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Effect of eco-friendly digital printing on the fastness properties of single jersey knitted fabrics

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Abstract
In this study, single jersey knitted fabrics were produced from 100 % Ne 12/1 cotton, 100 % Ne 30/1 cotton, Ne 12/1 70% cotton + 30% hemp, Ne 30/1 50% modal + 50 % cotton, Ne 30/1 100 % viscose, and Ne 30/1 50 % viscose + 50 % cotton. The raw materials were bleached and singed, after which reactive pretreatment paste recipes were padded onto the fabrics, and then colored with digital printing. Fastness analyses and spectrophotometric color measurements were applied to the samples. When the results were determined, it was obviously seen that the washing, ironing, and rubbing fastness are of very high degrees because reactive dyestuffs make covalent bonds with the fibers. Thus, the increase in the amount of thickener also increased the bonding and provided better adhesion of the color.

Keywords
Digital printing, ironing fastness, hemp fiber, rubbing fastness, thickener, CMYK.

1. Introduction

The increasing demand for cotton and the low production rate in trying to fulfill the world's requirements have boosted the production of regenerated cellulose-based fibers. Regenerated cellulosic fibers, such as viscose, and modal, combine the advantages of natural and synthetic fibers and offer unique properties in textiles. Their production is environment-friendly and pollution-free. Modal fabric produced from beech wood is a completely natural fiber type with high wet and dry durability. Modal is highly resistant to wear and has high moisture transfer properties. Fabrics knitted or woven using modal yarn have a soft texture. These fibers are also commonly used in knitted fabrics [1]. This type of product can be colored by printing. Digital printing technology eliminates the mechanical steps in the conventional printing method. It also saves time as it does not require many steps such as preparation. It also allows the necessary revisions and corrections to be made at the lowest cost. When conventional textile printing and digital textile printing are compared, it is seen that there are big differences between them in terms of cost and the fulfillment of customer demands quickly. In classical textile printing, pre-printing processes are required for the desired patterns and colors, such as screen preparation costs. On the other hand, high resolution and quality printing is possible without color limitation in digital printing. In addition, the energy and water consumption consumed by conventional printing methods is largely avoided. It is known that 95 % less water and 30 % less electricity are used in digital printing [2,3,4,5].

In 2012, Gorgani et al. performed a one-step digital printing pre-treatment by applying 4 different organic salts at different concentrations and different pH values to 100 % cotton fabric, and fixing the printed fabrics at 110 °C for 10 minutes. It was observed that organic salts improve light fastness in all types and concentrations and increase the fixation rate. Regardless of the type, it was stated that the pretreatment at pH value of 8 gives the best results [6].

Golam Kibria et al. aimed to investigate the effects of printing with different thickeners on the properties of cotton fabric with reactive dyes. Woven cotton fabrics were pretreated and mesh fabrics for printing prepared. Printing was done on the fabrics with various thickeners individually and at different ratios with the flat screen printing method. The printed samples were then assessed for strength, crease recovery, color fastness to wash and color fastness to rubbing. Finally, after comparing the test results, it was found that the properties of the fabrics printed with thickeners in combination with sodium alginate were better than those printed with a single thickener [7].

In another study, interlock knitted fabrics produced from 100 % cotton raw materials were colored with digital printing. After the printing, the fabrics were steamed to fix the dye and allow for maximum dye intake. This fixation process was carried out for two different times in saturated vapor at 103 °C, and the fabrics were washed to remove any residual unfixed material from them. The physical properties of the fabrics were determined and image analysis performed with an SEM (Scanning Electron Microscope). When the test results were evaluated; it was concluded that the fixing temperature had an effect on air permeability, but it did not lead to a significant change in bursting strength [8].

In an experimental research, cotton and tencel fibers were used, which are known as comfort fibers. By using yarns produced from these fibers, single jersey knitted fabric surfaces were formed on a circular knitting machine. The fabrics obtained were colored by a digital printing method. They were tested before and after digital printing to measure the effect of digital printing on drying behavior. The interaction of samples with water was analyzed by conducting a transfer capillary wetting ability test and determining the drying time. It was observed that, the time-dependent rate of drying, and thus the mass loss, and transfer capillary wetting ability were consistent with the results found in the literature [9].

In their study, Muhsin et al. investigated the performance of a digitally printed cotton fabric using three sustainable and formaldehyde free cross-linkers, three different softeners, C8-free oil and water repellent, and halogen free flame retardant. This study applied these finishes to steamed and non-steamed digitally printed fabric samples. The paper tested the performance of the finished digitally printed fabric in terms of key finishing properties. The results show that the sustainable finishes proposed significantly improved the performance of the digitally printed fabric as compared to the reference non-finished digitally printed sample [10].

In another study, single jersey knitted fabrics obtained from cotton, viscose, cotton-hemp, cotton-modal, and cotton-viscose mixed raw materials were used. Before the digital printing process, the amount of thickener in the pre-treatment paste was changed. After printing, the fixation time was changed and samples were obtained. In accordance with this purpose, the wale/course density, thickness, and weight properties of the fabrics were tested. Bursting strength tests were applied to all samples according to the BS EN 13938-2 standard. The effect of changes in the raw material, thickener amount and fixation time on the burst strength was determined. The statistical analysis of the experimental results was performed with the SPSS package program. It was determined that the printing process reduced the bursting strength in all fabrics. All fabrics treated with a 6 minute fixation time have a lower bursting strength than for 10 minutes. For the P12 and P30 fabrics, as the yarn number increased, the bursting strength also increased. The use of 150 g/l thickener for all Ne 30 fabrics reduced the bursting strength for both fixation times [11].

