PROGRESS IN COLOR, COLORANTS AND COATINGS

available online @ www.pccc.icrc.ac.ir

Progress in Color Colorants Coating 20 (2027), 339-351

Ministry of Science, Research and Technology
Institute for Color Science & Technology

Comparative Industrial Wet Processing of Cotton-Spandex Knit Fabric Using Conventional Scouring, Bio-Scouring, and Integrated One-Bath Reactive Dyeing

S. Sayam[*1], Md R. Hossen[2], Md. M. Islam[1]

[1.] Department of Fabric Engineering, Barishal Textile Engineering College, P. O. Box: 8200, Barishal, Bangladesh

[2.] Department of Wet Processing Engineering, Shahid Abdur Rab Serniabat Textile Engineering College, P.O. Box: 8200, Barishal, Bangladesh

ARTICLE INFO

Article history:
Received: 21 May 2026
Final Revised: 31 Aug 2026
Accepted: 01 Sep 2026
Available online: 01 Nov 2026

Keywords:
Cotton-spandex knit fabric
Reactive dyeing
One-bath dyeing
Bio-scouring
Sustainable wet processing

ABSTRACT

The overuse of water, thermal energy, chemicals, and auxiliaries in the processes of pretreatment and reactive dyeing in textile wet processing operations has created a huge burden on the environment and complicated the operations. In the present study, conventional scouring and enzymatic bio-scouring processes and a one-bath reactive dyeing process were compared and contrasted in scouring cotton-spandex knit fabric on a production scale. The single jersey knit fabric made with a batch weight of 435 kg with a liquor ratio of 1:6 was processed by using 95% BCI cotton and 5% spandex. The water consumption, steam requirement, electrical power consumption, process duration, chemical loading, and finished fabric quality performance were evaluated by comparative evaluation. The one-bath route (with integration) was the most energy-efficient of all the routes studied. A 29.4% reduction in water usage was achieved for one-bath processing, which used 56.5 L/kg of fabric compared to 80.0 L/kg of fabric for conventional scouring. The number of stages of operation was shortened from 45 to 27, and the actual processing time was shortened from about 11 h to 7 h 30 min without the need for separate pretreatment and intermediate washing operations. Other benefits include reduction in steam consumption, electrical power requirements, and severity of the chemicals. Quality assurance testing showed finished fabric properties of dimensional stability, spirality, GSM, pH, appearance retention, and color fastness were satisfactory for all processing methods. Prog Color Colorants Coat. 20 (2027), 339-351© Institute for Color Science and Technology.

1. Introduction

As one of the basic needs of human life after food, the textile industry has a significant contribution in making textile fibers into yarns, fabrics and garments by a series of wet processing. Wet processing is viewed as one of the most resource demanding stages in all textile manufacturing processes as it uses significant amounts of water, thermal energy, dyes, salts, alkalis, oxidising agents, surfactants and auxiliary chemicals [1]. In dyeing and finishing processes, large amounts of dyeing waste water are produced which contains a variety of organic and inorganic contaminants and are highly heterogeneous in nature and difficult to treat [2]. These effluents often contain dyes and surfactants, salts, enzymes, oxidizing agents, reducing agents, and heavy metals which can have considerable impacts on surface water and groundwater when discharged without adequate treatment [3]. However, wastewater treatment

*Corresponding author: * mahubu.sayamm@gmail.com
https://doi.org/10.30509/pccc.2026.167801.1507

plants are either under-developed or not provided in many developing countries, especially in small scale industrial plant, due to economic reasons which cause serious environmental pollution and ecological degradation [4]. In addition, Bangladesh is one of the important-textile producing countries and the rise of industries around greater Dhaka has escalated the groundwater depletion owing to the critical need of huge amount of water in textile wet processing for pretreatment, dyeing, washing, and finishing process [5]. The untreated textile effluents with high pollutant concentration has emerged as a serious environmental problem in the industrialized areas and the use of thermal energy and chemicals further aggravates the environmental footprint of the textile industry [6]. The textile industry also requires a lot of energy for production, besides water. A previous study found that 1.44 MJ of energy was used to produce one knit garment from dyed and finished fabric, and between 0.78 MJ and 1.44 MJ of energy to produce finishing operations for the knit garment [2]. As a result, the textile supply chain is a major emitter of GHG, responsible for almost 10 % of the global GHG emissions every year [7]. Because of these environmental issues, the fabric dyeing and chemical treatment industries in Bangladesh are classified as 'Red' industries under the Environmental Conservation Rules (1997) which stipulates upon strict compliance with the environment before operation [8].

The reactivity of the dye to cotton and its good chemical affinity with the cellulosic fibers make it a popular choice for cotton and cotton-blending fabrics. Reactive dyes have the best color stability and shade fidelity for cotton with over 50 % of the world's total dye usage [9]. But an appreciable quantity of electrolytes, such as NaCl or Na_2SO_4, are required to overcome the electrostatic repulsion between the cotton fiber and anionic reactive dye molecules in the case of Reactive cotton dyeing [10, 11]. Dissociated sodium ions decrease the zeta potential at the fiber-water interface and help dye exhaustion on the fiber surface [12]. Due to this, a huge amount of salt and alkali is needed in the reactive dyeing process and it leads to more pollution in the textile effluents. The pretreatment operations (scouring and bleaching) in a conventional (reactive dyeing) process are carried out separately before dyeing. To enable uniform dye absorption and penetration, cotton fibers must be scoured to remove the hydrophobic impurities such as waxes, pectins, proteins, and fats from the fibers [13]. Conventionally, this is done by hot alkaline solutions of sodium hydroxide and peroxide followed by several washing and neutralization steps. While successful, conventional pretreatment uses a large volume of water, steam, chemicals and processing time and produces an environmentally damaging, highly alkaline wastewater stream.

