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The Effect of the Pretreatment Print Paste Contents on Colour Yield of an Ink-jet Printed Cotton Fabric

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Abstract: Optimum condition concerning the content of pretreatment print paste and steaming time for ink-jet printing was newly developed through the orthogonal analysis. The cotton fabric treated under the newly developed optimum condition could achieve a high level of colour yield similar to that of the commercially pretreated cotton fabric available in the market for ink-jet printing. The results were discussed thoroughly in this paper.

Keywords: Ink-jet printing, Pretreatment paste, Sodium alginate, Sodium bicarbonate, Urea and steaming time

Introduction

In recent years, there are increasing interests in the application of ink-jet printing in the textile market. The ink-jet printing technique stands out benefits like speed, flexibility, creativity, cleanliness, competitiveness and also eco-friendliness [1,2]. However, the production process of ink-jet printing for cotton fabric with reactive dye was different from that of the conventional printing process [3,4].

In the conventional textile printing of cotton fabric, the reactive dye is applied with alkali and other additional chemicals in the form of a print paste. The print is then normally steamed to fix the dye onto the cotton fabric and then washed thoroughly to remove any unreacted dye, chemicals and thickener. However, due to the purity requirement and specific conductivity requirements for ink-jet printing [3-6], none of the conventional printing chemicals such as alkali, urea and sodium alginate thickener can be directly incorporated into the ink formulation. As a result, the cotton fabric should be pretreated with those printing chemicals used in the conventional textile printing. The chemicals necessary for fixing reactive dye should be padded onto the cotton fabric prior to the ink-jet printing stage.

For the ink-jet printing of cotton fabric with reactive dyes, the contents of pretreatment print paste, i.e. the use of alginate, urea and alkali, and the steaming time after ink-jet printing, play the major role in affecting the final colour yield of the printed cotton fabric [3]. In order to achieve the maximum colour yield, the combination of these factors must, therefore, be studied in depth. Hence, a detailed study of these factors that influence the colour yield of an ink-jet printed cotton fabric should be conducted. The findings from this study can provide a better understanding of the effect of pretreatment print paste and steaming time on the colour yield of ink-jet printed cotton fabric. Furthermore, the optimum condition used for the printing process can also be provided.

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It is a common practice that most of the commercially pretreated cotton fabrics available in the market for ink-jet printing have been padded with pretreatment print paste. However, due to commercial reason, the content of such pretreatment print paste used for the commercially pretreated fabric was not disclosed resulting in very expensive price for this fabric type. Hence, the study of the recipe of the pretreatment print paste with respect to the final colour yield in this study can provide helpful information for the industries to further develop their own pretreatment print paste recipe for ink-jet printing.

Experimental

Fabric

100 % singed, desized, scoured and bleached cotton plain weave fabric of 136 g/m^2 with 133 ends/inch (40 s) and 72 picks/inch (40 s) was used in this study. A commercially pretreated cotton fabric with the same fabric specification was adopted as the control fabric.

Preparation of Pretreatment Print Paste

Unless otherwise stated, all chemicals used were of A.R. grade. A stock alginate was prepared by dissolving 50 g sodium alginate in 950 m*l* deionised water. The amount of alginate used in the pretreatment print paste was measured directly from the stock alginate. Inside the pretreatment print paste, suitable amounts of urea and sodium bicarbonate ($NaHCO_3$) were also added. In order to achieve the optimum condition, a $L_9(3)^4$ orthogonal analysis was used with the details shown in Tables 1 and 2. The pretreatment print pastes were prepared in accordance with the requirements stated in Table 2 and made up to the final weight of 200 g with deionised water. The pH value of the pretreatment print pastes was kept at 9-10.

