Study on the process of infiltration for ink droplets in the inkjet printing substrate

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Abstract

The printing pressure of ink droplets in inkjet printing comes from the droplets kinetic energy after jetting, the energy of the ink droplets infiltrating and diffusing in the substrate is derived from the conversion of ink droplets kinetic energy, this is one of the main factors of producing the dot gain phenomenon in the inkjet printing. The mathematical model of ink droplets infiltrating in the substrate was researched in this paper, we analyzed the different structures of paper coatings at first, proved that the paper substrate was the porous medium, so the process of inkjet imaging was the process of droplets infiltrating the porous substrate and drying. But traditional model is no easy to use in practice, we studied this problem based on the energy dissipation and conversion view and obtained the new mathematical model. At the same time, the imaging results of the ink droplets in the paper coating were analyzed in this paper by QEA image analysis instrumentation, the experimental results showed that the imaging process of ink droplets in the substrate could be represented by the mathematical model of the discrete-phase fluid flowing in the porous media, these results described the causes of the inkjet imaging dot gain and provided a scientific theory in order to solve the dot gain problem in the inkjet imaging printing system.

Introduction

In the inkjet printing system, infiltration and diffusion of discrete flight ink droplets in paper coatings have significant influence on the image quality, usually the viscosity of water-based ink is very low, in the inkjet imaging, because the low viscosity ink droplets possessing of certain energy infiltrate into the paper substrate or diffuse on them, it will produce certain dot gain phenomenon, this is the complex physical interaction between ink droplets and paper substrate [1]. There is no accurate mathematical model to represent the process of the infiltration, diffusion, energy conversion and dissipation between ink droplets and porous paper coating. Based on profoundly researching on the porous structure of inkjet paper coating, this paper studied the infiltration and diffusion process of flying ink droplets, and proposed the new mathematical model of ink droplets. Meanwhile, this paper analyzed the phenomenon of infiltration and diffusion, especially energy conversion and dissipation, between ink droplets and porous paper coating, the imaging results of the ink droplets in the paper coating were analyzed by QEA image analysis instrumentation, the results showed that the surface microstructure of paper is one of the most fundamental factors in paper color gamut, and these results described the causes of the inkjet imaging dot gain and provided a scientific theory in order to solve the dot gain problem in the inkjet imaging printing system[2].

Experimental

The infiltration and diffusion mechanism of ink droplets

Diffusion in the paper surface and infiltration in the inner paper structure play a dominant role after ink droplets contacting with paper coating. The process that has happened between ink droplets and paper coating decides the final quality of images in inkjet printing system. If the diffusion (XY direction) velocity is faster than infiltration (Z direction) velocity, the process of ink droplets is mainly diffusion; on the contrary, the process is mainly infiltration [3]. If the diameter of the dot turns bigger, the image resolution will turn low and the image will appear color mixing phenomenon, it will impact on the clarity and fidelity of the images. The faster infiltration velocity will cause printing density to decrease and print through. Only two velocities are appropriate, we can obtain the ideal dot diameter, as well as gain clear image and high color density. Therefore, it is crucial that research on the surface structure and printability of paper coating, especially the contact angle of ink droplets. The contact process between flying ink droplet with paper coating was shown as below:

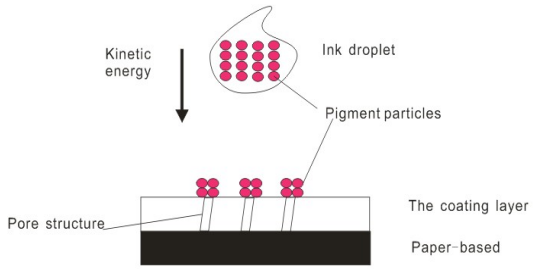

Figure 1. *The contact process of ink droplet on the paper coating*

Test experimental of paper surface coating

The surface structure of representative inkjet printing paper including the resin coating and paint coating was researched in this paper, including the optical performance of paper. The results showed that the high quality inkjet printing paper was composed of an ink absorption layer about 10um thick: coating and white diffuse reflector: paper fibers. In the infiltration process, the dye of ink stays on coating surface and the solvent infiltrates into the coating, in order to demonstrate ink infiltration ability on paper coating, we measured surface contact angle of the different paper coating.