The use of enzymatic bio-scouring as a wet processing method has emerged as an alternative to conventional scouring to minimize environmental impact. The main mechanism of bio-scouring involves the use of pectinase enzymes for the hydrolysis of pectic substances and the removal of other non-cellulosic impurities from cotton fibers under relatively mild processing conditions [14]. Enzymatic treatment makes it easier to absorb and helps the dyes penetrate and is less likely to damage the fibers as opposed to the more conventional alkaline scouring [15]. In addition, bio-scouring results in relatively small amounts of pollutants as it decreases the use of harsh chemicals like sodium hydroxide and peroxide. Further, bio-scouring can be performed with the existing textile machines and processing can be done on different blends of natural fibers. However, all these benefits have hindered the industrial application of bio-scouring because of the lack of reproducibility of the process, its high cost, the sensitivity of enzymes, and the need for optimization of the process on a large scale.

The growing awareness of the environment and pressure for sustainable textile production have led to the development of integrated wet processing technologies which aimed to minimize the number of process steps, consumption and generation of useful and wastewater [1, 16]. The one-bath dyeing technology is one such method where the pretreatment and dyeing processing are carried out in a single process. The previous studies on the one-bath and one-step dyeing techniques were primarily directed towards polyester/cotton blended fabrics with various combinations of dyes and process modifications to minimize the consumption of water, chemicals and production time [17-20]. One-bath systems can utilize process integration to minimize the number of washing stages, thermal cycles, and reduce complexity of operation thereby increasing productivity. A few studies were also conducted to explore some changes in the dye chemistry and fiber treatment for better

dyeability and process compatibility under integrated dyeing conditions [21-24]. Although, previous studies have primarily focused on laboratory-scale investigations, polyester/cotton blends, or individual process modifications. To the best of the authors' knowledge, a comprehensive industrial-scale comparison of conventional scouring, bio-scouring, and integrated one-bath reactive dyeing for 95 % BCI cotton/5 % spandex single jersey fabric under identical production conditions has not been reported. Consequently, direct comparison with previous studies is limited, although the present findings are generally consistent with the reported benefits of process integration and enzymatic pretreatment in reducing processing complexity and resource consumption. The present study addresses this gap by providing industrial-scale comparison of these three commercially relevant wet processing routes under identical production conditions. The study integrates the evaluation of utility consumption, process duration, chemical usage, operational simplification, and finished fabric quality within a single industrial production framework, thereby providing practical evidence for the implementation of integrated one-bath reactive dyeing in commercial textile manufacturing.

The aim of the present research was:

1. Analyze the use of utilities in various wet processing routes.
2. Compare the length of the process and stages of the process.
3. Evaluate the use of chemicals.
4. Analyze completed fabric quality end results.
5. Discuss about the use of one bath dyeing technology in industries.

2. Experimental

2.1. Experimental design and processing conditions

Single jersey knit fabric made of 95 % BCI cotton and 5 % spandex with a nominal fabric weight of 180 GSM was used in this study. Large-scale reactive dyeing for a black shade was carried out using three wet processing routes: conventional scouring, enzymatic bio-scouring, and integrated one-bath reactive dyeing. All experiments were conducted in a textile factory located in East Chandra, Gazipur, Dhaka, Bangladesh, using ATHENA 4 soft-flow dyeing machines under industrial production conditions. A fabric batch weight of 435 kg and a liquor ratio of 1:6 was maintained throughout the comparative evaluation. The manufacturer is not disclosed due to confidentiality agreements.

Table 1 provides an overview of the experimental design adopted for the three wet processing routes. The processing routes differed only in the pretreatment strategy, while the remaining experimental conditions were maintained consistently. Each route was performed according to its established industrial operating procedure without additional optimization specifically for this comparative investigation.

The evaluation was conducted using one full-scale industrial production batch for each wet processing route under standardized manufacturing conditions. Utility consumption, process duration, chemical usage, and finished fabric quality were obtained from the corresponding industrial production records and quality control measurements for each route. Since the study was designed as an industrial process comparison rather than a replicated laboratory experiment, the reported values represent actual production observations.

Table 1: Comparative experimental design for the three wet processing routes.

Item	Description
Variables kept constant	Fabric substrate, fabric composition, reactive dye shade, batch size, dyeing machine, liquor ratio, production condition
Variable intentionally changed	Wet processing route (conventional scouring, bio-scouring, and integrated one-bath reactive dyeing)
Process conditions	Each route followed its respective industrial operating procedure without additional optimization for this comparative study.

2.2. Wet processing routes

Wet processing routes were developed taking different pretreatment steps before the fixation of the reactive dyes and the final finishing steps. The conventional method used alkaline peroxide scouring followed by enzyme in the fabric before the application of Reactive dyeing and the bio-scouring method used enzyme-based bio-scouring in fabric under lower scouring temperatures before Reactive dyeing. The one-bath route, on the other hand, combined on-line auxiliary pretreatment and reactive dyeing in the same wash bath, thus eliminating the need for separate pretreatment and middle bath changing steps. A summary of the comparative process sequence, operating temperature and planned processing conditions of the three industrial routes is presented in Table 2.

2.3. Comparative process flowchart

The covalent bond formation between the reactive dye molecule and the hydroxyl groups of cotton cellulose during reactive fiber dyeing of cotton-spandex fabrics was one of the most interesting aspects of the study. The alkaline peroxide scouring pretreatment was used as a conventional method while the bio-scouring route was used as the enzymatic removal of impurities at relatively lower pretreatment temperatures. The water, steam and electrical power consumption were determined based on the total consumption per kg of processed fabric. The detailed processing sequence, operating conditions, and runtime for the three wet processing routes are presented in Supplementary Table A, while the corresponding chemical formulations and dosages are showed in Supplementary Table B.

