Effects of Ink-Paper Interaction and System Parameters on Drying Quality in High-Speed Color Inkjet with Infrared Ray Heater

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Abstract

Expanding high-speed full color inkjet system to production printing market requires applicability for various papers. However coated paper has difficulties such as interference among adjacent droplets, dryness and jetting stability, whereas normal paper has difficulties in achieving both fixing quality and image quality such as offset, optical density, color gamut and bleeding. Additionally, in normal paper, absorption speed depends on combination of inks and papers. Therefore, there are risks of insufficient fixing in slow absorption speed and bleeding or low optical density in fast absorption speed. In this study, focused on the combination of aqueous pigment ink and inkjet treated paper that shows relatively slow absorption speed, we studied on optimal condition which enhancing absorption and controlling fixed position of pigments in a paper. Setting up inkjet offline bench with infrared radiation heating system, relationship between fixing quality (smear) and optical density were investigate for following system parameters: drop volume, interval (time duration between inkjet head and the heater) and heating energy, which covered the conditions in actual high-speed inkjet printing system.

Introduction

Recent years, high-speed full color inkjet printing system has been introduced to the printing market. Expanding inkjet business from transaction print to commercial printing requires coping with following needs [1]:

- Varieties of paper applicability: coated printing paper, treated and untreated paper, paper thickness
- Image qualities (high resolution, optical density, color gamut and blur etc.)
- Compact size, light weight, energy saving

However coated paper has difficulties such as interference among adjacent droplets, drying and fixing performance and unstable jetting when applying fast dry ink because of poor penetration. Whereas normal paper basically dries ink by penetration, high absorption performance is required. However penetration speed and image quality usually provide a relation of the trade-off: high absorbability tends to show low image quality. Thus, improvement of ink or paper properties has been done for optimizing both dryness and image quality. On the other hand, drying system with heater or blower was developed to assist removing moisture from printed paper for preventing the off-set.

Figure 1 exhibits absorption coefficient (speed) of an aqueous pigment ink for various papers: inkjet paper (A, B), plain paper(C, D, E), different thicknesses of A (A-81gsm and A-157gsm) and coated paper (F) as reference. The absorption coefficient was measured using Dynamic Scanning Absorptometer (DSA).

From Fig.1, we can see that absorption speeds depend on paper types. There are possibilities to cause insufficient fixing when printing full color and high coverage image on relatively slow absorption papers. In contrast, there is a risk of causing bleeding, low optical density or narrow gamut in relatively fast absorption paper and ink. Therefore such differences in absorption speed should be controlled by inkjet system parameters including heating system to some extent for widening paper applicability.

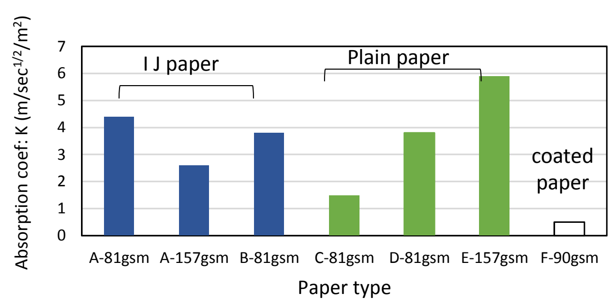

***Figure 1.** Absorption coefficient for various type of paper (DSA measurement)*

In this study, focused on the combination of aqueous pigment ink and inkjet treated paper that shows relatively slow absorption speed, we studied on optimal condition which enhancing absorption and controlling fixed position of pigments in a paper. Setting up inkjet offline bench with infrared radiation heating system, relationship between fixing quality (smear) and optical density were investigate for following system parameters: drop volume, interval (time duration between inkjet head and the heater) and heating energy, which covered the conditions in actual high-speed inkjet printing system. As the heating system, we applied an infrared radiation heating system considering the advantages over compact size, light weight and energy saving in industrial inkjet system as well as convenience for implementing parameter studies.

Experimental Apparatus

Schematic diagram of inkjet off-line bench equipped with heating system is depicted in Fig.2. Inkjet head is piezo type of 1200dpi, heating system is infrared ray (IR) type with three carbon heaters. Distance between inkjet head and heating system is adjustable (60 to 185mm), which enables separately changing interval (duration between head and heating system) and heating time to some extent according to print speeds. Driving frequency ranges from 2k to 25kHz, A paper moves with stage at 42 to 420mm/sec. Interval and heating time are designed to cover actual conditions in high-speed inkjet printing system, range from 0.14 to 4.37sec and from 0.43 to 4.25sec respectively. Ink type is aqueous pigment ink (cyan), drop volume ranges from 2 to 5pl at single ejection which are equivalent to the volume when two colors are combined.

