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Economy and Ecology in Dyeing-Cold Pad batch Dyeing Method for Cotton Knitted Fabric

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Abstract

Conservation of resources is not the exception in today's textile wet processing operations- it is the rule. Lower water, energy, time, chemical and labour consumption, while providing quality textile products, is the goal of all manufacturers who wish to continue in the business. Dyeing machinery and processes; especially designed to provide quality dyeing with savings in resources, are coming on stream. But still a lot of work is required to conserve the resources in wet processing especially in dyeing of knitted cotton fabric since most of the processes that are carried out recently use high amount of water, energy and chemicals. The most popular method of dyeing cotton knitted fabrics is exhaust method which requires high volume of water, high energy and chemicals.

This investigation aims at studying the dyeing of cotton knitted fabric by cold pad batch process and evaluates the feasibility of the process by comparing with the conventionally used exhaust method usually carried out at high material to liquor ratio in a soft-flow dyeing machine. The study has shown the possibilities of reducing the consumption of water, electrical and thermal energy and chemicals thereby offering cost advantage for a comparable colour value and physical properties. Besides, this process offers the reduction on the wastewater load which is the subsequent result of the overall conservation of the resources.

Keywords: Cotton knitted fabric • Pad batch dyeing • Saving potentials • Colour value • Physical properties

Introduction

The costs and the quality of a product define its success. The dyeing and subsequent washing of knitwear in open width form is a complex process and is particularly relevant to these two parameters. In the following, the essential points for the successful implementation of this process are described with clear emphasis on the situation in practice. Dyeing using the cold pad batch (CPB) method is an established and reliable process for woven cotton fabric for obtaining very good dyeing results with minimum use of resources [1,2]. The different stages of this method comprise:

1. Impregnating
2. Reacting
3. Washing off

The Schematic presentation of Cold pad batch (CPB) dyeing of cotton knitted fabric is shown in Figure 1 below.

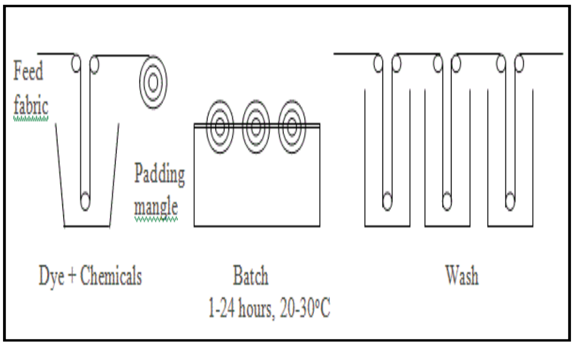

Figure 1. Pad-batch method.

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The steps are:

1. The fabric is first padded in a padding mangle with reactive dye in presence of an alkali.

2. The padded fabric is rolled in a batch and the batches are wrapped by polyethylene sheets and stored in wet condition for 16-24 hours at 20-30 °c in a room.

3. During the storage period, the rolls may be kept slowly rotated to prevent seepage of the dye liquor.

4. After storing time is finished fabric is washed in open-width washing machine to remove the unfixed dye from fabric surface.

The impregnation process

During impregnation the following parameters are important:

• Temperature and rate of circulation of the dye liquor

• Squeeze line in the padder

• Absorbency of the fabric

• Fabric tension

If these basic conditions are controlled correctly, there is nothing else in the way of a reproducible, controllable, high quality dyeing result [1].

Process requirements

a. Temperature of the dye liquor

As the fabric processed is generally cotton and viscose, reactive dyes are used in the majority of the cases. This class of dyestuff features a wide colour range and very high fastness. However, a constant temperature is required during dyeing. Here it is not the end value (which varies depending on the fixing method and dye class) that matters most, but the reproducibility. The temperature must always be the same in summer and winter, on Mondays and on Fridays, when things are going well and when things are going badly. This challenge is made more difficult by the fact that many dyes must be dissolved hot before they are added to the dye liquor [3,4].

b. Squeeze line in the padder

Vital when dyeing open wide knitwear using the cold pad batch method is the flexible nip line across the width of the fabric independent of the pressure.