Fabric Pretreatment

The pretreatment print paste was padded onto the cotton

Table 1. Factors and levels used in orthogonal analysis

Factor	Pretreatment print paste gradient			Post-treatment
Level	Alginate	Urea	$NaHCO_3$	Steaming time
I	50 g	5 g	2 g	3 min
II	100 g	10 g	4 g	5 min
III	150 g	20 g	8 g	10 min

Table 2. Experimental arrangement

Test Run	Pretreatment print paste gradient			Post-treatment
	Alginate	Urea	$NaHCO_3$	Steaming time
1	I	I	I	I
2	I	II	II	II
3	I	III	III	III
4	II	I	II	III
5	II	II	III	I
6	II	III	I	II
7	III	I	III	II
8	III	II	I	III
9	III	III	II	I

fabric using a padding machine (Labortex Co. Ltd) with the pressure of 2.6 kg/m^2 and padding speed of 2.5 rpm until a pick-up of 80 % was achieved. The pretreated fabrics were dried in oven at 80 °C and then conditioned before ink-jet printing.

Ink-jet Printing and After-treatment

The model of ink-jet printer was Mimaki Tx2-1600 (Mimaki Engineering Co., Ltd.), a piezo electric drop-on demand machine using eight refillable colour cartiridges. Four commercially available reactive dyes (TianLi Modern Office Articles (Shanghai) Co., Ltd.), with the colours of Cyan (C), Magenta (M), Yellow (Y), and Black (K), were used without further purification. A pattern of square with 8 cm × 8 cm size, which was printed for each single colour (cyan, magenta, yellow and black), was generated using by DGS (Dua Graphic Systems) software and through TexPrint software to commend operation with 360 dpi × 360 dpi for easy comparison. After ink-jet printing, the printed fabrics were air-dried and then steamed with superheated steam at 110 °C for fixing the colour. The steaming time was employed in accordance with the experimental arrangement listed in Table 2. The steamed fabrics were finally washed in 10 g/*l* nonionic detergent until all unreacted dyes and chemicals were removed.

Colour Yield Measurement

The printed fabrics were conditioned before colour yield measurement using Macbeth Colour Eye 7000 A spectrophotometer under illuminant D_{65}. In this study, the summation of K/S, i.e. $K/S_{(sum)}$, over wavelength interval within the visible spectrum was calculated. The K/S values from 400 nm to 700 nm wavelength with 20 nm interval were summed and calculated according to equation (1). The higher the $K/S_{(sum)}$ value, the more the dye-uptake resulting in better colour yield will be.

$$\frac{K}{S} = \frac{(1-R)^2}{2R} \tag{1}$$

where K = absorption coefficient, depending on the concentration of colorant
S = scattering coefficient, caused by the dyed substrate
R = reflectance of the coloured sample

Results and Discussion

The optimum condition of the pretreatment print pastes and steaming time was achieved by means of the orthogonal analysis with the results summarised in Table 3.

Effect of Sodium Alginate on the Pretreatment Print Paste

Sodium alginate is a very important print paste thickener in textile printing because of the ready solubility and excellent stability even after high-temperature fixation treatments. It is especially important for the preparation of print pastes for reactive dyes as the extent of its interaction with reactive dyes is very small. This is mainly due to the absence of primary hydroxyl groups in sodium alginate and the repulsion of dye anions by the ionised carboxyl groups of the polymer under alkaline condition (pH~9-10) [7]. Hence, sodium alginate was used in the present study and its effect on the colour yield of different colours is shown in Figure 1.

Figure 1 clearly shows that the Black colour had the best colour yield followed by Cyan, Magenta and Yellow colours. When the amount of sodium alginate used in the pretreatment print paste was increased, the colour yields of the printed fabrics were enhanced correspondingly. This concluded that sodium alginate could serve the function of increasing the colour yield of ink-jet printing. In the pretreatment print paste, the use of sodium alginate which served as a migration inhibitor in the printing paste was to control the sharpness of borders of the final ink-jet printed pattern [8,9]. During the steaming process, steam condensed onto the film of sodium alginate which would swell and contain a miniature dyebath on the fibre surface. The dye then dissolved and diffused through the swollen alginate film to the fibre surface. Although the condensed steam might cause a bleeding of the outlines due to the presence of urea in the pretreatment print paste, yet the sodium alginate could reduce the effect of bleeding. On the other hand, the sodium alginate could control the penetration of the dye into the fabric [4,8]. When the concentration of sodium alginate was too high, the fixation yield could be reduced. One reason was that a thick film of alginate might act as a diffusion barrier for the dye and so less dye was fixed on the fibre itself [4]. Furthermore, when the amount of