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Experimental of inkjet on paper surface coating

In our research, we used EPSON7800C digital proofing systems, Jetxper image analysis system, X-RITE EYE-ONE IO spectrophotometer, densitometer, QEA image quality analyzer, color management systems ProfileMaker5.08, EFI Colorproof XF proofing software and other digital equipment and professional computer software as the platform, and researched on the droplets imaging, dot gain and color gamut reproduction.

The infiltration and diffusion process between ink droplets and paper surface is the process of momentum and energy transfer among gas, liquid and solid. The experimental results showed that the imaging process of ink droplets in the substrate could be represented by the mathematical model of the discrete-phase fluid flowing in the porous media, when the ink droplets contact with the paper surface, they bulge spherically because of surface tension, then aggregate and form the dot. The area size of the dot depends on the droplet volume, flight kinetic energy and the affinity between droplets and paper surface. This is a process of energy conversion and dissipation [4].

Results and discussion

The surface structure of paper coating

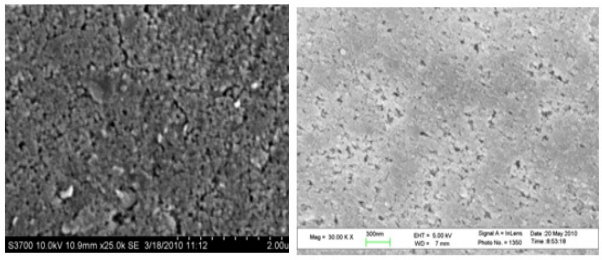
The paper surface smoothness includes macro smoothness and micro smoothness. The micro smoothness is a function of glossiness [5]. While paper-based and coatings are constant, we should alter the coating and calendaring processes to determine smoothness. The porosity of paper coating varies in these processes, it should be minimized. The surface smoothness indicates that smoothness is major factor, while the influence of surface porosity decreases on the same calendaring conditions.

The partly surface structure of different paper coating is shown as below:

Figure 2. *The SEM pictures of the paper surface coating*

Compared $1^{\#}$ paper with $2^{\#}$ paper, there are some crack on the $1^{\#}$ paper surface, they intersect with the surface of the pores on the paper coating, and form the network to absorb the ink droplet. $4^{\#}$ paper has highly smooth surface, this is attributed to the super calendar, and the pigment particles are distributed uniformly on the paper surface.

The optical performance of different paper surface



1# (×23K) 2# (×30K)

The optical performance of different paper surface was tested by the instrument (the type is Technidyne ColorTouch PC CTP-ISO), including whiteness, brightness and opacity, the unit are all GB. The results are shown as table 1.

Table 1 The optical performance of different paper surface

Paper type	Whiteness	Brightness	Opacity
$1^{\#}$	118.46	99.04	98.31
$2^{\#}$	153.61	106.46	99.67
$3^{\#}$	110.04	93.12	93.49
$4^{\#}$	88.58	92.62	92.75
$5^{\#}$	145.52	108.81	92.27
$6^{\#}$	114.04	93.51	98.28

From the table 1,we can draw a conclusion that the 2# paper has highly optical performance. The gamut results showed that it has good printability.

Contact angle of paper

The affinity of the ink droplet and paper surface is represented by the contact angle. From our research, we could find that the resin coating has the higher surface density and large contact angle. It can be inferred that the main action mechanism is diffusion between the ink droplets and paper coating; There are large numbers of uniformly distributed micro pores on the surface of paint coating, the shape and size of the pores are relatively uniform, and the ink contact angle is relatively small, porous coating structure gives excellent absorption properties, so the main action mechanism is diffusion and infiltration between the ink droplets and coating. In our experiment, we selected angular method as contact angle measurement.

