Green technology in textile processing: Part III — Eco-friendly dyeing of cotton goods

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A novel eco-friendly dyeing process is described for the dyeing of cotton with reactive, sulphur and vat dyes. Significant reduction in pollution load in terms of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) is achieved by modified processes (Eco-Process I and Eco-Process II) employing standing bath or by substituting the non-ecofriendly chemicals with the eco-friendly ones. The reductions achieved in BOD and COD respectively are 7.65% and 17.27% for reactive dyeing, 2.10% and 5.78% for sulphur dyeing and 11.41% and 17.92% for vat dyeing. A considerable amount of saving in water consumption is also achieved while dyeing with Eco-Process I and Eco-Process II. Eco-Process II, in particular, results in 38.70%, 50% and 83.33% savings in water consumption during dyeing with reactive, sulphur and vat dyes respectively. This has also reduced the volume of effluent in a process house.

Keywords: Cotton fabric, Dyeing, Eco-processes, Jaggery, Reactive dyes, Sulphur dyes, Vat dyes

1 Introduction

In the dyeing process, about 30-60 litres of water is consumed for 1 kg of cloth substrate. This amounts to about 16% of the total water consumed in a mill. The main challenge before the textile industry today is how to get production at a competitive price by using safe dyes and chemicals as well as by reducing pollution treatment costs. There is no single answer to these questions as it depends upon the various sectors under consideration, their competence and multidisciplinary research.

Dyes belonging to azoic, basic (cationic), direct, disperse and oxidation bases and developers are termed as affected classes of dyes as some of them find place in the banned list. However, none of the dyes from the remaining classes, viz. reactive, vat, sulphur and natural, has been banned. Although, these dyes are unaffected or safe dyes, the practical dyeing with them is not free from the environmental problems.

With the everincreasing consumption of cotton textile products, the use of vat, sulphur and reactive dyes has significantly increased. Dyeing with these dyes require large quantities of salts to achieve good exhaustion, which increase the total dissolved solids (TDS) in effluents. In sulphur dyeing, the alkaline sodium sulphide brings the dye into soluble state; however, it contributes sulphides in the mill effluent. Although the natural dyes are eco-friendly, the metallic mordants used for improved fastness and better fixation on textiles are not always eco-friendly.

The dyeing effluent contains unabsorbed dye, surfactants, auxiliaries and other chemicals which may increase the pollution load. Noteworthy work for the removal of dyes and surfactants from effluent has been reported.

Developments in reactive dyes are the Sumifix Supra dyes (marketed by Sumitomo Company, Japan) which are the mixed bifunctional reactive dyes containing both vinyl sulphone and monochlorotriazinyl groups. These dyes overcome the drawbacks of low degree of exhaustion and fixation, poor levelness and reproducibility, and low fastness properties. Dawson International patented a process and the equipment design for fixing dyes or chemicals using radio frequency energy. In the recent developments, an electrolytic process is used to achieve the reduction of sulphur or vat dyes.

In continuation of our earlier work to develop new eco-friendly methods of processing textile goods, an attempt has been made in the present work to dye the cotton goods with safe dyes, eco-friendly auxiliaries and chemicals. The work also deals with the reduction of waste concentration in effluents by reusing dyes.
and chemicals recovered from the effluents. The reuse of low-load effluents has been successfully tried and has resulted in considerable saving in water consumption in the dyeing process.

2 Materials and Methods

2.1 Materials

Cotton hanks (25s) and cambric fabric (warp count, 65s; weft count, 66s; ends/in., 62; and picks/in., 50) were used for the study.

Procion Brilliant Red M5B [C.I. Reactive Red 2 (18200)], Navion Jade Green FFB [C.I. Vat Green 1 (59825)] and Sulphur Black BO [C.I. Sulphur Black 1 (53185)] were used.

Sodium hydrosulphite (GR grade), common salt, sodium hydroxide, sodium carbonate, acetic acid, calcium chloride, magnesium sulphate, ferric chloride, mercuric sulphate, silver sulphate, potassium dichromate and ferrous ammonium sulphate, all of AnalR grade; were used.

2.2 Methods

The cotton hanks and cambric fabric were bleached and mercerized. The cambric fabric was dyed with reactive and sulphur dyes while the cotton hanks were dyed with vat dye using the conventional methods as well as Eco-Processes I and II developed in our laboratory.

2.2.1 Dyeing of Cambric Fabric with Reactive Dye

2.2.1.1 Conventional Method (Exhaust Dyeing)

The bleached mercerized cambric fabric (100 g) was dyed for 1% shade in a laboratory jigger dyeing machine, keeping the material-to-liquor ratio at 1:4. The dye fixing agent Sandofix WEI (2 g/l) and acetic acid (1 g/l) were added to the dyebath and two ends were given followed by soaping at 80°C using the conventional method.