Table 3. Orthogonal table for the optimisation of each colour

Test Run	Substrate			Post-treatment	Dye uptake (K/S)			
	Alginate	Urea	$NaHCO_3$	Steaming time	C	M	Y	K
1	I	I	I	I	78.66	51.02	44.53	143.45
2	I	II	II	II	87.84	66.11	59.23	165.94
3	I	III	III	III	70.10	40.05	34.71	114.12
4	II	I	II	III	81.53	57.21	56.05	162.81
5	II	II	III	I	95.79	68.81	69.77	190.71
6	II	III	I	II	71.77	43.93	43.57	119.33
7	III	I	III	II	96.78	89.10	72.53	217.71
8	III	II	I	III	95.77	67.59	61.36	167.57
9	III	III	II	I	81.19	52.40	53.53	146.34
Cyan (C)								
ΣI	236.60	256.97	246.20	255.64				
ΣII	249.09	**279.40**	250.56	**256.39**				
ΣIII	**273.74**	223.06	**262.67**	247.40				
Different	37.14	56.34	16.47	8.99				
Magenta (M)								
ΣI	157.18	197.33	162.54	172.23				
ΣII	169.95	**202.51**	175.72	**199.14**				
ΣIII	**209.09**	136.38	**197.96**	164.85				
Different	51.91	66.13	35.42	34.29				
Yellow (Y)								
ΣI	138.47	173.11	149.46	167.83				
ΣII	169.39	**190.36**	168.81	**175.33**				
ΣIII	**187.42**	131.81	**177.01**	152.12				
Different	48.95	59.15	27.55	23.21				
Black (K)								
ΣI	423.51	523.97	430.35	480.50				
ΣII	472.85	**524.22**	475.09	**502.98**				
ΣIII	**531.62**	379.79	**522.54**	444.50				
Different	108.11	144.43	92.19	58.48				

Figures in **bold** form showed the greatest value among the values in the levels of different factors used.

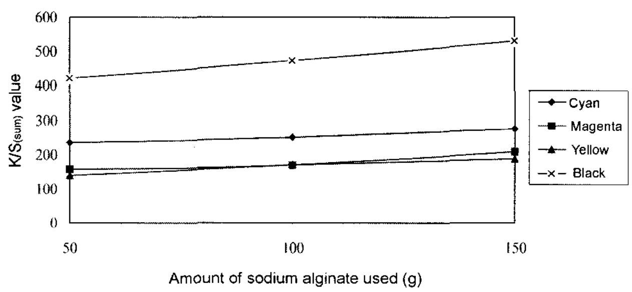

Figure 1. Effect of the amount of sodium alginate used on the colour yield of different colours.

sodium alginate was increased to 200 g, the viscosity became too great thereby imposing the difficulty of padding the pretreatment print paste on the fabric. As penetration was viscosity-dependent, it was necessary to find a carefully balanced compromise between penetration and diffusion [7,8].

Effect of Sodium Bicarbonate on the Pretreatment Print Paste

Similar to that in the dyeing process, alkali is used in the printing process for the colour development of all shades [7,9]. The presence of alkali is essential to produce ionisation of accessible cellulose hydroxyl groups which can then react with the reactive dyes in the fixation stage. Sodium bicarbonate has been the preferred alkali because it is cheap and can give sufficient pretreatment print paste stability with most reactive dyes available in the markets [7]. During steaming, sodium bicarbonate loses carbon dioxide and increases the ionisation of cellulose which thus promotes the dye-fibre interaction in the fixation stage.

From Figure 2, it was also noted that the Black colour had the best colour yield followed by Cyan, Magenta and Yellow.