In another study, 3 different fabrics obtained from cotton and hemp-blended raw materials were used. It was aimed at analyzing the color and performance characteristics of the fabric by changing the fixation time after the digital printing process. In this direction, besides physical tests, analyses such as spectrophotometric color analysis, ironing fastness, and visual determination by SEM were made on the fabrics, and the effect of the change in the raw material and fixation time on these properties were determined. When the physical test results were evaluated, it was seen that the fabric thickness and weight of the samples increased as along with the yarn thickness. When the color differences and the corresponding gray scale values were examined, it was determined that the fabric construction was more effective than the raw material and fixation time. It was observed that the raw material and the fixation time in the digital printing process did not have a partial effect on the color fastness to ironing. The most important parameter in color fastness to ironing is the use of reactive dyestuffs with high fastness. [12].

In Özdemir and Doba Kadem's study, single jersey knitted fabrics were produced from 100 % Ne 12/1 cotton, 100 % Ne 30/1 cotton, and Ne 12/1 70 % cotton + 30 % hemp. The raw materials were bleached, singed, and then colored with digital printing. After that, air permeability, bursting strength stiffness, ironing fastness, and SEM analyses were applied to the samples when the results were determined, from which it was obviously seen that heavier fabric have higher stiffness. Also, thicker yarns have higher bursting strength. It follows that cotton-hemp blended fibers (PK) have high unevenness, and the bursting strength of the fabrics produced from this raw material is lower than for cotton fabrics (P12). Similarly, since the thin-thick place values of cotton-hemp blended yarns are high, porosity is one of the most important factors affecting air permeability in fabrics. This porous structure also increased the air permeability of the fabric [13].

In another study, authors prepared cyan, magenta, yellow, and black (CMYK) inks using biodegradable natural dyes for inkjet printing, including gardenia blue, amaranth, gardenia yellow, logwood, and lac. They also evaluated the printing quality by measuring the color strength (K/S), ink penetration, printing sharpness, and color fastness in cotton and silk fabrics. Fabrics with biodegradable natural dye inks are less destructive to the environment than with synthetic dye inks. The rubbing fastness and washing fastness were good for both cotton and silk fabrics. The light fastness of magenta and black ink on silk fabrics was excellent with a rating of 4/5, but that of cyan ink on cotton and silk was low at a rating of 2. Another benefit is that the fabrics are harmless to humans and unlikely to cause allergies in people with sensitive skin [14].

In the literature on ink-jet printing, there is a lack of studies on the subject of pretreatment and steaming time. Thus, the aim of this study was to investigate the effect of different fixation times on fabric properties using different raw materials in digital ink-jet printing, as well as the possibilities of achieving higher color yields and better fastness properties.

2. Materials and Methods

2.1. Fabric Production Properties

The yarns used in the study were produced on a ring spinning machine. The samples were coded as follows: P12=Ne 12/1 100 % cotton, P30= Ne 30/1 100 % cotton, PK=Ne 12/1 70 % cotton+ 30% hemp, PM=Ne 30/1 50 % modal + 50 % cotton, V=Ne 30/1 100 % viscose and PV=Ne 30/1 50 % viscose + 50 % cotton. Yarn properties are given in Table 1.

The fabrics were produced with a single jersey knit structure at a speed of 20 rpm. The knitting process is explained in Table 2.

The purpose of the singeing process was to make the fabric surface smoother by removing the fiber ends from the yarns. There are differences in the singeing and pre-treatment processes for viscose-containing fabrics. The singeing process for fabrics not containing viscose was carried out on one side at a speed of 80 m/min, at 10 bar pressure, at a distance of 8-10 mm. The back position was vertical. Only for viscose fabrics, the back position was horizontal.

Thickeners in the digital printing process, play a role in ensuring contour clarity at edges and in corners. In addition, it retains moisture that will allow dyes and chemicals to melt and enter the fibers during steaming after printing and drying. Due to these additives, pre-treatment paste recipes prepared using thickeners were padded onto the singed and bleached knitted fabrics. The pre-treatment pastes were prepared according to the recipe in Table 3. Less peroxide was used in the pre-treatment of viscose-containing fabrics than cotton fabrics. As seen in Table 4, the effect of changing the amount of thickener on the colour was tested using 3 different amounts of thickener. Immediately afterward, the fabrics were dried.

