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Pigment Ink Formulation for Inkjet Printing of Different Textile Materials

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ABSTRACT: Cotton, polyester, and cotton polyester blended woven fabrics were printed using an ink jet print using by means of a prepared pigment ink. Literature indicated that the development of insoluble pigment-based inks presents enormous challenges to the ink formulator. Meanwhile, pigments face several application problems in terms of their dispersion stability within the ink formulation, and consequently blocking the nozzles within the inkjet print head.

Upon this, Two pigment colors : M.D. Blue 15:3 and Daicofast Yellow 1252 were successfully formulated and factors affecting the final color yield of inkjet printed fabrics such as, pigment concentration and other ink contents: dispersing agent, ethylene glycol and diammonium Phosphate concentrations, thermo-fixation time and temperature for the three printed substrates pretreated with binder were investigated in detail.

The study was done on two route bases, first: the preparation of pigmented inks for inkjet printing and the application of the ink on the three substrates, in order to determine the optimum concentration of pigment ink contents. Second: increasing the wash and crocking fastness properties of the printed fabrics with pigment inks. In addition, the two pigment inks physical properties: density, viscosity and surface tension were measured as well as fastness levels of their prints.

KEYWORDS: Binder system, Dispersing agent, Fastness properties, Ink formulation, Inkjet printing, Pigment colors.

1 INTRODUCTION

In recent years, there has been an increasing application of digital printing to textile substrates. This interest has been fueled by the rapid advances that have been made in digital printing technology. Inkjet is a non impact, dot-matrix printing technology in which droplets of ink are jetted from a small nozzle directly to a specified position on a media to create an image [1].

The size of the smallest drop determines the finest detail that can be reproduced in the inkjet process. Dots as small as 3 Pico-liter (diameter about 18 microns) can be generated at the present level of ink jet technology. Ink jet printing is the only non-contact printing method and because of this, it is the most ideal of all printing methods [2].

There are two kinds of inkjet inks on the market: one is a dye-based ink and the other is a pigment-based ink. Most inkjet printing inks involve multiple components making the design and optimization of the formulations a challenging task [3].

Such inks, depending on the printer for which they are intended, must meet very stringent criteria with regard to viscosity, surface tension, conductivity, storage stability and good fastness on the substrate [4]. However, most dye-based inkjet printing inks suffer from poor wet-fastness properties when printed on common office printing paper. Therefore, various attempts to develop colorants capable of improved water-fastness have been carried out [3].

Pigment inks need low viscosity for good jet-ability, because many print head for aqueous ink work at low viscosity. Consequently, highly functional dispersions are needed not only for preventing precipitation in low viscosity solution, but also for jetting well in the print head [5].

The single most significant fact the formulator must always keep in mind is the (keep it simple) fact. Having a large number of raw materials in the formulation will do two things: First, it will be very difficult to solve a problem should one arise in production. Secondly, a formulator who utilizes a large number of components in a formula will be very unpopular with the manufacturing supervisor [6].

Pigment binders play an important role in pigment printing. Binder is a film forming substance; the film encloses the pigment particles and adheres to the fiber. The rubbing, washing and dry-cleaning fastness of a pigment print is determined by the fastness of the binder film and the quality of the print depends on the quality of the binder [7].

Binders are generally made of polymer dispersions in water. These can include polymers and copolymers that are produced by the reaction of monomers in the presence of initiators or catalysts. Acrylics are commonly the best all-around binders, having good color fastness and good dry/wet strength. They also provide good durability and a wide range of fabric hand properties [8].

The present study aims to fulfill the preparation of pigment based inks to be applied on cotton, polyester and their blend via inkjet technique which reduces printing time and treatments of fabrics. The prints should have best color yield as well as satisfactory fastness properties.

2 Materials, Methods and Measurements

2.1 Materials

A 100% singed, desized, scoured and bleached cotton fabric was used with 135 g\m^2 fabric weight, polyester fabric with 135 g\m^2 fabric weight and cotton\polyester 65\35 blended fabric with 118 g\m^2 fabric weight were used in the present study. These fabrics were supplied by Misr for Spinning & Weaving Co., Mehalla El-Kobra, Egypt.

