which are aimed at the commercial printing market, pose a problem for users in that the systems are becoming very heavy. This is because the system's ink drying equipment, e.g., metal drum-type dryers, are becoming increasingly large to enable printing at higher speeds.

To address this problem, Fuji Xerox is researching a new ink drying method, which is called laser drying technology, with the dual objectives of downsizing current high-speed IJ continuous feed printing systems and enabling high image quality. This drying method enables heating of the ink alone over a short period of time using a compact laser that outputs near-infrared light. Because the paper is not heated, drying is then possible with little effect being derived from the thickness and composition of the paper. Thus, from this perspective, the proposed method can be expected to become highly versatile system.

In previous research, when printing using IJ paper and using laser exposure to dry the ink over a period of time of the same order as the ink penetration time, advantages were observed in terms of image quality, including reduced bleeding and show-through [1]. However, offset-coated papers are used widely in the commercial printing market, and the ink penetration is thus extremely slow because of the coating layer on the paper surface. When the ink attaches to the paper, a spotted "uneven density (large variation in optical density)," which is known as "mottling" [2], occurs on images when a particularly high printing rate is used. Because it is difficult to control this uneven density when using conventional drying methods, ways to control the rheological characteristics of the ink (ink flow) through methods such as changes to the ink composition and treatment of the paper using a pre-coating layer [3], [4] are being reviewed. However, when using the former method, it is difficult to establish both discharge stability and dryness, and when using the latter method, larger equipment is required, which in turn increases costs.

In our research, ink was dried by laser exposure to produce printed images when using offset-coated paper. Additionally, to control the uneven density problem when using laser drying, the laser exposure conditions were optimized based on the results of observations using a high-speed camera and a mechanism of uneven density analyzed based on fluid simulations.

As a result, the application of this drying method to offset-coated paper is shown to be both feasible and effective for uneven density control.

Experimental Setup

1) Laser Exposure Experiment

Figure 1 shows a rough illustration of a printer with the proposed laser drying equipment. The IJ printhead and the laser exposure equipment are fixed, and the printing and laser exposure processes are performed by moving the stage on which paper is placed. The laser beam width is 10 mm, and the distance from the rear end of the IJ printhead to the area where the laser exposure begins is 25 mm. Therefore, when the stage speed is 50 m/min, the time interval from the printing process to laser exposure is approximately 30 ms. In this case, a matrix-type piezo-driven printhead was used for the IJ printhead, a JOLD-120-CPNN-1N940 (Jenoptik Laser) was used for the laser diode. In addition, the model ink (water-based pigment ink) that was used for the experiment was created to ensure that the uneven density effects can be observed easily.

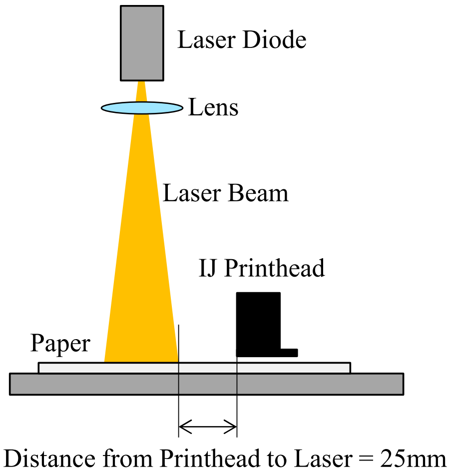

***Figure 1.** Experimental setup for laser exposure after ink jetting*

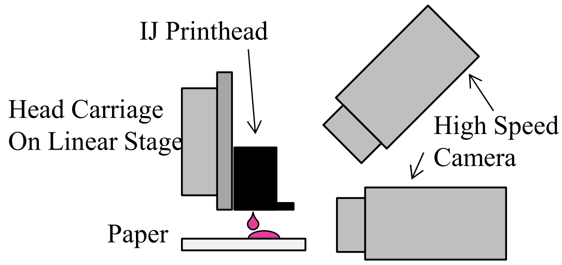

***Figure 2.** Experimental setup for observation of inks on paper using high-speed cameras*

2) Observation of Ink Droplet Behavior

Figure 2 shows a rough illustration of the high-speed camera system to observe ink droplet behavior when the ink lands on the paper. The FASTCAM-APX RS 250K camera (Photron) and the VW-6000 motion analysis microscope (Keyence) were used for the camera system. Ink was jetted while moving the IJ printhead, which was placed on the movable stage, and the temporal changes in the ink droplets on the paper were then observed using the fixed high-speed camera observation system. The arrangement of the camera and the shooting method (reflected light observation/projective observation) were selected in accordance with the size and scale of the observation target.