Yarn Properties	P30	V	PV	PM	P12	PK
Uniformity(%)	9.33	10.66	9.14	8.96	10.25	19.61
CV- %	11.78	13.45	11.51	11.33	13	25.37
Thin -40%	16.5	137.5	14	11	40.5	3987
Thin places-50%	0	2	0	0	0	70
Thick places +35%	187	282	144	146	618	5076
Thick places +50%	14	23.5	7.5	15.5	86	2652
Neps +200%	15	37	34	49.5	46.5	3912
Neps +280%	3	9	7	11.5	6.5	1296
Hairiness	4.67	5.6	5.64	6.43	7.44	9.35
B-Force (gF)	408.6	405.9	310.1	373.8	8.04	595.5
Elongation (%)	5.63	14.72	5.88	6.7	6.94	6.53
Rkm (km)	20.76	20.62	15.75	18.99	16.11	11.61
B-Work (N.cm)	6.137	18.6	5.405	7.549	13.802	9.44

Table 1. Yarn properties

Sample properties	Yarn count (Ne)	Machine fineness	Machine diameter (inch)	Total number of needles
P30	30	28	30	2640
PM	30	28	30	2640
PV	30	28	30	2640
V	30	28	30	2640
P12	12	12	30	1128
PK	12	12	30	1128

Table 2. Knitting process

For viscose fabrics		
Chemicals	**Rate**	**Amount**
Beam bunder	1.25 g/L	627.5 g
Alkaline	2 g/L	1004 g
Stabilized Peroxide	%8 /fabric weight	264 g
Acedic Acid	0.35 mL/L	175.7 mL
Anti-peroxide	0.32 mL/L	160.64 mL
For other fabrics		
Chemicals	Rate	Amount
Beam bunder	1.25 g/L	627.5 g
Wetting Agent	2 g/L	1004 g
Caustic(48-49 Be)	4mL/L	3220 mL
Stabilized Peroxide	%4 /fabric weight	2440 g
Acedic Acid	1 mL/L	805 mL
Anti-peroxide	0.7 mL/L	563.5 mL

Table 3. Pretreatment recipes

2.2. Digital Printing

The reactive pretreatment paste recipes were padded onto the singed and bleached knitted fabrics. The pretreatment pastes were prepared with thickener, sodium bicarbonate, urea, and water. After padding the paste, the fabrics were dried.

A pattern (Figure 1) was designed in order to evaluate the color yield and printed onto the pre-treated fabrics with cyan (C), magenta (M), yellow (Y) and black (Key=K) reactive inks, at 540 × 360 dpi, using a Nassenger PRO60 ink-jet printer with a piezoelectric drop on-demand print head. After the patterns dried, the printed fabrics were steamed for 6 and 10 minutes at 110 °C with a steamer for the fixation of dyes. Finally, the fabrics were washed off to remove unfixed dyes and residual materials on the surface, and then dried.

2.3. Testing Methods

All the tests were performed under standard atmospheric conditions (temperature: 20 ± 2 ºC and relative humidity: 65 ± 2 %). Physical properties of the fabrics used, such as yarn count, thickness and mass per unit area, were determined according to TS EN 14971:2006 [15], TS 7128 EN ISO 5084 [16] and TS 251 [17], respectively. Color measurements of the samples were

Chemicals	Thickener Amount (g/L)		
	100 g	150 g	200g
Heraprint Aqua Ink	100	150	200
Setaprint NDG	25	25	25
sodium bicarbonate	25	25	25
Setaprint AP	3	3	3
Soda	5	5	5
Urea	100	100	100
Water	742	692	642
Total	1000		

Table 4. Thickener amount

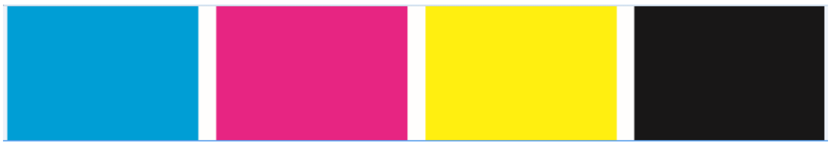

Fig. 1.Digital printing pattern

carried out using a spectrophotometer (Minolta CM 3600, at a wavelength of 400-700 nm, under D65 day light with an observer 10˚ angle. ΔE* total color difference values between samples were calculated using CIELAB 1976 formulas. The color fastness to ironing of the printed fabrics was assessed by ISO 105-X11. This method was used to assess the resistance of the textile color to ironing. The test was carried out for dry, damp and wet fabrics [18]. Colour fastness to rubbing: dyed samples were tested for rubbing fastness as directed in ISO 105 X12 [19]. This test is designated for determining the degree of colour that may be transferred from the surface of coloured textile materials to another surface by rubbing. Two tests were carried out, one for dry rubbing, and the other for wet rubbing. In the dry rubbing test, a piece of white cloth was rubbed against the dyed fabric for 10 complete turns using a crock meter. The white sample was removed and the change of colour noted according to the standard grey scale. While in the wet rubbing, a white test specimen was made wet by distilled water. After rubbing for 10 cycles, the specimen was dried by air, and then the change of colour was assessed according to the grey scale for the rubbing test. A washing fastness test was performed according to Standard ISO 105-C06 A2S: 2010 (Textiles—Tests for colour fastness—Part C06: Colour fastness to domestic and commercial laundering) [20].

3. Results and Discussion

The printing pattern chosen while producing the samples had been specially created in CMYK (Cyan-Magenta-Yellow-Key=black) colors to facilitate color measurements. During the analyses, the samples were evaluated separately for 4 different colors in the fabric.

