Indigo Dyeing on Rotor and Open-End Spun Yarn at Different Parameters

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Abstract

Indigo dyeing is a widely adopted coloration technique in the denim industry, where shade depth, color durability, and process efficiency are strongly influenced by yarn structure and dyeing parameters. In the present study, the effect of yarn type, dye concentration, and dye bath pH on the color characteristics and washing fastness of indigo-dyed cotton yarns was systematically investigated. Rotor-spun (ring) and open-end spun cotton yarns of 10 Ne were dyed using indigo at two shade concentrations (2.0% and 3.5% owf) under varying alkaline pH conditions ranging from 10.5 to 13.5. Indigo dyeing was carried out through controlled reduction–oxidation cycles, followed by standard washing treatment.

Color properties of the dyed yarns were evaluated using spectrophotometric measurements in terms of CIE L*, a*, b* coordinates and color strength (K/S) values, both before and after washing. Washing fastness was assessed using multi fiber adjacent fabrics comprising cotton, polyester, and wool. The results revealed that dye concentration and dye bath pH significantly influenced shade depth, color strength, and durability. Higher dye concentration (3.5%) resulted in increased color strength and darker shades, while also exhibiting slightly greater shade loss after washing.

Rotor-spun yarns consistently showed higher K/S values, lower L* values, and superior shade retention compared to open-end spun yarns, attributed to their compact yarn structure and pronounced ring dyeing behavior. An optimal dye bath pH range of approximately 11.5–13.0 was identified, providing enhanced reduction efficiency, stable blue hues, and improved washing fastness. Excessively low or high pH conditions led to reduced color strength and inferior dye fixation.

Overall, the study demonstrates that controlled optimization of dye bath pH, dye concentration, and yarn structure is essential for achieving consistent color performance and acceptable washing durability in indigo-dyed cotton yarns. The findings offer valuable insights for process optimization and sustainable indigo dyeing in denim manufacturing.

1. Introduction

In the textile business, one standard dyeing method is used to dye denim fabric, i.e. indigo ring dyeing on rotor yarn(1). This method is well-known for creating vivid and distinctive blue hues on cotton rotar yarns, which are frequently used to make denim. The dyeing process entails meticulously regulating the dyeing parameters, including pH, dye shade percentage, and dye characterization utilizing L, a, and b values and K/s color strength, in order to attain the intended blue hue and guarantee color fastness and durability(2).

The quality of the dyed result is largely dependent on the yarn structure(3). The amount of dye that can be absorbed by the fiber, the depth of dye penetration, and the overall color fastness and durability of the dyed yarn are all influenced by the rotor yarn's structure. When it comes to resistance to dye penetration, rotar yarns outperform other

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yarn structures because of their compact and twisted structure(4). That same quality, meanwhile, also makes them more resilient and perfect for making denim.

One crucial factor that affects the final shade of blue on the dyed rotar yarn is the percentage of dye used in the indigo ring dyeing procedure. For deeper blue tones, a larger proportion of dye is used; for lighter blue tones, a lower proportion of dye is used(5). The type of yarn being used, the required amount of color fastness and durability, and the intended shade all influence the dye shade %.

In addition to controlling the concentration of the indigo dye vat and the number of immersions, the temperature of the dye vat can also affect the color strength. Indigo dyeing is an oxidation-reduction process, meaning that the indigo powder is reduced to a soluble form before it can bind with the cotton fiber(6). This reduction process is more efficient at higher temperatures, resulting in a more intense color. However, higher temperatures can also lead to more dye consumption per immersion, which can lead to a lower color strength overall. By finding the optimal temperature, the desired color strength can be achieved while minimizing dye consumption(7).

An additional crucial factor influencing the indigo ring dyeing process on rotar yarn is the pH of the dye solution. For the dyeing procedure, a pH of 10 to 11 is ideal. If the pH is less than 10, the dye may become insoluble and create uneven dyeing; if it is higher than 11, the dye may break down and lose its color fastness(8).

One approach that is frequently used to describe the color of textile materials is the L,a,b color space. The brightness, red-green, and yellow-blue color components of the dyed material are described by the L, a and b values, which are measured using a spectrophotometer. A higher L value denotes a brighter substance(9). The L value represents the brightness of the material. The red-green and yellow-blue color components are represented by the numbers a and b, respectively; positive values denote the presence of red or yellow, and negative ones, of green or blue. In order to compare the dyed yarn's color to the intended color and to guarantee consistency in the dyed yarn's color, L, A, and B values are utilized.

