Effect of Inter Yarn Fabric Porosity on Dye Uptake of Reactive Dyed cotton Woven Fabric

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ABSTRACT

Fabric Porosity is an important property in determining the functional properties of a fabric. It relates to the count of a yarn as well as to the type of weave. Twill and satin cotton woven fabrics in three different weft densities (warp density kept constant) were used to investigate the effect of porosity on the dye-uptake within one weave. The effects of change in weave type, keeping yarn densities the same, on the porosity were also investigated. Objective determination of porosity was carried out using an image analysis technique while, colour yield was determined using K/S values. Higher the weft density in a satin fabric low will be the porosity of that fabric. Porosity values varied from 6.85-10.98% for S1 and S3 respectively. However, for the twill fabric no substantial change in porosity have been observed as the porosity values varied from 6.4-5.3% for T1 and T3 respectively. Colour strengths for S1 and T1 are lower than S3 and T3 respectively for all the primary colours at 0.25, 1.00 and 2.00% depth levels. It is observed that the change in colour strength is more prominent at 2% depth level as compared to 0.25% depth level.

Key Words: Porosity, Colour Strength, Warp and Weft Densities, Pore Area, Satin and Twill.

1. INTRODUCTION

Dyeing is a very complex phenomenon as it involves number of variables which need to be controlled. Source of variability may include substrate, dyeing process parameters or pre and post treatment differences. Right shade is always an utmost desire of a dyer. Automation in textile machineries has significantly reduced the variability due to equipment and process. It has been reported that most of the problems which a dyer faces during colour matching is attributed to the substrate [1-3]. The problem for dye houses is caused by the differences between the structural parameters of a reference fabric of which dyeing recipe is known and the fabric to be dyed[4].Fabric structural properties which may influence dye uptake include type of weave, constructional parameters, and porosity of a fabric. If the constructional parameters (yarn count, weight of the fabric, yarn twist, warp and weft density, thickness) are kept constant then weave pattern and porosity play vital role in producing precise depth of shade.

Fabric Porosity affects the flow of the dye liquor in between the yarn and between the individual fibres or filaments of a yarn of a fabric. If the origin of fibre and the technical properties (fineness, twist, cross sectional area) of the yarn for warp and weft are same then change in fabric porosity solely be dependent upon spacing between two yarns

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thus any variation in shade depth will be a result of this inter yarn spacing. It is known that compactness of the yarns in the fabric will resist flow of dye liquor. Cotton material on wetting swells, reducing the pore area hence hampers the liquid flow. Therefore we can say that dye liquor flow can be predicted by knowing the porosity of the fabric. Plain weave being tight in nature will offer highest resistance while sateen (satin) with minimum number of intersections offer minimum resistance to the fluid flow between the yarns.

Porosity of a fabric can be determined both theoretically and objectively. Cay determined the porosity of a fabric as the inter-yarn porosity calculated by Equation (1) [5].

$$\varepsilon = \frac{Open\ pore\ area}{(Total\ area)} = \frac{P_1 P_2}{((P_1 + d_1)(P_2 + d_2))} \quad (1)$$

Where P_1 is the yarn spacing for warp yarns, P_2 is the yarn spacing for weft yarns, d_1 is the diameter of warp yarns, and d_2 is the diameter of weft yarns.

The porosity of the fabric may be regarded as the inter-yarn and inter-fibre porosity. It is based on the density of fabric and the fibre and is calculated by Equation (2) [4-5].

$$\varepsilon = 1 - \frac{\rho_a}{\rho_b} \quad (2)$$

Where ρ_a is the fabric density in g/cm^3 and ρ_b is the fibre density in g/cm^3.

If a single pore is considered the porosity of a 2D pore unit cell is calculated using Equation (3) [7].

$$PA(\%) = \frac{((P_1 + d_1)(P_2 + d_2))}{P_1 P_2} \quad (3)$$

Where is the yarn spacing for warp yarns, is the yarn spacing for weft yarns, is the diameter of warp yarns, and is the diameter of weft yarns.

Differences in the porosity depend on pore area, number of pores, and distribution of pores and shape of a pore. Pore area was determined by Xie [8] where a unit cell of a fabric was treated as a rectangular box and circular equivalence of this box was also considered as shown in Fig. 1.