The coding of the samples is explained as follows: for P12-100 g-6m, 100 g of thickener was applied to the 100 % cotton fabric with a 12 Ne yarn number and fixed for 6 minutes.

Some physical tests were performed on the samples in accordance with the standards. The results of these tests are given in Table 5.

In addition, the samples were subjected to the ironing fastness (color fastness to ironing with a hot press) test, which is one of the fastest tests to use. Ironing fastness test results are also given in Tables 6-9. While evaluating the ironing fastness, both the results immediately after the test and those after 4 hours were analyzed in the same way. According to the results, while the values of the damp and wet measurements were low immediately , the ironing fastness values of all samples were high after 4 hours. It was concluded that these results were obtained because of the high fastness of the reactive dyestuffs.

To detect color differences, two comparisons were made. Firstly, the effect of changing the fixation time on the color was investigated. Then, a comparison of the amount of thickener was made. Table 10 shows the spectrophotometric color differences of the samples for the fixing time.

In Table 11, the amount of thickener is compared. With the Minolta brand CM 3600 model device, measurements were made under D65 daylight at an observer angle of 10˚. In the study of Kasikovic et al. in 2011, the gray scale equivalent of ΔE color difference limit values was given [21].

These values are indicated on the gray scale in Table 10 and 11 When the color measurement values are examined, except for exceptional cases, it can be observed that the optimum value of the thickener amount is 150 g. As the results of 150 g of thickener were better than those of 100 g and 200 g, considering this situation, it can be commented that increasing the amount of thickener does not always lead to better results.

4. Conclusion

Today, digital printing is in demand by manufacturers because it can respond quickly to orders, reduce stock requirements, produce in desired quantities, and it is an environmentally friendly method. In this study, the effects of changes in digital printing pre-treatment and post-treatment parameters on the fastness properties of knitted fabrics of different raw materials were investigated.

Since reactive dyestuffs make covalent bonds with the fibers, their washing, ironing and rubbing fastness are of very high degrees. The choice of dyestuff plays a critical role here.

Samples		mass per unit area (g/m²)	Thickness (mm)	Wale per cm	Course per cm
P12	100 g-10 m	180.457	0.385	9.84	8.66
	100 g-6 m	146.622	0.369	9.45	7.87
	150 g-10 m	182.14	0.367	9.84	8.66
	150 g-6 m	197.56	0.355	9.84	8.66
	200 g- 10 m	191.64	0.387	9.84	8.66
	200 g- 6 m	156.026	0.359	9.84	8.27
P30	100 g-10 m	167.928	0.354	18.91	16.08
	100 g-6 m	148.106	0.341	17.16	15.83
	150 g-10 m	130.82	0.390	18.08	14.5
	150 g-6 m	132.52	0.356	18.83	14.75
	200 g- 10 m	150.582	0.369	18.41	15.58
	200 g- 6 m	126.257	0.357	17.75	14.91
PK	100 g-10 m	161.853	0.370	9.06	8.27
	100 g-6 m	142.635	0.369	10.33	7.91
	150 g-10 m	166.68	0.388	9.40	8.79
	150 g-6 m	141.02	0.369	8.86	8.22
	200 g- 10 m	166.782	0.389	9.45	8.27
	200 g- 6 m	143.902	0.360	9.06	7.68
PM	100 g-10 m	154.533	0.382	30.83	18.58
	100 g-6 m	143.884	0.353	30.25	18.33
	150 g-10 m	152.044	0.370	30.5	18.83
	150 g-6 m	145.666	0.407	29.83	18.25
	200 g- 10 m	125.96	0.386	28.91	18.16
	200 g- 6 m	135.471	0.359	29.66	18.41
PV	100 g-10 m	151.195	0.548	30.25	18.75
	100 g-6 m	139.155	0.502	28.58	18.5
	150 g-10 m	143.257	0.58	26.83	18.5
	150 g-6 m	132.92	0.532	27.91	18.16
	200 g- 10 m	158.737	0.579	30.16	18.5
	200 g- 6 m	135.6	0.521	28.16	18.42
V	100 g-10 m	145.035	0.572	30	17.75
	100 g-6 m	133.733	0.559	28.83	17.83
	150 g-10 m	141.635	0.581	29	18.16
	150 g-6 m	127.306	0.564	28.83	17.66
	200 g- 10 m	175.364	0.589	30.83	18.33
	200 g- 6 m	152.24	0.557	30.66	18.66

Table 5. Physical properties of fabrics

Thickeners hold moisture, which will allow the dyestuff and chemicals to melt into the fibers during saturated steam steaming at 110 degrees, after printing and drying in digital printing. For this reason, the increase in the amount of thickener also increased the bonding, and provided better adhesion to the color. The color difference between the amounts of thickener can be explained in this way.

When the fastness tests were examined, for all thickeners and fixation time changes, the washing fastness was found to be very good for all raw materials. The bleeding degree of cyan and magenta is slightly worse than for yellow and key. The staining rate is very good in all colors. The color change degree is also at its lowest value of 4, which is a very good value.

It can be seen that especially in viscose fabrics, rubbing fastness was very high. Dry rubbing fastness was higher than wet rubbing fastness. Consistent with the literature, the wet rubbing fastness of some cotton blends was slightly lower. When the 4 colors are analyzed, the best results are generally found in the key color.