An indicator of a dyed material's color intensity is the K/s color strength. Using a spectrophotometer, the amount of light absorbed by the material is measured in order to calculate the K/s value. More intensity in color is indicated by a higher K/s value, whereas lighter color is indicated by a lower K/s value. The quality of the dye, the structure of the yarn, and the dyeing parameters are some of the variables that affect the K/s value(10).

When making denim fabrics, washing durability of the coloring process on cotton rotar yarn is a crucial consideration. The quality of the dye, the structure of the yarn, and the dyeing parameters are some of the elements that affect how long the dyed yarn will last. To guarantee that the yarn maintains its strength and durability and that the dye enters the fibers uniformly, the dyeing process needs to be closely regulated. The durability of the yarn that has been dyed is also greatly influenced by the quality of the indigo dye that was used in the procedure(11).

Important elements that affect the final dyed product's quality are the yarn's structure and the indigo dye's quality. The quality of the dyed yarn is also influenced by dyeing parameters, which include dye shade percentage, pH, and dye characterization using L, a, and b values, Delta E and K/s color strength(12). Knowing these elements is essential for calculating the amount of chemicals and color used, which reduces environmental risks and makes the process more cost-effective and sustainable.

2. Materials and Methods

Materials

Two types of cotton yarns were used in this study: rotor-spun (ring) yarn and open-end (OE) spun yarn, each with a linear density of 10 Ne. Commercial indigo blue dye in powder form was employed as the colorant. Sodium hydrosulphite was used as the reducing agent to convert indigo into its leuco-soluble form. Sodium hydroxide (caustic soda) was utilized to adjust and maintain the alkalinity of the dye bath. A non-ionic wetting agent and a dispersing agent were added to ensure uniform wetting and proper dispersion of the dye in the liquor. All chemicals used were of industrial textile grade.

Preparation of Indigo Dye Vat

The indigo dye vat was prepared by dissolving the required amount of indigo powder in water, followed by the addition of sodium hydroxide to achieve the desired alkaline pH. Sodium hydrosulphite was then added gradually under continuous stirring to reduce the indigo to its leuco form. The dye bath was allowed to stabilize until a clear yellow-green solution was obtained, indicating complete reduction of indigo. The pH of the dye bath was carefully adjusted and maintained in the range of 10.5 to 13.5, depending on the experimental condition.

Dyeing Procedure

Yarn samples were dyed using two different dye concentrations, namely 2.0% and 3.5% (owf), for both rotor-spun and open-end spun yarns. The yarns were immersed in the reduced indigo dye bath for a fixed duration to allow surface dye deposition, followed by removal from the bath and exposure to air for oxidation. This oxidation step reconverted the leuco indigo into its insoluble blue form, resulting in characteristic ring dyeing on the yarn surface. Multiple dipping and oxidation cycles were carried out to build the desired shade depth. The dyeing was conducted at controlled temperature and liquor ratio to ensure reproducibility.

Washing Treatment

After dyeing, the yarn samples were thoroughly rinsed with water to remove unfixed and loosely adhered dye particles. A standard washing process was then carried out using a mild detergent solution at controlled temperature and time conditions. The washed samples were subsequently air-dried under ambient conditions before further evaluation.

Color Measurement and Color Strength Analysis

The color characteristics of the dyed yarns were evaluated using a reflectance spectrophotometer. Color coordinates were determined in the CIE L*, a*, b* color space, where L* represents lightness, a* indicates the red–green axis, and b* represents the yellow–blue axis. Measurements were carried out before and after washing to assess shade variation and color stability. The color strength (K/S) values were calculated from the reflectance data using the Kubelka–Munk equation at the wavelength of maximum absorption (λmax). The effect of pH, dye concentration, yarn type, and washing on color strength was systematically analyzed.

Washing Fastness Testing

Washing fastness of the dyed yarn samples was evaluated according to standard textile testing methods using multifiber adjacent fabrics comprising cotton, polyester, and wool. The samples were subjected to a controlled washing cycle, after which the degree of color change and staining on adjacent fabrics was assessed using the grey scale. Fastness ratings were reported on a numerical scale, allowing comparison of the performance of rotor-spun and open-end spun yarns under different dyeing conditions.

Experimental Design and Data Analysis:

All dyeing experiments were carried out under controlled laboratory conditions to minimize experimental variability. Each test was repeated to ensure consistency and reliability of results. The collected data were analyzed to study the influence of yarn structure, dye concentration, and dye bath pH on color strength, color coordinates, and washing fastness, forming the basis for the results and discussion presented in this study.

3. Results and discussions

Graphical representation of K/S value Vs λ max

This graphical representation shows the colour strength of the yarn dyed at different pH and different concentrations.