2.3.1. Reactive dye fixation mechanism

Reactive dye fixation to cotton fiber took place by covalent bond formation between hydroxyl groups of cellulose and the molecules of the dyes under alkaline conditions.

Cell-OH + Dye-X → Cell-O-Dye + HX
X = reactive leaving group.

2.3.2. Oxidative and enzymatic pretreatment reactions

In the conventional scouring, hydrogen peroxide produced reactive peroxide ions in alkaline condition for the removal of natural impurities from the surface of cotton.

$$H_2O_2+OH^- \rightarrow HOO^- + H_2O$$

Bio-scouring route involves the use of pectinase enzyme to break down the pectic substances in the primary wall of cotton along with mild processing conditions.

$$\text{Pectin} + H_2O \xrightarrow{\text{Pectinase}} \text{Galacturonic Acid Derivatives}$$

Table 2: Comparative planned wet processing routes.

Parameter	Conventional Scouring	Bio-Scouring	One-Bath Dyeing
Main stages	Pretreatment, dyebath, post-treatment, fixing	Pretreatment, dyebath, post-treatment, fixing	Dyebath, post-treatment, fixing
Pretreatment type	Alkali-peroxide scouring with enzyme treatment	Enzymatic bio-scouring	Special chemical dosing within dye bath
Maximum pretreatment temperature	98 °C	80 °C	40 °C initial auxiliary treatment
Dyeing temperature	60 °C	60 °C	60 °C
Soaping temperature	95 °C	95 °C	95 °C
Planned process time	648 min	569 min	485 min
Step	45	34	27

2.3.3. Utility consumption calculation

Water consumption equation:

$$\text{Water Consumption (L/kg)} = \frac{\text{Total Water Consumption (L)}}{\text{Fabric Weight (kg)}}$$

Steam consumption equation:

$$\text{Steam Consumption (kg/kg)} = \frac{\text{Total Steam Consumption (kg)}}{\text{Fabric Weight (kg)}}$$

Power consumption equation:

$$\text{Power Consumption (kWh/kg)} = \frac{\text{Total Power Consumption (kWh)}}{\text{Fabric Weight (kg)}}$$

2.4. Finished fabric testing

The industrial production testing of the finished dyed fabrics from the conventional scouring route, bio-scouring route and integrated one bath route was carried out. Dimensional stability to washing was determined by ISO 5077 and ISO 6330 with ISO 3759 test procedure. The rubbing fastness, water fastness and perspiration fastness were tested as per ISO 105-X12, ISO 105-E01 and ISO 105-E04 standards respectively. The pH of the fabric was determined by ISO 3071. The fabric weight was determined using the method of EN 12127. Further testing such as repeated washing, spirality, stretch and recovery was carried out following standard in laboratory testing methods. Testing all performed under nominated QA conditions.

3. Results and Discussion

3.1. Utility consumption analysis

3.1.1. Water consumption

The water usage varied significantly between the different wet processing routes evaluated depending on the type of pretreatment arrangement, wash frequency, and bath replacement procedures. The conventional scouring method had the highest water requirement of all and the total consumption was 34.880L, which is 80.0 L/kg of fabric, as shown in Figure 1. The increased fresh water use was associated with the separate alkaline peroxide pretreatment, multiple hot washing cycles, neutralization, enzyme treatment and multiple drainage and refill cycles in the process sequence. Water distribution in the conventional method was also machine recorded, which revealed that the water was consumed in two stage-wise pretreatment washing processes of 8 L/kg and 5 L/kg water usage before dyeing, and in two stage washing processes of 10 liters per kg and 8 L/kg water usage after dye fixation and soaping treatment. The amount of water needed for the drain and fill cycles was also significant for some of the process steps used in industrial processing, with 4 L/kg water per cycle.

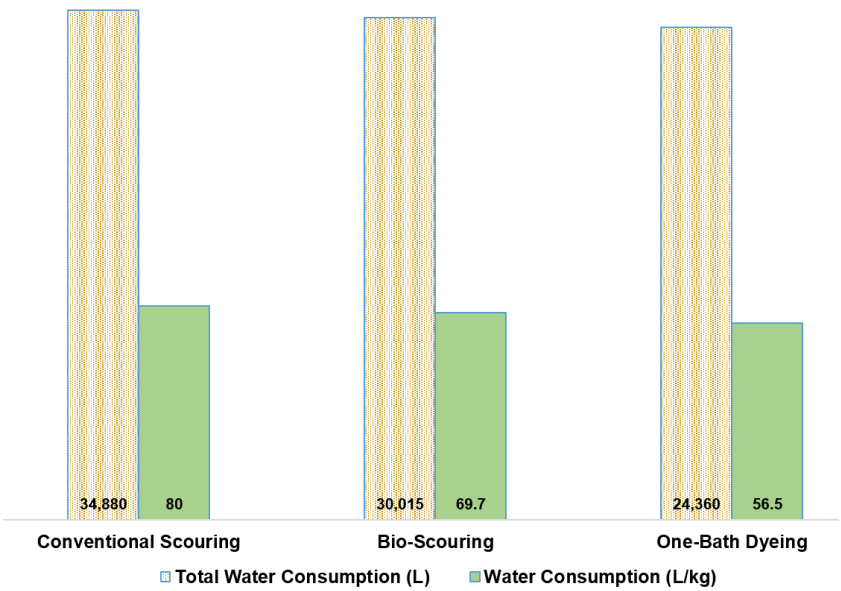

Figure 1: Total and specific water consumption of conventional scouring, bio-scouring, and one-bath dyeing processes.