The pore area was calculated using Equation (4).

$$P_{pore} = (P_1 - \frac{D_{11}}{2} - \frac{D_{12}}{2})(P_2 - \frac{D_{21}}{2} - \frac{D_{22}}{2}) \quad (4)$$

If the pore is considered as equivalent to a circle as shown in Fig. 1, then the radius of the circle is calculated by using Equation (5).

$$R_{2d} = \sqrt{\frac{(P_1 - \frac{D_{11}}{2} - \frac{D_{12}}{2})(P_2 - \frac{D_{21}}{2} - \frac{D_{22}}{2})}{\pi}} \quad (5)$$

Some researchers have used the method of image analysis to determine the porosity of the woven fabric objectively [5,8-9]. This method is faster and accurate as it takes into account different pore parameters. However, differences between calculated and measured values have been reported [9].

Taking the above discussion into consideration this paper will discuss about the effects of fabric porosity on dye uptake for twill and satin fabric. This work will also focus the relationship between different weave types and their respective porosities. Image analysis technique is used to calculate porosity objectively [6].

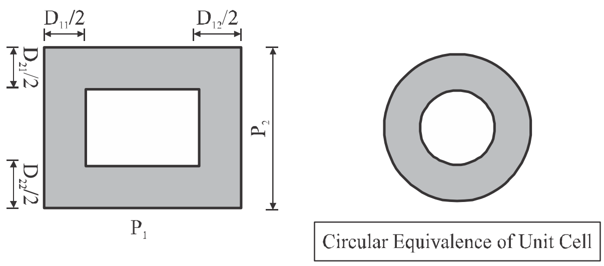

FIG. 1. UNIT CELL OF A WOVEN FABRIC [8]

2. MATERIALS AND METHOD

Fabrics of different weave types i.e. twill (3/1) and satin (4/1) were manufactured by using 100% cotton yarn 22/s Ne in warp and 20/s Ne in weft directions. The details of the fabric warp and weft densities are shown in Table 1 [6]. These fabrics were de-sized, bleached and dyed using the recipe given in Table 2.

Sodium hydroxide, hydrogen peroxide and acetic acid of commercial grade were used. Drimarene red CL-5B, Drimarene blue CL-3LB, Drimarene yellow CL-2R reactive dyes were kindly supplied by Clariant Pakistan. All of these dyes are bi-functional MCT/VS reactive dyes. The fabric was dyed according to the profile given in Fig. 2.

Colour strength of the dyed samples was calculated using Kubelka-Munk equation given in Equation (6). The measurements were taken by folding the material into four layers in order to make it opaque. Five readings were taken for each type of samples.

$$K/S = (1-R^2)/2R \tag{6}$$

R indicates the % reflectance value at 530, 620 and 430nm of the dyed sample. The reflectance values of the blank and dyed material were measured using a Datacolor Spectrophotometer SF650 with 100% UV filter off and specular reflection included, using Illuminant D-65.

TABLE 1. WARP AND WEFT DENSITIES OF DIFFERENT TYPES OF FABRICS [6]

Sample ID	Warp Density in Ends (per cm)	Yarn Spacing for Warp yarn P_1 (cm)	Weft Density in Ends (per cm)	Yarn Spacing for Weft yarn P_2 (cm)
S1	33	0.03	27	0.037
S2	33	0.03	23	0.043
S3	33	0.03	18	0.056
T1	33	0.03	27	0.037
T2	33	0.03	23	0.043

2.1 Determination of Porosity of Fabric

Porosity of the given fabrics was determined by an image analysis technique for which Image J software was used. It is to be noted that image analysis technique demands expertise to analyze the image and to calculate the threshold values. For this purpose an image size of 6.9 by 5.17mm was considered. An optical microscope Leica EZ 4D along with the digital camera was used to take these images under transmitted light mode at 16x magnification. Samples were taken at unknown transmittance value. The fabric samples were desized and bleached for taking the images [6].

The following steps were taken to determine the number of pores, porosity and pore area of the given samples [6].

TABLE 2. RECIPE FOR THE PRETREATMENT OF THE FABRIC

Process	Chemicals	Quantity
Desizing	Desizer (Invazyme ADC)	15 g/l
	Detergent Ultravone CX)	4 ml/l
	Sequestering agent (CIBA CEL DS)	4 ml/l
Scouring and Bleaching	Hydrogen peroxide 50% Commercial Grade	30 ml/l
	NaOH 48 Be Commercial Grade	10 g/l
	Stabilizer Peristal PSK (PSC)	4-8 g/l
	Wetting Agent Ultravam-PRE (Swisstex)	4 ml/l
	Sequestering Agent (CIBA CEL DS)	4 ml/l
Dyeing	Drimarene Red CL-5B	X% owf
	Drimarene Blue CL-3LB	
	Drimarene Yelloy CL-2R	
	Sodium Carbonate Commercial Grade	20 g/l
	Salt Commercial Grade	40 g/l
	Wetting Agent	0.1% owf
	Wetting Agent	0.1% owf

A The contrast of the image was enhanced in order to differentiate between the white pores and black yarns.

