J. Innovative Eng. Nat. Sci., vol. 3, no. 2, pp. 127-136, 2023.
http://dx.doi.org/10.29228/JIENS.70020

Journal of Innovative Engineering and Natural Science
(Yenilikçi Mühendislik ve Doğa Bilimleri Dergisi)
journal homepage: https://jiens.org

Original Paper

Development of reactive digital printing process for cellulosic fabrics

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ARTICLE INFO

Article history:
Received 12 May 2023
Received in revised form 20 June 2023
Accepted 05 July 2023

Available online

Keywords:
Digital printing
Reactive dyeing
Cellulosic fabrics

ABSTRACT

In this study, the development processes of reactive digital printing for cellulosic fabrics are discussed. In the study, viscose fabric qualities were evaluated with the same content and different impregnation process numbers, according to pH value, washing fastness, rubbing fastness, water fastness, and perspiration fastness tests, after digital printing application under the same conditions. In addition, print patterns were visually examined. It has been determined that the visual quality of the fabrics with one pass impregnation is better than two passes impregnations and the test results have similar values for all samples. Viscose fabric qualities, with one pass application, were tested by applying different recipes and the optimum recipe was determined by making a cost analysis and sustainability aspect. It was determined that the wet rubbing fastness values were low. Fabric pH test results were determined to be in the range of 5.5-7.5, as expected. Washing, water, and perspiration fastness values were determined to be in the range of 4-5 as expected.

I. INTRODUCTION

The foundations of digital printing technology date back to 1878. The continuous ink jet printing method, which is widely used in today's printing technology, was invented by Sweet in 1965. It was developed by Hertz in 1967. Another important step in this field was taken in 1979 when HP and Canon found DOD (drop-on-demand) technologies. This invention has enabled the printing of dots in the desired color at the desired point [1]. Inkjet printing systems have had an extremely important area of use in offices, homes, and the advertising sector in the last 20 years. This technology, which developed primarily in the direction of printing on paper in the 1980s, has advanced considerably, especially with the developments in dye chemistry, digital printing is widely used in the textile industry today. Since the first systems used in production had a very low resolution (12–20 doi), they were only used for printing suitable products such as carpets and blankets, where the patterns are of low resolution. Since the early 1990s, high resolution inkjet printing systems have been used for printing on fabrics. Although the first applications were for sample purposes, today there is a trend towards printing in smaller quantities. Most recently, Reggiani Company launched a machine with a speed of 150 m^2/hour [2]. Digital printing technology is applied in the textile industry, which provides green production processes with smart equipment and saves a lot of water. The products produced with this technology in the textile sector have high quality and high resolution [3]. The printing process on the fabric can be finished in a short time, it is not limited to the pattern size, and it provides repeatability advantages. Another advantage is fast production, sensitivity, and no waste paint released into the environment [4]. In recent years, the application of digital inkjet printing on textiles has attracted increasing attention at both the academic and industrial levels due to its flexibility, cleanliness, versatility, and competitiveness [5-7]. Reactive printing ink is most commonly used in digital printing for cellulose-fiber fabrics

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such as cotton and linen. But reactive dye is very easy to hydrolyze. Dye fixation rate and color strength are low during steaming. Hydrolyzed reactive dyes in wastewater can also pose an environmental hazard [8-13]. The viscosity of digital printing inks is low. For this reason, without applying printing paste, the penetration of the printing ink into the fabric cannot be controlled, and it spreads on the fabric surface. This prevents the acquisition of clear patterns. Therefore, printing paste is required as a pre-treatment in digital printing. With digital printing paste, thickeners, fixing agents, and auxiliary materials are applied to the fabric [14].

The pastes used in digital printing are prepared like the printing pastes used in conventional printing. Since digital printing is not widespread yet, it is not preferred for expensive long-length prints. Digital prints are commonly made on cotton, viscose, and polyamide fabrics in the textile sector. Therefore, reactive and acid dyestuffs are used in printing, and printing pastes of these dyestuffs are prepared [15].

Covalent bonds between the dye and the cellulose are created by reactive dyes reacting with each other in an alkaline environment. Sodium bicarbonate is often recommended because is affordable, provides adequate pretreatment, and stabilizes print paste while causing the least amount of hydrolysis. Oxidizing agent is used for avoid the risk of reduction, and decolourisation, of the dye during steaming. Urea is mainly used to swell cotton fibers during the steaming process. It also acts as a moisture absorbing agent. Urea accelerates the transfer of dye to cotton fiber and urea also reduces yellowing of cotton under warm, dry alkaline conditions [16-20].