2.2.1.2 Eco-Process I

The bleached mercerized cambric fabric (100 g) was dyed for 1% shade in a laboratory jigger dyeing machine, keeping the material-to-liquor ratio at 1:4. The following sequence was adopted for the dyeing:

- The fabric was loaded into machine containing dye fixing agent Sandofix WEI (2 g/l) and two ends were given at room temperature,
- The bath was drained,
- The dissolved dye was added over two ends,
- Two more ends were given without making any additions to the dyebath,
- Predissolved salt (10 g/l) was added and one end given,
- Predissolved salt (10 g/l) was added again and one end given,
- The goods were run for two ends,
- Predissolved sodium carbonate (7.5 g/l) was added and one end given,
- Predissolved sodium carbonate (7.5 g/l) was added again and one end given,
- The goods were given four ends, and
- Bath was drained and soaping was carried out as per the conventional method.

2.2.1.3 Eco-Process II

The batch to be dyed by the Eco-Process II is preceded by another batch to be dyed following the conventional method, with a difference that instead of draining the solutions the same are collected for recycle and reuse in the Eco-Process II. Thus, the first batch is dyed by the conventional method followed by dyeing of one or more batches.

In the Eco-Process II, all the sequences were exactly the same as followed in conventional dyeing. However, cold wash, dye-fixing treatment, soaping, hot wash and cold wash were carried out with recycled water. The wash liquors generated during cold washing, dye fixing, soaping, hot washing and cold washing of conventionally-dyed fabric were segregated from the dye solution and then treated with 50 mg/l lime followed by 150 mg/l ferrous sulphate. The contents were stirred and kept stagnant for 3 h. The sludge formed was allowed to settle at the bottom. The clear supernatant liquor was passed through a column of activated carbon and the colourless water was collected and reused in Eco-Process II.

2.2.2 Dyeing of Cambric Fabric with Sulphur Dye

2.2.2.1 Conventional Method (Exhaust Dyeing)

The bleached mercerised cambric fabric (100 g) was dyed for 8% shade in a laboratory jigger dyeing machine, keeping the material-to-liquor ratio at 1:4.

2.2.2.2 Eco-Process I

The bleached mercerised cambric fabric (100 g) was dyed for 8% shade in a laboratory jigger dyeing machine, keeping the material-to-liquor ratio at 1:4.
The following sequence was adopted for the dyeing.

- Fabric was loaded into machine containing 10 g/l of liquid jaggery (prepared by treating commercial jaggery with 0.05% citric acid for 20 h) and 2 g/l of sodium carbonate. Two ends were given,
- Predissolved dye was added in two lots over two ends, gradually raising the temperature to 60°C,
- Fabric was given two more ends at 60°C in the same bath,
- Common salt (20 g/l) was added at 60°C in lots over two ends,
- Temperature was raised to boil and dyeing continued at boil for four ends,
- Bath was drained,
- Cold rinsing was done over two ends,
- 2% hydrogen peroxide (100 vol) and little ammonia were added into the above bath and oxidation was carried out at 40°C for four ends,
- Bath was drained,
- Soaping was carried out at boil with 1 g/l soap and 1 g/l soda ash while giving two ends,

2.2.3 Eco-Process II

The dye liquors and wash liquors from conventional dyeing were segregated from each other and reused in Eco-Process II. The dye liquor was replenished with fresh dye, sodium sulphide and sodium carbonate (each 4.96 g) and used for dyeing a fresh batch. The wash liquors obtained from conventional dyeing were treated with 65 mg/l lime and 180 mg/l ferrous sulphate. The contents were stirred and kept stagnant for 3 h. The clear liquor was passed through a activated carbon column and the colourless effluent was reused in Eco-Process II for dyeing as well as for other operations. The entire dyeing process was exactly the same as followed in the conventional method.

2.2.4 Tests

Total solids, suspended solids, total dissolved solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and pH were determined as reported earlier10.

The cotton substrate dyed by the Eco-Process I and Eco-Process II were compared with those dyed by conventional method for their depth of shade and tone using the Computerised Colour Matching (CCM) System.

The colour changes of dyed yarn and fabric samples were measured in terms of CIE L* a* b* values with illuminants D 65, A and TL 84 respectively at a 10° observer. The work was carried out on Spectraflash SF 300 system of Datacolor International, USA.

Wash fastness was determined according to ISO4 (BS 1006, CO4 : 1974) and ISO5 (BS 1006 CO5 : 1978) methods11. The colour fastness to day light was determined according to BS 1006 (1978) method11.

2.2.5 Bulk Trials

Bulk trials for dyeing of cambric fabric with reactive (Procion Brilliant Red M5B) and sulphur (Sulphur Black BO) dyes and cotton hanks with vat dye (Navinon Jade Green FFB) using conventional
and Eco-Processes I and II were carried out. The cambric fabric was dyed in a jigger, while cotton hanks were dyed in a typical yarn dyeing unit. The batch size of cambric fabric was 100 kg while that of hanks was 50 kg. The chemicals used were of commercial grade.

3 Results and Discussion

Table I shows that the fabric sample dyed with Procion Brilliant Red M5B by Eco-Process I gives higher K/S value as compared to the sample dyed by the conventional method. The colour difference values also indicate that the sample dyed by Eco-Process I is darker, stronger and more red as compared to the conventionally-dyed sample. Though the sample dyed by Eco-Process II is comparatively lighter than the conventionally-dyed sample, the colour difference is negligible. The results indicate that the treatment of undyed fabric with a dye fixing agent before dyeing can improve the dye uptake.