Effect of pH and Dye Concentration on Color Strength (K/S)

The color strength of indigo-dyed rotor-spun and open-end spun yarns was evaluated in terms of K/S values as a function of wavelength (λmax), dye concentration (2.0% and 3.5%), and dye bath pH. Figures illustrating K/S versus λmax clearly indicate that color strength increases with increasing dye concentration for both yarn types, confirming greater surface deposition of indigo at higher shade percentages.

For rotor-spun yarns, the K/S values were consistently higher than those of open-end yarns at comparable dyeing conditions. This behavior can be attributed to the compact yarn structure of rotor yarns, which promotes pronounced ring dyeing and higher surface dye concentration. Among the studied pH range, optimal color strength was observed between pH 11.5 and 13.0. At lower pH values, incomplete reduction of indigo may have limited dye uptake, while excessively high pH resulted in marginal reduction in color strength, possibly due to instability of the leuco-indigo form.

After washing, a decrease in K/S values was observed for all samples, indicating partial removal of unfixed dye. However, rotor-spun yarns retained a higher proportion of color strength compared to open-end yarns, demonstrating better dye fixation and resistance to washing. The reduction in K/S after washing was more pronounced at lower dye concentrations, highlighting the role of dye loading in color durability.

Ring 2%

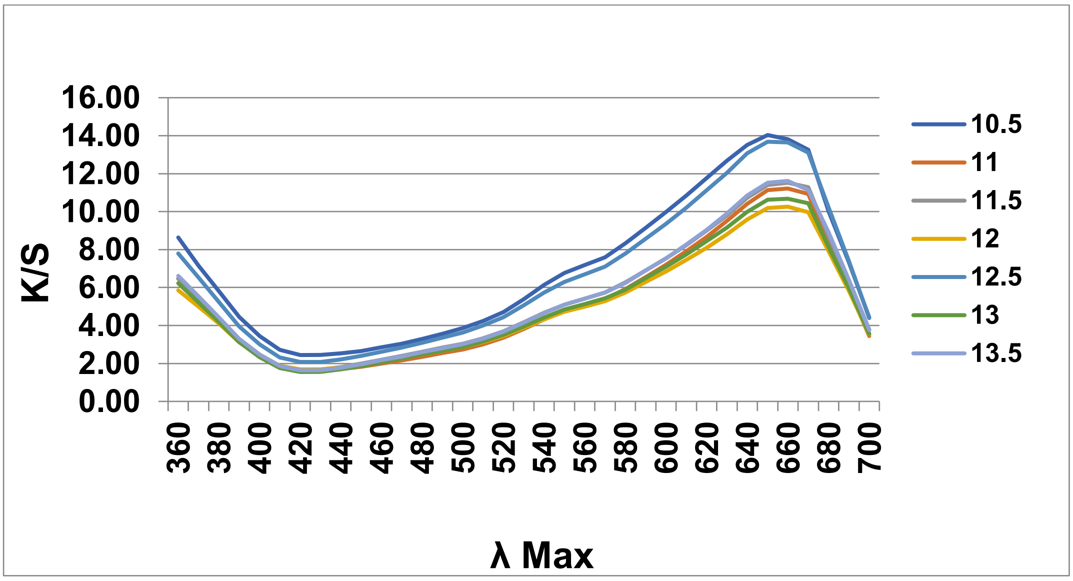

Fig: K/S value at different λ max of yarn dyed at different pH

Ring 2% (After Wash)