Printing pastes; contain monomers that can cause air emissions, such as ammonia, formaldehyde, methanol, alcohols, esters, aliphatic hydrocarbons, acrylates, vinyl acetate, styrene, and acrylnitrile. In addition, reactive printing pastes can contain up to 150 g/kg of urea. Urea causes eutrophication in wastewater.

It has been observed that digital printing is cleaner than rotary screen printing in terms of depletion of natural resources and the environmental effects of acidification. The environmental impact of rotary printing (such as the Global warming effect, eutrophication, ozone depletion, and photochemical oxidation) increases, as the number of colors used in rotary screen printing increases [21]. Complex multi-color printing patterns make digital printing more advantageous. In addition, optimization of the digital printing preparation process and reducing its environmental load have been recognized as important work areas.

Digital and conventional printing pastes are prepared differently. In conventional printing, it is difficult to measure the amount of dye applied to the fabric. More dye is used than necessary to ensure sufficient dye penetration into the fabric. For this reason, the dyestuffs used in general are fixed at a rate of 65-70% in fabric. In digital printing, the amount of dye applied to the fabric can be precisely controlled, and the fixation rates are over 90%. In conventional printing, thickeners and carriers are used in printing paste for both reactive and disperse dyes. After the dyeing process, these substances are removed from the fabric by washing. These chemicals are not used in digital printing [22, 23] While there is an optimized recipe for rotational printing, the digital printing recipe needs to be optimized at the plant.

Harput Tekstil has invested in a digital printing machine both to gain a place in the clothing market and to build up a sustainable alternative to the rotary printing process. With this investment, both an alternative printing method in small quantities and an environmentally friendly process that generates less waste have been reached. Since the digital printing machine investment was made for the first time in this study, the need for process optimization before and after digital printing in the enterprise was determined, and this need was met with recipe optimizations.

The aim of this study is to reduce the amount of chemicals released into the environment and reduce the process cost by optimizing the paste content and amount in the digital printing process. In this study, the reactive digital printing process was optimized with paste impregnation studies before reactive digital printing, and the cost has been reduced. Reactive digital printing applications were carried out by working on three different preferred qualities. In addition, with the optimizations made, the amount of chemicals in the paste recipe has been reduced, and the process's environmental load has been reduced.

II. EXPERIMENTAL METHOD

2.1. Materials

Paste auxiliary chemicals (touching and color efficiency enhancer, thickener, reduction inhibitor) were supplied from Setas. Sodium bicarbonate, sodium sulfate, and urea chemicals were supplied by Ozan Kimya. Viscose fabric qualities were supplied from the company's own resources. Printing design was chosen for reactive digital printing, and recipe optimization was carried out for paste impregnations. The paste recipe is given in Table 1.

Table 1. Quantity of Chemicals in Digital Paste Recipe

Chemicals	**Quantity** *(g/L)*
Sodium bicarbonate	35
Paste Auxiliary Chemicals (3 different chemicals)	36
Urea	200

2.2. Method

Viscose fabrics have been made ready for the digital printing process by applying one or two layers of paste impregnation. Visual quality control, pH, washing fastness, rubbing fastness, water fastness, and perspiration fastness tests were performed on fabrics that were digitally printed at the same conditions. Fabrics were compared after application. After the paste impregnation applications, different sustainable paste recipes were determined, a cost analysis was performed, and the most suitable paste recipe was determined. Old and new paste recipes were applied to different commercially preferred cellulosic fabric qualities. In addition, fabric qualities were compared by pH, washing fastness, rubbing fastness, water fastness, and perspiration fastness tests.

2.3 Characterization

The pH value was calculated, according to the TS ISO 3801 test standard. Color fastness to rubbing was determined according to the ISO 105-X16:2016 test standard. Color fastness to perspiration was determined according to the TS EN ISO 105-E04 test standard. Color fastness to water was determined according to the TS EN ISO 105-E01 test standard. Color fastness to washing was determined according to the TS EN ISO 105-C06 test standard. Paste impregnation applications were carried out in a stenter machine at 120 ºC at a speed of 40 m/min. Digital printing applications were carried out at 90 ºC at a speed of 5 m/min. After digital printing, viscose fabrics were fixed at 1200 kg of steam and 102 ºC for 12 minutes then washing and drying processes occured.

III. RESULTS AND DISCUSSIONS

3.1. Fabric Analysis

At first, three different cellulosic fabric analyses, which are more preferred in the market, were made (Table 2). The process was optimized with paste applications on viscose fabric quality before digital reactive printing. Viscose fabrics are made ready for digital printing application by impregnating the paste once and twice in the stenter machine. Front and back side images of viscose fabric qualities with digital reactive printing are given in Figure 1.

