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Research Article

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Evaluation of Integrated Pollution Prevention Control in Textile Coloration through New Generation Macromolecular Colorants

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Abstract

Textile dyeing effluents containing recalcitrant dyes are polluting waters due to their color and by the formation of toxic or carcinogenic intermediates such as aromatic amines from azo dyes. Since conventional treatment systems based on chemical or physical methods are quite expensive and consume high amounts of chemicals and energy, alternative technologies for this purpose have recently been studied. A number of new generation dyestuffs have been developed at laboratory scale to replace conventional dyestuff. Additionally, new generation dyestuffs show very promising results for reduction of utilities and chemical consumption. In this contribution, we made a novel approach to detailed onsite investigation on water, steam, electricity and chemical minimization employing high exhaustion-fixation dyestuffs and analysis on production processes performed according to UNFCC clean Development Mechanism (CDM) promotion. Specific consumptions in wet processes were calculated by mass balance analyses. The multi-criteria decision-making methods were employed to determine suitable best available techniques.

Keywords: New generation colorants; Utility; Dyeing; Cleaner Production
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1. Introduction

In textile dyeing considerable amounts of dyestuff, e.g. up to 30% of reactive dyes, are lost and discharged with the effluents. Therefore, elimination of dyes from textile dyeing effluents currently represents a major ecological concern. Due to their high brilliance, low concentrations of dyes are highly visible and therefore, undesired in industrial effluents. Depending on the process used and on national regulations, the limits of dye concentration in rivers, about 1 ppm in the UK, would require a reduction of the dye concentration by up to 98% [1]. The textile manufacturing process is consuming high amount of resources like water, steam, electricity and a variety of chemicals in a long process sequence. The common practices of low process efficiency result in substantial wastage of resources and a severe damage to the environment [2]. Industrial activities thus polluting the limiting source of energies. The global water demand is expected to be 1500 billion m3 according to average economic growth scenario 2030[3] . Which brings the questing of avoiding the wastage of water, unless the world on behalf of avoiding global fresh water crisis in the future. Different tactics that upkeep the sustainable use of natural resources and sustainable production processes have been developed in the last 20-30 years [4]. Cleaner production is one of them, which defines the protection of resources and environment as a whole with an integrated approach [5]. Cleaner production is to avoid the wastages of natural resources and be aware of discharge such waste which may pollute the natural substances. Cleaner production is also referred as a proactive environmental protection strategy [6]. Besides, cleaner production in the industrial enterprises may provide reduced production costs, improved competitiveness to meet the requirements of existing and future regulation or standards [6]. Water is one of the most significant inputs of wet processes in textile industry. The specific water consumption is reported to range 3-932 L/kg product depending on fiber type, applied techniques and technologies [7-9]. Different investigation showed that, specific water consumption ranges from 10 to 645 L/kg product (average 22-184) in the textile industry and such values are 21-645 L/kg product (average 92-162) in mills employing cotton fabric finishing-dyeing [10]. Textile production processes are characterized by their comparatively high specific chemical consumption. Chemical consumption is about 10-100% in proportion to total fiber weight in textile processing [11]. A large number of chemicals are needed to impart the desired properties to textile fibers such as acids, bases, surfactants, enzymes, stabilizers, dispersing agents, retarders, salts, dyes, solvents, emulsifiers and fixing agents [12-13]. Literature indicated that chemical consumption could be reduced 20-50% by the implementation of various measures of cleaner production techniques in the textile industry [14-16]. Thus, there is a strong demand for new technologies to reduce this enormous water consumption. In this study, onsite cleaner production assessment study was carried out by a sustainable solution of reduce the wastage of water and chemicals by replacing conventional dyestuffs. With a systematic approach, this research investigated this sustainable solution. The employed unique methodology and the findings of this study (i.e., potential reductions in water, steam, electricity and chemical usages and potential savings) will be useful to similar textile mills, stakeholders and regulators. The structure of this study may provide a road map to textile industry for their cleaner production applications.

2. Experimental

In this research, minimization of water and chemical consumptions were taken as a priority considering the reduction of production costs and improved efficiency and environmental performance of the mill. In this context, it was decided to implement a systematic assessment.