Results

1) Application of Laser Drying to Offset-Coated Paper

The time taken from the point at which the ink lands on the paper to the time when it penetrates completely (ink penetration time) was found to be approximately 100 ms for IJ paper but more than 1 s for the offset-coated paper.

Figure 3 shows the optical density of the printed surface on both IJ paper and offset-coated paper when the interval from printing to laser exposure is varied for a coverage of printing area (Cin) of 100%.

On the IJ paper, the optical density is improved by laser exposure within the ink penetration time, because the pigment in the ink remains on the paper surface. A shorter interval also generates a significant increase in the optical density. Meanwhile on the offset-coated paper, the optical density is higher than that on the IJ paper, even without laser exposure, because the pigment in the ink is trapped in the coating layer on the paper surface. At the same time, because both the penetration and drying processes are extremely slow, ink flow occurs easily, and this results in uneven density.

2) Improvement of Uneven Density using Laser Exposure

Ink Behavior Observation Experiment

Figure 4 shows the results of observations of an image that changes immediately after being printed at high print speed. There is no uneven density on the printed surface just after printing, with the exception of the white line, but as time subsequently passes, mm-order mottling was generated.

Figure 5 shows the changes with time of the mottle index value when Cin=20% to 100%. The mottle index values were quantified by performing a frequency analysis of the luminance distribution within the surface of a printed image that was observed using the high-speed camera. A mottle index value of ≥10 is a level at which the mottling can be visually recognized in sensory evaluations. At a low printing rate of Cin=20%, the ink droplets are distributed independently, and the mottle index value remains at a low level because the ink droplets do not move much or change their shape after printing. In contrast, at higher printing rates, neighboring ink droplets connect together to generate a flow, and the mottle index value increases over the period from 1 to 2 s after printing. In particular, when Cin≥80%, the mottle index value increases significantly, and the mottle index value exceeds a value of 10 a few hundreds of milliseconds after printing. Based on the above analysis, it was found that mottling, which is an image quality problem, is only formed in images at a high printing rate, and that the time scale for mottling formation is thus a few hundred milliseconds after printing.

Figure 6 shows the luminance (density) distribution of an image at Cin=100%, with Figure 6(a) showing the image 0 s after printing, and Figure 6(b) showing the image 0.5 s after printing. Immediately after printing, there is an almost flat luminance (density) distribution, but after 0.5 s (Figure 6(b)), the densities of the image edges become high (luminance drops), and the so-called "coffee stain" was observed. Based on the above observations, it was found that the shape of the uneven density area differs depending on the printing rate, and at high printing rates in particular, mottling and coffee stains are both formed. The time order at which these problems start to form is again a few hundred milliseconds after printing.

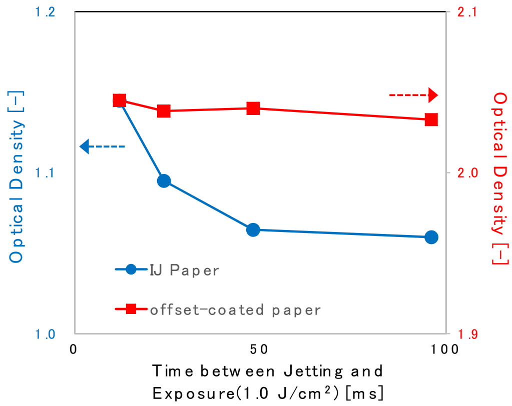

Figure 3. *Optical density changes relative to time interval*

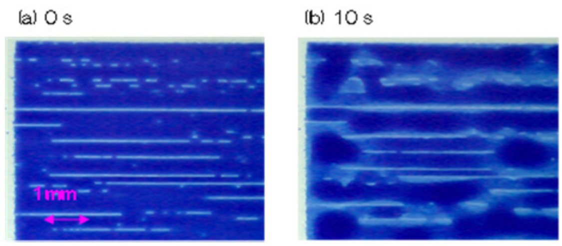

Figure 4. *Image inhomogeneity on offset-coated paper at (a) 0 s and (b) 10 s after printing*