The bio-scouring route reduced the water consumption to 30,015 L (specification of 69.7 L/kg fabric) which is 12.9 % less water consumption than conventional scouring method and 4,865 L water per production batch compared with conventional scouring method. The reduction was correlated with the elimination of peroxide based oxidative treatment and decrease in the pretreatment washing frequency under enzymatic processing condition. The bio-scouring route was different in that only one hot washing step and pretreatment (5 L/kg) was needed prior to dyeing, but the dyeing and post washing were relatively the same as for the conventional route.

The one-bath route, which was integrated, had the lowest water usage of 24, 360 L, or 56.5 L/kg of fabric, of all the processes evaluated. The one bath process showed a saving of 10,520 L of water in the production batch of 435 kg when compared with conventional scouring, which resulted in a water saving of 29.4 %. The integrated process successfully put in place an additional 18.9 % reduction compared to bio-scouring route with 5,655 L of lower water demand. This significant water savings was directly correlated to the removal of separate pretreatment baths, decrease in intermediate washing steps, and fewer drains during the operational sequence. The integrated route had a lower cumulative stage-wise water usage of 62 L/kg fabric than bio-scouring (71 L/kg) and conventional scouring (79 L/kg).

3.1.2. Steam consumption

There was a notable difference in steam consumption in the evaluated wet processing routes because of the difference in the pretreatment temperature and the frequency of the thermal cycles. This conventional scouring method had the maximum steam consumption of 4.3 kg steam/kg fabric due to the need for separate alkaline peroxide pretreatment, repeated hot washing steps, enzyme treatment and reheating steps during the dyeing sequence. The cumulative thermal energy demand was significantly increased in the pretreatment stage due to the higher temperature of 98 °C. The bio-scouring process however resulted in 3.8 kg steam/kg fabric which is 11.6 % lower than conventional scouring. The reduced steam requirement was due to the replacement of peroxide oxidative pretreatment with enzymatic pretreatment under relatively mild thermal pretreatment conditions, where maximum pretreatment temperature was 80 °C.

The one-bath integrated route was the lowest steam consumption process from all the processes considered, with steam consumption of 3.0 kg of steam/kg of fabric. It was found that the steam consumption was reduced by 30.2 % with the one-bath process when compared with the conventional scouring method and 21.1 % when compared with the bio-scouring method. The reduction was directly linked to the elimination of stand-alone pretreatment heating cycles, decreased inter-mediate (drainage and refill) operations, and decreased cumulative thermal transitions in the operational sequence. Reduced thermal cycling resulted in a gradual decrease in steam usage from conventional scouring to one bath integrated processing, as shown in Figure 2.

3.1.3. Power consumption

There were differences in power consumption between the different wet processing routes evaluated as a result of differences in the complexity of the process, the machine occupancy times, and the length of the process. Power consumption (kWh/kg fabric) was measured using the machine energy meter integrated into the industrial dyeing machine and calculated by dividing the total electrical energy consumption by the fabric weight (kg). The conventional scouring process required the maximum electrical power of 0.47 kWh/kg fabric as it had a long pretreatment, washing processes were repeated, machine running for a longer period of time and number of drainage cycles during the dyeing sequence. The separation of alkaline peroxide scouring, enzyme treatment and repeated bath replacement operation increased the circulation, pumping and machine running time to raise the total electrical energy demand during industrial processing. The use of enzymatic bio-scouring instead of oxidative pretreatment significantly reduced the degree of scouring and the processing time, which in turn led to a lower power consumption of 0.16 kWh/kg fabric. This was equivalent to a 66.0 % reduction in electrical energy consumed in comparison with the conventional scouring. Further reduction was seen in the integrated one-bath route where electric power consumption was reduced to 0.10 kWh/kg fabric by eliminating the standalone pretreatment and reducing the intermediate process steps from the same dye bath. The power consumption was found to be 78.7 % less in the one-bath compared to the conventional scouring process and an extra 37.5 % less than in the bio-scouring process.

Electrical energy dependency in industrial cotton-spandex wet processing can be seen in Figure 3, as the power consumption was reduced from the conventional scouring to one-bath integrated processing under the integrated system, showing the reduction of the operational sequence and machine occupancy.

3.2. Process duration and operational simplification

The different pretreatment arrangements, washing frequencies, and complexity of operation of the evaluated wet processing methods resulted in significant differences in the duration of the processes. The conventional scouring route had the longest process time with the process time being 11 h 3 min for the scouring step with alkaline peroxide, whereas the actual industrial processing time was around 11 h due to the separate step of neutralization, scouring by alkaline peroxide and repeated washing step, enzyme treatment, and multiple washing/draining steps before the fixation step of reactive dyes and finishing step.

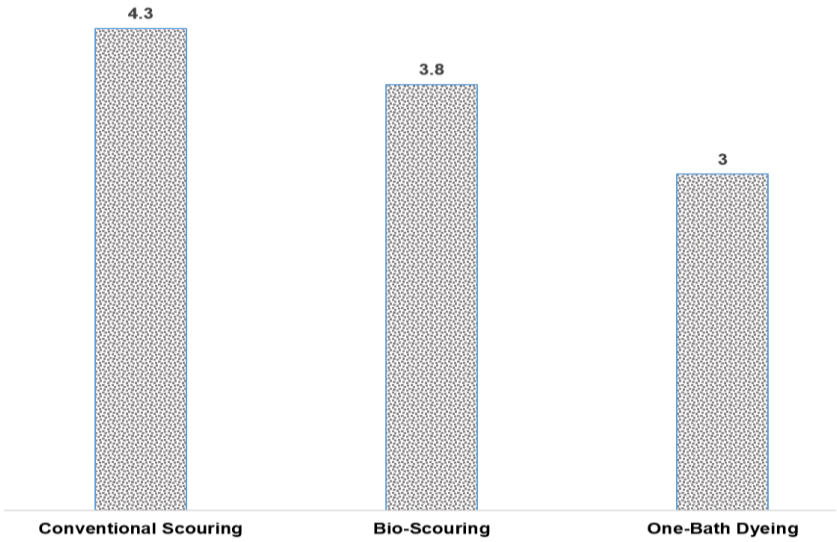

Figure 2: Steam consumption of different wet processing routes.