2.1. Materials

In this research, 1000kg of 180 GSM single jersey cotton fabric (from Grameen Knitwear's Limited, Dhaka, Bangladesh) was taken as sample fabric to be dyed with conventional dyestuff and new generation dyestuffs. Conventional dyestuffs were donated by Grameen Knitwear's Limited, Dhaka, Bangladesh from their regular stock and high new generation dyestuffs were bought from local supplier of a chemical company (name cannot be disclosed due to confidentiality issue) and use without further modification.

2.2 Methods

In the first phase of the study, investigation of applied process flow diagrams, data collection of water and chemical consumptions, identification of inefficiencies were carried out. On-site investigations were performed and water/chemical consumptions of the production processes were evaluated. In the second phase of the study, mass-balance calculations were conducted for the production processes based on specific inputs and outputs. Specific water and chemical consumptions were calculated. In the third phase of the study, the multi-criteria decision methods were used to quantitatively evaluate CDM options. Multi-criteria decision-making is an effective approach that can be successfully used for revealing eco-innovative solutions [12]. In this decision process, potential CDM options were listed for the solution of the problems in the production processes of the mill.

Table 1 Unit price of utilities is based on current global price*
(*Variable with market strategy)

Types	*Unit price*
Electricity price	57.69 USD/Mwh.
Water cost	0.064 USD/Cubic meter.
Steam price	4.79 USD/Ton.
Depreciation cost (for 1000 kgs machine)	0.205 USD/hrs.
Conventional yarn price	3.30 USD/Kg (30s Ne).
Good quality yarn price	3.50 USD/Kg (30s Ne).
Wastewater treatment cost	0.102 USD/Cubic meter

2.3 Conventional Practices

2.3.1 Dyeing

Conventional dyeing of process of cotton fabric with exhaust method consists of several preliminary process includes Heat setting, scouring, bleaching, bio-polishing etc. These process consumes four to five hours before dyeing. The dyeing process starts with levelling the fabric for dyeing and later on dyeing process starts, several dyeing process are available according to fabric construction, composition of yarn, type of shade required and quality of the goods. In our experiment, for a typical coloration of cotton fabric with reactive dyes (Show in figure 1) starts with addition of chemical and auxiliaries require at around temperature 40°C. Later on dossing of dyes done immediately after that, temperature raise to 60°C and continue dyeing until highest exhaustion of dyes appeared [17]. This process took several hours due to low exhaustion rate of conventional dyestuffs. After reaching the highest exhaustion state of dyes the dye fabric was unloaded after successive washing and after treatment. It has been observed that a large number of wash required to make the dye bath clean due to hydrolyzed dyes precipitated into the bottom dyeing machine. These hydrolyzed dyes mixed water discharged into effluent treatment plant inlet. Thus pointing high effluent load and increasing of cost of water treatment on effluent treatment plant.