In this study, different amounts of thickener and different fixing times were applied with digital printing on single jersey knitted fabrics made of cellulose-based raw material. As a result of the study, it was observed that generally high fastness values were obtained in all fabrics. Reactive dyestuffs react with the -OH groups of cellulose and bind to the fibers with covalent bonds. Especially, in the printing of fabrics made of cellulose-based raw materials, the fact that reactive dyestuffs allow vibrant and high-fastness colors in textile printing and offer various fixation options makes this dyestuff preferred. It was observed that the advantages of reactive dyestuffs, such as printing quality with vibrant colors, good fastness properties, and preservation of fabric softness after printing, support the results obtained in this study.

In today's environmentally conscious climate, industry is increasingly called upon to reduce the environmental impact of its products. Digital printing of textile fabrics is known to be less harmful to the environment than traditional methods. Based on this evaluation, water footprint studies of the digital printing process can be carried out by correlating it with thickener consumption.

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Conflict of Interest

The Author declares there is no conflict of interest.

Samples			Cyan														
			Washing Fastness							Ironing Fastness						Rubbing Fastness	
			Staining white cotton fabric						Change in colour shade	Dry		Dump		Wet		Dry	Wet
			Wool	Acrylic	Polyester	Nylon	Cotton	Acetate		Immediately	After 4 Hours	Immediately	After 4 Hours	Immediately	After 4 Hours		
P30	100 g	6 m	5	5	5	5	5		4	4/5	5	4/5	4/5	3	4/5	4	3
	100 g	10 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	3	4/5	4/5	4
	150 g	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	5	4	3/4
	150 g	10 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	4/5	4	3/4
	200 g	6 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	2/3	4/5	4/5	4
	200 g	10 m	5	5	5	5	5	5	4	4/5	5	4	4/5	2/3	4/5	4	3/4
P12	100	6 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	2/3	4/5	4/5	4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	5	4/5	4
	150	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3/4	4/5	4/5	3/4
	150	10 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3/4	5	4/5	4
	200	6 m	5	5	5	5	5	5	4	4/5	5	4	4/5	2/3	4/5	5	4
	200	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	5	4
PK	100	6 m	5	5	5	5	5	5	4	4/5	4/5	4/5	5	3	4/5	4/5	3/4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4	4/5	3	4/5	4	3/4
	150	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	5	4/5	4
	150	10 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	4/5	4/5	3/4
	200	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	2/3	4/5	4/5	3/4
	200	10 m	5	5	5	5	5	5	4	4/5	5	4/5	5	2/3	4/5	4	3/4
PM	100	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	2/3	4/5	4/5	3/4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	5	2/3	4/5	4/5	3/4
	150	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3/4	4/5	4/5	4
	150	10 m	5	5	5	5	5	5	4	5	4/5	4/5	5	3	4/5	4/5	4
	200	6 m	5	5	5	5	5	5	4	4/5	4/5	4	4/5	3	4/5	4/5	4
	200	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	2/3	4/5	4/5	4
PV	100	6 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	3	4/5	4	3/4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	2/3	4/5	4	3
	150	6 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	4/5	4
	150	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3/4	4/5	4/5	3
	200	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	2/3	4/5	5	4
	200	10 m	5	5	5	5	5	5	4	5	5	4/5	4/5	2	4/5	45	3
V	100	6 m	5	5	5	5	5	5	4	5	5	5	5	3	5	5	4
	100	10 m	5	5	5	5	5	5	4	4/5	5	5	5	3	5	5	4
	150	6 m	5	5	5	5	5	5	4	5	5	5	5	3/4	5	5	4
	150	10 m	5	5	5	5	5	5	4	5	5	5	5	3/4	5	5	4
	200	6 m	5	5	5	5	5	5	4	4/5	5	5	5	3	5	5	4/5
	200	10 m	5	5	5	5	5	5	4	5	5	5	5	3	5	5	4