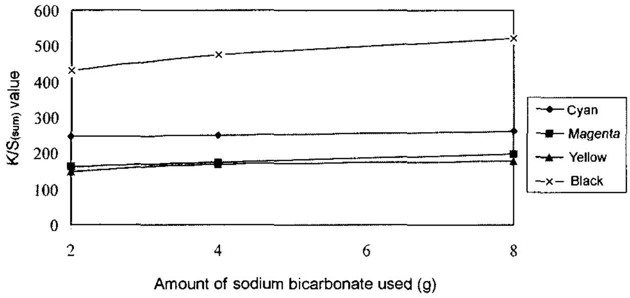

Figure 2. Effect of the amount of sodium bicarbonate used on the colour yield of different colours.

However, the effects of Cyan, Magenta and Yellow colours were not significant when compared with the Black colour. Generally speaking, when the amount of the sodium bicarbonate used in the pretreatment print paste was increased, the colour yields of the printed fabrics were increased.

Effect of Urea on the Pretreatment Print Paste

Urea is essential in the pretreatment print paste because during the steaming process, particularly in the superheated steam right after ink-jet printing, it is mainly used for swelling the cotton fibres so that the dye can penetrate the fibres rapidly [9,10]. The urea acts as a solvent for the reactive dye as it performs as a moisture-absorbing agent in the pretreatment print paste to increase the moisture regain during the steaming process, and thus accelerates the migration of dye from the thickener film, i.e. sodium alginate, into the cotton fibre. The urea also reduces the yellowing of cotton under hot, dry alkaline conditions [7,10].

Figure 3 shows the colour yield of different colours under the influence of various amounts of urea used in the pretreatment print paste. The results showed that the urea could apparently deepen the colour of the ink-jet printed cotton fabric with the maximum colour yield at the amount of 10 g in the pretreatment print paste. When compared, the Black colour obviously showed the greatest colour yield followed by the Cyan, Magenta and finally Yellow colours. The order of effect was similar to that of the results reported previously [10]. However, an interesting thing observed in Figure 3 was that when the amount of urea used in the pretreatment print paste was more than 10 g, the colour yield of the ink-jet printed fabrics would decrease. When the amount of urea used was further increased to 20 g, the colour yield of the ink-jet printed fabric dropped significantly which was even paler than that of 5 g of urea used. Such drop of colour yield with respect to the increasing amount of urea used in the pretreatment print paste might be due to the increase of moisture regain of fibres during the steaming process. Owing to the hygroscopic nature, urea was used as a moisture-absorbing agent during the steaming process. A large amount of urea used in the pretreatment print paste could enhance the moisture absorption and also cause the hydrolysis of reactive dye during the steaming process.

Effect of Steaming Time on the After-treatment

Steam serves as a convenient source of both water and heat which can be transferred rapidly and uniformly over the surface areas of the ink-jet printed cotton fabrics. Superheated steam is used because it shows the advantages of faster heating, shorter fixation time and fewer colours spread [11].

Figure 4 reflects the effect of steaming time on the colour yield of different ink-jet printed colours on the cotton fabric. The Black colour showed the best colour yield followed by Cyan, Magenta and Yellow with the same sequence shown in the previous sections. It was noted that the optimum K/S values of all colours were obtained at the steaming time of 5 minutes. However, when the steaming time was extended to more than 5 minutes, the colour yield of the ink-jet printed fabrics would be reduced to different extents. The reduction of colour yield at prolonged steaming time might be a combined effect of both chemicals and steaming time used. With regard to the prolonged steaming time at high temperature, i.e. 110 °C, decomposition of urea would occur producing ammonia and biuret-type products inside the steaming chamber [11]. Owing to the reaction of reactive dyes with ammonia and the loss of alkali, lower colour yield would be obtained under these conditions. Furthermore, prolonged steaming time would also provide sufficient moisture for the moisture-absorbing agent, i.e. urea, to absorb. As a result of the combination effect, hydrolysis might occur and reduce colour yield.