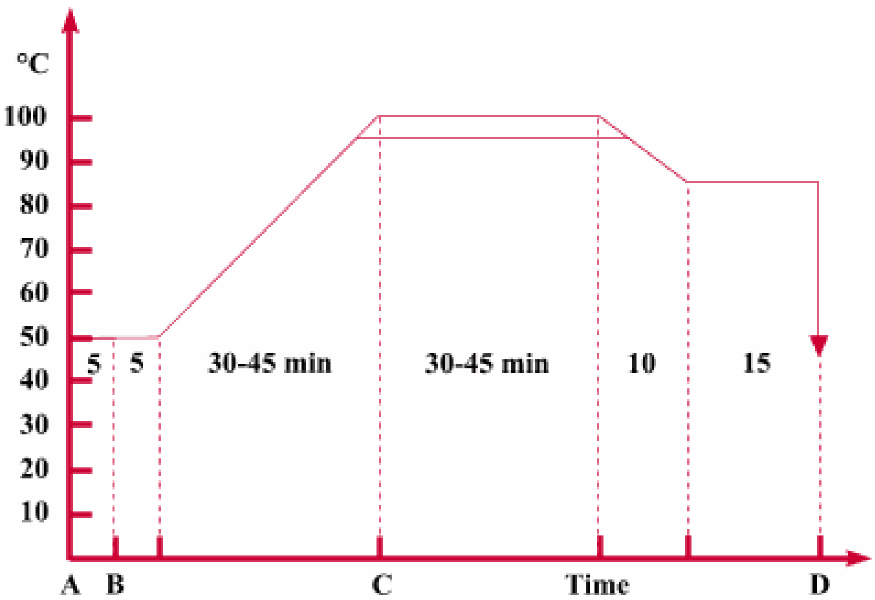

Figure 1 Dyeing curve with conventional reactive dyes with exhaust method

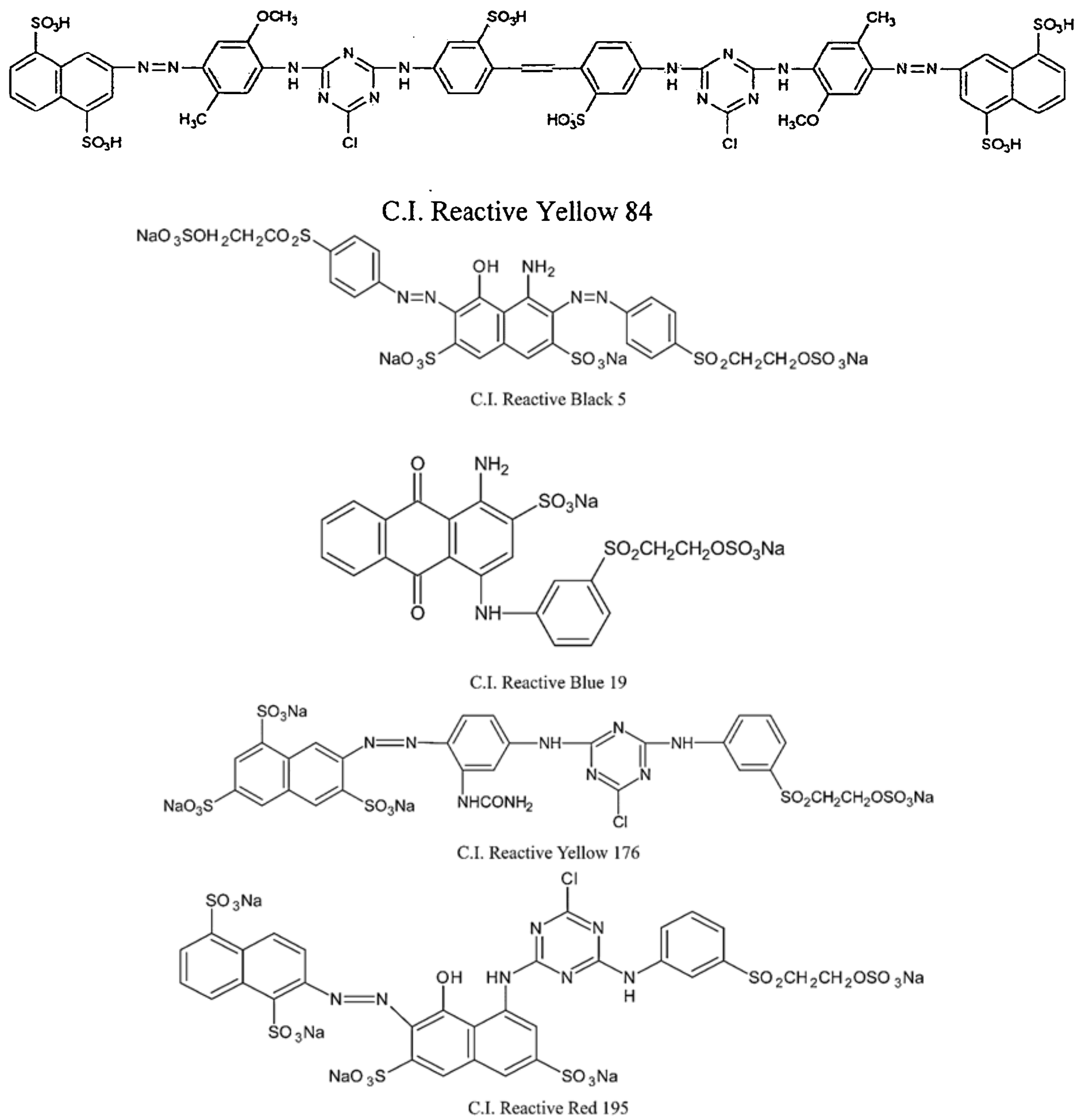

Figure 2 Chemical Structure of conventional reactive dyes

2.3.2 Dyes

Choice of Reactive class of Dyes has become indispensable for application of colors on the cellulosic to provide bright range of shades with reasonably good fastness features. No other class of colors can boast of the versatile range of shades with unmatched brilliance, yet economically viable and cost effective that this class of dyes can offer.