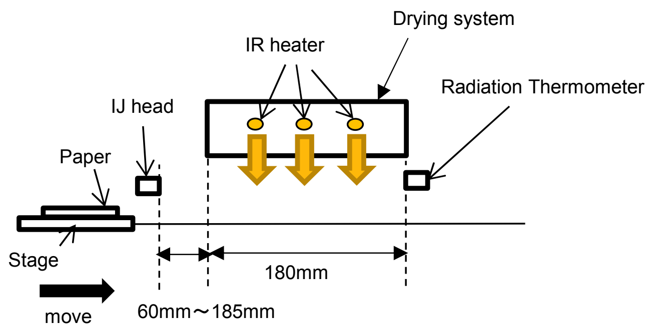

***Figure 2.** Experimental Apparatus (jetting and drying off-line bench).*

Evaluation Method of Drying Quality

Drying (fixing) quality is evaluated by a smear index, which we define as the value quantitatively characterizing the amount of removed pigment from printed surface. Smear index exhibits positive correlation with optical density and fixing performance.

Pre-Experiment

Experimental Condition

We compared the fixing performance between two inkjet papers, A-81gsm and A-157gsm (thick) in Fig.1, that showing relatively large difference in absorption coefficient. Experimental conditions are listed in Table 1.

Table 1. Parameter list for pre-experiment

Paper Type	IJ paper:A-81gsm, A-157gsm
Ink	Aqueous pigment ink (Cyan)
Drop volume	2.3pl(small), 4.3pl(medium), 5pl(large)
Patch size	2cm*2cm solid pattern
Print speed	210mm/s(fast), 105mm/s(slow)
Interval (1) and heating time (2)	Case1:(1)0.39sec ,(2) 0.42sec Case2:(1)0.78sec ,(2) 0.84sec
Target temperature of printed surface	45degC, 55degC

Result

Figure 3 indicates relationship between drop volume and smear index, here Fig.3 (a) and (b) mean that temperature of printed area after heating is 45degC and 55degC, respectively.

Focused on the paper type, A-81gsm, which had relatively fast absorption rate, satisfied the threshold value of the smear indices for all conditions. In contrast, in case of the A-157gsm, which had relatively slow absorption rate, smear index showed rapid gain over 4pl, which did not satisfy the threshold value at (a)45degC in both fast and slow print speed and at (2)55deg in slow print speed. However the case of (b)55degC and fast print speed only improved the smear index (circle in Fig.3(b)). Long interval (slow speed) appeared to provide the worse smear index against the expectation.

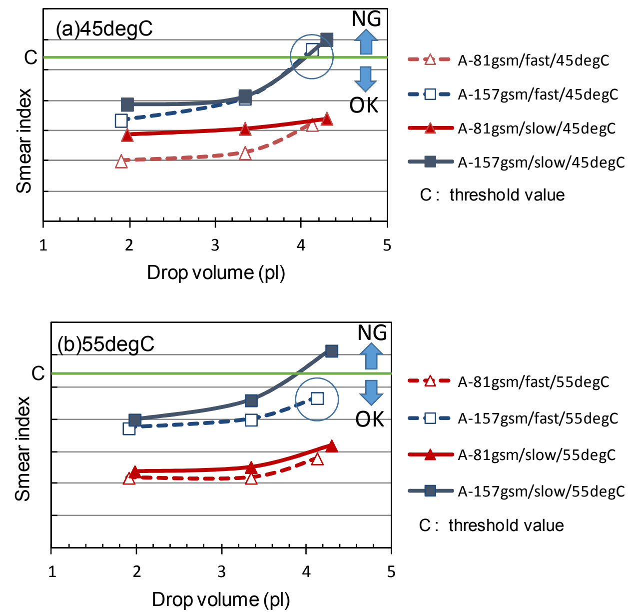

***Figure 3.** Relationship between drop volume and smear index: print speed (fast / slow), paper thickness and heater energy: (a) temperature of printed surface: 45degC and (b)55degC*

Here, note that the interval and the heating time could not change independently in the pre-experiment. Since the smear index was evaluated at same temperature of the printed area, the heater power was controlled according to the print speed. Therefore dT/dt (rate of temperature rise) varied depending on the print speeds simultaneously. Next, we investigate the each effect of interval, heating time and heating rate (dT/dt) on fixing performance.