Two pigment colors are used: M.D. Blue 15:3 and Daicofast Yellow 1252, a synthetic thickener Daicothick1600, Scaural CA (non-ionic detergent) all kindly supplied by Daico Chemicals Industry, Egypt. Ethylene glycol and diammonium phosphate supplied by El-Nasr Pharmaceutical Chemicals Co., Egypt. Also, a dispersing agent (Avolan IW) supplied by Bayer AG Co., Switzerland, a defoamer (Nofoam SE) supplied by Sybron-Tanatex, Egypt and Printofix binder N86 supplied by Clariant Co., Egypt have been used.

2.2 Methods

2.2.1 Pretreatment of Fabrics

For samples that will be printed later on with the blue pigment-based ink, the fabrics are pretreated by overprinting using an opened silk screen with a paste containing 40 g\kg Printofix binder and 960 g\kg Daicothick1600 stock thickener for cotton, 60 g\kg binder and 940g\kg stock thickener for both polyester and blended fabrics. On the other hand, samples to be printed with the yellow pigment-based ink are pretreated with 100 g\kg Printofix binder and 900 g\kg stock thickener for cotton and blended fabrics, 80 g\kg Printofix binder and 920 g\kg stock thickener for polyester fabrics.

2.2.2 Inkjet Inks Formulation

The following recipe is prepared as an inkjet ink formulation (with stirring):

X	gm	Pigment color (varies according to color and fabric)
10	ml	Avolan IW (dispersing agent)
100	ml	Ethylene glycol
4	ml	Nofoam SE (defoamer)
40	gm	Diammonium phosphate
Y	cm^3	Distilled water
1000	gm	

The prepared inks are filtered with (Whitman) filter paper to remove large particles and impurities.

2.2.3 PRINTING

The pretreated samples are then printed and subjected to thermofixation at 150° C for 5 min. after which they are thoroughly rinsed in cold and hot water and washed off using 1.5 g/l non-ionic detergent at 70° C for 10 min. All the inkjet printed patterns reported here were fabricated using a Hewlett Packard (hp) Office Desk Jet 656c inkjet printer. Although a piezo-based inkjet print head offers a greater range of ink compatibility than thermal inkjet heads, we preferred to use a simple thermal head printer because of the simplicity of filling cartridges with the ink. For the purpose of passing the fabric samples through the inkjet printer, the samples were glued (in the edges) to a sheet of A4 paper.

2.3 MEASUREMENTS

The color strength (K\S) of the printed samples was evaluated by color reflectance technique at λ maximum. The used spectrophotometer was of model ICS-Texicon Ltd., England. The viscosity of the pigment–based ink was measured using Ostwald viscometer. The surface tension of the ink was measured using Stalagmometer. The density of the ink was measured using Pycnometer.

Color Fastness Properties

The color fastness to washing, rubbing, and perspiration were determined according to AATCC test methods (61, 8, 15 – 1989, respectively). Fastness to light was evaluated according to AATCC test method (16-1990).

3 RESULTS AND DISCUSSIONS

3.1 EFFECT OF PIGMENT CONCENTRATION

The effect of pigment concentration of the inkjet ink is investigated through adding different pigment concentrations and the K/S values of the printed fabrics are plotted in Figs. (1&2).

The results imply that, maximum color strength values are obtained using the concentrations 20, 30, and 30 g\l for cotton, polyester and blended fabrics, respectively using the blue pigment. These concentrations caused increasing in the K/S by 126.6, 88.7 and 97% for cotton, polyester and cotton /polyester blended fabrics, respectively compared with adding 10 ml/l pigment to the ink.

The maximum color strength values are obtained using a concentration of 50 g\l for all fabrics using the yellow pigment since this concentration resulted in enhancements in K/S values by 14, 8 and 12.7% for cotton, polyester and cotton /polyester blended fabrics, respectively also compared with adding 10 ml/l pigment to the ink. The variation of K/S enhancements from one color to another may be referred to both pigment chemical structure and the dispersion level of pigment particles inside the printing ink.