Only in this way it is possible to compensate for varying fabric compression [5].

c. Absorbency of the fabric

Like every finishing process, pre-treatment also plays a major role. In this case, the fabric should have an absorbency of one to two seconds and a degree of whiteness of min. 65% [6].

d. Knitted fabric tension

A vital aspect during the treatment of knitwear is the tension. Here the motto "less is more" is particularly appropriate. Differences in tension can cause colour variations. Also, a constant low knitted fabric tension is crucial for low knitted fabric elongation and consequential for the shrinking values in addition attention must be paid to a finely tuned balance between web guiding mechanisms and the resulting fabric tension. Curved expanding rollers and scroll rollers contribute significantly to the increase in the fabric tension. For this reason, selvedge uncurler is used for knitted fabrics susceptible to curling. These devices spread the curled selvedges outwards without any direct action on the overall width of the knitted fabric [7].

Machine components

A modern cold pad batch dyeing centre for knitwear should meet the following criteria:

• Centre unwinder (if fabric from batch)

• Segment control roller for centralizing and feeding of knitwear

• Selvedge uncurler in front of trough and squeezing nip

• As many drives as possible

• Good accessibility and view

An important aspect of dyeing knitwear is how the knitted fabric is guided during wetting and on entry into the squeezing nip. In both cases it is imperative that the knitted fabric is fully expanded. On the entry of the knitted fabric into the squeezing nip, a further difficulty is that curled edges cause press marks during squeezing. Glueing the knitted fabric selvedges is one way of fully expanding rolled edges. However a disadvantage here is the high cutting losses. After squeezing, the knitwear is guided 100% positively but without tension to winding. This fabric guiding prevents renewed curling of the fabric selvedges and at the same time ensures that the knitwear does not elongate in an uncontrolled manner. Important is that the hardness of the batch remains constant even with increasing diameter [8].

The reaction process

Reaction is performed with continuous rotation of the batch to prevent trickling of the padded dyeing liquor. No energy is consumed during this process, no personnel are involved and with intelligent production planning, the time the fabric spends in the reaction process is not even affected.

The washing process

Washing off of the padded dyeing liquor places various requirements on the washing processes used. After rinsing the fabric, there follows a boiling and soaping process (fastness wash) that should ideally according to best industry process. Acid treatment and washing out complete this part.

Process requirements

As per usual washing cycle, the parameters chemistry, time, mechanics and temperature are very important for all washing processes. While the rinsing process at the start must primarily provide significant turbulence and the related mechanical washing action to quickly remove the surface dye and alkali from the fibres. During the fastness wash, time and temperature parameters are of primary importance. The final neutralization stage with final rinse again requires a large amount of turbulence along with chemistry.

Some advantages of Pad Batch Dyeing

Pad Batch Dyeing is a type of semi-continuous dyeing process, which is mainly used in the dyeing of cellulosic fiber like cotton or viscose with reactive dyes. Pad batch dyeing is a textile dyeing process that offers some unique advantages in the form of versatility, simplicity, and flexibility and a substantial reduction in capital investment for equipment. It is primarily a cold method that is the reason why it is sometimes referred to as the cold pad batch dyeing.

Special features of pad batch dyeing

• Significant cost and waste reduction as compared to other conventional dyeing processes

• Total elimination of the need for salt and other specialty chemicals. For example there is no need for anti-migrants, leveling agents and fixatives that are necessary in conventional dye baths.

• Optimum utilization of dyes that eliminates specialty chemicals cuts down chemical costs and waste loads in the effluent. All this result in a formidable reduction in wastewater treatment costs.

• Excellent wet fastness properties.

• Pad batch dyeing cuts energy and water consumption owing to low bath ratio (dye: water) required for the process. This is because unlike other dyeing processes it does not function at high temperatures.

• A uniform dye quality is achieved with even colour absorbency and colour fastness.

• As compared to rope dyeing, Pad batch dyeing produces much lower defect levels.