B The image was calibrated as 296 pixels per mm.

C The threshold value of the image was calculated by the averaging method. [10]

D The image was then thresholded in order to separate the white pores from the black background.

The whole procedure given above is shown in Fig. 3(a-d) [6].

A minimum value of pore area was assigned to the software so while counting the pores software considered only those pores whose area is higher than this minimum value. The suggested minimum value is $0.005 mm^2$. Five images were taken for each type of fabric samples for the determination of porosity. The fibrils are not clearly apparent in the threshold images. During the determination of number of pores, fibrils may affect by 2-3%.

3. RESULTS AND DISCUSSION

3.1 Effect of Weave Structure on Porosity

The overall objective of this work was to develop relationship between fabric structure and Colour yield. In order to accomplish this task porosity, pore area and number of pores of these fabrics were calculated by the image analysis technique described above.

Porosity, pore area and number of pores of these samples determined by image analysis technique are given in Table 3 [6].

From Table 3, it was observed that for both twill and satin woven fabrics the pore area had increased with the reduction in the weft density. it was further concluded that for satin woven fabric the porosity increases with the decrease in the weft density. But for the twill woven fabric the porosity decreases slightly. We know that porosity is affected by the pore area, pore shape, number of pores and pore distribution. If there is any variation in these parameters than porosity will be different. It is evident from Figure 4D that most of the pores are irregular in shape and number of pores for satin and twill with same warp and weft densities are different (Table 3). This variation is responsible for the abnormality in the %P values. Twill with minimum floats has smaller pore area in comparison to satin.

3.2 Effect of Porosity and Weave Type on Colour Yield

Three concentration levels (0.25, 1 and 2%) were identified. Sateen (S1, S2 and S3) and twill (T1, T2 and T3) both were

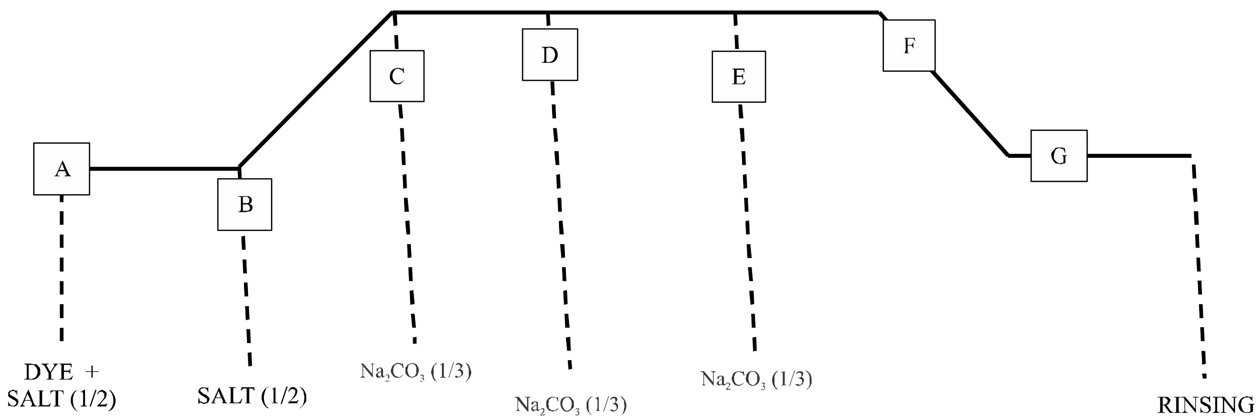

FIG. 2. DYEING PROFILE OF A REACTIVE DYE

dyed at these three concentration levels. The K/S values for all the dyed samples are given in **Table 4.**

Fig. 4 shows changes in Colour yield with change in fabric porosity at different dye concentrations. It is apparent that change in weave type did not contribute significantly at paler shades but effects were significant at higher depth values for all three primary colours. It was also seen that fabric with higher weft density (S1 and T1) show lower K/S values. This is probably due to the resistance in flow to dye liquor in S1 and T1 as both have minimum pore area and least porous (%P) with higher weft density.

It was reported by Cay [4] that fabric with higher number of weft threads have low porosity and low colour yield.

