Effect of Paper Properties on Ink Transfer Properties

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Abstract. The ink transfer rate has an important influence on the printing quality. The primary aim of the printing process is always to achieve a high ink transfer rate. This paper used a printability tester to test three different types of paper: coated paper, offset paper, and newsprint, and adopted an approximate method to calculate the ink transfer equation to test the absorbency, surface smoothness, and elasticity of the papers. Furthermore, we developed a linear regression model based on the measured values. Analyzed and explored the influence of paper properties on the parameters of the ink transfer equation. The experimental results show that the maximum ink transfer rate of a newsprint paper is higher than that of an offset paper and coated paper under the same ink and printing conditions, with the optimal ink supply to the coated paper being the smallest. The ink absorption and smoothness of a paper were found to significantly influence the ink transfer parameters.

Keywords: Ink transfer equation · Ink transfer rate · Paper performance test

1 Introduction

Ink transfer is the process of transferring the ink on the printing plate to the substrate. Effective ink transfer is the key to printing high-quality prints. An in-depth discussion of the law of ink transfer can not only ensure the stability, uniformity, and appropriate amount of ink transfer, but also improve the ink transfer rate by controlling and adjusting printing conditions to obtain the best printing effects with the smallest possible quantity of ink, which could effectively prevent the excessive consumption of ink and save costs [1].

The ink transfer rate directly affects the reproduction effect of the image, the clarity of the printed material, and the saturation of the ink color. During the printing process, it is always aimed that a high ink transfer rate is achieved, however, the ink transfer process is very complicated. There are many factors affecting the rate of ink transfer, such as ink performance, paper performance, type of printing machine, and environmental factors, etc., with varying degrees of impact. During the process of ink transfer, paper properties have a great influence on the ink transfer rate. In this study, three different types of paper were used in ink transfer experiments. The WF ink transfer equations of the various papers were established by approximation method, and the various papers were tested, and a performance parameter to study the influence of the performance of the different papers on the three parameters b, f', and k of the ink transfer equation was investigated.

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2 Experiment

2.1 Experimental Equipment and Materials

AIC2–5 printability tester, Three-roll grinding machine, Paper KN ink tester, Bekk smoothness tester, squeegee, ink injector, Self-made Laboratory UV offset printing ink, coated paper 100 g/m^2, coated paper 120 g/m^2, offset paper 80 g/m^2, offset paper 90 g/m^2, newsprint 60 g/m^2, and newsprint 80 g/m^2.

2.2 Experimental Method

Ink Transfer. Under a temperature of 25 °C and a humidity of 55%, we set the printing speed to 0.2 m/s, the printing pressure to 625 N/m, changed the ink supply, and use the printing suitability meter to test the offset and coated papers respectively. The newsprint is proofed, and the ink transfer amount is calculated using the weight difference method.

Ink Absorption. Take a paper sample and use a spectrophotometer to measure the reflection factor R0 before applying the absorbent ink to the surface of the sample. The sample under test should be lined with several layers of the same sample until it becomes opaque. Evenly smear the absorbent ink on the sample and wait for 2 min. Wipe off the unabsorbed ink with ink-wiping paper, to leave a uniform ink mark on the sample. Subsequently, a spectrophotometer is used to measure the reflection factor R1 at the original detection point, (R0–R1)/R0 is the absorbency value of the ink.

Paper Smoothness. Take a paper sample and place the sample between the upper and lower pressure plates of the Buick smoothness meter, lower the upper-pressure plate, select the appropriate gear according to the paper, press the start button, and the vacuum pump will automatically start. When there is no change in the smoothness of the display, the test ends, and the smoothness value of the paper is noted.

2.3 Calculation Method of Ink Transfer Rate

The calculation of the ink transfer rate adopts the differential weight method.

$$x = \frac{m_1 - m}{s}. \tag{1}$$

$$y = \frac{m_1 - m_2}{s} \tag{2}$$

$$f = \frac{m_1 - m_2}{m_1 - m} \tag{3}$$

where m is the net mass of the printing disc;m_1 is the mass of the printing disc after the distribution of the ink;m_2 is the mass of the printing disc after printing; s. is the area of the printed image and text. Next, e calculate the ink transfer rate f according to formulas (1) and (2).