Even as Reactive dyes are most popular for dyeing solid shades it is equally sought after for various resist and discharge printing styles, thanks to its suitability to be resisted or discharged readily and effectively. But presence of toxic or carcinogenic intermediates such as aromatic amines from azo dyes is a threat for environment need to address before late. Figure 2 shows chemical structure of some common reactive dyes.

2.4 Utility consumption reduction

The utility consumption, processing time, process loss% and CO2 emission for one kg cotton knitted fabric was investigated for both conventional dyestuffs and new generation high exhaustion and fixation dyestuffs. Average reduction of utility consumption along with CO2 emission, process loss and time consumption shown in table 2 to table 7.

2.4.1 Water

The Average water consumption for processing one kg of knitted fabric lies between 40 liter to 100 liter based on type and depth of shade for conventional dyestuffs where new generation dyestuffs required lowest 20 liter/kg and highest 80 liter/kg for turquoise dark shade. Which lead average reduction of 35% water consumption. The lowest water consumption comes for white and highest for turquoise dark shade. Table 2 shows the statistical data for reduction of water consumption due to replace of conventional dyestuffs with new generation high exhaustion and fixation dyestuffs.

Table 2 Water consumption analysis of dyeing with conventional and new generation dyestuffs

Shade name	Average water consumption of conventional dyestuffs (liter/kg)	Average water consumption of new generation dyestuffs (liter/kg)	Reduction (liter/kgs)	Average reduction %
Light	70	40	30	43
Medium	80	50	40	38
Dark	90	55	45	39
Black	90	50	40	44
White	40	20	20	50
Turquoise-light	80	60	20	25
Turquoise-medium	90	70	20	22
Turquoise-dark	100	80	20	20

2.4.2 Steam

Steam is vibrant utilities fir textile coloration. Steam consumption indirectly related to water and electricity consumption. In this study for conventional dyestuffs, it has been found that, to process one kg of knitted fabric for light shade average 7.0 kg of steam required to long exhaustion time where high exhaustion and fixation dyestuffs consumes about half of this value for light shade. After a vigorous investigation, same phenomena were observed for other shade showing in Table 3.

Table 3 Steam consumption analysis of dyeing with conventional and new generation dyestuffs

Shade name	Average steam consumption OF conventional dyestuffs (kg/kg)	Average steam consumption of new generation dyestuffs (kg/kg)	Reduction (kg/kg)	Average reduction %
Light	7.0	4.0	3	43
Medium	7.0	3.8	3.2	46
Dark	8.0	5.0	3	38
Black	9.0	6.0	3	33
White	5.0	2.0	3	60
Turquoise-light	8.0	5.0	3	38
Turquoise-medium	8.0	5.5	2.5	31
Turquoise-dark	9.0	6.0	3	33

2.4.3 Electricity

According to shade type as shown in table 4, 0.15 kWh to 0.35 kWh electricity required for process one kg knitted fabric with new generation dyestuffs where addition of around 50% of electricity required for conventional dyestuffs. It has been noticed that, maximum 50% of reduction can be achieve by approaching new generation high exhaustion and fixation dyestuffs.

Table 4 Electricity consumption analysis of dyeing with conventional and new generation dyestuffs

Shade name	Average electricity consumption of conventional dyestuffs (kwh/kg)	Average electricity consumption of new generation dyestuffs (hrs.) /batch	Reduction (kwh/kg)	Average reduction %
Light	0.40	0.20	0.2	50
Medium	0.45	0.25	0.2	44
Dark	0.45	0.28	0.17	38
Black	0.50	0.30	0.2	40
White	0.35	0.15	0.2	57
Turquoise-light	0.45	0.25	0.2	44
Turquoise-medium	0.45	0.30	0.15	33
Turquoise-dark	0.55	0.35	0.2	36

2.4.4 CO_2 Emission

The CO_2 emission of all types of shade has not far difference for conventional dyestuffs. The lowest CO_2 emitted by white color processing and highest for all dark and turquoise medium shade. The use of new generation Dye stuff and process optimization can save enormous amount of water, energy and contribute to reduce the carbon footprint. This method can save money which can easily cover the extra cost of high exhaustion-fixation dyestuffs. Table 5 describes average possible reduction of CO_2 Emission though new generation dyestuffs.