• In pad batch dyeing, qualities like high shade reliability and repeatability are common. This is because of high reactivity dyes with rapid fixation rate and stability.

• Lastly Pad batch dyeing can also improve product quality. The fabric undergoing the cold pad batch dyeing process is able to retain a uniformly coloured appearance. It shows added luster and gives a gentle feel. The fabric gives a brighter look in shades.

Materials and Methods

Materials

Knitted fabric

A single jersey fabric of 165 GSM was scoured and bleached in a textile mill by the conventional alkali boil scoring followed by peroxide boiling methods. This fabric was boiled with mild soda ash and bleached with peroxide in the EiTEX laboratory. The fabric showed water absorbency of less than 3 seconds by drop absorbency test and CIE whiteness of 78%.

Dyes and chemicals

Commercial fibre reactive dyes and chemicals were supplied by Huntsman, Switzerland. Reactive dyes used had vinyl sulfone reactive group having moderate reactivity to avoid tailing effects which are commonly observed with dyes having high substantivity. The chemicals used for dyeing and washing were supplied by CHT Bezema plc.

Methods

Dyeing by pad batch method

The fibre reactive dyes which were used in this study are shown in Table 1. The dye solution was prepared in warm water (40^{o}C) to ensure complete dissolution of dye. A separate solution containing alkali, sodium silicate and wetting agent was prepared using the concentrations as shown in Table 1. Both dye and chemical solutions were mixed prior to carrying out the padding operation. The dye recipe used was the same as used for dyeing by exhaust method in a soft flow machine by the mill. The objective was to determine the difference in colour value by comparing the two methods.

Table 1. Chemical concentrations and application conditions for pad-batch dyeing of cotton knitted fabrics.

The scoured and bleached dry fabric was passed through dye and chemical mixture and squeezed through pad rolls at 80% wet pick up. The fabric was batched on a roller, covered with polyethylene to prevent from drying and rotated for a period of 16 hours at a slow motion say 4 r.p.m-5 r.p.m. The dyed fabric was rinsed with cold and hot water followed by soaping with 2 gpl sodium carbonate and 5gpl non-ionic soap. Soaping was carried out at boil for 15 minutes as shown in Figure 2. The fabric was dried and subjected to colour measurement and fastness to washing, rubbing, and water by using ISO methods.

Dyeing by exhaust method

With a view to implementing this process in the textile mills after optimizing the process conditions, the cotton knitted fabric dyed in a soft flow dyeing machine in a knitting, dyeing and finishing mill were collected. These fabrics were dyed and washed in a textile mills. The typical dyeing process of one of the dyes that were used under this study i.e. Novacron brilliant blue H-GR is shown in Figure 3.

Colour measurement and evaluation

The colour measurement and evaluation was done on Gretag-Macbeth

Table 1. Chemical concentrations and application conditions for pad-batch dyeing of cotton knitted fabrics.

No.	Dyes, Chemicals and application conditions	Oncentration	Remarks
1	Novacron Brilliant Blue H-GR	20 gpl	
2	Novacron Ruby S-3B	20 gpl	
3	Novacron Orange F-NR	-	
4	Novacron Brilliant Red FN-3GL	-	
3	Caustic soda	20 ml/l	Used against sodium carbonate to eliminate the addition of common salt as recommended by the manufacturer
4	Urea	80 gpl	
5	Sodium silicate	50 g/l	
6	Non-ionic Wetting agent (Kolasol CDA)	2 g/l	
7	PH	11	
8	Percent wet pick up	80%	
9	Liquor Temp.	25°C	
10	Batching time	16 hours	

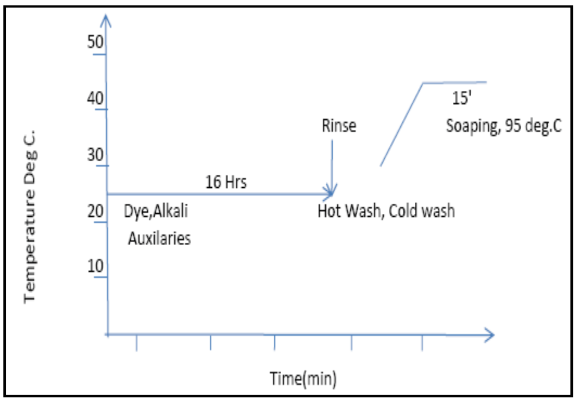

Figure 2. Process flow of pad batch dyeing.