2.4 Ink Transfer Equation

Fetsko and Walker proposed the W.F ink transfer equation (Fetsko-Walker), which is a mathematical model for studying the process of ink transfer [2].

$$y = \left(1 - e^{-kx}\right)\{b\left(1 - e^{-\frac{x}{b}}\right) + f'\left[x - b\left(1 - e^{-\frac{x}{b}}\right)\right] \tag{4}$$

In the formula above, y is the amount of ink transferred, x is the ink supply by the printing plate, parameter b is the maximum amount of ink that may be filled in the depression on the surface of the paper at the moment of printing, parameter f' is the split rate of free ink, and parameter k is the proportional coefficient, under the condition of a certain amount of printing plate ink to determine the area of the paper surface in contact with the ink per unit printing area.

3 Consequence and Analysis

3.1 Analysis of Ink Transfer Experiment Approximate Method

Using three different papers, the ink type and printing conditions remain unchanged, the ink supply is changed, and ten replications of the experiments are performed on each paper. The amount of ink transferred to the paper is weighed to obtain the ink transfer volume curve of each paper, as shown in Fig. 1.

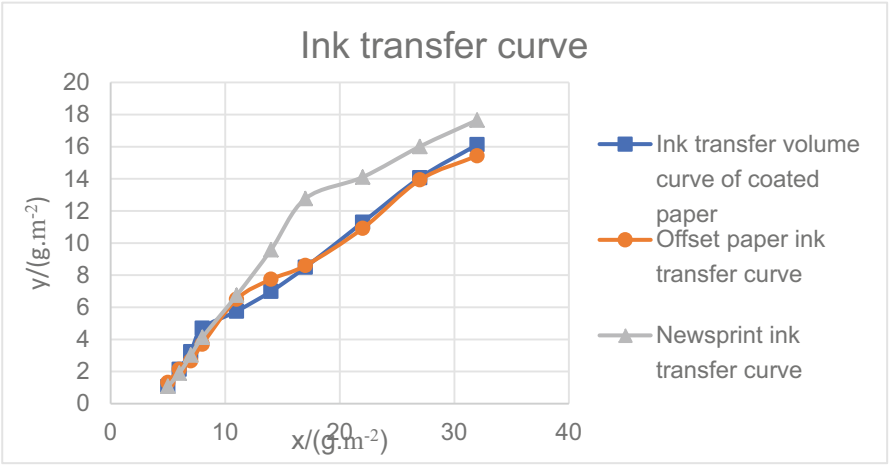

Fig. 1. Ink transfer curve of different types of paper

Figure 1 shows that the amount of ink transfer increases with an increase in the amount of ink supply. When the amount of ink supply is relatively small, the amount of ink transfer increases rapidly. When the ink supply is sufficient, the amount of transferred ink basically increases in a linear relationship with the amount of ink on the printing plate [3]. In combination with the ink transfer equation, when the ink supply is large

enough, sine b and k in the ink transfer equation are both finite values, the e^{-kx} and $e^{-x/b}$ items in the ink transfer equation can be ignored to obtain a simplified linearized ink transfer equation as follows:

$$y = f' + b(1 - f') \tag{5}$$

The approximation method is used to obtain the b, f′, and k values in the ink transfer equations for different papers, and corresponding ink transfer equations for the three types of papers are established as shown below:

Coated paper:

$$y = \left(1 - e^{-5.57x}\right)\left\{2.56\left(1 - e^{-\frac{x}{2.56}}\right) + 0.41\left[x - 2.56\left(1 - e^{-\frac{x}{2.56}}\right)\right]\right\} \tag{6}$$