Experiment

Experimental Condition

Focused on the paper A-157gsm which did not satisfy the threshold value of smear index at large drop volume in pre-experiment, we precisely investigated the following system parameters;

- **Interval** :Changing the interval (penetration time) by the combination of distances between inkjet head and heating system (60mm, 110mm, 185mm) and print speed (42.3, 84.7, 211.7, 423.3mm/sec). Examined the effects of interval for fixed heating time.
- **Heating energy**: for fixed interval, controlling the number of heating passes, which paper passing through reciprocally (from 1 to 9 times) in the heating system aiming at providing much more heating energy to printed area.

- **Heating rate**: Adjusting the heater power (voltage), controlling heating rate and the target temperatures.
  The experimental conditions are listed in Table 2.

Table 2. Parameter List

Paper Type	IJ paper: A-157gsm
Drop volume	2.3pl(small), 4.3pl(medium), 5pl(large)
Patch size	2cm*2cm solid pattern
Interval	0.2sec~4.4sec
Heating time	0.43sec~9sec
Heater energy	35degC~80degC

Result

Effects of Interval

Figure 4 shows the relationship between intervals and the smear index for heating time. In this figure the results with drop volume 4.1 to 4.4pl, which did not satisfy the threshold value of the smear index in the pre-experiment, are plotted. The dotted line depicts the relationship between intervals and the smear index. This figure suggests that the interval might be a dominant factor which determines the condition of fixing performance, and the intervals near 0.4sec appear to be the best for improving the smear. Shorter and longer intervals than 0.4sec would make the smear index be worse. However, there are a few plots over the threshold value despite the interval of around 0.4sec. They correspond to the high temperature case of 65degC and low temperature case of 35degC on the printed surface after heating. This implies that there exists the proper range of temperature.

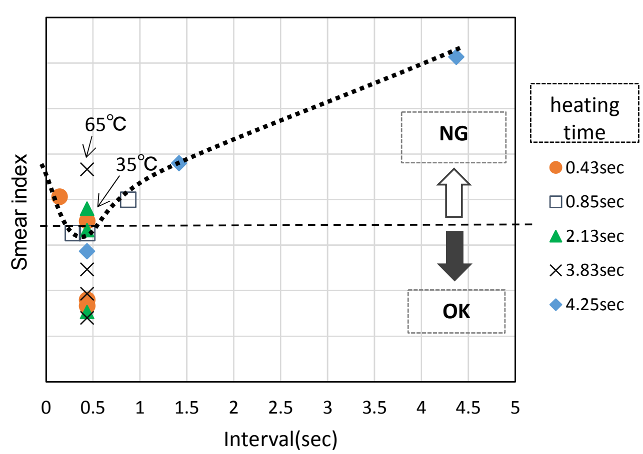

Figure 4. *Effects of intervals for different heating condition: drop volume of 4.1pl-4.4pl (1200dpi) are plotted.*

Effects of Heating Energy and Heating Rate

Heating Condition

Setting the interval to 0.42sec, we precisely investigated the effects of heating condition.

Figure 5 indicates relationship between number of heating passes (namely heating time) and temperature of printed surface after heating. In this figure, Case-1 corresponds to relatively fast and high power heating condition, which provides large heating rate: dT/dt and high temperature at the first pass. On the contrary, Case-2 corresponds to relatively medium heating condition.

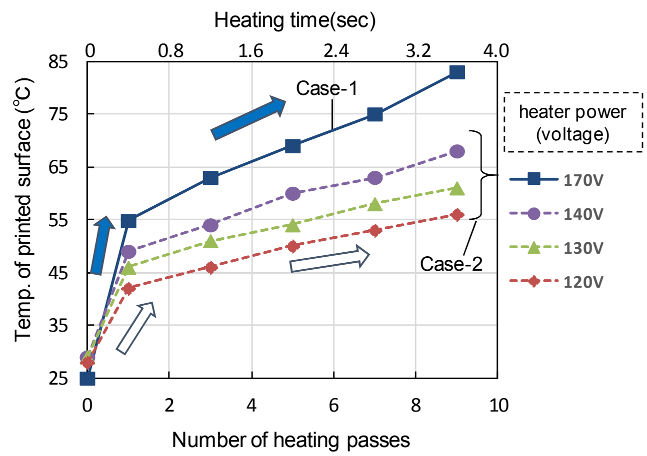

Figure 5. *Heating condition. Case-1: relatively fast and high power heating condition, Case-2: relatively medium heating condition.*

Relationship between Drop Volume and Heating Condition

Figure 6 shows the relationship between drop volumes and smear index in Case-1 condition. In drop volume of 4.7pl, the first heating pass achieved the best value of the smear index. Large heating energy did not help to improve the smear index, in such case smear index indicated almost same value without depending on heating energy.