Table 2. Fabric Analysis

30/1 Viscose			50/1 Poplin		Cotton + Elastane	
115 *(g/m²)*			108 *(g/m²)*		144 *(g/m²)*	
	Yarn Type	**Density** *(w/cm)*	**Yarn Type**	**Density** *(w/cm)*	**Yarn Type**	**Density** *(w/cm)*
Weft	Ne 30/1 Viscose	21	Ne 50/1 Cotton	32	Ne 30/1 Cotton	23
Warp	Ne 30/1 Viscose	26	Ne 50/1 Cotton	56	Ne 40/1 Cotton + Elastane	53
Plain			Plain		Twill	

3.2. Paste Impregnations

As a result of the paste impregnations, it has been determined that there is a difference in handle and color between the viscose fabric qualities. When we look at the fabrics that have been impregnated twice, it has been determined that the applied dyestuff has more transitions to the back surface, but in visual quality control, the colors are more dull and the handle is harder. In addition, it has been observed that the colors of the fabrics that have been impregnated with the paste at one time are more vivid, and the handle is softer and more draped.

3.3. Test Results

After digital reactive printing applications, the visual quality control, pH, washing fastness, rubbing fastness, water fastness, and perspiration fastness tests were performed, and paste impregnations were compared. Washing fastness, perspiration fastness, and water fastness test results are given in Table 3. In this context, the fastness test results of the sample fabrics, which were applied once and twice, were almost the same and also desired values. The visual quality of one and double pass impregnation studies is similar.

Wet and dry rubbing fastnesses and pH values of viscose fabric qualities are given in Table 4. The pH test range, which is determined as the acceptance criterion for garments according to DIN EN/ISO 3071 is between 4 and 7.5, and the pH value of the sample fabrics was determined as 5.5-5.6 in the tests. In lighter tones, the wet rub test was 3-4 and the dry rub test was 4-5, while the pH was 6-6.5. In this study, the rubbing fastness values of cellulosic fabrics were compared over dark colors. Other fastness values were higher for all colors.

a) b)

c) d)

Figure 1. The front and back side images of digital printed fabrics **(a)** Front side image of one pass application **(b)** Front side image of two passes application **(c)** Back side image of one pass application **(d)** Back side image of two passes application

Table 3. Fastness test results of 30/1 viscose fabric qualities

	Wool	Acrylic	Polyester	Polyamide	Cotton	Acetate
			Fastness to Washing			
One pass	5	5	4-5	5	4-5	4
Two passes	5	5	4-5	4-5	4-5	4-5
			Fastness to Perspiration (Acid)			
One pass	5	5	4-5	4-5	4-5	4-5
Two passes	5	5	4-5	4-5	4-5	4-5
			Fastness to Perspiration (Alkali)			
One pass	5	5	4-5	4-5	4-5	4-5
Two passes	5	5	4-5	4-5	4-5	4-5
			Fastness to Water			
One pass	5	5	4-5	4-5	4-5	4-5
Two passes	5	5	4-5	4-5	4-5	4-5

Table 4. Wet and dry rubbing fastnesses and pH values of 30/1 viscose fabric qualities

	Wet Rubbing Fastness	**Dry Rubbing Fastness**	**pH**
One pass	2	3-4	5.6
Two passes	2	4	5.5

With the paste impregnation study, it has been determined that impregnations with one paste are more suitable for digital printing processes. For comparison of viscose qualities with different cellulosic fabric qualities, comparisons were made on three different fabric qualities preferred in the garment sector. Fastness tests and pH tests were carried out to compare the fabric qualities with reactive digital printing under the same conditions. Rubbing fastness test results and pH values are given in Table 5. Washing, water, and perspiration fastness test results are given in Table 6. Reactive digital print images of viscose, poplin, and cotton fabric qualities are given in Figure 2.

Table 5. Rubbing fastness test results and pH results

Fabric Quality	Wet Rubbing Fastness	Dry Rubbing Fastness	pH
Viscose	2	4	6.9
Poplin	2-3	3-4	6.5
Cotton + Elastane	1-2	3-4	6.9

Wet color fastnesses are at least one point lower than dry color fastnesses, especially in dark tones, consistent with studies on reactive digital printing on cellulosic materials in the literature [24].