Offset paper:

$$y = \left(1 - e^{-0.84}\right)\left\{5.56\left(1 - e^{-\frac{x}{5.56}}\right) + 0.29\left[x - 5.56\left(1 - e^{-\frac{x}{5.56}}\right)\right]\right\} \tag{7}$$

Newsprint:

$$y = \left(1 - e^{-0.37x}\right)\left\{6.81\left(1 - e^{-\frac{x}{6.81}}\right) + 0.32\left[x - 6.81\left(1 - e^{-\frac{x}{6.81}}\right)\right]\right\} \tag{8}$$

The ink transfer rate is calculated and the ink supply is plotted on the x-axis to draw the relationship curve between the ink transfer rate and the ink supply, as shown in Fig. 2.

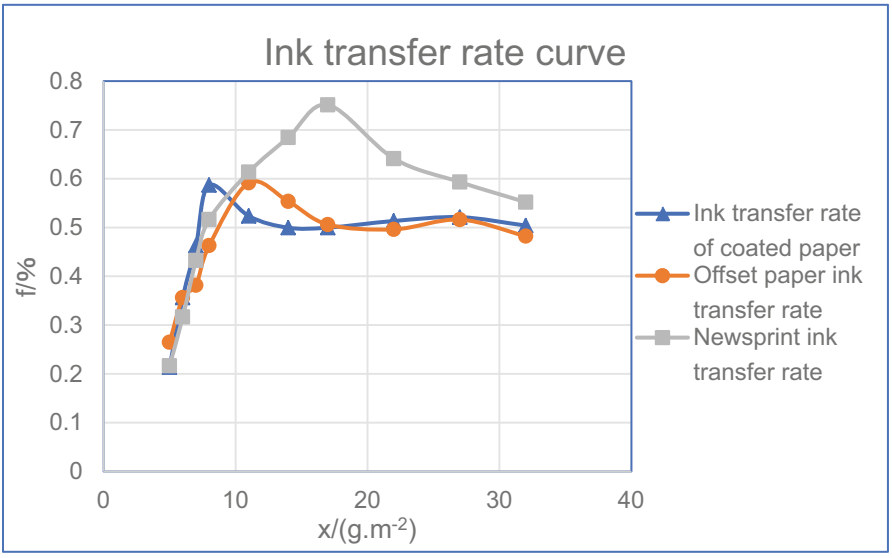

Fig. 2. Ink transfer rate curves of different paper types

Figure 2 shows that the ink transfer rates of the three papers all increased first, then decreased, and subsequently remained stable. The coated paper had the highest initial

ink transfer rate, followed by the offset paper and lastly the newsprint paper, however, the maximum ink transfer rate of the coated paper is close to that of the offset paper, but the newsprint has a slightly higher ink transfer rate. For the same paper, the higher the ink transfer rate, the better the quality of the printed material. To find the maximum ink transfer rate of the paper and the corresponding ink supply, it is paramount to print high-quality prints. Figure 2 indicates that the ink supply to the coated paper is the lowest, followed by the offset paper, with the newsprint having the highest ink supply. This indicates that newsprint needs more ink supply to get the best printing effects. The best printing effect can be exerted with very little ink supply.

3.2 Influence of Paper Properties on Ink Transfer Parameters

Based on the ink supply and ink transfer volume curve, and by using the approximation method, the values of the parameters b, f′, and k of the ink transfer equation corresponding to the three different types of paper are calculated. Using the same experimental method to test the three different brands of coated paper, offset paper, and the newsprint again, the values of b, f′, and k are calculated to list the measured paper properties as depicted in Table 1.

Table 1. The performance parameters, b, f′, and k values of different types of paper

Type of paper	Smoothness/s	Ink absorption %	b	f	k
Coated paper 1	1056	16	2.56	0.41	5.57
Offset paper 1	457	51	5.56	0.38	2.84
Newsprint 1	58	58	6.81	0.32	0.87
Coated paper 2	619	15	3.72	0.39	3.57
Offset paper 2	51	52	6.09	0.42	0.84
Newsprint2	47	52	6.14	0.39	1.14

Table 1 indicates that the greater the smoothness of the paper, the less ink the surface of the paper accepts at the moment of printing, the smaller the b value, and vice versa, the larger the b value [4]. Also, the ink absorbency of the paper has an effect on the b value. Paper with a good ink absorbency has a larger b value.

