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Salt-free reactive dyeing of cotton hosiery fabrics by exhaust application of cationic agent

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ABSTRACT

Reactive dyes are most preferred dyes for dyeing of cellulosic fibres as they are chemically bonded to the fibre which is being dyed and also inexpensive to apply. But the application of reactive dyes onto the cellulosic materials requires a very high concentration of salt since fibre and dyes are anionic in nature. Even with required amount of salt only 65–70% of reactive dyes are exhausted, remaining 25–30% of dyes are removed as a coloured effluent after dyeing. The present work aims to eliminate salt usage in the reactive dyeing of cellulosic material, especially in cotton hosiery fabrics dyeing industry. In this study, the cationization of cotton fabric was carried out by varying concentration of cationic agent from 20 to 60 g/L by an exhaust method with the goal to achieve 100% dye utilization and fixation during the salt-free reactive dyeing process. All the dyes taken for the study showed excellent dye exhaustion, fixation and colour strength properties on the cotton fabrics.

1. Introduction

Reactive dyes are quite often used for dyeing of cotton fabric as they produce bright and brilliant colour in various shade ranges. Reactive dyes are applied to cotton in two stages that is exhaustion and fixation. Exhaustion step is achieved by using salt, preferably Glauber's salt (Na_2SO_4) or common salt (NaCl) to overcome the negative zeta potential of cotton and by salting out of dyes (Ristic, 2012; Tarbuk, Grancaric, & Leskovac, 2014). The exhausted dyes are fixed to the cotton fabric by using alkalies such as sodium hydroxide (NaOH) or sodium carbonate (Na_2CO_3). The unfixed dye is eluted out as a coloured effluent in the hydrolysed form. The addition of salt and alkali depends on the depth of the shade to be produced (Agarwal & Bhattacharya, 2010; Chattopadhyay, Chavan, & Sharma, 2007; Chinta & Vijaykumar, 2013; Kanana et al., 2006; Lewis & Mcllroy, 1997a, 1997b; Montazer, Malek, & Rahimi, 2007; Teng, Ma, & Zhang, 2010).

The hydrolysed dye along with added salt and alkali are disposed as an effluent at the end of the reactive dyeing process. The effluent released from the processing house has a high total dissolved solid content and poses a serious challenge during the tertiary effluent treatment process (Chen, Wang, Ruan, Chen, & Yang, 2015; Chequer et al., 2013). This is one of the major environmental problems in the area like Tiruppur, which is a part of Tamil Nadu in India. Tiruppur is the hub for knit goods processing with more than 700 dyeing units and it accounts for 85% of India's total export of cotton hosiery fabrics, thus the city is popularly known as a "Knitwear Cluster of India" or "Banian City". The dyeing industry in Tiruppur generates almost 100–120 million liters of effluent per day and these effluents are reported to have high biological oxygen demand, chemical oxygen demand, colour and salt content (Allègre, Moulin, Maisseu, & Charbit, 2006; Joseph, 2000; Nelliyat, 2007; Vishnu & Joseph, 2008; Vishnu, Palanisamy, & Joseph, 2008). To solve these effluent problems, the concept of zero liquid discharge system is in vogue for the last few decades and they fairly serve as constraints to effectively reuse the salt (Nelliyat, 2007; Vishnu et al., 2008). Moreover, the adoption of zero liquid discharge system has led to significant increase in dyeing cost due to the salt recovery system and industries are also hesitant to reuse the salt due to poor shade matching. Thus, industries are seeking an alternative solution for the reduction of salt in reactive dyeing process to overcome the problem posed by them (Ma, Zhang, Tang, & Yang, 2005; Wang & Lewis, 2002).

The major attempts on reduction or elimination of salt can be summarized under three categories; reduction of liquor ratio dur-

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ing the dyeing process, modification of dyes such as usage of low salt or polyfunctional dyes like Cibacron LS, Novacron LS, Teegafix HE reactive dyes (Cai, Pailthorpe, & David, 1999; Paluszkiewicz, Matyjas, & Blus, 2002; Singha, Maity, & Singha, 2013; Taylor, 2000; Vishnu & Joseph, 2008) and modification of cotton using chemicals, compounds, enzymes, nanoparticles, ultrasonic waves, plasma, gamma, ozone treatments (Burkinshaw, Mignanelli, Froehling, & Bide, 2000; Gashti, Pournaserani, & Ehsani, 2013;; Gulzar et al., 2015; Hao et al., 2015; Kamel, Zawahry, Ahmed, & Abdelghaffar, 2011; Parvinzadeh et al., 2010; Patiño et al., 2011; Zhang, Ju, Zhang, Ma, & Yang, 2007).