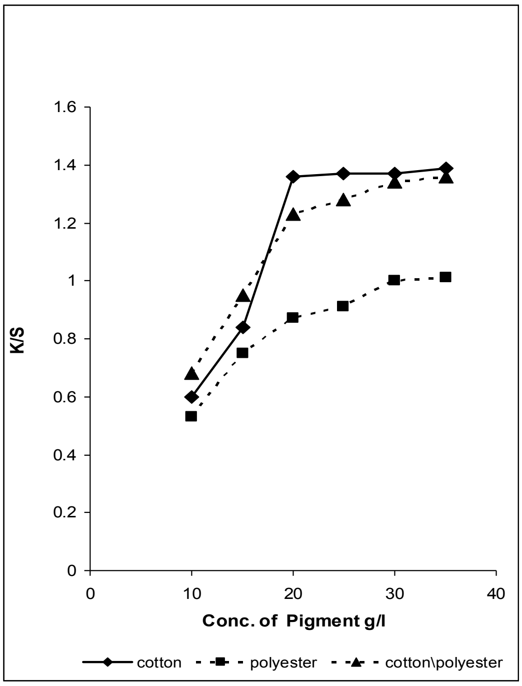

Fig. 1. Effect of blue ink concentration on K\S of printed fabrics

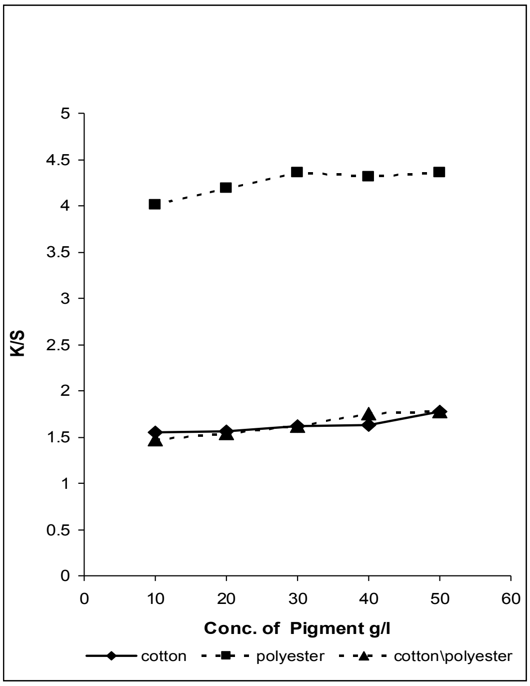

Fig. 2. Effect of yellow ink concentration on K\S of printed fabrics

3.2 EFFECT OF DISPERSING AGENT CONCENTRATION

The dispersing agent helps in dispersing the pigment particles and keeps them in a stable dispersing state in the ink. [9] Surfactants frequently increase the affinity of pigment and ensure that wetting proceeds rapidly. To break down the agglomerates, sufficient force must be exerted to overcome the forces holding the agglomerates together: (1) by physical impact, (2) by particle-particle attrition and (3) by shear transmitted through an intermediate fluid layer [10]. All types of surfactant systems are known to dissolve insoluble dyes, break-up dye aggregates into monomers or partially soluble dyes via incorporation into surfactant micelles [11].

According to the literature, [9] there are three main types of forces which determine the stability of pigment dispersion: (1) the electrostatic forces of repulsion which arise from the ions or charged groups on the particle surface, (2) the Van Der Waals' forces of attraction which arise from the difference in dielectric constant between the particles and the medium and (3) steric stabilization which arises from the presence of uncharged groups on the particle surface.

The action of the dispersing agent as one of several ink components and its effect on K/S values of the prints was studied using various concentrations of dispersing agent and the results are plotted in Figs. (3&4).

It may be concluded from the figures that, maximum color strength values are obtained using 12, 4 and 10 ml\l of the dispersing agent for cotton, polyester and blended fabrics, respectively using the blue pigment. Concerning the yellow pigment, maximum K\S values are achieved by using 10 ml\l dispersing agent for the three fabrics.

The direct relation between dispersing agent concentration and K/S of cotton samples is logical since on increasing dispersing agent concentration, the optimum pigment particles dispersion is obtained which enhances cotton affinity to pigment. While for polyester samples, increasing dispersing agent concentration increases pigment particles dispersion inside the ink which makes the particles lose some of their hydrophobic nature on which they rely on in attaching to the polyester substrate in the first place so, K/S values decrease on increasing dispersing agent concentration.