TABLE 3. POROSITY AND PORE AREA CALCULATION BY IMAGE ANALYSIS METHOD [6]

Sample ID	Number of Pores	CV (%)	Porosity (%)	CV (%)	Average Pore Area (mm^2)	CV (%)
S1	108	7.79	6.85	10.6	0.026	5.25
S2	139.88	8.3	10.07	15.11	0.026	11.6
S3	139.43	14.79	10.98	23.27	0.0281	19.29
T1	147.75	9.62	6.42	9	0.0155	5.97
T2	122.13	15.96	5.53	12.91	0.0163	9.2

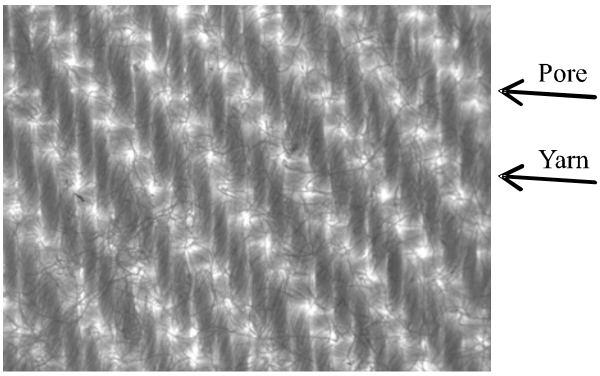

FIG. 3(A). IMAGE FROM THE MICROSCOPE

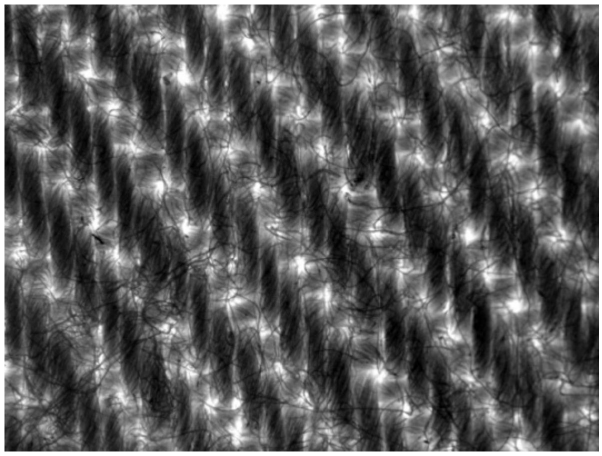

FIG. 3(B). ENHANCED CONTRAST IMAGE

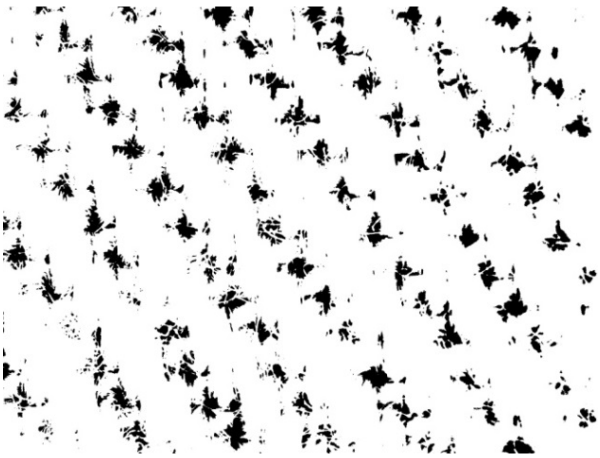

FIG. 3(C). IMAGE AFTER THRESHOLD

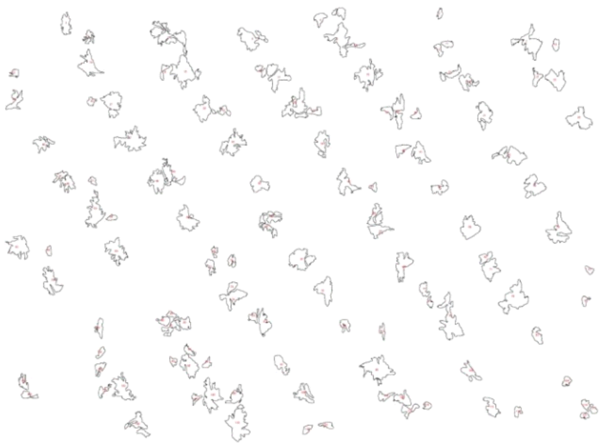

FIG. 3(D). IMAGE OF PORES

Table 3 and **Fig. 3** also show that satin woven fabric is in agreement to this statement where S1 with maximum number of threads have low porosity and low dye yield. In case of twill woven fabric this statement is partially true as T1with maximum number of threads have low dye yield but at the same time have highest porosity within T1, T2 and T3. This abnormality in porosity might be due to the variation in the pore area and shape, number of pores and its distribution.