Among those efforts, the most promising method to reduce salt consumption in reactive dyeing process is to chemically modify cotton by introducing cationic sites on the fibre using cationic agents, thereby increasing the substantivity and reactivity of fibres towards reactive dyes (Fang, Zhang, & Sun, 2013; Micheal, Tera, & Ibrahim, 2002; Tarbuk et al., 2014; Wang, Ma, Zhang, Teng, & Yang, 2009; Zheng, Yuan, Wang, & Sun, 2012). Several researchers have investigated the effect of cationization on the colour strength, dyeing and fastness properties of cotton fabric dyed with reactive dyes using various cationic agents and these cationic agents can be grouped into a polymer, non-polymer based agents and commercial agents such as polyamide-epichlorohydrin type of polymers, dendritic polymers, biopolymers like chitosan, starch & their derivatives, keratin hydrolysate and chicken feather, poly-(4-vinylpyridine) quaternary ammonium compounds, glycidyltrimethyl-ammonium chloride (Glytac), epichlorohydrin based quaternary ammonium compounds, chlorotriazine type quaternary compounds, choline chloride, *N*-methylolacrylamide, *N*,*N*′-dimethylazetidinium chloride, 2,4-dichloro-6-(2-pyridino-ethylamino)-*s*-triazine (Ali, Saleem, Umbreen, & Hussain, 2009; Arivithamani, Agnes Mary, Senthil Kumar, & Giri Dev, 2014; Chattopadhyay, 2001; Kim & Choi, 2014; Kitkulnumchai, Ajavakom, & Sukwattanasinitt, 2008; Pal, Mal, & Singh, 2005; Tutak, 2011; Wang & Liu, 2014). Among all the agents 3-chloro-2-hydroxypropyl trimethylammonium chloride (CHPTAC) has been most preferred cationic agent in a last decade for cationization of cotton (Fu, Hinks, Hauser, & Ankeny, 2013; Hashem, Hauser, & Smith, 2003; Hauser & Tabba, 2001; Hauser, Smith, & Hashem, 2004; Tarbuk et al., 2014).

CHPTAC is commercially available as a 65% solution, and it has been widely used for cationization of starch. The usage of CHPTAC has been extended to cationization of cotton for dyeing with acid, direct and reactive dyes (Hashem et al., 2003). This cationic agent was applied or fixed onto the cotton fabric by the cold pad-batch process (CPB–continuous method) and pad dry cure process (E-control process). The formed cationized cotton (CC) fabric was dyed with reactive dyes without the addition of salt and resulted in increased colour strength. However, the CPB method is not successful for producing all the variety of shades as the CC fabric showed tone variation at the end of the dyeing process and the repeatability of the shade or depth was not being achieved. Secondly, the CPB process takes 18–24 h dwell time for fixation of the padded cationic agent onto the cotton fabric (Acharya, Abidi, & Rajbhandari, 2014; Hashem, 2006, 2007; Hauser & Tabba, 2001; Kanik & Hauser, 2004; Tarbuk et al., 2014). The modification of cotton by padding process and subsequent dyeing of cotton by exhaust method are complicated and increase the dyeing cycle time. It is an energy intensive process and is not adopted in the textile dyeing industries.

With this background, efforts were made in this study to adopt an exhaust method for cationization of cotton fabrics with CHPTAC and subsequent salt-free dyeing of CC with reactive dyes by exhaust method. In this study, the cotton samples were treated with various concentrations of cationic agent and optimized the cationic agent concentration at which almost 100% of dye fixation was achieved. The CC dyed fabrics showed excellent wash and light fastness similar to that of the conventionally dyed (CD) cotton fabrics.

2. Materials and methods

2.1. Materials

100% cotton single jersey knitted fabric–scoured, bleached and ready for dyeing fabric with a cover factor of 180 g/cm^2 was used for this study. CHPTAC used as a cationic agent for modification of cotton in this study was supplied by Dow Chemical Pvt. Ltd., Tiruppur. Drimarene yellow HF–CD, Drimarene red HF–CD and Drimarene blue HF–CD reactive dyes used for dyeing studies were procured from Archroma dyes Ltd., Bangalore, India. Other laboratory chemicals such as Glauber's salt (Na_2SO_4), sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3), acetic acid and soap solution (labloene) were supplied by Fisher Scientific Chemicals Ltd., Chennai, India.

2.2. Methods

2.2.1. Modification of cotton by exhaust method and evaluation of fabrics

The cationization of bleached cotton fabric was carried out by exhaust method using CHPTAC and NaOH with a mole ratio of 2:1. The bleached fabric was first exhaust treated with NaOH solution with material to liquor ratio (MLR) of 1:6 at 40 °C for 10 min. The CHPTAC was added into the bath at the same temperature, run for 5 min, and then the temperature was raised to 80 °C at a heating rate of 4 °C/min and run for 30 min. The fabric was then taken out and washed with water at 70 °C (Hot wash), followed by neutralization using 1.5 g/L acetic acid at 70 °C for 5 min. Finally, the fabric was washed at room temperature (cold wash) to obtain a neutral pH.

Further, the CC fabrics were characterized using an elemental analyser (Perkin-Elmer 2400 Series CHNS/O analyser) for identification of chemical composition and thermogravimetry analyser for modification of cotton.

2.2.2. Effect of alkali addition in cationization process

The cationization of cotton fabric involves the reaction between CHPTAC and cotton in the presence of alkali. The sequence of addition of alkali played a significant role in the degree of cationization achieved. Two different methods were adopted, the addition of alkali at the start of the process and CHPTAC at the start of the process. In the former case, the fabric was first treated with alkali followed by addition of CHPTAC and in the case of the latter; the fabric was first treated with CHPTAC followed by addition of alkali. The effect of the alkali addition was evaluated in terms of colour parameters.

2.2.3. Dyeing of bleached and CC fabrics

The bleached fabrics were dyed with Drimarene group of yellow HF–CD, red HF–CD and blue HF–CD reactive dyes at 1% shade with 30 g/L of Glauber's salt and 10 g/L of Na_2CO_3 in laboratory IR dyeing machine with MLR ratio of 1:6 by exhaust method. The CC fabrics were also dyed as per the above conditions without the addition of salt. All dyeing was performed as per the standard method prescribed by the dye manufacturers and dyeing cycle for BLEACHED& CC are given in Figs. S_1 and S_2 (Appendix A in the Supplementary data). The influence of the concentration of alkali used for fixation of reactive dyes was also studied.