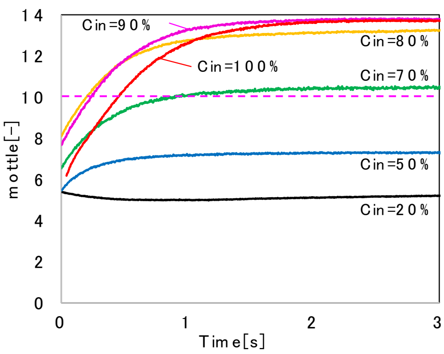

Figure 5. *Time dependence of mottle index value with Various values of Cin*

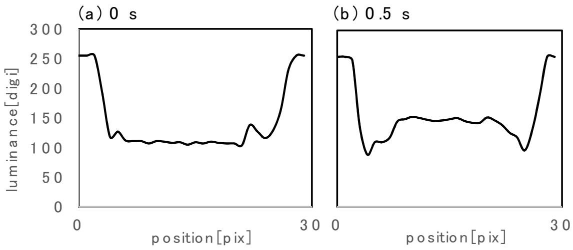

Figure 6. *Luminance profile along cross-section of Cin=100% image (low: dark; high: light): (a) 0 s, flat; (b) 0.5 s, coffee stain*

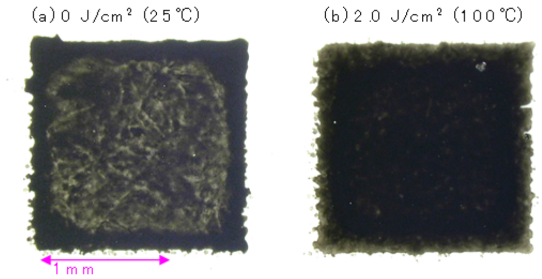

Figure 7. *Inhibition effect of laser exposure on uneven density*

Uneven Density Improvement using Laser Exposure

When using laser drying equipment, it is possible to perform laser exposure for dozens of milliseconds after printing takes place. Therefore, at high printing rates, it is possible to control the generation of uneven print density by performing laser exposure before the uneven density area forms.

Figure 7 shows the images at Cin=100% (a) without laser exposure, and (b) with laser exposure performed 30 ms after printing. The image without laser exposure shows an increased density around the edges of image, while the density at the center of the image falls, indicating that an uneven density that is a result of the coffee stain phenomenon occurs. When the laser exposure energy is increased to approximately 2.0 J/cm2 (for a paper surface temperature of 100°C), the uneven density then improves.

Figure 8 shows the laser exposure energy and its relationships with the ink temperature on the paper surface and the amount of liquid ink remaining on the printed surface after laser exposure. When the laser exposure energy is approximately 2.0 J/cm2, the ink temperature reaches 100°C, and the amount of water in the ink after laser exposure falls to approximately 10%. In addition, as shown in Figure 9, the ink viscosity suddenly increases after evaporation of the water from the ink. In this way, it was found that laser exposure increases the ink temperature over a short period of time, thus causing rapid evaporation and thickening of the ink, and enabling control of the uneven density problem.

Simulation Analysis

The mechanism for improvement of the uneven print density based on laser exposure, as shown in Figure 7, was investigated using fluid simulations that take pigment deposition based on ink evaporation into consideration. The general-purpose fluid analysis software Flow-3D (Flow Science) was used to perform the analysis.

According to the literature [5], coffee stains are reported to be formed based on the following conditions and processes. (1) Immediately after an ink droplet lands on a paper surface, the edges of the ink droplet become pinned (i.e., fixed) to the paper. (2) The evaporation rate is faster around the edges of the ink droplet than at the center. (3) As the evaporation progresses, the shape of the ink droplet changes, and an outward flow from the center towards the edges is generated. (4) Because of this outward flow, the solids contained in the ink move toward the edges of the ink droplet. (5) The pigment is deposited from the edges of the ink droplet and then accumulates.

The simulation results are shown in Figure 10. The calculation conditions were set as an ink viscosity of 6 mPas, surface tension of 30 mN/m and pigment content of 10 wt.%. The edges of the ink droplet were fixed, and an evaporation speed that is equivalent to that of natural drying was applied to the gas-liquid interface. Figure 10(a) shows that the reproduction of an outward flow from inside the ink droplet towards the edges and pigment deposition at the edges of the ink droplet as the evaporation process progresses were possible. The broken line shown in Figure 10(b) represents the pigment density distribution in the ink droplet radius direction.

Next, an analysis was conducted based on the conditions of an increasing ink evaporation rate and rapidly progressing thickening due to the laser exposure. The pigment density distribution for this analysis is represented by the solid line shown in Figure 10(b). When comparing the results for the two sets of conditions, it was confirmed that an increase in the viscosity and the evaporation rate led to a reduction in the pigment density that was deposited around the edges of the image, and the distribution became flatter overall. This indicates that control of the ink flow is effective in improving an uneven density.