It is also evident that satin weave fabrics have slightly lower colour yield than the twill woven fabric with the same warp and weft density at higher depth levels. When we change the type of a weave it is not only the number of weft or warp density but also the way how they interlace with each other play a vital role. Yarn in satin weave with less number of interlacements can displace easily thus void apace between the yarns will be more which results in reducing the Colour yield. However, this change is dependent upon the colour and its depth level. Change in weave does not contribute significantly for paler shades in three primary colours but became significant with an increase in dye concentration.

TABLE 4. L* a* b* C* h VALUES OF DIFFERENT FABRIC SAMPLES

Blue (0.25%)	K/S	CV (%)	Blue (1.00%)	K/S	CV (%)	Blue (2.00%)	K/S	CV (%)
S1	0.53	9.74	S1	1.47	5.10	S1	2.60	6.49
S2	0.58	5.98	S2	1.74	9.88	S2	2.94	13.66
S3	0.57	9.49	S3	1.85	16.33	S3	3.28	8.16
T1	0.57	4.35	T1	1.58	10.50	T1	2.74	15.90
T2	0.64	13.41	T2	1.61	16.71	T2	2.78	19.01
T3	0.59	14.80	T3	1.74	18.38	T3	3.03	20.17
Red (0.25%)	K/S	C V(%)	Red (1.00%)	K/S	CV (%)	Red (2.00%)	K/S	CV (%)
S1	0.84	7.69	S1	2.63	5.93	S1	4.77	9.30
S2	0.87	5.43	S2	2.90	5.73	S2	5.01	6.75
S3	0.84	6.71	S3	2.98	10.69	S3	5.38	10.23
T1	0.79	13.42	T1	2.68	13.01	T1	4.91	9.87
T2	0.80	13.86	T2	2.93	7.41	T2	5.29	9.11
T3	0.82	11.88	T3	3.07	15.79	T3	5.55	11.93
Yellow (0.25%)	K/S	CV(%)	Yellow (1.00%)	K/S	CV(%)	Yellow (2.00%)	K/S	CV (%)
S1	1.20	17.92	S1	3.52	6.81	S1	5.97	4.44
S2	1.28	15.91	S2	3.58	9.31	S2	6.10	6.23
S3	1.36	12.57	S3	3.60	14.60	S3	6.23	10.88
T1	1.26	5.15	T1	3.88	8.66	T1	6.42	13.31
T2	1.29	9.28	T2	4.21	11.16	T2	6.41	21.02
T3	1.36	6.09	T3	4.27	13.73	T3	6.46	25.14