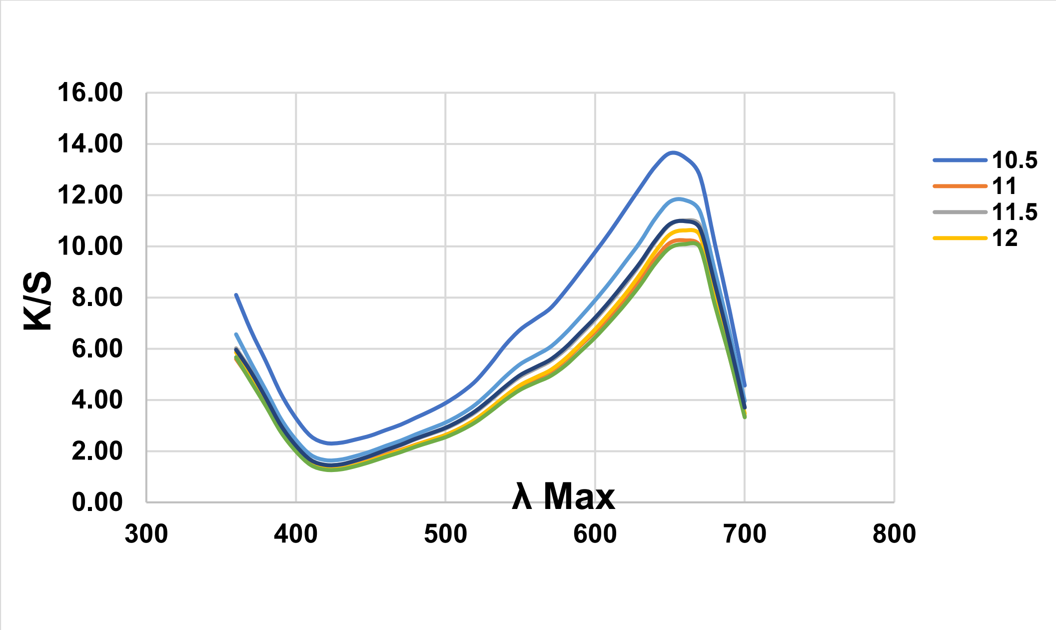

Fig: K/S value at different λ max of yarn dyed at different pH after wash

Ring yarn 3.5 %

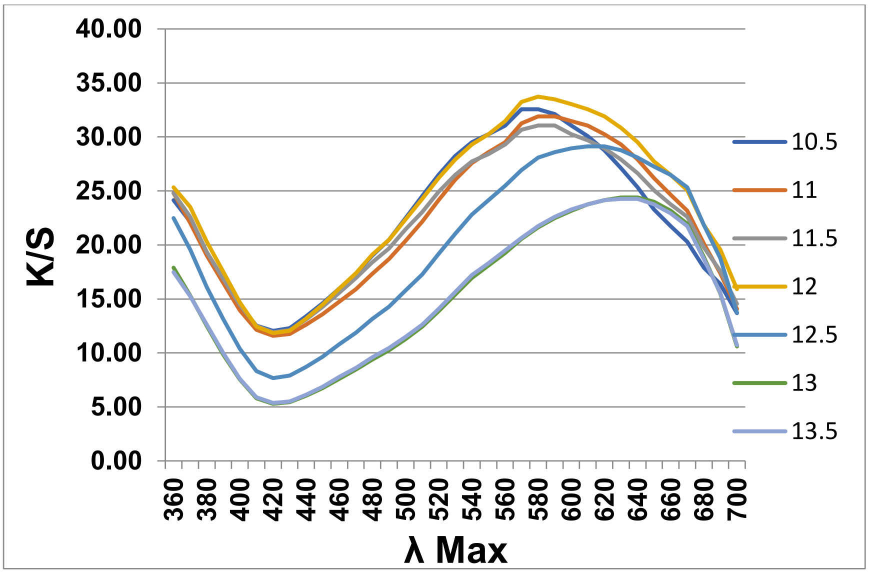

Fig: K/S value at different λ max of yarn dyed at different pH

Ring 3.5% (After wash)