Table 6. Fastness values of samples for Cyan color

Samples			Magenta														
			Washing Fastness							Ironing Fastness						Rubbing Fastness	
			Staining white cotton fabric						Change in colour shade	Dry		Dump		Wet			
			Wool	Acrylic	Polyester	Nylon	Cotton	Acetate		Immediately	After 4 Hours	Immediately	After 4 Hours	Immediately	After 4 Hours	Dry	Wet
P30	100 g	6 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	3	4/5	4/5	4
	100 g	10 m	5	5	5	5	5	5	4	5	5	4/5	4/5	3	4/5	4	3/4
	150 g	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	5	4	3
	150 g	10 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	4/5	4	3
	200 g	6 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	2/3	4/5	4	3/4
	200 g	10 m	5	5	5	5	5	5	4	5	5	4	4/5	3	4/5	4	4
P12	100	6 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	2/3	4/5	4/5	4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	5	4/5	3/4
	150	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3/4	4/5	3/4	3/4
	150	10 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	5	4	3/4
	200	6 m	5	5	5	5	5	5	4	5	5	4	5	2/3	4/5	4	3/4
	200	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	5	4
PK	100	6 m	5	5	5	5	5	5	4	4/5	4/5	4/5	5	3	4/5	4/5	4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4	4/5	3	4/5	3/4	3/4
	150	6 m	5	5	5	5	5	5	4	4/5	5	5	5	3	5	4	3/4
	150	10 m	5	5	5	5	5	5	4	4/5	5	5	5	3	4/5	4/5	3/4
	200	6 m	5	5	5	5	5	5	4	5	5	5	5	2/3	4/5	4/5	4
	200	10 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	4/5	4	3/4
PM	100	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	2/3	4/5	4	3/4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	5	2/3	4/5	4/5	4
	150	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3/4	4/5	4/5	4
	150	10 m	5	5	5	5	5	5	4	5	4/5	4/5	5	3	4/5	4	3/4
	200	6 m	5	5	5	5	5	5	4	4/5	4/5	4	4/5	3	4/5	4/5	3/4
	200	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	4	3
PV	100	6 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	3	4/5	4	3/4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	4	3/4
	150	6 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	4	3
	150	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3/4	4/5	4	3
	200	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	2/3	4/5	4	3/4
	200	10 m	5	5	5	5	5	5	4	5	5	4/5	4/5	2	4/5	4	3/4
V	100	6 m	5	5	5	5	5	5	4	5	5	5	5	3	5	4/5	4
	100	10 m	5	5	5	5	5	5	4	4/5	5	5	5	3	5	5	4/5
	150	6 m	5	5	5	5	5	5	4	5	5	5	5	3/4	5	4/5	4
	150	10 m	5	5	5	5	5	5	4	5	5	5	5	3/4	5	4/5	4
	200	6 m	5	5	5	5	5	5	4	4/5	5	5	5	3	5	5	4
	200	10 m	5	5	5	5	5	5	4	5	5	5	5	3	5	5	4

Table 7. Fastness values of samples for Magenta color

Samples			Yellow														
			Washing Fastness							Ironing Fastness						Rubbing Fastness	
			Staining white cotton fabric						Change in colour shade	Dry		Dump		Wet		Dry	Wet
			Wool	Acrylic	Polyester	Nylon	Cotton	Acetate		Immediately	After 4 Hours	Immediately	After 4 Hours	Immediately	After 4 Hours		
P30	100 g	6 m	5	5	5	5	5	5	4/5	4/5	5	4/5	4/5	3	4/5	4/5	4
	100 g	10 m	5	5	5	5	5	5	4/5	5	5	4/5	4/5	3	4/5	4/5	4/5
	150 g	6 m	5	5	5	5	5	5	4/5	4/5	5	4/5	5	3	5	4/5	4
	150 g	10 m	5	5	5	5	5	5	4/5	5	5	4/5	5	3	4/5	4/5	4
	200 g	6 m	5	5	5	5	5	5	4/5	4/5	4/5	4/5	4/5	3	4/5	4/5	4/5
	200 g	10 m	5	5	5	5	5	5	4/5	5	5	4	4/5	3	4/5	4/5	4/5
P12	100	6 m	5	5	5	5	5	5	4/5	4/5	5	4/5	4/5	3	4/5	4/5	4
	100	10 m	5	5	5	5	5	5	4/5	4/5	4/5	4/5	4/5	3	5	4/5	4/5
	150	6 m	5	5	5	5	5	5	4/5	4/5	5	4/5	5	3/4	4/5	4/5	4
	150	10 m	5	5	5	5	5	5	4/5	4/5	5	4/5	5	3	5	4/5	4
	200	6 m	5	5	5	5	5	5	4/5	5	5	4	5	3	4/5	4/5	4/5
	200	10 m	5	5	5	5	5	5	4/5	4/5	4/5	4/5	4/5	3	4/5	4/5	4/5
PK	100	6 m	5	5	5	5	5	5	4/5	4/5	4/5	4/5	5	3	4/5	4/5	4
	100	10 m	5	5	5	5	5	5	4/5	5	4/5	4	4/5	3	4/5	4/5	4
	150	6 m	5	5	5	5	5	5	4/5	4/5	5	5	5	3	5	5	4/5
	150	10 m	5	5	5	5	5	5	4/5	4/5	5	5	5	3/4	4/5	4/5	4
	200	6 m	5	5	5	5	5	5	4/5	5	5	5	5	3	5	4/5	4
	200	10 m	5	5	5	5	5	5	4/5	4/5	5	4/5	5	3	5	4/5	4
PM	100	6 m	5	5	5	5	5	5	4/5	4/5	5	4/5	5	3	4/5	4/5	4
	100	10 m	5	5	5	5	5	5	4/5	4/5	4/5	4/5	5	3	4/5	4/5	4/5
	150	6 m	5	5	5	5	5	5	4/5	5	5	4/5	5	3/4	4/5	4/5	4/5
	150	10 m	5	5	5	5	5	5	4/5	5	5	4/5	5	3	4/5	5	4/5
	200	6 m	5	5	5	5	5	5	4/5	4/5	4/5	4	4/5	3	4/5	4/5	4
	200	10 m	5	5	5	5	5	5	4/5	4/5	4/5	4/5	5	3	5	4/5	4/5
PV	100	6 m	5	5	5	5	5	5	4/5	4/5	5	4/5	4/5	3	4/5	4/5	4
	100	10 m	5	5	5	5	5	5	4/5	4/5	4/5	5	5	3	4/5	4/5	4
	150	6 m	5	5	5	5	5	5	4/5	4/5	4/5	4/5	4/5	3	4/5	4/5	4
	150	10 m	5	5	5	5	5	5	4/5	4/5	4/5	4/5	4/5	3/4	5	4/5	4
	200	6 m	5	5	5	5	5	5	4/5	4/5	5	4/5	5	3/4	5	4/5	4
	200	10 m	5	5	5	5	5	5	4/5	5	5	4/5	4/5	3	4/5	4/5	4
V	100	6 m	5	5	5	5	5	5	4/5	5	5	5	5	3	5	5	4/5
	100	10 m	5	5	5	5	5	5	4/5	4/5	5	5	5	3	5	5	4/5
	150	6 m	5	5	5	5	5	5	4/5	5	5	5	5	3/4	5	5	4/5
	150	10 m	5	5	5	5	5	5	4/5	5	5	5	5	3/4	5	5	4/5
	200	6 m	5	5	5	5	5	5	4/5	4/5	5	5	5	3	5	5	4/5
	200	10 m	5	5	5	5	5	5	4/5	5	5	5	5	3	5	5	4/5