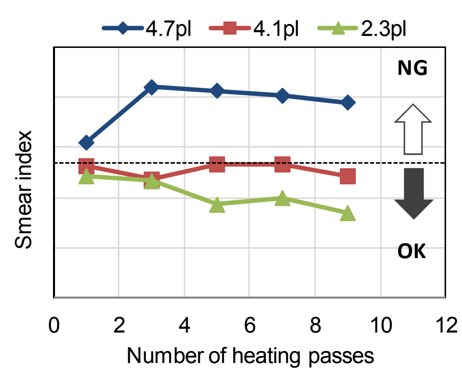

Figure 6. *Relationship between drop volume and smear index in Case-1 condition: large heating rate and high temperature at the first pass,*

Figure 7 shows the relationship between drop volumes and smear index at the 9th pass in Case-2 condition, where the terminal temperatures on the surface were 55degC, 65degC and 70degC.

From this figure, these heating condition achieved the threshold value of the smear index even in the large drop volume of 4.7pl for all temperature. Case-2 appears to be a most suitable heating condition. These results suggests that the existence of optimal heating condition to accelerate penetration.

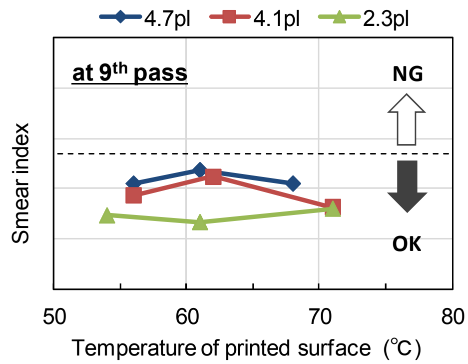

Figure 7. *Effects of heating condition on smear index: Case-2 at medium heating condition.*

Moisture Content after Heating

Figure 8 indicates moisture contents of printed area right after heating in Case-1. In a legend of Fig.8, initial means the moisture content before heating. We can see that the moisture contents drop down below the initial condition according to the number of drying passes increasing. Drying performance is sufficient, but which did not necessarily provide good fixing performance in large drop volume case.

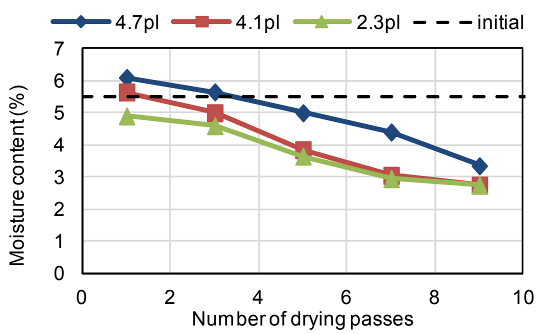

Figure 8. *Moisture content for number of drying passes (Case-1)*

Optical Density

Optical density (OD) measured in samples of Case-1 and Case-2, not shown in figure, expressed almost same values despite heating condition for each drop volume. Generally, while OD exhibits positive correlation with smear index, no deterioration in improved samples in the Case-2 was observed.

Discussion

Mechanism Hypotheses

Summed up the experimental results, we obtained the following three typical phenomena concerned with the smear index and system parameters such as interval and heating energy in combination of the large drop volume and the paper with relatively slow absorption speed;

1. Longer interval provides worse smear indices, after that any heating condition does not contribute to improvement.
2. Shorter interval plus weak or strong heating condition (low or high temperature on printed surface) makes smear indices worse.
3. Shorter interval plus medium heating condition only achieves the value of target smear indices.

Concerning three phenomena listed above, we illustrated the mechanism hypotheses in Fig.9, where (1) to (3) corresponding to above list number.