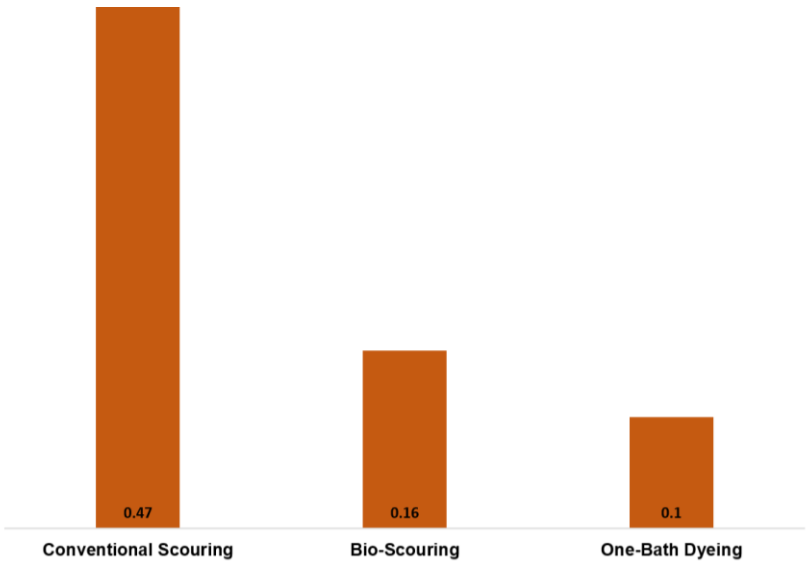

Figure 3: Power consumption of different wet processing routes.

The number of operational stages resulted in an occupancy of the machine and extended the total production cycle in industrial processing. The conventional oxidative pretreatment was replaced by enzymatic bio-scouring to shorten the planned process time to 9 h 33 min and actual industrial process time to 10 h 10 min with process holding and transition to operation performed during the production. The bio-scouring route saved 13.6 % processing time as compared to the conventional scouring. Compared to the conventional scouring process the one-bath route led to a further reduction in the actual process time, which equates to around 31.8 % of the process time as almost 3 h 30 min of machine occupancy per production batch was saved, as shown in Figure 4. The integrated route showed another 26.2 % reduction in the actual run time compared to bio-scouring. Bio-scouring and conventional scouring also had the most stages with 34 and 45 operational processes respectively, compared to the one-bath that had 27 process steps.

3.3. Chemical consumption evaluation

The chemical consumption also differed between the evaluated wet processing routes, the sequence of application of the auxiliary chemistry, and the integration of the processes. The scouring method showed the maximum chemical loading due to the presence of separate alkaline peroxide pretreatment before the fixation of the reactive dyes. In the pre-treatment process, the multiple auxiliaries used; Matquest FE Plus Liquid, Matclean BA Liquid, Matclean SCA Liquid, Matlube ACA Liquid and Matclean OSR Liquid were used with 5.23 kg caustic soda and 10.46 kg hydrogen peroxide to remove the impurities of cotton spandex fabric. Other chemicals such as Matacid AS Liquid, Matzyme VHK Liquid and Matzyme DS Ultra were then needed for the neutralization and enzymatic treatment prior to dyeing. The levelling agents, lubricants, reactive dyes, 261.60 kg salt and 52.32 kg soda ash were used in the dyebath stage, soaping agents and fixing chemicals were used in the post-treatment and fixing stages, and pH controlling auxiliaries were used in the fixing stage. The industrial processing operations of pretreatment, neutralization, dyeing, post-treatment, and fixing operations significantly increased the total amount of chemicals used in the process.

Replacing alkaline peroxide scouring by enzymatic bio-scouring resulted in a notable decrease of the chemical severity of the pre-treatment process as it did not require caustic soda or hydrogen peroxide. However, comparatively less severe process conditions were used for the enzymatic removal of impurities (ERI) with the use of Matclean RWD Liquid, Matclean OSR Liquid, Antifoam MX Liquid and 6.53 kg Matzyme PC Liquid as auxiliaries. The dyebath stage was provided with Matquest 1090 Liquid, Matlevel DLR Liquid, Matlube ACA Liquid, reactive dyes, 234.90 kg salt and 52.20 kg soda ash for reactive dye fixing while the post-treatment and fixing processes were relatively the same as conventional. The use of removal of intense oxidative chemicals in the pretreatment process during the production process was significantly reduced.

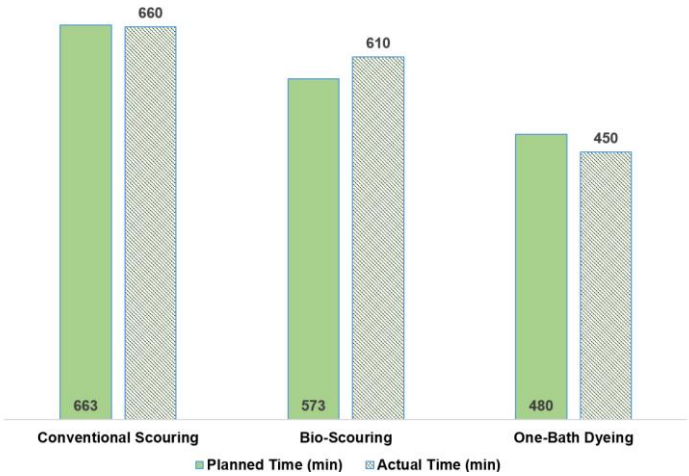

Figure 4: Planned and actual process duration of different wet processing routes.