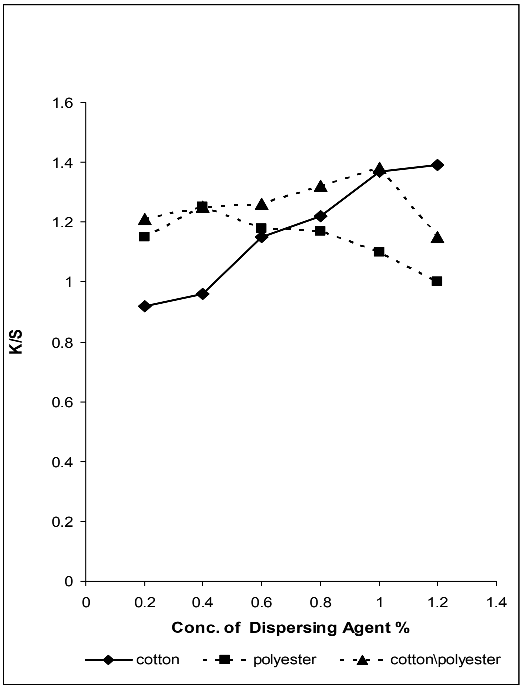

Fig. 3. Effect of dispersing agent concentration on on the K\S of printed fabrics with the blue ink

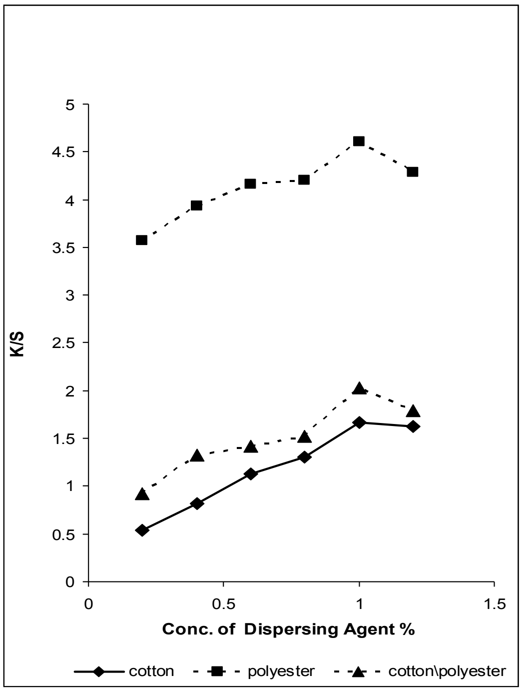

Fig. 4. Effect of dispersing agent concentration on the K\S of printed fabrics with the yellow ink

3.2.1 EFFECT OF ETHYLENE GLYCOL CONCENTRATION

It is established that, adding ethylene glycol acts as a humectant and adjusts the viscosity and surface tension of the ink and prevents it from drying upon the print head and also helps the ink to penetrate into the substrate quickly. In order to study the influence of the addition of a solvent to ink formula, different concentrations of ethylene glycol were used and the data of are shown in Figs. (5&6).

The results obtained in Fig. (5) imply that, as ethylene glycol concentration increases a marked decrease in the color strength takes place in case of polyester fabrics. The prints have the highest K\S values at concentrations 50, 100 ml\l for cotton and blended fabrics, respectively since it caused enhancements in K/S values by 13 and 12.5% for cotton and cotton/polyester blend, respectively compared with the pretreated samples without the addition of ethylene glycol to their printing recipes. However, 100 ml/l is chosen as the optimum concentration for printing the blended substrate since it caused an increase in the K/S by 11.6% which represents a small difference from the higher concentration. While the highest K\S values for polyester fabrics can be achieved without ethylene glycol with the blue pigment.

Cotton fabrics need high solubility or dispersion of pigment color so high concentrations of ethylene glycol can affect pigment dispersion because of its low solubility in water. So, the dispersing agent has two effects: first, as a dispersing agent which helps to break down the agglomerates to a smaller particle size which disperses pigment particles in the ink and second, as an emulsifying agent which helps to disperse ethylene glycol in water.

Pigment particles are held together by attraction forces of various physical chemical natures including Van Der Waals' forces which affect their dispersion stability within the ink formulation that consequently blocks the nozzles of the inkjet print heads and decreases the color strength [13].