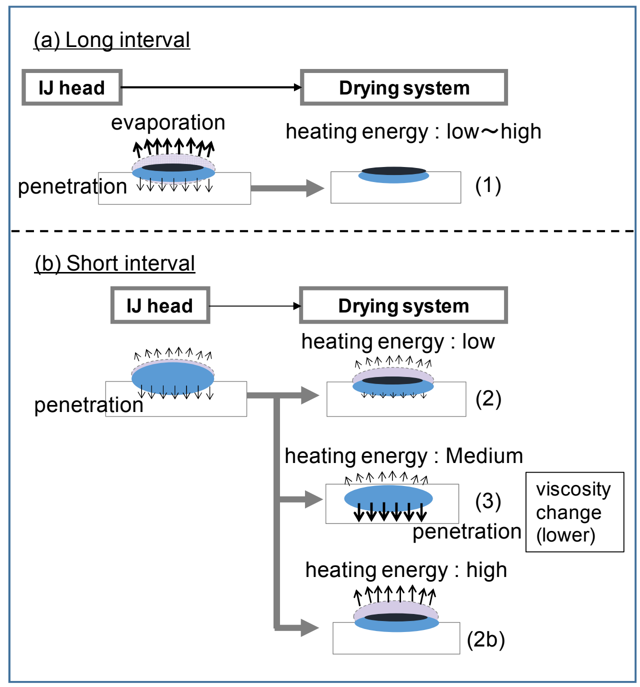

Figure 9. *Schematic diagram of mechanism hypotheses.*

Figure 9 (1) represents the long interval case, where effect of evaporation increasing due to slow absorption speed. The pigment content and moisturizing agent of ink on the paper would become richer. That could interfere further penetration, consequently very thin layer of the pigments and moisturizing agent would leave on the surface. After that, entering into the heating system in such a situation could not improve penetration despite the any heating condition.

Figure 9 (2) represents the short interval plus low heating energy case. Although entering into the heating system in the condition before evaporation and penetration proceeding so much, low heating energy might suppress penetration of ink since viscosity of ink not becoming lower. On the other hand, in high heating energy case, exceeding evaporation would rather prevent penetration as shown in Fig.9 (2b).

Figure 9 (3) describes the short interval and medium heating energy case. In this case, behavior during the interval is same as (2), but medium heating condition could assist penetration much because that condition could obtain suppression of the evaporation and lower viscosity of the ink at the same time.

Verification

Distribution of pigment near the printed surface

In order to verify the hypotheses mentioned above, we observed the pigment profiles along the cross-section of the printed papers for each case shown in Fig.9 using the optical microscope. Here, the samples were prepared by embedding the printed paper using epoxy resins and then slicing them after solidifying.

Figure 10 (1) to (3) demonstrate the observation results, where paper type is A-157gsm and drop volume is 4.3pl. Fig.10 (4) is the case of paper A-81gsm, which is a reference of Fig.10 (2).

Images on the left show enlarged view of the distribution of the pigments near the paper surface, images on the right show distribution of the ink in the paper. Here, Fig.10 (1) to (3) corresponds to Fig.9 (1) to (3) respectively.

As seen in Fig.10 (1), the long interval case, and in Fig.10 (2), short interval plus low heating energy case, pigments form very thin layer on the surface of the paper. On the contrary, in the short interval plus medium heating energy case, Fig.10 (3), pigments exist below the surface. In case of the paper A-81gsm, Fig.10 (4) where absorption speed being relatively fast, the pigments also do not exist on the surface even the same experimental condition with Fig.10 (2).