Further simplification in chemical application was realised by the application of combined one-bath reactive dyeing - pretreatment chemicals and reactive dyeing chemicals in a single dyebath stage. Chemicals such as Matclean SDB Liquid, Matclean MSP Liquid, Matzyme PC Liquid, Reactive dyes, 261.0 kg salt and 52.2 kg soda ash were used in the sequence of the integrated process without any intermediate treatment steps or peroxide scouring or alkali treatment or enzyme neutralisation. Post-treatment and fixing chemicals, such as Matacid AS Liquid, Matwash DSP CONC, Matwash CSI Liquid, Albafix ECO and Matacid CN Liquid, were only applied after dye fixation. Along with the effective elimination of standalone pretreatment chemistry and several intermediate auxiliary applications, process reduction also observed in industrial production, as shown in Table 3.

Table 3: Chemical consumption of different wet processing routes.

Chemical Name	Conventional Scouring (kg)	Bio-Scouring (kg)	One-Bath Dyeing (kg)
Pre-treatment			
Matquest FE Plus Liquid	1.31	-	-
Matclean BA Liquid	2.62	-	-
Matclean SCA Liquid	1.83	-	-
Matlube ACA Liquid	5.23	-	-
Matclean OSR Liquid	3.92	1.31	-
Caustic Soda Liquid	5.23	-	-
H_2O_2	10.46	-	-
Matacid AS Liquid	2.09	-	-
Matzyme VHK Liquid	1.31	-	-
Matzyme DS Ultra	1.31	-	-
Matclean RWD Liquid	-	1.31	-
Antifoam MX Liquid	-	0.26	-
Matzyme PC Liquid	-	6.53	6.525
Dye bath			
Matclean SDB Liquid	-	-	2.61
Matclean MSP Liquid	-	-	1.305
Matquest 1090 Liquid	1.31	1.31	-
Matlevel DLR Liquid	5.23	2.61	-
Matlube ACA Liquid	2.62	2.61	-
Antifoam MX Liquid	0.26	0.26	-
Yellow Dye	4.796	3.48	3.48
Red Dye	5.232	4.70	4.698
Black Dye	41.856	39.15	39.15
Glober Salt	261.60	234.90	261.00
Soda Ash	52.32	52.20	52.20

Table 3: Continue.

Chemical Name	Conventional Scouring (kg)	Bio-Scouring (kg)	One-Bath Dyeing (kg)
Post-treatment			
Matacid AS Liquid	1.31	2.09	1.305
Matwash DSP CONC	2.62	2.61	2.61
Matwash CSI Liquid	2.62	2.61	2.61
Albafix ECO	5.23	5.22	5.22
Matacid CN Liquid	0.52	0.52	0.522
Total chemical consumption (kg/batch)	422.83	363.68	383.24
Total chemical load (kg/kg fabric)	0.972	0.836	0.881

3.4. Finished fabric performance evaluation

Table 4 provided the comparative quality assessment results for the three dyeing methods. In case of dimensional stability, after repeated laundering indicated gradual changes in the length and width directions. Bio-scouring exhibited relatively higher dimensional changes after repeated washing, with length and width variations of up to -1.5 and -1.3 cm, respectively, after 10 washing cycles, compared with conventional scouring. The one-bath route also showed dimensional variation after multiple laundering cycles, although the changes were comparable to those observed for the bio-scouring route. Twisting remained within 1 % for the conventional and bio-scouring routes, while the one-bath route showed values ranging from 0.5-1 %. All three routes demonstrated good color fastness performance, with color change and color staining ratings generally between 4 and 5 after repeated laundering. Similarly, dry rubbing, water fastness, and perspiration fastness (acidic and alkaline) remained within the acceptable quality requirements.

Table 4: Comparative quality assessment of fabrics produced by the conventional, bio-scouring, and one-bath wet processing routes.

Quality parameter	Conventional	Bio-scouring	One-bath	Acceptance criterion / Test standard
Fabric weight (GSM)	178.33	184.00	184.33	180 ± 5% (EN 12127)
pH	6.4	6.4	6.3	4.5-7.0 (ISO 3071)
Dimensional stability - Length (%)	-2.3	-4.3	-4.6	ISO 5077 / ISO 6330 / ISO 3759
Dimensional stability - Width (%)	-3.7	-4.3	-2.3	ISO 5077 / ISO 6330 / ISO 3759
Spirality (%)	1.0	1.0	0.5-1.0	-
Dry rubbing fastness	4-5	4-5	4-5	ISO 105-X12
Water fastness (Color change / Staining)	4-5 / 4-5	4-5 / 4-5	4-5 / 4-5	≥4 / ≥3-4 (ISO 105-E01)
Perspiration fastness (Acidic)	4-5	4-5	4-5	≥3-4 (ISO 105-E04)
Perspiration fastness (Alkaline)	4-5	4-5	4-5	≥3-4 (ISO 105-E04)
Stretch & recovery	Pass	Pass	Pass*	ISO 20932-1

The finished fabrics also satisfied the specified pH (6.3-6.4) and GSM (178.33-184.00 g/m²) requirements, indicating that all three processing routes produced fabrics meeting the required industrial quality standards. The sequential surface appearance changes from grey fabric to scoured or bio-scoured fabric, dyed fabric, and final dyed fabric are shown in Supplementary Table C.