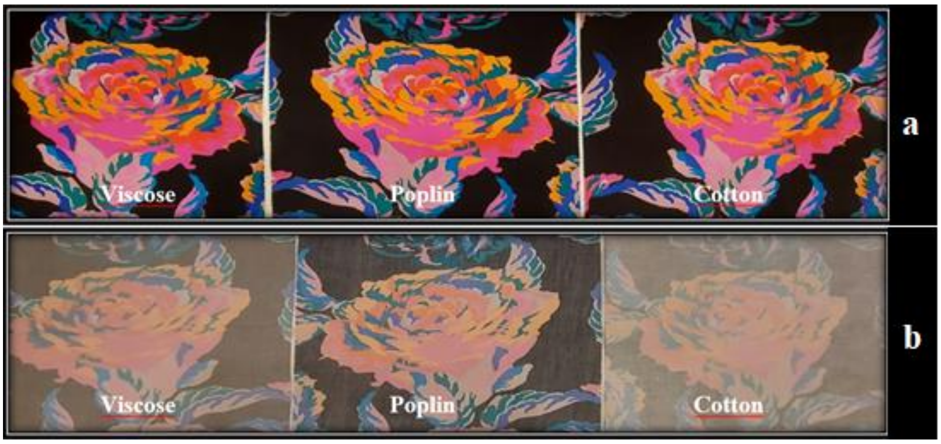

Figure 2. Reactive digital printing images of viscose, poplin and cotton fabrics (a: front side, b: back side)

According to visual quality control, the best performance with the most vivid color tones was seen in viscose fabric. The lowest performance was seen in poplin due to the paste passing to the back side of the fabric.

Table 6. Washing, water and perspiration fastness test results

	Wool	Acrylic	Polyester	Polyamide	Cotton	Acetate
Fabric Quality			**Fastness to Washing**			
Viscose	5	5	5	5	4-5	5
Poplin	4-5	5	4-5	4-5	4-5	5
Cotton + Elastane	5	5	5	5	5	5
Fabric Quality			**Fastness to Perspiration (Acid)**			
Viscose	4-5	4-5	4-5	4-5	4-5	5
Poplin	4-5	4-5	4-5y	4-5	4-5	5
Cotton + Elastane	4-5	4-5	5	5	4-5	5
Fabric Quality			**Fastness to Perspiration (Alkali)**			
Viscose	4-5	4-5	4-5	4-5	4-5	5
Poplin	4-5	4-5	4-5	4-5	4-5	5
Cotton + Elastane	4-5	4-5	5	5	4-5	5
Fabric Quality			**Fastness to Water**			
Viscose	5	5	5	5	4-5	5
Poplin	4-5	4-5	4-5	4-5	4-5	5
Cotton + Elastane	4-5	4-5	5	5	4-5	5

When the obtained fastness data were compared to the literature regarding reactive digital printing on cellulosic materials, it was discovered that the results were consistent with the literature [24].

3.4. Optimization of the Pat Recipe

The current recipe for different fabric qualities preferred in the market has been optimized. Samples that were impregnated once, under the same conditions were compared. Costs were reduced by changing the type of paste auxiliary chemicals (different commercial product with similar chemical properties) and the amounts of urea chemicals in the existing recipes (the old recipe).The current paste recipe and the developed paste recipe are given in Table 7.

Table 7. Paste recipes developed for cost reduction

Chemical	Old recipes *(g)*	New recipes 1 *(g)*	New recipes 2 *(g)*
Sodium bicarbonate	35	35	35
Paste Auxiliary Chemicals (3 different chemicals)	36	36	36
Urea	200	200	100
Total Cost *(€/kg)*	**0.330**	**0.292**	**0.229**

With the new recipes, digital printing was applied, and as a result of the fastness tests, the values were close to the quality of the old recipe. New Recipe 1 was developed for viscose and cotton qualities. Recipe 2 is developed for poplin grades. The cost of paste in poplin grades has been reduced from 0.33 €/kg to 0.229 €/kg. In viscose and cotton qualities, the cost of paste has been reduced from 0.33 €/kg to 0.292 €/kg. A new recipe has started to be used in the enterprise. After the study, the fabric qualities were tested and evaluated. The data for the test results are given in Table 8. Washing, water, and perspiration fastness test results are given in Table 9.

Table 8. Rubbing fastness test results and pH values of old and new recipes

Fabric Quality	Wet Rubbing Fastness	Dry Rubbing Fastness	pH
Viscose (Old recipes)	2-3	4-5	6.7
Viscose (New recipes)	2-3	4	6.6
Poplin (Old recipes)	2-3	4	6.5
Poplin (New recipes)	2	4	6.5
Cotton + Elastane **(Old recipes)**	2	3-4	6.9
Cotton + Elastane **(New recipes)**	1-2	3-4	6.8

All the pH values remained in the range of 6.5-6.9, ensuring DIN EN/ISO 3071 (the standard range is between 4 and 7.5). Wet rubbing test values of cellulosic fabrics are quite low, dry rubbing test values are at a medium level, and other fastness values are high and at desired values.