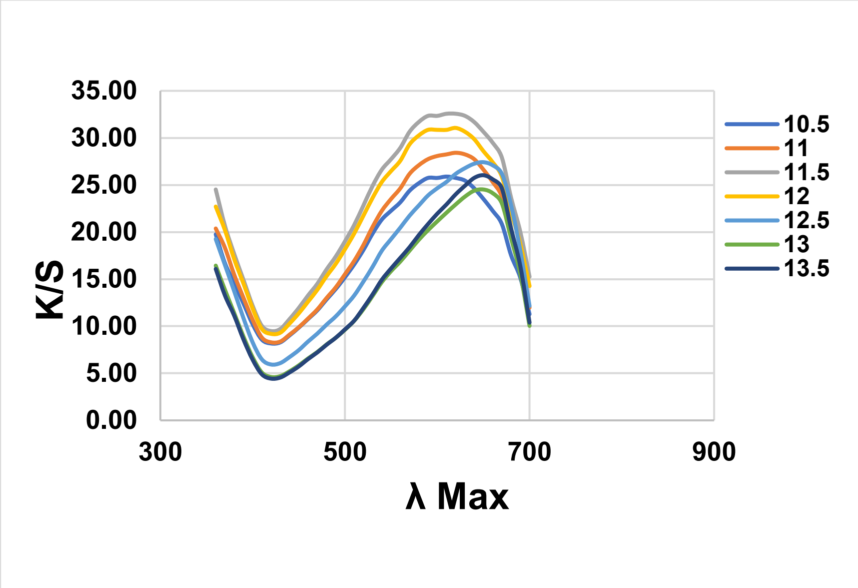

Fig: K/S value at different λ max of yarn dyed at different pH after wash

Open end 2%

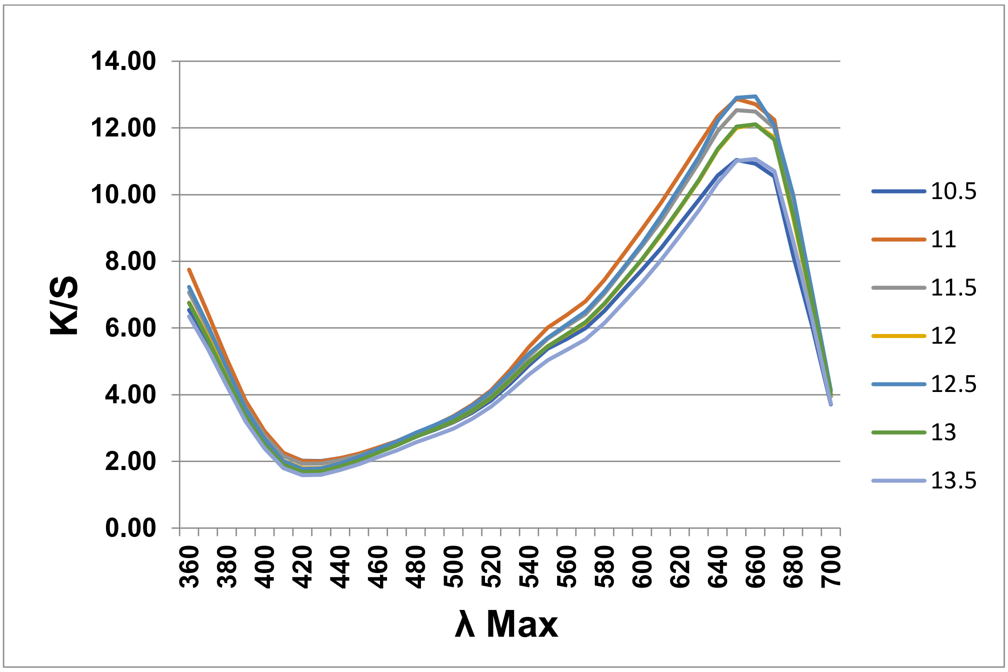

Fig: K/S value at different λ max of yarn dyed at different pH

Open end 2% (After wash)