3.5. Industrial implications of one-bath processing

The integrated one-bath route was found to be practically applicable to the large-scale production of cotton-spandex knit fabric dyed with reactive dyes in industry. The process compared to conventional scouring reduced the number of working stages from 45 to 27 and the processing time from about 11 to 7 h 30 min in the industrial production. Additionally, water use was reduced from 80.0 to 56.5 L/kg fabric by eliminating the operation of separate pretreatment, intermediate washing and repeated drainage before fixation of the reactive dyes. Reduced steam consumption and shorter machine runtime indicate the potential for lower indirect energy-related environmental impacts. Although, carbon emissions were not quantified in the present study. The removal of the peroxide based pretreatment also reduced the dependency on harsh chemical substances and reduced the amount of chemicals that can be discharged in the process sequence. The resulting fabrics achieved the desired physical and color fastness performance under nominated quality assurance testing conditions for a well-known European clothing buyer. Thus having a good industrial potential for resource-efficient large-scale knit fabric dyeing with lower dependency to freshwater, energy and simplified production flow. Future research should include statistical analysis with multiple production batches to further validate and generalize the findings.

3.6. Study limitations

The findings of this study are based on an industrial-scale evaluation of 95 % BCI cotton/5 % spandex single jersey fabric (180 GSM) processed with reactive dyes using a specific soft-flow dyeing machine under the operating conditions of one textile manufacturing facility. Therefore, the results should be interpreted within the context of these material and process conditions, as variations in fabric construction, fiber composition, elastane content, dye chemistry, machine configuration, or processing parameters may influence the observed performance. Dyeing quality was evaluated using the industrial quality assurance parameters routinely adopted by the manufacturing facility, including color fastness, dimensional stability, spirality, GSM, pH, and stretch and recovery, whereas spectrophotometric parameters such as color strength (K/S), dye fixation, dye exhaustion, CIELAB coordinates, and color difference (ΔE) were not assessed. Similarly, pretreatment efficiency parameters, including absorbency, wettability, capillary rise, weight loss, residual wax content, and whiteness index, were not evaluated. Future studies should incorporate these measurements and validate the proposed process on different fabric types and industrial production systems. Artificial intelligence and data-driven process optimization may also be explored to optimize chemical dosing, predict process performance, and further improve resource efficiency in integrated textile wet processing [25, 26].

4. Conclusion

In the present study, conventional scouring, enzymatic bio-scouring and integrated one-bath reactive dyeing of industrial wet processing of cotton-spandex knit fabric has been comparatively studied under the large-scale production conditions. The routes evaluated were found to be very different in terms of utilization, process time, process sequence and chemical dependence. The one-bath process was superior in terms of water use (56.5 L/kg fabric) than the other processes. Other operational conditions, such as reduction in steam requirements, electrical power usage, number of processing stages and total processing time were observed as well as a result of eliminating the separate pretreatment, intermediate washing and repeated drainage operations. The one bath treatment reduced operational stages from 45 to 27 and the real industrial processing time was reduced from around 11 h to 7 h 30 min.

The bio-scouring shortened the pretreatment process and lowered the amount of chemicals used without compromising dyeing or finishing performance in the industrial production environment. The one bath application sequence was also integrated, which further reduced the complexity of the auxiliary

application sequence in the dyeing process of the reactive dyes. The end-of-line testing of finished fabric showed good dimensional stability, spirality, pH, GSM, appearance retention and color fastness for all the routes tested, and was met to the required levels. The one bath route also met quality assurance requirements for a well-known European clothing buyer for the finished fabrics. The results obtained suggest that integrated one-bath reactive dyeing has a good industrial application potential to improve resource efficiency in large-scale knitted fabric production through reduced water, energy, and chemical consumption and a simplified production process.

Future perspectives

More research can be undertaken to characterize effluent and wastewater pollutant loads created from various wet processing pathways in an industrial environment. Future investigations should also evaluate wastewater quality parameters, including chemical oxygen demand (COD), biochemical oxygen demand (BOD), salt load, and other relevant effluent characteristics, to provide a more comprehensive environmental assessment of different wet processing routes. Detailed carbon footprint analysis also can be conducted based on steam consumption, electrical energy consumption, and chemical processing which can yield further understanding about environmental sustainability of integrated wet processing systems. The production costs analysis, life cycle assessment and industrial economic feasibility evaluation will also be included for the large scale adoption of one-bath reactive dyeing technology for future studies. Further optimization of the sequence of chemical dosing, dye fixation efficiency and process compatibility for various structures and shade categories of fabrics could further enhance competitiveness of the industrial applications and sustainable wet processing performance. In addition, future studies involving multiple industrial production batches would enable statistical assessment of process variability and further strengthen the quantitative comparison of different wet processing routes.

Acknowledgements

The authors declare that they did not receive any internal or external funding for the research.