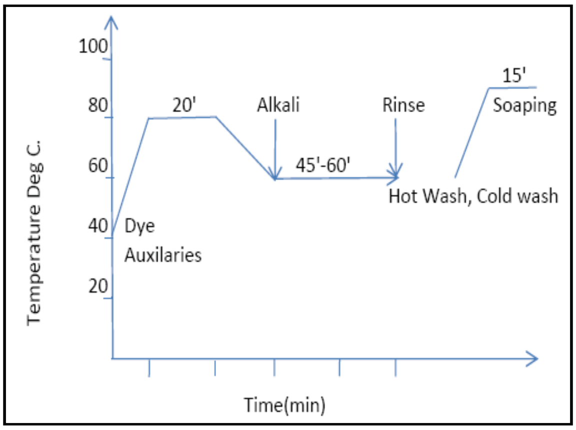

Figure 3. Process flow of Novacron Brilliant Blue H-GR.

spectrophotometer colour eye 3100 using D65/10° illuminant/observer conditions in wavelength range of 400 nanometers-700 nanometers using a white tile as a standard. The reflectance values were recorded against the wavelength at an interval of 20 nanometers. For determining the residual colour difference the reflectance at the λmax (maximum absorption of light) was selected and converted into K/S value by using the following equation(1).

$$K/S=(1-R)^2/2R \quad (1)$$

Where, K/S is the Kubelka Munk function which denotes a ratio of light absorbed [K] to that scattered [S] from the textile surface, "S" is generally assumed as "1" [2].

R=light reflected from the textile substrate

Colour difference (DE) was determined by computation of reflectance values using CIE Lab equation. In all evaluations the value of fabric dyed using exhaust method as standard against which those of pad batch dyeing were evaluated. It is important to note that the objective of this study is to evaluate the colour value obtained by using pad batch method and, therefore, the cost effectiveness and not to obtain equivalent colour depth.

Colour fastness evaluation

The colour fastness to various tests was determined by following ISO methods.

Results and Discussion

The Reflectance behavior of dyeings

The reflectance values of Novacron Brilliant Blue H-GR dyed by both the methods are shown in Figure 4. The curve patterns suggest similarity in reflectance behavior except at 440 nm.

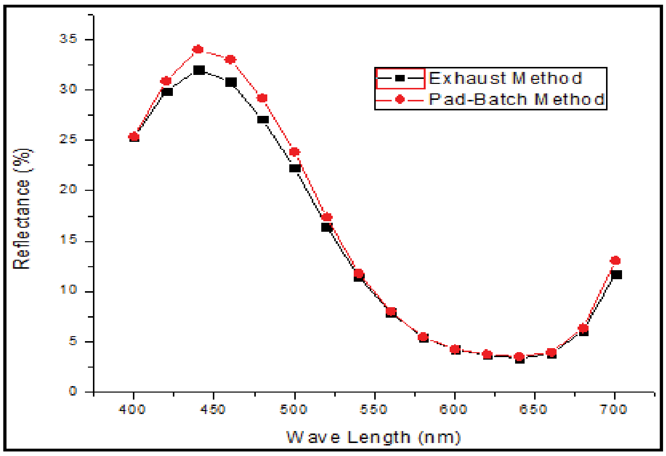

Figure 4. Reflectance value of Novacron Brilliant Blue H-GR.

Determination of residual colour strength

Comparisons in residual colour strength between the fabrics dyed by exhaust and pad batch methods is shown in Table 2.

Table 2. Residual colour strength.