The K/S and colour difference values of fabric samples dyed with Sulphur Black BO by various methods do not show significant difference. This indicates that liquid jaggery can give the same degree of reduction as obtained with sodium sulphide. It could be good eco-friendly substitute as reducing agent in sulphur dyeing of cotton.

The K/S and colour difference values of hanks dyed with Navillon Jade Green FFB show that the sample dyed by Eco-Process I is darker, stronger and more green in comparison to that dyed by the conventional method, indicating that intermediate air oxidation step is more effective in increasing the dye uptake as compared to the chemical oxidation. The lower dye uptake for the sample dyed by Eco-Process II may be due to the higher concentration of dissolved solids in the recycled water.

The wash and light fastness ratings showed the improved wash fastness for the sample dyed with reactive dye by Eco-Process I. This may be due to the dye fixing treatment given in Eco-Process I which helps in retaining higher amount of dye on the substrate during washing. No change in wash fastness rating was noticed in case of sulphur and vat dyeings. The light fastness of all the dyed samples remained same.

The waste water generated in dyeing of cotton substrates by different processes was analysed for pH, total solids, total dissolved solids (TDS), suspended solids, and biochemical oxygen demand (BOD) and chemical oxygen demand (COD). The results are tabulated in Table 2.

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solids, BOD and COD and the results are given in Table 2. The effluent generated in dyeing of cambric fabric with reactive dye by the conventional method shows alkaline pH and high TDS contents which may be due to the usage of large quantity of salt in dyeing for exhaustion. The BOD and COD values for the effluents generated by the conventional method of dyeing are 170 mg/l and 608 mg/l respectively, which are quite high. Therefore, certain modifications become essential in the existing process. In the Eco-Process I, the use of acetic acid, which contributes to high BOD, is avoided. Further, more exhaustion of the dye on the fabric is also achieved, thereby reducing the concentration of residual dye in the effluent. Therefore, Eco-Process I shows lower values of BOD and COD (147 mg/l and 503 mg/l respectively) for the effluent as compared to that shown by the conventional method. Due to the recycling of wash liquors from conventional dyeing, higher values of total solids, total dissolved solids, BOD and COD are observed for Eco-Process II effluent. However, due to the recycling of wash liquors, not only the saving in water consumption but also the reduction in volume and average pollution load of the effluent are achieved.

The effluent from conventional dyeing of cambric fabric with sulphur dye shows alkaline pH, very high values of total solids, BOD and COD. The effluent also contains more harmful chromium. By substituting sodium sulphide, which contributes to the sulphide ions in the effluent, with eco-friendly liquid jaggery in Eco-Process I, substantial reduction of the sulphide content in the effluent is achieved. Moreover, the foul smell of sodium sulphide is also eliminated. Further, non-eco-friendly chemicals like potassium dichromate, acetic acid, etc. used in the conventional method have been substituted with the eco-friendly hydrogen peroxide. As a result, the effluent from Eco-Process I shows lower values of total solids, BOD and COD than shown by the effluent from the conventional method. The leftover dyebath used in the conventional method was replenished with fresh amounts of dye, sodium carbonate, sodium sulphide and salt in Eco-Process II and the dyeing of the second batch was carried out. Similarly, the wash liquors generated in post-dyeing operations of conventional method are put to reuse, after giving suitable treatments, for washing, soaking and oxidation in Eco-Process II. Slightly higher values of total solids, BOD and COD are observed for the Eco-Process II effluent as compared to that for the conventional method effluent.

Fairly large volume of effluent is generated in the dyeing of cotton hanks with vat dye. The effluent generated by the conventional method shows higher values of pH, total solids, BOD and COD. However, in the Eco-Process I, the chemical oxidation with non-eco-friendly dichromate-acetic acid system has been replaced by the intermediate air oxidation process. Hence, Eco-Process I effluent shows lower values of BOD and COD. The Eco-Process II shows some increase in BOD and COD values but achieves good amount of savings in water consumption.

Table 3 shows savings in water consumption in the dyeing process compared to the conventional method.
dyeing of cambric fabrics with Procion Brilliant Red M5B and Sulphur Black BO using Eco-Processes I and II instead of the conventional one. For reactive dyeing, Eco-Process I results in saving of 800 litres water per batch of 100 kg fabric and Eco-Process II results in saving of 1200 litres water per batch. In monetary terms, the savings obtained per batch in Eco-Process I and Eco-Process II are 37.20% and 38.70% respectively. In sulphur dyeing, Eco-Process I does not give any saving in water consumption, but Eco-Process II results in saving of 1200 litres water per batch. In monetary terms, the saving per batch is 50%.

In hank dyeing with Navinon Jade Green FFB, the Eco-Process II results in saving of 5000 litres water per batch of 100 kg fabric. In monetary terms, the saving per batch is of the order of as high as 83.33%.

References