5. References

1. Catarino ML, Sampaio F, Gonçalves AL. Sustainable wet processing technologies for the textile industry: a comprehensive review. Sustainability. 2025; 17:3041. https://doi.org/10.3390/su17073041.
2. Sayam S, Das N, Akter S, et al. Water and electricity consumption patterns with effluent quality in the textile processing industry of Bangladesh. RSC Adv 2025;15:46627-48. https://doi.org/10.1039/D5RA05917H.
3. Sayam, Das N. Biotransformation of textile dyes: mechanism and application. biocentric approaches text. Waste Manag. 2026, 81-102. https://doi.org/10.1007/978-3-032-04974-2_5.
4. Hossen MR, Sayam S, Akter S. Sustainable dyeing of silk fabric with mango leaf extract: comparative assessment of natural and metallic mordants on colorimetric and fastness properties. Prog Color Colorant Coat. 2026;19:231-45. https://doi.org/10.30509/pccc.2025.167632.1433.
5. Mamun A Al, Bormon KK, Rasu MNS, et al. An assessment of energy and groundwater consumption of textile dyeing mills in bangladesh and minimization of environmental impacts via long-term key performance indicators (KPI) baseline. Textiles. 2022; 2:511-23. https://doi.org/10.3390/textiles2040029.
6. Shefa J, Xames MD, Hasan AA, et al. Feasibility study of common effluent treatment plant for management of industrial wastewater: Case study of Bangladeshi textile industries. Environ Qual Manag. 2024; 33:165-78. https://doi.org/10.1002/tqem.22033.
7. Imran S, Mujtaba MA, Zafar MM, et al. Assessing the potential of GHG emissions for the textile sector: A baseline study. Heliyon. 2023;9:e22404. https://doi.org/10.1016/j.heliyon.2023.e22404.
8. Rahman M, Rahman MM. Study of the dyeing industry pollution after mandatory installation of ETP in Madhabdi municipality, Bangladesh. Water Sci. 2024;38:158-71. https://doi.org/10.1080/23570008.2024.2313874.
9. Kadınkız N, Asma A, Demirel G, et al. A comparative study on dyeing capability of conventional and organic cotton fabrics. Tekst Ind. 2023;71:47-62. https://doi.org/10.5937/tekstind2302047K.
10. Mao X, Zhong Y, Xu H, et al. A novel low add-on technology of dyeing cotton fabric with reactive dyestuff. Text Res J. 2018;88:1345-55. https://doi.org/10.1177/0040517517700195.
11. Shu D, Fang K, Liu X, et al. Cleaner coloration of cotton fabric with reactive dyes using a pad-batch-steam dyeing process. J Clean Prod. 2018;196:935-42.

https://doi.org/10.1016/j.jclepro.2018.06.080.
12. Sayam, Das N. Biotransformation of textile dyes: mechanism and application. biocentric approaches. Text Waste Manag. 2025,81-102. https://doi.org/10.1007/978-3-032-04974-2_5.
13. [13]Bristi U, Pias AK, Lavlu FH. A Sustainable process by bio- scouring for cotton knitted fabric suitable for next generation. J Text Eng Fash Technol. 2019; 5. https://doi.org/10.15406/jteft.2019.05.00179.
14. Raafi SM, Arju SN, Asaduzzaman M, et al. Eco-friendly scouring of cotton knit fabrics with enzyme and soapnut: An alternative to conventional NaOH and synthetic surfactant based scouring. Heliyon 2023; 9:e15236. https://doi.org/10.1016/j.heliyon.2023.e15236.
15. Khan MF. Recent advances in microbial enzyme applications for sustainable textile processing and waste management. Sci. 2025;7:46. https://doi.org/10.3390/sci7020046.
16. Sayam S, Das N, Hossain S. Assessment of ETP performance for sustainable denim wastewater management. 3rd Int. Conf Text Sci Eng (ICTSE 2025) with Spec Focus Fash Innov Sustain Appar Prod. 2025, 1-12.
17. Muralidharan B, Laya S. A new approach to dyeing of 80 : 20 polyester/cotton blended fabric using disperse and reactive dyes. ISRN Mater Sci. 2011;2011:1-12. https://doi.org/10.5402/2011/907493.
18. Ristić N, Jovančić P, Canal C, et al. One-bath one-dye class dyeing of PES/cotton blends after corona and chitosan treatment. Fibers Polym. 2009; 10:466-75. https://doi.org/10.1007/s12221-009-0466-1.
19. Hilal N, Gomaa S, Elsisi A. Improving dyeing parameters of polyester/cotton blended fabrics by caustic soda, chitosan, and their hybrid. Egypt J Chem 2020;63:2-3. https://doi. org/10.21608/ejchem.2020.25571.2498.
20. Tegegne W, Tesfaye T, Zeleke Y, et al. One-bath one-dye class dyeing of polyester/cotton blend fabric with disperse dye after esterification of cotton fabric. Discov Mater. 2022;2:14. https://doi.org/10.1007/s43939-022-00034-2.
21. Tegegne W, Haile A. Effect of papain enzyme surface modification on hydrophilic and comfort properties of polyester/cotton blend fabric. Discov Mater. 2024; 4:2. https://doi.org/10.1007/s43939-023-00071-5.
22. Koh J. Alkali-hydrolysis kinetics of alkali-clearable azo disperse dyes containing a fluorosulphonyl group and their fastness properties on PET/cotton blends. Dye Pigment. 2005;64:17-23. https://doi.org/10.1016/j.dyepig.2004.03.017.
23. Kumsa G, Gebino G, Ketema G. One-bath one-step dyeing of polyester/cotton (PC) blends fabric with disperse dyes after acetylation of cotton. Discov Mater. 2021;1:19. https://doi.org/10.1007/s43939-021-00019-7.
24. Borisova A. One-bath dyeing technology for cotton blended fabric-part 1: elaboration of a dyebath content. Key Eng Mater. 2018; 762:385-9. https://doi.org/10.4028/www.scientific.net/KEM.762.385.
25. Amin MB, Hossain MI, Bahar MI, et al. A Model for the integration of AI technologies into IT management frameworks. Saudi J Eng Technol. 2026;11:338-48. https://doi.org/10.36348/sjet.2026.v11i04.019.
26. Bahar MI, Hossain MI, Akter A, et al. A structured engineering framework for cloud-based IT resource management. Int J Eng Technol. 2026;15:1-9. http://doi.org/10/14419/wz5nfj29.

How to cite this article:
Sayam S, Hossen MdR, Islam MdM. Comparative Industrial Wet Processing of Cotton-Spandex Knit Fabric Using Conventional Scouring, Bio-Scouring, and Integrated One-Bath Reactive Dyeing. Prog Color Colorants Coat. 2027;20(3):339-351. https://doi.org/10.30509/pccc.2026.167801.1507.