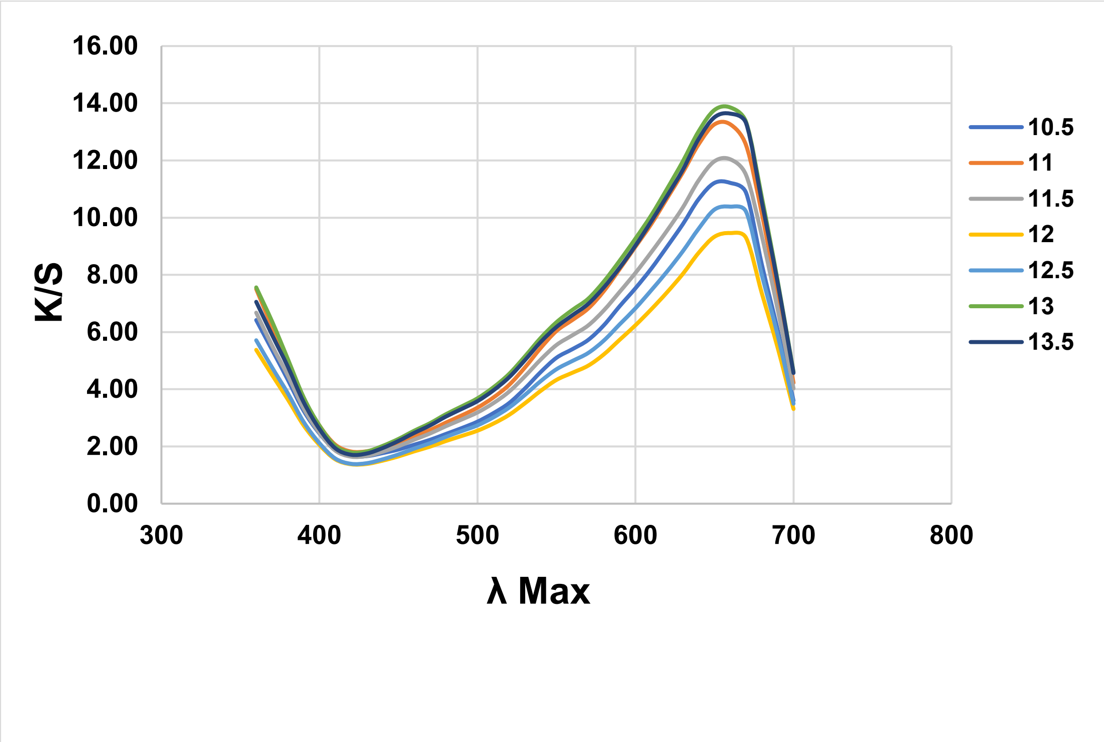

Fig: K/S value at different λ max of yarn dyed at different pH after wash

Open end 3.5%

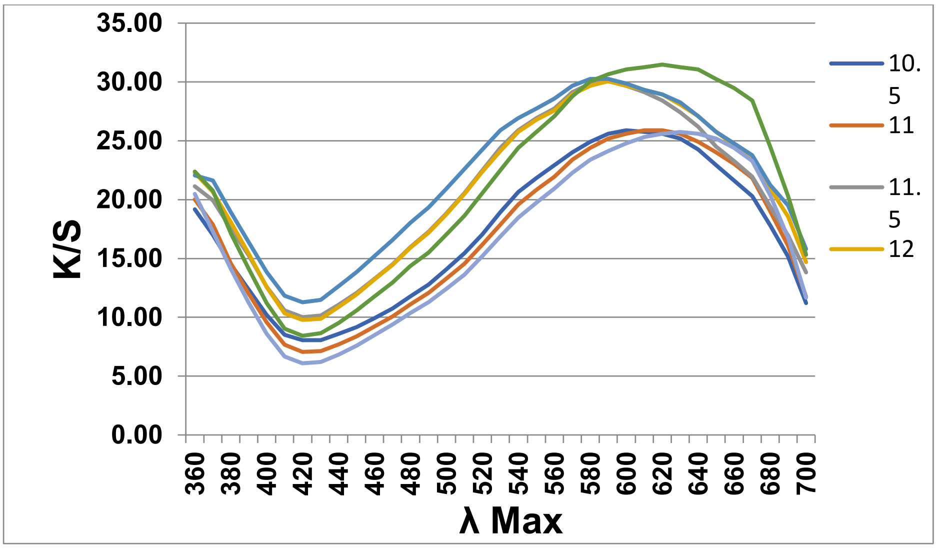

Fig: K/S value at different λ max of yarn dyed at different pH

Open end 3.5 %(After Wash)

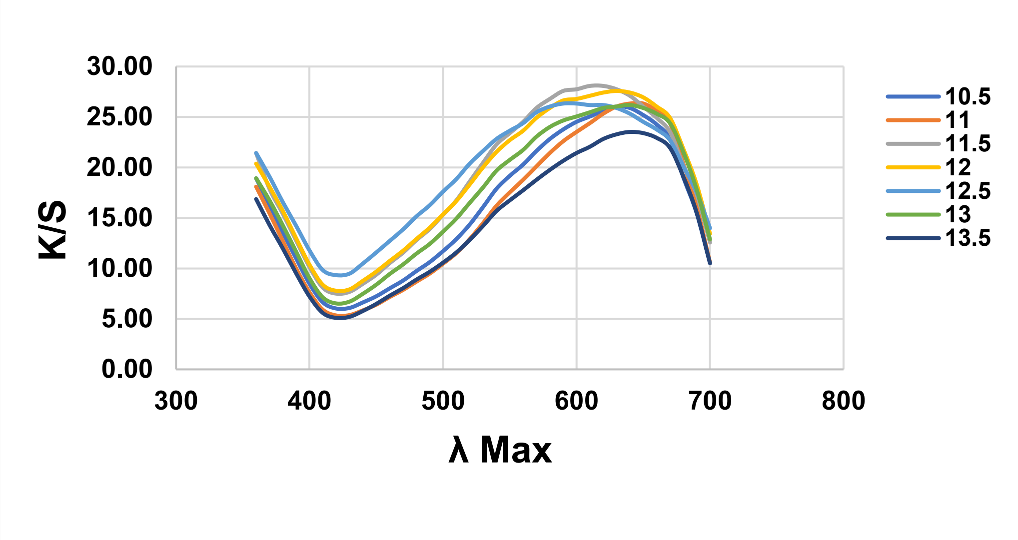

Fig: K/S value at different λ max of yarn dyed at different pH after wash

Influence of pH on CIE L*, a*, b* Color Coordinates:

The effect of dye bath pH on the color characteristics of dyed yarns was analyzed using CIE L*, a*, and b* values. For both yarn types and dye concentrations, L* values decreased with increasing dye concentration, indicating darker shades at 3.5% compared to 2.0%. Rotor yarns exhibited lower L* values than open-end yarns at the same dye concentration, corroborating the higher color strength observed in K/S measurements.

The a* values remained close to zero for most samples, indicating minimal red–green contribution in the dyed shades. Slight positive or negative shifts in a* values were observed with changing pH, but no systematic trend was evident. The b* values were consistently negative, confirming the dominance of blue hues characteristic of indigo dyeing. Increasing alkalinity generally resulted in more negative b* values, suggesting enhanced blue tone development due to more effective reduction and oxidation cycles.