The f' value of the various f papers differs slightly and the f' value is not significantly affected by the performance of the paper.

The k value is significantly affected by the smoothness of the printing, the greater the smoothness of printing, the greater the k value. However, the smoothness of newsprint 2 in Table 1 is slightly higher than that of newsprint 1 and offset 2, which are similar in smoothness. This is because newsprint 2 has better elasticity, and the smoothness of newsprint 2 is higher when printed under the effect of printing pressure than the smoothness when measured.

Input the data obtained into SPSS software, take paper smoothness, ink absorbability as the independent variables, respectively, and set x_1, x_2, b, f', k as the dependent variables to perform a multiple linear regression analysis to obtain the detailed analysis of paper performance on variables b, f', and k.

The first is the regression analysis of the b value, the test results showed that the correlation coefficient (R^2) value is 0.965, the model interpretation degree is very high. The Durbin-Watson value is used to detect the autocorrelation between the independent variables. Generally speaking, the closer the value is to 2, the better. The Durbin-Watson value obtained is 1.133, showing that there is no significant correlation between the two independent variables. Further analysis may be performed.

The analysis results are shown in Table 2.

Table 2. Linear regression analysis of paper properties on b values

Paper parameters	Unnormalized coefficient B	Significance
Constant	4.214	0.015
Smoothness	−0.002	0.054
Ink absorption	0.043	0.059

The linear regression model of the effect of paper properties on b value is obtained as:

$$b = -0.002x_1 + 0.043x_2 + 4.214 \tag{9}$$

Significance indicates the degree of influence of the independent variable on the dependent variable; <0.05 indicates a statistically significant impact, and the smaller the influence is, the greater the influence is. Table 2 shows that the smoothness of the paper and ink absorbability have an impact on the b value, but the impact appears not to be statistically significant.

Similarly, regression analysis is carried out on the f′ value, and the fitness of the model is first tested. The correlation coefficient R^2 is 0.146, indicating a very low degree of interpretation, indicating that the smoothness and absorbability of the paper have a nonlinear relationship with the F′ value, which cannot be further analyzed.

Finally, the regression analysis of the k value is carried out to test the fitness of the model. The correlation coefficient R^2 was 0.994, indicating a high degree of model interpretation. The Durbin-Watson value was 2.116, and there was almost no correlation between the two independent variables. Further analysis was carried out. The analysis results are shown in Table 3.

Table 3. Linear regression analysis of paper properties on k values

Paper parameters	Unnormalized coefficient B	Significance
Constant	0.739	0.165
Smoothness	0.005	0.001
Ink absorption	0.00042	0.956

The linear regression equation of the effect of paper properties on the k value is obtained.

$$k = 0.005x_1 - 0.00042x_2 + 0.739 \tag{10}$$

According to the significant value of paper smoothness and ink absorbability in Table 3, it can be seen that the k value is significantly affected by the smoothness value of the paper, but not significantly affected by the absorbability of ink.

4 Conclusions

In different types of paper, newsprint has the maximum ink transfer rate, and there is no significant difference between the ink transfer rates in the offset paper and the coated paper, with the coated paper having the least ink supply. To obtain the best printing quality, the ink supply of the corresponding printing paper should be adjusted to ensure the maximum ink transfer rate.

From the linear regression analysis, paper smoothness and ink absorbability will affect the value of b and k. Paper smoothness will greatly affect the k value, the smoother the paper, the greater the k value. Ink absorbability appears not to have any effect on the k value. Both paper smoothness and ink absorbability affect the b value, absorbability at the same time, paper smoothness, the smaller the b value, the smoothness at the same time, the greater the absorbability, the greater the b value.

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