Table 5 CO_2 Emission analysis of dyeing with conventional and new generation dyestuffs

Shade name	Average co_2 emission (kg/kg) of conventional dyeing	Average co_2 emission (kg/kg) of new generation dyeing	Reduction kg/kg	Average reduction %
Light	0.8	0.6	0.2	25
Medium	0.9	0.7	0.2	22
Dark	1.1	0.8	0.3	27
Black	1.2	0.9	0.3	25
White	0.9	0.6	0.3	33
Turquoise-light	1.0	0.7	0.3	30
Turquoise-medium	1.2	0.8	0.4	33
Turquoise-dark	1.3	0.9	0.4	31

2.4.5 Time

Consumption of time for coloration of conventional dyestuffs and new generation dyestuffs has been reported in table 6. It has been shown that, the average reduction of 25% of time consumption for different shade of cotton dyeing can be achieve though new generation dyestuffs, which will lead to increase the productivity and profit on the enterprise owners.

Table 6 Time consumption analysis of dyeing with conventional and new generation dyestuffs

Shade name	Time (hrs.) /batch of conventional dyeing	Time (hrs.) /batch of new generation dyeing	Reduction (hrs.) /batch	Average reduction %
Light	08	06	2	25
Medium	09	07	2	22
Dark	10	08	2	20
Black	10	09	1	10
White	07	05	2	29
Turquoise-light	11	07	4	36
Turquoise-medium	12	08	4	33
Turquoise-dark	13	09	4	31

2.5 Dyes Exhaustion Rate Analysis

Table 7 shows the data of dyes exhaustion rate investigated for different types of shade of cotton knitted fabric for both conventional and new generation dyestuffs. It has been clearly seen that conventional dyes have low exhaustion rate percentage in compare with new generation dyestuffs due to high hydrolysis rate.

Table 7 Dye exhaustion rate analysis of dyeing with conventional and new generation dyestuffs

Shade name	Average dye exhaustion rate (%) of conventional dyestuffs	Average dye exhaustion rate (%) of new generation dyestuffs	Average increase in %
Light	65	95	30
Medium	60	93	33
Dark	60	92	32
Black	60	95	35
Turquoise-light	60	95	35
Turquoise-medium	60	91	31
Turquoise-dark	60	90	30

Around 60 to 70 % of the dyestuff are going inside the fiber the remaining are going to the Effluent Treatment Plant. Due to low exhaustion rate it needs several high temperature washing and soaping to remove all the unfixed dyestuff from the fabric surface. Resulting high effluent treatment cost (due to high dosing of de- colorant agent) increasing the process cost. Increasing process time due to wash off the remaining unexhausted dyestuff from the fabric surface. Consume high amount of water, steam and electricity.

2 Results and discussion

3.1. Evaluation of potential implementation

The current dyeing practices used classic dyes have some backdrops like, 60 to 70 % of the dyestuff are going inside the fiber the remaining are going to the Effluent Treatment Plant. Due to low exhaustion rate it needs several high temperature washing and soaping to remove all the unfixed dyestuff from the fabric surface. Resulting high effluent treatment cost (due to high dosing of de- colorant agent) increasing the process cost. Increasing process time due to wash off the remaining unexhausted dyestuff from the fabric surface. Consume high amount of water, steam and electricity, time and low exhaustion rate in dyeing showing in Figure 3 to figure 7. The high exhaustion and fixation dyestuffs has higher exhaustion rate, thus requires less wash after dyeing. Due to less wash after dyeing its saves water cost, steam cost, electricity cost, effluent treatment cost, and chemical cost and depreciation costs in a considerable level which can overcome the price of high exhaustion and fixation dyes [18].