In this study, for the digital printing preparation phase, a more sustainable process was achieved by obtaining 50% less chemical urea waste for viscose, poplin, and cotton qualities. Water consumption was reduced by 50% with one pass applications.

Table 9. Washing, water and perspiration fastness test results

	Wool	Acrylic	Polyester	Polyamide	Cotton	Acetate
Fabric Quality			**Fastness to Washing**			
Viscose (Old recipes)	5	5	5	5	5	5
Viscose (New recipes)	5	4-5	5	5	4-5	5
Poplin (Old recipes)	5	5	4-5	4-5	4-5	5
Poplin (New recipes)	5	4-5	4-5	4-5	4-5	5
Cotton + Elastane **(Old recipes)**	5	5	5	5	5	5
Cotton + Elastane **(New recipes)**	5	4-5	5	4-5	4-5	5
Fabric Quality			**Fastness to Perspiration (Acid)**			
Viscose (Old recipes)	4-5	4-5	5	5	4-5	5
Viscose (New recipes)	4-5	4-5	5	5	4	4-5
Poplin (Old recipes)	4-5	4-5	4-5	4-5	4-5	5
Poplin (New recipes)	4-5	4-5	4-5	4-5	4-5	5
Cotton + Elastane **(Old recipes)**	4-5	4-5	5	5	4-5	5
Cotton + Elastane **(New recipes)**	4-5	4-5	5	4-5	4-5	5
Fabric Quality			**Fastness to Perspiration (Alkali)**			
Viscose (Old recipes)	4-5	4-5	5	5	4-5	5
Viscose (New recipes)	4-5	4-5	5	5	4	4-5
Poplin (Old recipes)	4-5	4-5	4-5	4-5	4-5	5
Poplin (New recipes)	4-5	4-5	4-5	4-5	4-5	5
Cotton + Elastane **(Old recipes)**	4-5	4-5	5	5	4-5	5
Cotton + Elastane **(New recipes)**	4-5	4-5	5	4-5	4-5	5
Fabric Quality			**Fastness to Water**			
Viscose (Old recipes)	4-5	4-5	5	5	4-5	5
Viscose (New recipes)	4-5	4-5	5	5	4	4-5
Poplin (Old recipes)	4-5	4-5	4-5	4-5	4-5	5
Poplin (New recipes)	4-5	4-5	4-5	4-5	4-5	5
Cotton + Elastane **(Old recipes)**	4-5	4-5	5	5	4-5	5
Cotton + Elastane **(New recipes)**	4-5	4-5	5	4-5	4-5	5

IV. CONCLUSIONS

Reactive digital printing paste impregnation processes were optimized for cellulosic fabric qualities. With the optimized paste recipe, more efficient results were obtained in the viscose fabric qualities that were impregnated once. Thus, the study was continued with one layer of paste impregnation. The visual quality, pH, and fastness values of three different cellulozic fabric qualities (viscose, poplin, and cotton + elastane fabrics), which were impregnated once with paste, met expectations. After reactive digital printing, rubbing, washing, water, pH tests, and visual quality controls were performed on three different fabric qualities. When the obtained fastness results were compared to the research on reactive digital printing on cellulosic materials, the results were found to be consistent.

Viscose fabrics have been found to have more vibrant colors than other fabric types. It has been found that the dye penetrates up to the rear surface of the fabric because poplin fabric qualities have a lighter and tighter structure than viscose fabric qualities. As a result, it has been found that viscose fabrics have better visual quality than poplin materials. In addition, it was predicted that the dye could not form integrity on the fabric surface due to the different weave structure of the cotton + elastane fabric, and the visual quality decreased compared to other fabric qualities. It was determined that the optimized paste recipe was costly, and the existing recipe was improved again for three different cellulosic fabric qualities. In cost reduction studies, low-cost recipes have been obtained by changing the high-cost paste auxiliary chemicals and amounts of urea chemicals. Fastness tests, fabric pH tests, and visual quality controls were performed in all studies.

While the fastness values were high for all color tones, the rubbing fastness values were observed lower. Especially the wet rubbing fastness values are quite low for dark tones. This shows that more studies are needed to improve the wet rubbing fastness of reactive digital printing processes, especially in dark tones. The developed process provided a significant reduction in water and chemical consumption, enabling the application of a more sustainable process.

ACKNOWLEDGMENT

This work was supported by the Harput Tekstil R&D Center with the equity project numbered HRPT-PR-K55

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