Table 8. Fastness values of samples for Yellow color

Samples			Key														
			Washing Fastness							Ironing Fastness						Rubbing Fastness	
			Staining white cotton fabric						Change in colour shade	Dry		Dump		Wet		Dry	Wet
			Wool	Acrylic	Polyester	Nylon	Cotton	Acetate		Immediately	After 4 Hours	Immediately	After 4 Hours	Immediately	After 4 Hours		
P30	100 g	6 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	3	4/5	4/5	4
	100 g	10 m	5	5	5	5	5	5	4	5	4/5	4/5	4/5	3	4/5	4/5	4
	150 g	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	5	4	¾
	150 g	10 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	4/5	4	¾
	200 g	6 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	2/3	4/5	4/5	3
	200 g	10 m	5	5	5	5	5	5	4	5	5	4	4/5	3	4/5	4/5	4
P12	100	6 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	2/3	4/5	4/5	4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	5	4/5	4
	150	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3/4	4/5	4	4
	150	10 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	5	4/5	4
	200	6 m	5	5	5	5	5	5	4	5	5	4	5	2/3	4/5	4/5	4
	200	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	4	4
PK	100	6 m	5	5	5	5	5	5	4	4/5	4/5	4/5	5	3	4/5	4/5	3/4
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4	4/5	3	4/5	4/5	3/4
	150	6 m	5	5	5	5	5	5	4	4/5	5	5	5	3	5	4/5	4/5
	150	10 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	3	4/5	4/5	¾
	200	6 m	5	5	5	5	5	5	4	5	4/5	5	5	2/3	4/5	4/5	4
	200	10 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	3	4/5	4	3/4
PM	100	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	2/3	4/5	4/5	¾
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	5	2/3	4/5	4	3/4
	150	6 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	3/4	4/5	4	3/4
	150	10 m	5	5	5	5	5	5	4	5	4/5	4/5	5	3	4/5	4/5	3
	200	6 m	5	5	5	5	5	5	4	4/5	4/5	4	4/5	3	4/5	4/5	¾
	200	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	4/5	¾
PV	100	6 m	5	5	5	5	5	5	4	4/5	5	4/5	4/5	3	4/5	4/5	3
	100	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	4	3
	150	6 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3	4/5	4/5	¾
	150	10 m	5	5	5	5	5	5	4	4/5	4/5	4/5	4/5	3/4	4/5	4	3
	200	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	2/3	4/5	4/5	¾
	200	10 m	5	5	5	5	5	5	4	5	5	4/5	4/5	2	4/5	4	4
V	100	6 m	5	5	5	5	5	5	4	5	5	5	5	3	5	5	4/5
	100	10 m	5	5	5	5	5	5	4	4/5	5	5	5	3	5	4/5	4
	150	6 m	5	5	5	5	5	5	4	5	5	5	5	3/4	5	4/5	4
	150	10 m	5	5	5	5	5	5	4	5	5	5	5	3/4	5	4/5	4/5
	200	6 m	5	5	5	5	5	5	4	4/5	5	4/5	5	3	5	5	4/5
	200	10 m	5	5	5	5	5	5	4	5	5	4/5	5	3	5	5	4/5