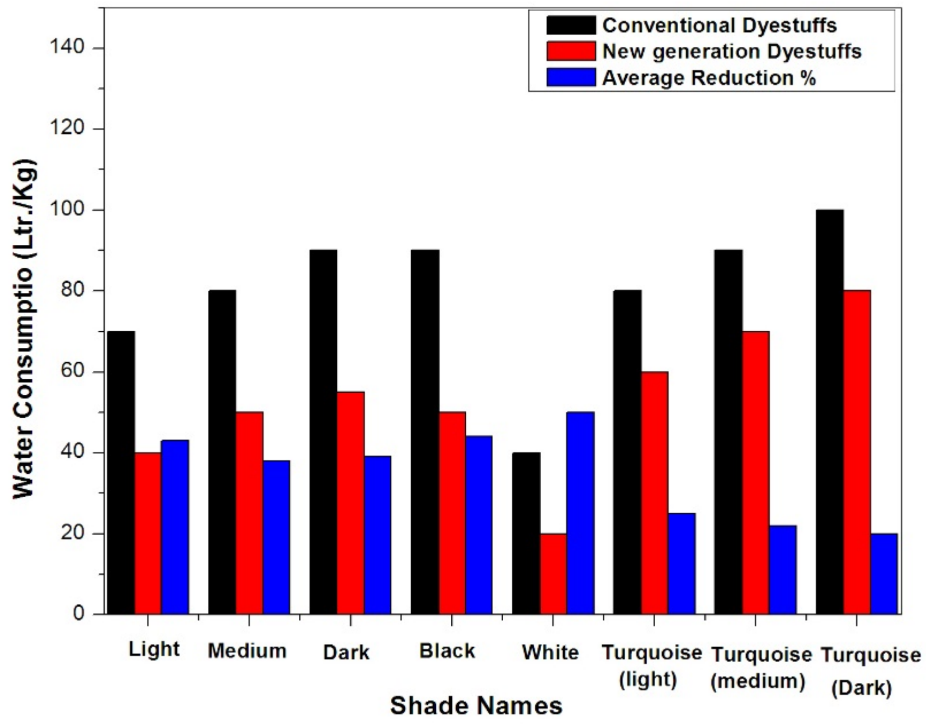

Figure 3 Water Consumption Reduction Analysis and new generation dyestuffs

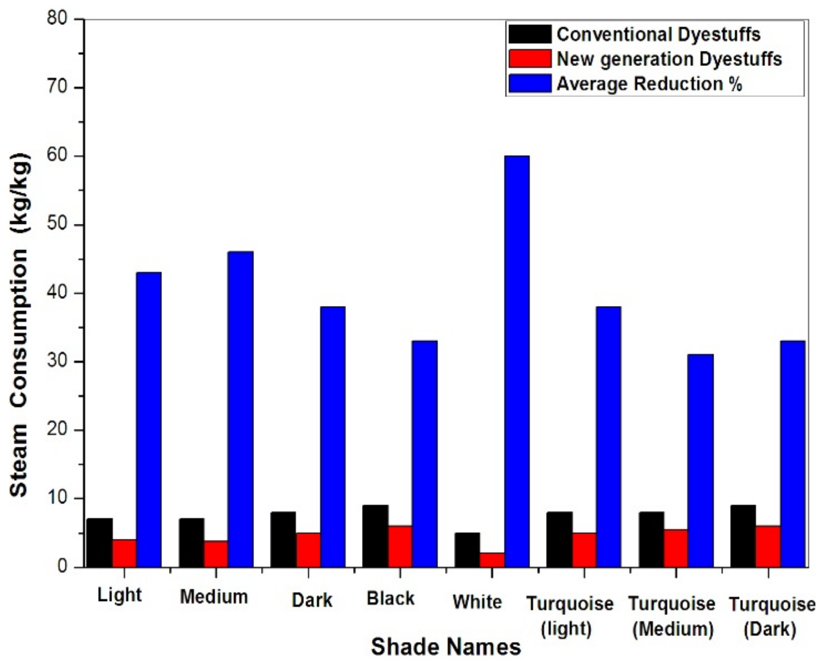

Figure 4 Steam consumption reduction analysis and new generation dyestuffs

The savings will not only recover the investment of high exhaustion and fixation dyestuffs but also reduce the CO2 emission. The overall costs can be reducing as much as 20 ~30% or more by implementing no-cost and low-cost changes. Furthermore, overall savings can be doubled or tripled when the associated saving in raw materials is taken into account. The chemical inventory study indicated that total of 74 chemicals could be replaced with more biodegradable and less toxic counterparts. Specific water consumption was found to range from 95 to 100 L/kg product in the mill. The average specific dyestuff and auxiliary consumptions of the mill were calculated as 10 and 366 g/kg product, respectively.