	K/S		
Dye (λmax)	**Exhaust method**	**Pad–batch method**	**Relative difference (%)**
Novacron ruby S-3B (540 nm)	12.98	11.56	89.06%
Novacron brillinat blue h-gr(640 nm)	13.99	13.28	94.50%

This residual colour strength data of the two dyes shown here suggest that with some minor difference in the strength almost comparable depth can be obtained by using pad batch method as compared to the exhaust method. It is worthwhile, however, to study more dyes to understand the fixation behavior by the pad batch method.

CIELAB Measurement

The reflectances of dyeings carried out by exhaust and pad batch methods were computed to determine CIELAB values which are shown in Table 3.

Table 3. Colour difference (CIELAB) comparison.

Dye	**Lab Calculations**			
	DL	**Da**	**Db**	**DE**
Novacron ruby S-3B	0.83	-0.40	0.06	0.92
Novacron brillinat blue H-GR	0.77	-0.55	0.66	1.15

From this data it can be inferred that there is a marginal difference in DL (lightness-darkness) values that contributes to DE values. In both the dyes studied, DE values are within the acceptable tolerances which can also be reduced by increasing the initial dye concentration in the pad liquor.

Colour fastness to washing

The test was carried out according to the method ISO 105-CO6, Test No C2S. From Table 4, we it can be stated that the wash fastness of the fabric dyed with pad-batch method has a comparable result with that of the fabric dyed using exhaust method.

Table 4. Wash fastness results.

	Wash fastness			
	Exhaust method		**Pad–batch method**	
Dye	Staining	Colour change	Staining	Colour change
Novacron ruby S-3B	04-May	04-May	4	04-May
Novacron brillinat blue H-GR	04-May	04-May	4	04-May

Colour fastness to water

This assessment was done according to ISO 105-EO1. From Table 5, this data suggest that fastness to water is comparable.

Table 5. Water fastness results.

	Colour fastness to water			
	Exhaust method		**Pad–batch method**	
Dye	Staining	Colour change	Staining	Colour change
Novacron ruby S-3B	4	04-May	4	04-May
Novacron brillinat blue H-GR	03-Apr	04-May	4	04-May

Colour fastness to rubbing

This assessment was done according to ISO105-X12. From Table 6, it can be inferred that the rubbing fastness of the fabrics is comparable.

Table 6. Rubbing fastness results.

	Colour fastness to Rubbing			
	Exhaust method		**Pad-batch method**	
Dye	WET	DRY	WET	DRY
Novacron ruby S-3B	03-Apr	04-May	03-Apr	04-May
Novacron brillinat blue H-GR	03-Apr	04-May	03-Apr	04-May

Economical Analysis-A Typical Case Study

The economic analysis which is focused mainly on electricity and steam consumption are dealt with. The electrical and steam requirements between Exhaust dyeing in soft-flow and Pad-batch process for dyeing of knitted fabric are calculated and shown below.

Exhaust dyeing method

Fabric lot size: 100 kg-knitted fabric dyed with reactive dyes

Exhaust dyeing method: Soft Flow machine M:L: 1:6

Water quantity = 600 lit/filling,

Filling 1- dyeing = 600 lit*

Filling 2- rinse =600 lit

Filling 3- hot wash = 600 lit*

Filling 4- soap boil = 600 lit*

Filling 5- hot wash = 600 lit*

Filling 6- cold wash = 600 lit

*Total volume heated to boil= 2400 lit

No of fillings (only for dyeing & post washing) = 6

Total quantity of water required = 3600 lit

A. Steam consumption

Quantity of water heated to boil: 2400 lit

Steam required Kg/ kg (lit) water: 1680 kg (measured quantity 280 kg steam required for heating 400 liter water)

Cost of steam: Birr 0.75*/kg, therefore for 1680 kg, the steam cost is 1680 X 0.75 =Birr 1260.00

(*assumed)

B. Electricity consumption

Capacity of Motor fitted to the soft flow machine: 10 Hp

10 X 750 watts=7.5 KW

Machine running time for a lot size 100 kg=7 hours

Electrical energy required for running the machine=7X7.5=52.5 KWH

Cost of Electricity @ Birr 0.58/unit = 52.5X0.58=Birr 30.45 for a lot of 100 kg fabric/ shift of 8 hours.