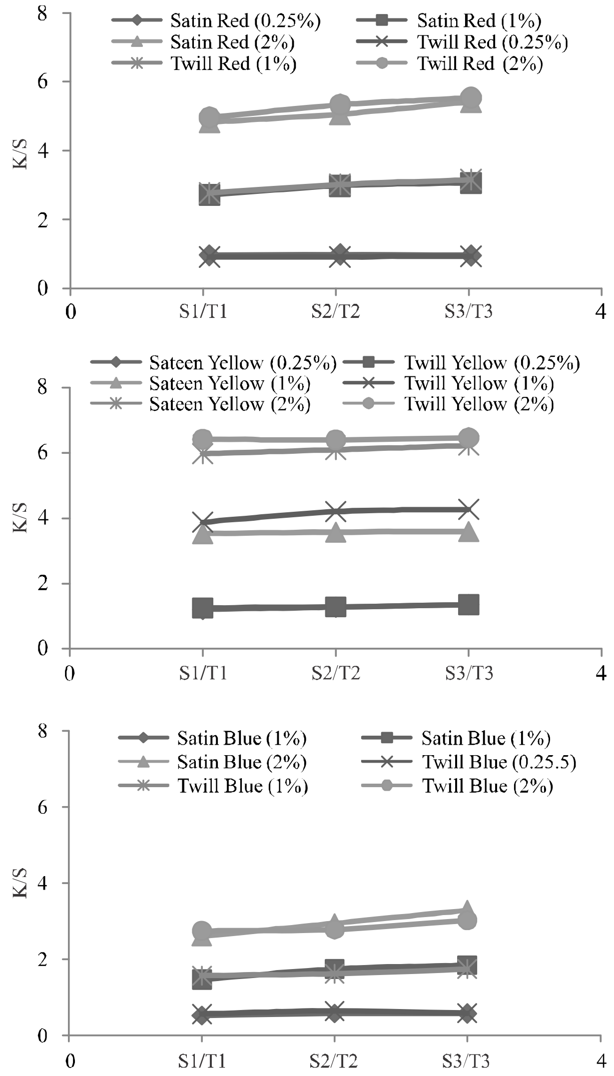

FIG. 4. K/S VALUES OF SATIN AND TWILL WOVEN FABRICS

TABLE 5. CORRELATION COEFFICIENT OF POROSITY VS. COLOUR DEPTH OF SATIN AND TWILL FABRIC

Color	R		
	0.25%	1.00%	2.00%
Yellow			
Within Stain	0.95	0.99	0.95
Within Twill	0.85	0.99	0.77
Red			
Within Satin	0.99	0.99	0.9
Within Twill	0.87	0.98	0.97
Blue			
Within Satin	0.92	0.99	0.95
Within Twill	0.56	0.78	0.75

Correlation coefficient of porosity vs. colour depth of satin and twill fabric was determined using regression analysis and tabulated in **Table 5**. It again suggests that change in fabric porosity is affecting the colour depth of a dyeing at each level of dyeing.

4. CONCLUSION

From the above discussion it can be concluded that porosity of a fabric will vary not only with increasing and decreasing the warp and weft densities but also with the change in weave type. It has been observed that S1 has least porosity in comparison to S2 and S3 while for twill no significant change in porosity has been observed among T1, T2 and T3. It is interesting to note here that number of warp and weft of S1, S2 and S3 are similar to T1, T2 and T3 respectively but the porosity is different from one another. Twill is found to be less porous than satin with the same number of warp and weft yarns. Similarly colour strengths of S1 and T1 fabrics are lower than S3 and T3 fabrics respectively. It indicates the direct relationship of the porosity with the colour depth of the dyeings within one weave type. It can further be concluded that for the pale shades change in weave type and weft density is not contributing significantly but for the dark shades these factors are significant. Overall satin fabric has lower k/s values than twill fabrics with the same warp and weft densities.

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REFERENCES

[1] Parka, J., and Shore, J., "Evolution of Right-First-Time Dyeing Production", Coloration, Technology, Volume 125, No. 3, pp. 133-140, 2009.

[2] Mhetre, S.K., "Effect of Fabric Structure on Liquid Transport, Ink Jet Drop Spreading and Printing Quality", Ph.D. Thesis, Georgia Institute of Technology, USA, May, 2009.

[3] Hasan, M.M.B., Calvimontes, A., Synytska, A., and Dutschk, V., "Effects of Topographic Structure on Wettability of Differently Woven Fabrics", Textile Research Journal, Volume 78, No. 11, pp. 996-1003, 2008.

[4] Cay, A., Atav, R., and Kerim, D., "Effect of Warp and Weft Density Variation and Fabric Porosity of Cotton Fabric on their Colour in Reactive Dyeing", Fibres and Textile Eastern Europe, Volume 15, No. 1, pp. 91-94, 2007.

[5] Cay, A., Vassiliadis, S., Rangoussi, M., and Tarakcnoglu, I., "On the Use of Image Processing Techniques for the Estimation of Porosity of Textile Fabrics", International Journal of Computer, Information, Systems and Control Engineering, Volume 1, No. 2, pp. 402-405, 2007.

[6] Farooq, S., and Yousufahani, S., "Determination of Fabric Porosity by Using Image Analysis Technique", Proceeding of 2nd International Textile conference Covitex, Pakistan, March, 2013.

[7] Turan, R.B., and Okjur, A., "Investigation of Pore Parameters of Woven Fabrics by Theoretical and Image Analysis Method", Journal of Textile Institute, Volume 103, No. 8, pp. 875-884, 2012.

[8] Xie, S., "Characteristics of Inter Yarn Pore Size and its Distribution in Plain Woven Fabrics", Masters Thesis, NCSU, USA, 2002.

[9] Angelova, A.R., "Determination of Pore Size of Woven Structures through Image Analysis", Central Europe, Journal of Engineering, Volume 2, No. 1, pp. 129-135, 2012.

[10] Ridler, W.T., and Calvard, S., "Picture Thresholding using an Iterative Selection Method", IEEE Transactions on Systems, Man, and Cybernetics, Volume 8, No. 8, pp. 630-632, 1978.