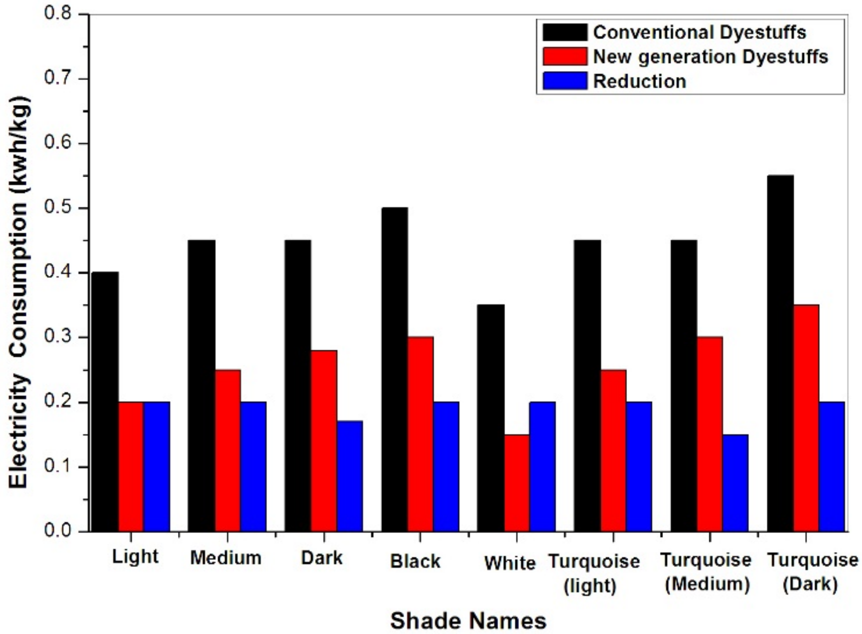

Figure 5 Electricity consumption reduction analysis and new generation dyestuffs

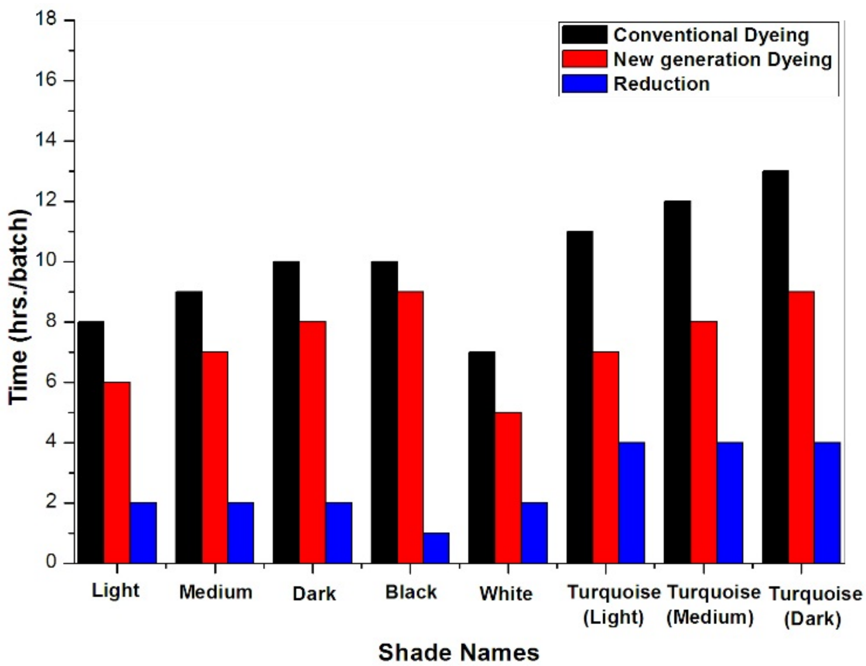

Figure 6 Time consumption analysis and new generation dyestuffs

Suggested techniques to minimize water consumptions included reuse of washing/rinsing and softening wastewaters, reuse of suitable dyeing bath, optimization of water softening unit, reuse of resin regeneration wastewater, application of counter-washing techniques in the pad-batch washing process. After the implementation, high exhaustion and fixation dyestuffs in the mill, it is estimated that the following reductions can be potentially achieved: 30-35% in water consumption, 16% in chemical consumption, 30% in steam consumption, 50% in electricity consumption and 25%-time consumption and CO_2 emission.