The method makes droplet on the solid surface to project onto the screen, and then directly measures the angle between the tangent and the interface, directly measures the size of the contact angle. The contact angle is measured by the surface tension instrument, the method and results are shown as below:

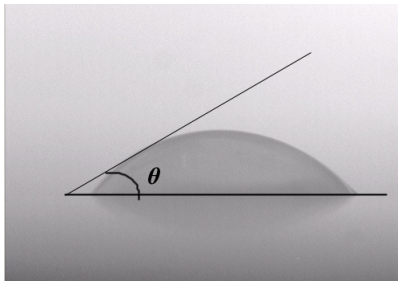


Figure 3. *The measurement of contact angle*

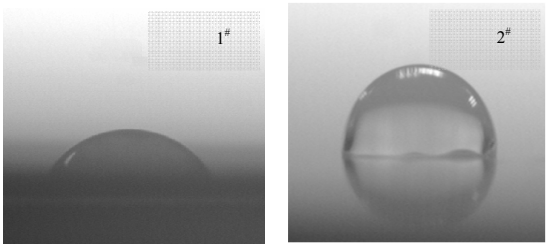


Figure 4. *The measured results of different paper coating*

Dot gain and color gamut reproduction in paper coating

We can conclude that there is a certain phenomenon of dot gain in the inkjet printing, the coating structure has the great impact on the image color gamut reproduction. If the coating is evenly distributed and has the uniform micro pore and the moderate contact angle, it will restore the good effect of the color. The pictures of color gamut and dot gain are shown as below:

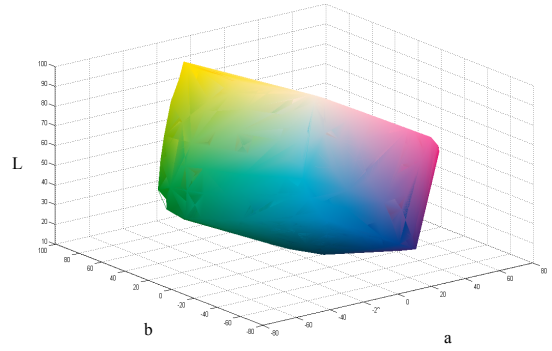


Figure 5. *The color gamut of 2# paper*

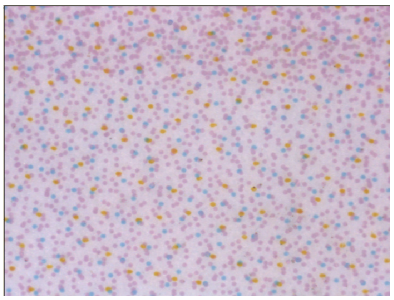


Figure 6. *The dot gain picture of 2# paper by QEA*

As shown in figure 5 and figure 6, the color gamut enlarges while surface porosity decreases, the dot gain also decreases. The printability plays a leading role in the inkjet imaging system. When pigment particles gather on the paper surface, the paper color gamut will enlarge because of the small surface porosity.

Conclusion

the imaging process of ink droplet in the substrate could be represented by the mathematical model of the discrete-phase fluid flowing in the porous media, The resin coating has the higher surface density and large contact angle and the main action mechanism is diffusion between the ink droplets and coating; There are large numbers of uniformly distributed micro pores on the paint coating, and the ink contact angle is relatively small, porous coating structure gives excellent absorption properties, the main action mechanism is diffusion and infiltration between the ink droplets and coating.

The coating structure has the great impact on the image color gamut reproduction. High-quality paper coating will restore the good effect of the color in inkjet imaging system. The imaging mechanism and the factor of dot gain in inkjet printing system was preliminary established in this paper, they have a certain significance to get higher quality inkjet printing images. The color gamut becomes wider as the smoothness increases and the surface porosity decreases.

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