Table 9. Fastness values of samples for Key color

Samples	Amount of thickener	Color	ΔE	Grey scale values
PK	100 g	C	3.57	3
		K	3.58	3
		M	3.25	3
		Y	4.39	2/3
	150 g	C	3.64	3
		K	2.48	3/4
		M	2.79	3/4
		Y	1.81	4
	200 g	C	4.24	2/3
		K	3.41	3
		M	4.19	2/3
		Y	4.6	2/3
P12	100 g	C	2.65	3/4
		K	0.93	4/5
		M	2.7	3/4
		Y	3.49	3
	150 g	C	2.51	3/4
		K	0.38	5
		M	2.86	3/4
		Y	3.09	3
	200 g	C	5.18	2/3
		K	0.87	4/5
		M	3.31	3
		Y	5.22	2/3
P30	100 g	C	0.51	4/5
		K	3.19	3
		M	3.44	3
		Y	2.68	3/4
	150 g	C	1.73	4
		K	0.48	4/5
		M	0.72	4/5
		Y	1.35	4
	200 g	C	4.38	2/3
		K	2.49	3
		M	5.78	2/3
		Y	4.52	2/3
PM	100 g	C	1.83	4
		K	1.02	4/5
		M	1.38	4/5
		Y	0.94	4/5
	150 g	C	1.85	4
		K	0.37	5
		M	1.72	4
		Y	3.34	3
	200 g	C	5.02	2/3
		K	0.26	5
		M	3.6	3
		Y	1.9	4
PV	100 g	C	4.82	2/3
		K	1.43	4
		M	5.52	2/3
		Y	4.56	2/3
	150 g	C	3.98	3
		K	0.86	4/5
		M	2.03	3/4
		Y	2.28	3/4
	200 g	C	5.75	2/3
		K	1.59	4
		M	3.58	3
		Y	3.23	3
V	100 g	C	2.87	3/4
		K	1.49	4
		M	3.49	3
		Y	3.2	3
	150 g	C	5.57	2/3
		K	3.17	3
		M	3.28	3
		Y	4.64	2/3
	200 g	C	3.96	3
		K	1.7	4
		M	4.88	2/3
		Y	4.09	3

Table 10. Color differences of fabrics (6 minutes and 10 minutes fixation times)

Samples	Fixing time	Amount of thickener	Color	ΔE	Grey scale values
PK	10 minutes	150 g and 100 g	C	2.47	3/4
			K	1	4/5
			M	3.01	3
			Y	1.7	4
	6 minutes	150 g and 100 g	C	3.3	3
			K	0.69	4/5
			M	3.9	3
			Y	1.59	4
	10 minutes	150 g and 200 g	C	2.84	3/4
			K	1.29	4
			M	1.19	4/5
			Y	2.73	3/4
	6 minutes	150 g and 200 g	C	1.22	4/5
			K	0.51	4/5
			M	3.62	3
			Y	1.76	4
P12	10 minutes	150 g and 100 g	C	3.99	3
			K	0.72	4/5
			M	3.35	3
			Y	2.56	3/4
	6 minutes	150 g and 100 g	C	3.42	3
			K	1.41	4
			M	2.74	3/4
			Y	3.32	3
	10 minutes	150 g and 200 g	C	1.89	4
			K	0.48	4/5
			M	2.96	3/4
			Y	4.12	3
	6 minutes	150 g and 200 g	C	2.9	3/4
			K	1.3	4
			M	1.72	4
			Y	2.74	3/4
P30	10 minutes	150 g and 100 g	C	2.35	3/4
			K	3.12	3
			M	3.71	3/4
			Y	3.8	3/4
	6 minutes	150 g and 100 g	C	2	4
			K	3.11	3
			M	5.02	2/3
			Y	3.87	3
	10 minutes	150 g and 200 g	C	1.57	4
			K	2.18	3/4
			M	3.2	3
			Y	2.62	3/4
	6 minutes	150 g and 200 g	C	3.18	3
			K	0.42	4/5
			M	2.61	3/4
			Y	5.18	2/3
PM	10 minutes	150 g and 100 g	C	3.28	3
			K	1.99	4
			M	2.42	3/4
			Y	4.08	3
	6 minutes	150 g and 100 g	C	2.02	4
			K	2.59	3/4
			M	0.53	4/5
			Y	1.27	4

Table 11. Color change of thickener amount

Samples	Fixing time	Amount of thickener	Color	ΔE	Grey scale values
PM	10 minutes	150 g and 200 g	C	5.62	2/3
			K	1.31	4
			M	2.66	3/4
			Y	2	4
	6 minutes	150 g and 200 g	C	2.32	3/4
			K	1.74	4
			M	1.73	4
			Y	1.31	4
PV	10 minutes	150 g and 100 g	C	2.32	3/4
			K	1.84	4
			M	2.84	3/4
			Y	5.05	2/3
	6 minutes	150 g and 100 g	C	2.09	4
			K	0.42	4/5
			M	1	4/5
			Y	1.17	4
	10 minutes	150 g and 200 g	C	2.92	3/4
			K	2.95	3
			M	3	3
			Y	4.89	2/3
	6 minutes	150 g and 200 g	C	3.68	3
			K	0.63	4/5
			M	1.41	4
			Y	1.75	4
V	10 minutes	150 g and 100 g	C	1.12	4/5
			K	1.29	4
			M	1.67	4
			Y	2.26	4
	6 minutes	150 g and 100 g	C	4.85	2/3
			K	3.36	3
			M	4.53	2/3
			Y	4.36	2/3
	10 minutes	150 g and 200 g	C	1.7	4
			K	1.42	4
			M	2.94	3/4
			Y	2.8	3/4
	6 minutes	150 g and 200 g	C	3.76	3
			K	3.33	3
			M	4.73	2/3
			Y	4.92	2/3

Continued *Table 11. Color change of thickener amount*

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