Cold pad batch (CPB) process

Machine used for dyeing: Padder and Batching Device

Dye the fabric by Pad-batch method

Padding time required for 100 kg (=1000 mts) Approximately 66 minutes–Say 60 min or 1 hour @ 15 mts/min speed

A. Steam consumption

(a) Steam consumption for drying of fabric before padding=1.2 kg/kg of fabric

Drying cost =1.2*0.75=0.90 Birr/kg of fabric OR 90 Birr for 100 kg fabric

(b)Quantity of water heated to boil: 1800 lit

Steam required Kg/kg (lit) water: 1260 kg (measured quantity 280 kg steam required for heating 400 liter water)

Cost of steam: Birr 0.75/kg, therefore for 1260 kg, the steam cost is 1260X0.75 = Birr 945.00

Total steam cost is =90+945=Birr 1035

B. Electricity consumption

Motor HP=7.5X750 Watts=5.63 KWX1=5.63KWH

Cost of Electricity @ Birr 0.58/unit=5.63X0.58=Birr 3.27 for a lot of 100 kg fabric

Electricity consumption in washing: (Assuming that the dyed fabric is washed in a soft-flow machine. The practice is to wash in an open soaper which consumes less steam)

Machine run time for cold, hot, soap-boil and cold rinse steps= 3 hoursX7.5 KW=22.5 KWH

Cost of electricity@ Birr 0.58/unit=22.5 KWHX0.58=13.05 Birr for washing.

Total cost of electricity=For Dyeing=3.27 Birr

For Washing=13.05 Birr

=16.32 Birr

Savings on Electricity and Steam cost

(a) Savings on Electricity cost

Cost of electricity by exhaust dyeing method (Birr) 30.45

Cost of electricity by CPB dyeing method (Birr) 16.32

Savings on Electricity cost (Birr)=14.13

(b) Savings on Steam cost

Cost of steam by exhaust dyeing method (Birr) 1260

Cost of steam by CPB dyeing method (Birr) 1035

Savings on Steam cost (Birr)=225

Total savings on electricity and Steam energy (Birr)=14.13+225=239 for a lot of 100 kg fabric OR approximately 2.39 Birr per kg of fabric.

From the above economic analysis, assuming that the factory producing 80 tonnes per month of 100% cotton knitted fabric having 180 GSM or daily production of approximately 3 tonnes would have savings in steam cost (18%); More savings could be accrued if the post dyeing washing is done in open soaper instead of loading the fabric back in soft flow machine as assumed here. Savings in electricity could be up to (46%) if mill follows dyeing by cold pad batch method. Not included in this comparison is the advantage resulting from better quality (smooth surface, no pilling, and no creases).

The other saving areas are:

(1) Reduction in chemical consumption as in the exhaust method the chemical dosing is done on grams per liter basis and since the liquor volume is high in exhaust method

(2) Elimination of salt from the dyeing process considerably reduces the total dissolved content in waste water and also the reverse osmosis treatment cost which is expensive.

(3) Reduced volume of water and the chemicals in the waste water reduces the waste water treatment cost.

(4) Reduced wages as the labor requirement is during padding operation.

Conclusions

The results obtained from this study allow us to conclude that there exists considerable scope for reducing the thermal and electrical energy by adopting the cold pad batch process of dyeing for cotton knitted fabrics substituting the conventionally used exhaust dyeing method. Besides the cost factors shown here, other important areas of savings are water, chemical and waste water treatment. The CPB method thus is more eco-friendly than the conventional exhaust dyeing method. There are, however, apprehensions about the dimensional stability of the knitted fabric if dyed by the pad batch method due to longitudinal tension. This process is well established in many European countries, in USA and is gaining acceptance in Asian countries too. With continuous efforts in the direction of implementing the process in the knit fabric production the questions can be answered eventually.

Acknowledgment

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