The results obtained from Fig. (6) imply that, as ethylene glycol concentration increases, a marked increase in the color yield takes place. The prints have optimum K\S values at ethylene glycol concentrations of 200, 250 and 200 ml\l for cotton, polyester and blended fabrics, respectively on printing with the yellow pigment since enhancements in K/S values by 18.4, 13.8 and 16% for cotton, polyester and blended fabrics, respectively are observed.

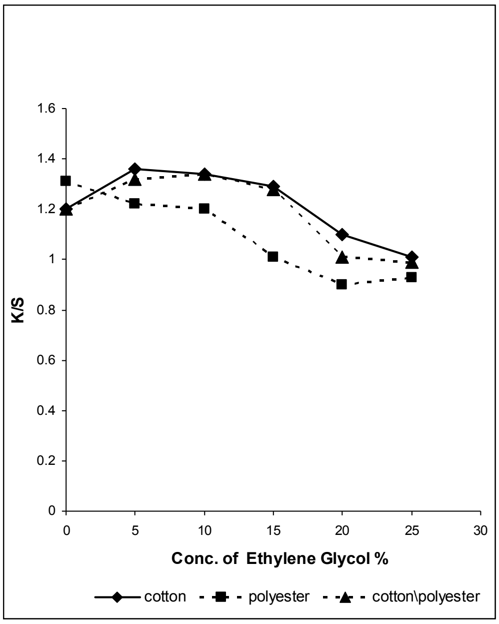

Fig. 5. Effect of ethylene glycol concentration on the K\S of printed fabrics with the blue ink

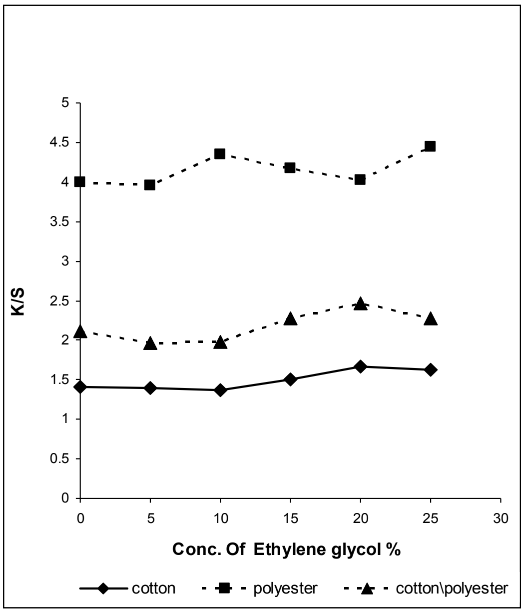

Fig. 6. Effect of ethylene glycol concentration on the K\S of printed fabrics with the yellow ink

3.2.2 Effect of Diammonium Phosphate Concentration

Condensation reactions of the used binder in the present study (N-methylol compounds) require an acid medium and the pigment print paste will have therefore an added weak acid such as diammonium phosphate [13]. This compound causes reduction of the pH of the print paste film during curing, promoting crosslinking. To investigate the role of diammonium phosphate on the color yield of the printed fabrics, different concentrations of diammonium phosphate are added to printing recipes, and the results are illustrated in Fig. (7) &(8).

It is clear in Fig. (7) that, there is an increase in color yield on adding diammonium phosphate and the K\S values of the prints give their maximum values at concentrations of 30, 40 and 20 gm\l for cotton, polyester and their blend, respectively using the blue pigment since these concentrations increase the K/S values by 77.5, 40.7 and 9.5% for the three substrates, respectively compared with the printed samples on adding 10 ml/l diammonium phosphate.

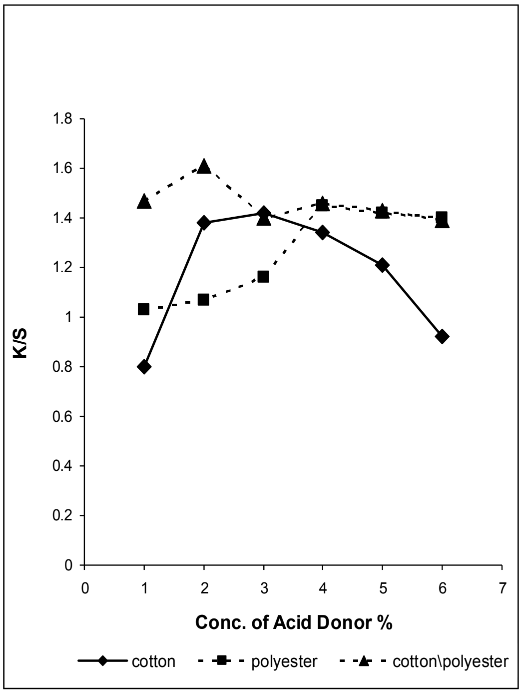

Fig. 7. Effect of diammonium phosphate concentration on on the K\S of printed fabrics with the blue ink