After washing, an increase in L* values was noted across all samples, indicating shade lightening due to dye loss. Nevertheless, the relative trends among different pH levels and dye concentrations remained similar, implying that washing did not significantly alter the fundamental color tone but primarily affected shade depth.

L, a and b value at different pH

RING-3.5%			
pH	L	a	b
10.5	14.3	3.83	-10.91
11	14.78	2.51	-11.4
11.5	14.71	2.95	-10.63
12	14.12	3	-11.39
12.5	16.66	2.7	-15.36
13	19.81	2.35	-17.99
13.5	19.68	2.47	-17.8

RING-2%			
pH	L	a	b
10.5	32.08	-3.59	-19.65
11	36.86	-3.92	-21.23
11.5	35.76	-2.85	-21.1
12	36.81	-3.4	-19.89
12.5	33	-2.85	-20.93
13	36.57	-2.62	-21.44
13.5	35.81	-2.76	-21.4

OE-3.5%			
pH	L	a	b
10.5	17.79	1.82	-14.3
11	18.25	1.9	-15.57
11.5	15.49	3.08	-12.6
12	15.51	3.01	-12.83
12.5	14.93	2.93	-10.95
13	15.92	2.38	-14.72
13.5	18.85	2.16	-16.9

OE-2%			
pH	L	a	b
10.5	35.17	-3.81	-19.26
11	33.84	-3.41	-21.16
11.5	34.44	-3.44	-20.83
12	34.92	-2.9	-21.1
12.5	34.25	-2.41	-21.83
13	34.92	-2.26	-21.95
13.5	36.03	-2.41	-21.62

L, a and b value at different pH After wash

RING-3.5%(AFTER WASH)			
pH	L	a	b
10.5	17.38	2.32	-13.73
11	16.88	2.02	-14.38
11.5	15.08	2.66	-13.7
12	15.56	2.67	-13.8
12.5	19.05	1.71	-16.96
13	21.33	1.47	-18.81
13.5	21.16	1.68	-19.55

RING-2%(AFTER WASH)			
pH	L	a	b
10.5	32.15	-2.88	-20.09
11	37.62	-2.89	-22.03
11.5	36.48	-2.02	-22.38
12	37.56	-2.19	-23.25
12.5	35.22	-2.31	-22.02
13	38.11	-2.25	-22.97
13.5	36.33	-1.89	-22.48

O E-3.5%(AFTER WASH)			
pH	L	a	b
10.5	19.26	1.6	-17.1
11	20.24	1.09	-18.21
11.5	17	2.78	-15.35
12	17.18	2.26	-14.47
12.5	16.52	2.55	-11.92
13	18.2	2.51	-15.91
13.5	20.62	1.86	-17.61

O E-2%(AFTER WASH)			
pH	L	a	b
10.5	36.14	-3.47	-21.55
11	33.84	-2.53	-22.33
11.5	34.89	-1.97	-22.34
12	38.29	-2.77	-21.57
12.5	37.15	-2.16	-22.48
13	32.94	-1.13	-22.67
13.5	33.31	-1.05	-22.92

Washing fastness

Ring – 3.5%	Color Fastness Rating		
	Cotton	Polyester	Wool
pH - 10.5	2 - 3	3 - 4	3 - 4
11	3	3 - 4	4
11.5	3	3 - 4	4
12	3	2 - 3	4
12.5	3	3	4
13	3 - 4	4	4
13.5	3	4	4

Ring – 2.0%	Color Fastness Rating		
	Cotton	Polyester	Wool
pH - 10.5	3 - 4	4	4
11	4	4	4
11.5	3 -4	3 - 4	4
12	3 - 4	4	4
12.5	4	4	4
13	3 - 4	3	4
13.5	4	3 - 4	4

OE – 3.5%	Color Fastness Rating		
	Cotton	Polyester	Wool
pH - 10.5	3	4	4
11	3	3	4
11.5	3	3	4
12	2 - 3	4	4
12.5	2 - 3	4	4
13	3 - 4	4	4
13.5	2 - 3	4	4

OE – 2.0%	Color Fastness Rating		
	Cotton	Polyester	Wool
pH - 10.5	3 - 4	3 - 4	4
11	3 - 4	3 - 4	4
11.5	3 -4	4	4
12	3 - 4	4	4
12.5	3- 4	4	4
13	3 - 4	4	4
13.5	4	4	4

Comparison between Rotor-Spun and Open-End Spun yarns:

A comparative assessment of rotor-spun and open-end spun yarns revealed distinct differences in dyeing behavior. Rotor yarns consistently demonstrated higher color strength, lower L* values, and better shade retention after washing. This can be attributed to their tighter yarn structure, which facilitates surface dye deposition and restricts dye migration during washing. In contrast, open-end yarns exhibited relatively lower color strength and greater shade loss, possibly due to their more open structure and higher fiber accessibility to washing action.