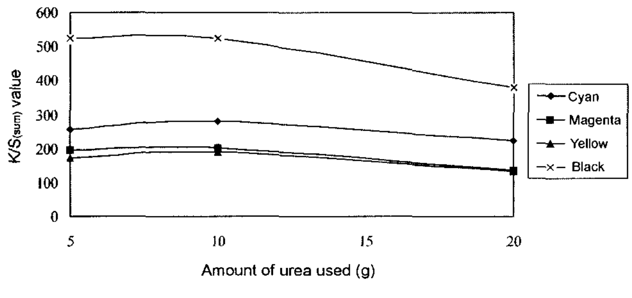

Figure 3. Effect of the amount of urea used on the colour yield of different colours.

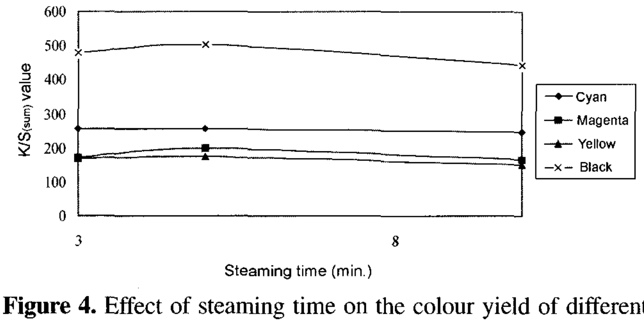

Figure 4. Effect of steaming time on the colour yield of different colours.

Table 4. Colour yield of fabric treated under the newly developed optimum condition

Colour	Cyan	Magenta	Yellow	Black
Control fabric	100.25	90.28	77.16	276.25
Treated fabric	110.75	95.66	90.30	260.88

Newly Developed Optimum Condition

Orthogonal analysis is a useful and simple technique for analysing the process variables or factors involved in a production process. Previous researches [12-14] showed that it could provide a simple and convenient way for finding out the optimum condition and the level of importance of different factors in a production process.

After considering the results obtained from the orthogonal analysis as shown in Table 3, it was concluded that all four factors used namely sodium alginate, urea, sodium bicarbonate and steaming time could affect the K/S value by contributing different effect on the final colour yield. However, the level of importance based on the orthogonal analysis was in the order of urea > sodium alginate > sodium bicarbonate > steaming time. Based on the results of the orthogonal analysis, the newly developed optimum condition obtained for the pretreatment print paste and steaming time was concluded as sodium alginate = 150 g, urea = 10 g, sodium bicarbonate = 8 g and steaming time = 5 minutes.

In order to verify the accuracy of the newly developed optimum condition, further experiments were conducted using the commercially pretreated fabric as the control fabric with the results shown in Table 4.

The results shown in Table 4 demonstrated clearly that the cotton fabric treated under the newly developed optimum condition had the best colour yield when compared with those shown in Table 3. Furthermore, the treated cotton fabric had a better final colour yield in Cyan, Magenta and Yellow colours when compared with the control fabric. Although the control fabric had a better colour yield in Black colour than the treated fabric, yet their actual difference was not great. Reactive dyes would have various reactivity and fixation properties, thus one working condition normally could not be applied to all types of reactive dyes [15]. On the whole, the newly developed optimum condition could still enhance the achievement of the treated cotton fabric to reach a high level of colour yield similar to that of the commercially pretreated fabric.

Conclusion

Optimum condition concerning the contents of pretreatment print paste and steaming time was newly developed and verified in order to obtain the maximum colour yield. It was confirmed that the final colour yield of the cotton fabric treated under the newly developed optimum condition could compete with the commercially pretreated cotton fabric available in the market. Hence, the newly developed optimum condition could provide helpful information for the industries for developing their own pretreatment print paste recipe for ink-jet printing and so the main aim of this study was achieved. However, based on the newly developed pretreatment paste formulation, it was recommended that further investigation should be conducted to study the effect of pretreatment print paste and steaming time on the individual reactive dye and in addition, the sharpness of the printing image and the durability of the pre-treated cotton fabric should be studied.

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