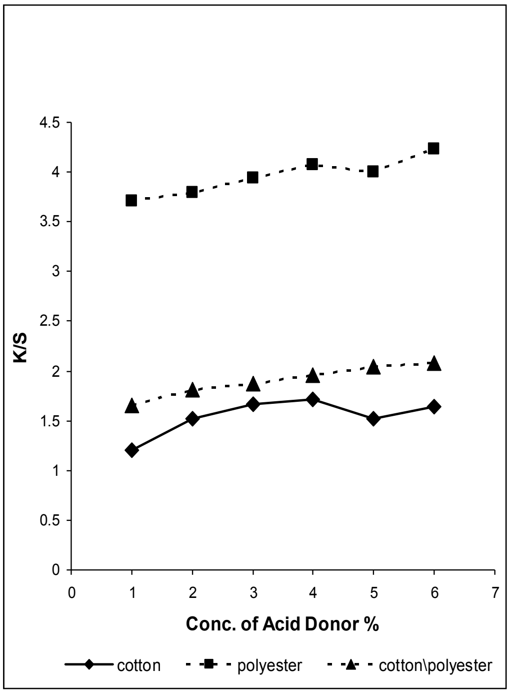

Fig. 8. Effect of diammonium phosphate concentration on the K\S of printed fabrics with the yellow ink

From Fig. (8) it is clear that, the maximum color strength values can be obtained on adding 40g\l diammonium phosphate to the printing pastes used on cotton fabrics and 60g\l for both polyester and blended fabrics using the yellow pigment. The results also indicate that, during the fixation process the medium of the ink is converted into acidic medium which helps to fix pigment particles that enhances the K/S values. On the other hand, high concentrations of diammonium phosphate affect the dispersion of pigment particles which results in the formation of pigment agglomerates that precipitate and block the nozzles in the ink jet print head.

3.3 THERMOFIXATION CONDITIONS

During curing, the active groups along the polymer chains undergo intermolecular polymerization reactions producing a number of crosslinks [13]. The crosslinks are, however, reasonably stable to hydrolysis during mild washing and are not present in sufficient number to produce a rigid film. They ensure good film stability, little swelling of the film in dry cleaning solvents and improve the adhesion to the fiber surface. To investigate the best temperature and sufficient time for fixing pigment prints, using printing recipes that include the optimum ingredients' concentrations as previously mentioned, different temperatures as well as periods of time are used and the resulted K/S values of the printed samples are given in Table (1).

Table 1. Effect of thermo-fixation temperature and time on the K/S of printed fabrics

Substrate	Time (minutes)	K\S Values									
		M.D. Blue 15:3 pigment.					Daicofast Yellow 1225 pigment				
		110°c	130°c	150°c	170°c	190°c	110°c	130°c	150°c	170°c	190°c
Cotton	1	1.40	1.51	1.46	1.55	1.52	1.94	1.66	2.09	2.27	2.09
	3	1.39	1.57	1.54	1.55	1.46	2.07	1.65	1.86	2.30	2.18
	5	1.48	**1.62**	1.47	1.57	1.47	2.01	1.63	1.73	**2.39**	2.11
	7	1.53	1.55	1.46	1.24	1.45	2.10	1.71	1.78	2.25	2.14
	9	1.56	1.48	1.50	1.14	1.31	2.23	1.81	1.92	2.24	2.21
Polyester	1	1.30	1.43	1.43	1.44	1.51	3.85	4.34	3.74	4.53	4.79
	3	1.38	1.53	1.46	1.47	1.55	4.12	4.45	4.01	4.79	**5.42**
	5	1.40	1.52	**1.55**	1.51	1.49	4.07	4.06	4.23	4.67	5.13
	7	1.47	1.51	1.44	1.48	1.48	4.21	4.00	4.34	4.07	5.26
	9	1.46	1.50	1.46	1.48	1.50	4.24	3.83	3.97	4.93	5.02
Cotton\polyester	1	1.67	1.61	1.86	2.08	1.96	2.08	2.30	2.36	2.32	2.29
	3	1.83	1.67	2.01	**2.13**	1.98	2.17	2.14	2.23	2.37	2.52
	5	1.84	1.65	1.98	2.00	1.91	2.27	2.21	2.29	2.40	2.39
	7	1.86	1.77	2.01	2.04	1.93	2.34	2.17	2.32	2.32	2.56
	9	1.72	1.76	1.92	1.98	1.76	2.23	2.25	2.16	2.24	**2.69**