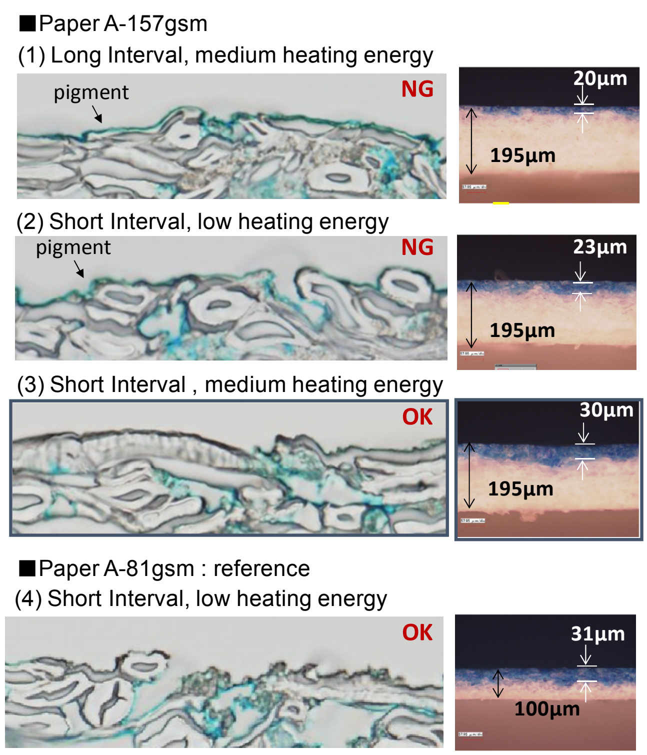

Figure 10. *Distribution of pigment in cross-section of printed paper (resolution:1200dpi, drop volume 4.3pl, coverage 100%)*

Table 3 shows the experimental and the observation results. As can be seen in this Table, ink depth seems to have good correlation with smear quality. Considering the relationship between interval and ink depth in #1 and #3, longer interval produces shorter ink depth, it implies that amount of evaporation during the interval might associate with the difference in ink depth. In contrast, in the case that same interval but different heating energy, #2 and #3, the difference in ink depth seems to be caused by amount of evaporation in the heating system.

Table.3 Experimental and observation results

#	Interval	Temperature (printed area)	Paper thickness	Ink depth	Smear quality
1	2.1sec	55degC	195um	20um	NG
2	0.4sec	35degC	195um	23um	NG
3	0.4sec	55degC	195um	30um	OK
4	0.4sec	35degC	100um	31um	OK

Observation of penetration behavior by high speed camera

We observed actual behavior of ink penetration during the interval by the high speed camera (frame rate of 50usec, resolution of 512*256pixcel). Setting drop volume to 5pl (1200dpi) and print patterns to one line and ten lines, we estimated the penetration times.

Figure 11 shows the penetration times for each combination of paper and image pattern. In A-81gsm paper, penetration time indicates around 100msec even in 10 lines, however in A-157gsm paper, penetration time increases up to 550 or more msec in 10 lines. This result suggests that insufficient penetration could be caused using A-157gsm paper and large drop volume in the long interval more than 0.4sec. In such a condition, there would be a possibility of forming the pigment cake [2], [3] that interferes the further penetration.

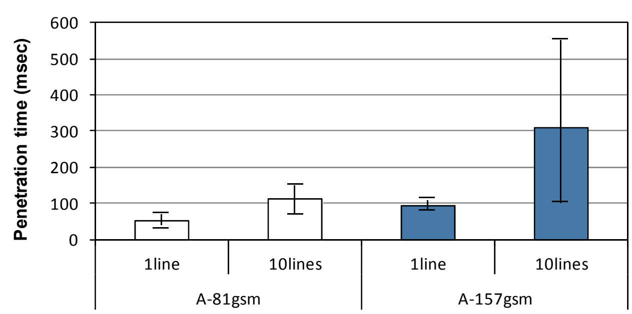

Figure11. *Absorption time of line image (1200dpi, drop volume: 5pl)*

Summary

In this study, focusing on the combination of aqueous pigment ink and inkjet treated paper that shows relatively slow absorption speed, we investigated the relationship between fixing quality (smear) and optical density for the system parameters: drop volume, interval and heating energy setting up inkjet offline bench with infrared radiation heating system.

Consequently, we demonstrated following results:

- There exists the optimal condition of enhancing penetration: short interval and medium heating condition. That condition suppresses evaporation and penetration during the interval and, realizes low ink viscosity in the heating system, which assists penetration of ink.
- Long interval has no contribution for the penetration, rather helps forming the very thin layer of pigment on the surface of the paper owing to the amount of evaporation increasing.
- High and rapid increase of heating energy rather enhances evaporation, and that consequently preventing penetration.
- Optimization of balance between penetration and evaporation in both interval and heating process is important.

In the Infrared ray radiation heater which heating from the printed side, evaporation of the ink left on the paper surface might especially be enhanced, consequently that would assist to create the cake of pigments or condensed moisturizing agent. Therefore the system buffering such phenomena would be required.

References

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Author Biography

Satoshi Hasebe received his PhD (1997) in mechanical engineering from Hokkaido University. Since then he has worked in the Research and Technology Division at Fuji Xerox. His work has focused on the development and application of the simulation techniques for marking process mainly in electrophotography and ink jet system. He is now engaged in research of drying and fixing mechanism. He is a member of Imaging Science of Japan and Japan Society of Mechanical Engineering.