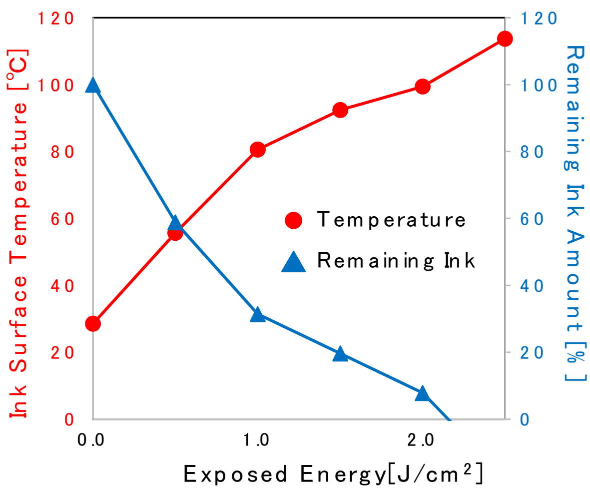

Figure 8. *Surface temperature and water content remaining in ink after laser exposure*

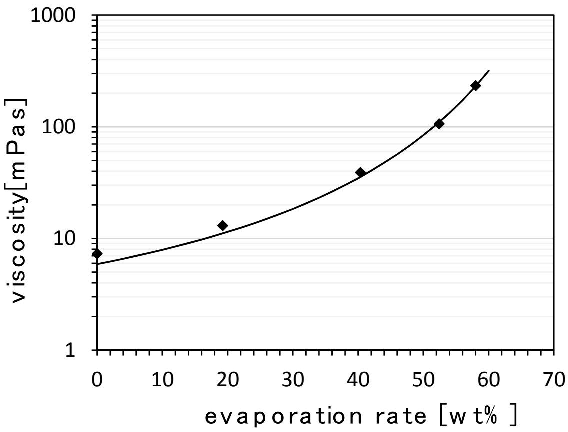

Figure 9. Relationship between viscosity and evaporation rate

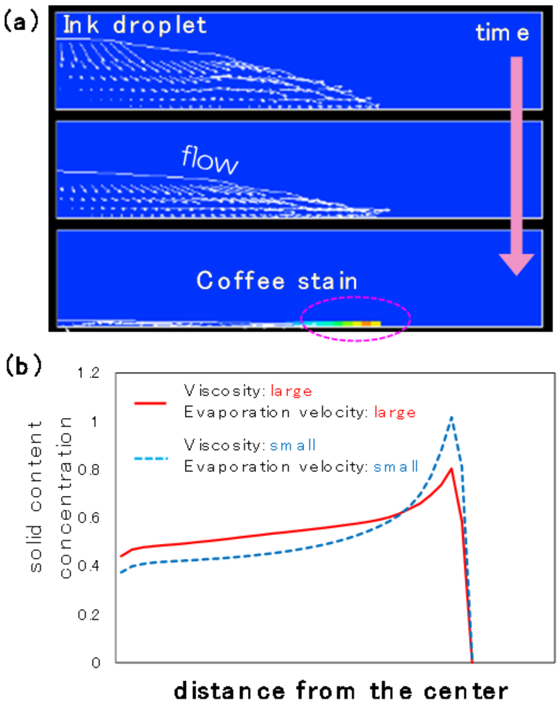

Figure 10. Simulated results of (a) coffee stain, flow pattern in the droplet and deposition of pigment; (b) effects of evaporation rate and viscosity on coffee stain

Conclusions

In our research, laser drying on the offset-coated paper was investigated. The mechanism behind the occurrence of uneven densities and the time order of the mechanism were analyzed. Additionally, by making the ink evaporate rapidly using laser drying technology, it was verified that control of the uneven density problem is possible. As a result, the following points were determined:

Based on high-speed camera observations, the time scale of the uneven density (mottling, coffee stains) formation that occurs at high printing rates is of the order of a few hundred milliseconds.

The uneven density problem can be controlled using laser drying equipment and by performing the laser exposure over a shorter time period than the uneven density formation time at high printing rates.

Based on coffee stain simulations, it was confirmed that when the ink is made to evaporate and thicken rapidly, the outward flow from the center of the ink droplet towards the edges and the transfer of the pigment to the edges are both controlled, and it is thus possible to improve the coffee stains.

Laser drying technology thus offers a method for ink drying for which there are high expectations for improved image quality on both IJ paper and offset-coated paper.

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Author Biography

Takuma Ishihara received his ME (2013) in physics from the University of Tokyo. He joined Fuji Xerox in 2013 and has worked on inkjet research and development.