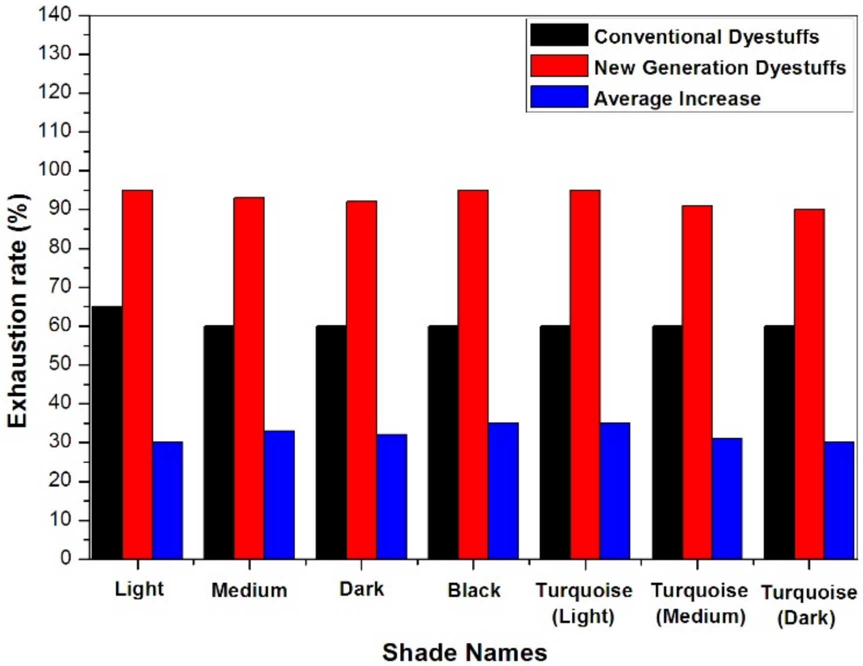

Figure 7 Dyes exhaustion analysis and new generation dyestuffs

3.2. Calculation of savings/benefits after the potential implementation

Table 8 shows the saving of water cost, steam cost, electricity cost, waste water treatment cost and depreciation cost for 1000 kg of knitted fabric.

Table 8 Saving from using high exhaustion and fixation dyestuffs (For 1000 kgs of Knitted fabric)

Type of cost	*Value (USD per 1000 kgs)*
Water	4.24
Steam cost	12.32
Electricity cost	4.04
Waste water treatment cost	6.74
Depreciation cost	6.15

Here, Electricity, Water, Steam is considered 57.69 USD/Mwh., 0.064 USD/Cubic meter, 4.79 USD/Ton respectively. The depreciation cost for 1000 Kg machine was considered 0.205 USD/hrs. Up charge for dyes & chemical cost 0.15 USD/Kg for average shade. And wastewater treatment cost 0.102 USD/Cubic meter. It has been come to light that, the arithmetic sum of saving for using high exhaustion and fixation dyestuffs is about 33.49 USD. In this technique by the 1400 kgs of knitted fabric can be processed with the same time for processing of 1000 kgs of fabric by keeping all infrastructure constant.

This indicated that, this change can increase the production of around 400 kgs. By a cost analysis of the factory it was found that, this increasing production influences on all the section of this factory and can save the cost worth around 160 USD. The total savings from using high exhaustion and fixation dyestuffs become 193.49 USD for 1000 kg of fabric. On the other hand, the additional price of high exhaustion and fixation dyestuffs for 1000 kgs of fabric has been investigated upon different shade percentage. The average additional cost is around 150 USD for 1000 kg of fabric. By the arithmetic analysis, the net savings from 1000 kg of fabric come out after overcoming the additional prices of high exhaustion and fixation dyestuffs is 43.49 USD.

3 Conclusions

After the study, it come to front that, use of compact yarn shows effective outcome against use of bio polish. On the other hand, use of new generation high exhaustion & fixation dyestuffs can lead process optimization as well as can save enormous amount of water, energy and contribute to reduce the carbon footprint. It is possible for manufacturers to reduce their water, steam, electricity & carbon footprint through environmental friendly technology practices.

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