From the above table it is obvious that, curing the prints at 150° C for 5 min. can be chosen as optimum thermofixation conditions regardless of the kind of substrate or pigment used. This conclusion may be due to obtaining appropriate K/S values as well as satisfactory fastness levels (as will be illustrated later) using these conditions without affecting tensile strength or substrate color negatively.

3.4 Physical Properties of Ink Formulation

In continuous ink jet printing, surface tension helps to control the meniscus at the nozzle. Inks for ink jet printing should have a very low viscosity in the range of two to ten centipoises [14]. Table (2) illustrates the measurements of density, viscosity and surface tension of both prepared inks.

Table 2. Physical properties of both prepared inks

Substrate type	Pigment based ink	Density (g\cm$^{3)}$	Viscosity (Pa.s)	Surface tension (Dyn/cm)
Cotton	M.D. Blue 15:3 pigment.	1.0434	1.3	54.3
Polyester		1.0424	1.2	54.75
Cotton\Polyester		1.0503	1.5	55.6
Cotton	Daicofast Yellow 1225	1.0762	2.1	35.3
Polyester		1.0766	1.9	35.9
Cotton\Polyester		1.0886	2.2	34.68

It is clear from the table that, the surface tension values at 25 °C ranged between 35 and 55 Dyn/cm while the values of viscosity at the same temperature ranged between 1.2 and 2.2 Pa.s.

3.5 Color Fastness Properties

The results of fastness properties of the printed fabrics are listed in Table (3). The results show good fastness to washing, from good to very good in case of perspiration fastness. The results of rubbing fastness indicate that the prints have from fair to good fastness to dry and wet rubbing and from good to very good fastness to light. These results are considered good since they are similar to those obtained from regular pigment printing.

Table 3. Fastness properties of printed fabrics with both pigment based inks

Pigment based ink	Substrate	Rubbing fastness		Washing fastness			Perspiration fastness						Light fastness
							Acidic			Alkaline			
		Dry	Wet	Alt.	St.*	St.**	Alt.	St.*	St.**	Alt.	St.*	St.**	
M.D. Blue 15:3	Cotton	3	2	4	4	4	4	4-5	4-5	4	4-5	4	6
	Polyester	2	2	4	4-5	4	4-5	4-5	4-5	4	4-5	4-5	6-7
	Blend	2-3	2-3	4	4	4-5	4-5	4-5	4-5	4	4-5	4-5	6
Daicofast Yellow 1225	Cotton	3	3	4	4	4	4	4	4	4	4-5	4	6-7
	Polyester	3	2-3	4	4	4-5	4	4-5	4-5	4	4-5	4-5	4-5
	Blend	3	3	4	4	4	4	4-5	4-5	4-5	4-5	4-5	5

Alt. = Alteration St.* = Staining on cotton St. ** = Staining on wool

4 CONCLUSION

Inkjet printing on textiles can give fine, delicate images on fabrics using a high resolution device and printing system. Although there are specialized inkjet printing machines for textiles, printing on textile is still a challenge. In this work, three different substrates: cotton, polyester and their blend are pretreated with a specific concentration of binder (according to fabric type) and are printed with two pigment-based inks (blue and yellow) via inkjet technique. In order to maintain good ink stability and satisfactory fastness levels, ink formulations include a dispersing agent, ethylene glycol, a defoamer and diammonium phosphate, with concentrations depending on substrate type and ink color. Thermofixation of the prints is carried out in constant conditions to fix the binder which helps to form a film that encloses pigment particles and adheres them to the fibers. The results obtained revealed good fastness properties of the prints as well as good physical properties of both inks.

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