Washing Fastness Performance:

The washing fastness results for cotton, polyester, and wool adjacent fabrics showed satisfactory to good fastness ratings for all dyed samples. Rotor-spun yarns dyed at 3.5% concentration generally exhibited slightly lower fastness on cotton compared to 2.0% shades, likely due to higher surface dye presence. However, fastness ratings improved at higher pH levels, particularly in the range of pH 12.5 to 13.5, indicating improved dye fixation.

Open-end yarns showed comparable fastness ratings on polyester and wool but marginally lower performance on cotton, especially at lower pH values. Overall, washing fastness ratings ranged from moderate to good, confirming that indigo-dyed yarns maintained acceptable durability under domestic washing conditions.

Overall Interpretation:

The results demonstrate that dye bath pH, dye concentration, and yarn structure play a critical role in determining the color strength, shade characteristics, and washing durability of indigo-dyed cotton yarns. Rotor-spun yarns exhibited superior dyeing performance compared to open-end spun yarns. An optimal pH range of approximately 11.5–13.0 was identified as favorable for achieving higher color strength, stable blue shades, and improved washing fastness, making these conditions suitable for industrial indigo dyeing applications.

4. Conclusion:

This study systematically investigated the influence of yarn structure, dye concentration, and dye bath pH on the indigo dyeing performance of rotor-spun and open-end spun cotton yarns. The results clearly demonstrate that both dyeing parameters and yarn morphology play a decisive role in determining color strength, shade characteristics, and washing durability of indigo-dyed yarns.

Rotor-spun yarns consistently exhibited higher color strength (K/S values), lower L* values, and superior shade retention after washing compared to open-end spun yarns under identical dyeing conditions. This behavior is attributed to the compact structure of rotor yarns, which promotes pronounced ring dyeing and enhances surface dye fixation. In contrast, open-end spun yarns showed relatively lower color strength and greater shade loss, owing to their more open and less compact structure.

Dye concentration had a significant effect on shade depth, with 3.5% dye concentration producing deeper and more intense blue shades than 2.0% for both yarn types. However, higher dye concentration also led to slightly increased shade loss after washing, emphasizing the importance of optimizing dye loading to balance shade depth and durability.

The dye bath pH strongly influenced the reduction efficiency of indigo and subsequent color development. An optimal pH range of approximately 11.5 to 13.0 was identified as most favorable for achieving higher color strength, stable blue tones (more negative b* values), and improved washing fastness. Dyeing at excessively low or high pH resulted in reduced color strength and inferior dye fixation.

Overall, the findings highlight that careful control of dyeing parameters, particularly pH and dye concentration, combined with appropriate yarn selection, is essential for achieving consistent shade quality and acceptable washing fastness in indigo dyeing.

References

1. American Association of Textile Chemists and Colorists. (2021). *AATCC technical manual*. AATCC.
2. Aspland, H. R. (1997). *Textile dyeing and coloration*. American Association of Textile Chemists and Colorists.
3. Aspland, J. R. (1993). *Textile dyeing and coloration*. AATCC Press.
4. Clark, M. (Ed.). (2011). *Handbook of textile and industrial dyeing: Principles, processes and types of dyes* (Vol. 1). Woodhead Publishing.
5. Hunter, A. (2008). *The measurement of appearance* (2nd ed.). Wiley-Interscience.
6. Hunger, K. (Ed.). (2003). *Industrial dyes: Chemistry, properties, applications*. Wiley-VCH.
7. International Organization for Standardization. (2010). *ISO 105-C06: Textiles – Tests for colour fastness – Part C06: Colour fastness to domestic and commercial laundering*. https://www.iso.org/standard/51276.html
8. Lewis, D. T. (2014). *Fundamental principles of textile dyeing*. Society of Dyers and Colourists.
9. McDonald, R. (Ed.). (2002). *Colour physics for industry* (2nd ed.). Society of Dyers and Colourists.
10. Shore, J. (Ed.). (2002). *Cellulosics dyeing*. Society of Dyers and Colourists.
11. Trotman, E. R. (2006). *Dyeing and chemical technology of textile fibres*. Charles Griffin.
12. Xin, J. H., & Hallett, J. P. (2002). Influence of dyeing parameters on indigo dyed cotton yarn. *Coloration Technology, 118*(5), 243–249.