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The impact of corona modified fibres' chemical changes on wool dyeing

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ABSTRACT

The main contribution of the present work was to study the impact of Corona-treated wool fabrics' induced surface properties on dye-bath exhaustion, in order to optimize different dyeing systems. Firstly, the differing chemical aspects of a woven wool fabric's surface were determined using two dissimilar analytical skills (XPS and polyelectrolyte titration). With the intention to establish the ability of low-temperature plasma treatment to change wool fibre morphology which could have an impact on sorption properties, fabrics were dyed with blue acid and blue metal-complex dyes, and dyeing behaviour were studied by means of on-line VIS spectrophotometry. Finally, dyed samples were colourimetricaly evaluated and colour differences calculated. The results provided evidence that the overall carbon C 1s content was decreased while oxygen and nitrogen atoms were increased when using ionized air for fabric modification. It has also been noted that the amount of positive-charged functional groups in various pH ranges are higher for Corona-treated wool fabric in comparison with the untreated that improves hydrophylicity and dyeing properties.

1. Introduction

The wool fibre is morphologically composed of two types of cell, the inner cortical cells and the cuticle cells that are located on the outermost part of the fibre surrounding the cortical cells (Simpson and Chrawshaw, 2002). Cuticle cells consist of the endocuticle, the A and B exocuticles, and a 5–7 nm thin hydrophobic epicuticle that is chemically constituted of an external fatty-acid monolayer (F-layer) and a protein layer with hydrophilic groups (Molina et al., 2003). The fatty-acids are covalently bound to the proteins via ester or thioester linkages. Hydrophobicity of the epicuticle F-layer has a considerable impact on the wettability, shrinking and dyeing properties of wool fibres, and consecutively on textile finishing processes. The principal component of wool fibre is the protein keratin that consists of a long polypeptide chain constructed from 18 amino acids (Simpson and Chrawshaw, 2002). As a result of the diverse chemical nature of these amino acids, the protein side-chains are of widely varying character, containing functionality which includes amino and imino, hydroxyl, carboxylic acid, thiol and alkyl groups and heterocyclic functionality. At intervals, the polypeptide chains are linked together by disulfide (–S–S–) bridges derived from the amino acid cystine. There are also ionic links between the protonated amino ($–NH_3^+$) and carboxylate ($–COO^-$) groups, which are located on the amino acid side-groups and at the end of the polypeptide chains. Christie (2001) elucidated that many of these functional groups on the wool fibre play an important role in the attraction forces involved when dyes are applied to the fibres. The dyeing process of wool fab-

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rics in industrial production can be performed by exhaustion using acid, metal-complex and less frequent reactive dyes, respectively. Acid dyes are water-soluble anionic dyes, with a relatively low molecular weight, that are attracted to cationic groups within the wool, primarily the ammonium ($-NH_3^+$) groups. Metal-complex dyes are a special sub-group of acid dyes which form resonance-stabilized dye:metal complexes with metals such as chromium, cobalt, copper, etc. In these complexes the valence and the coordination number of the chromium are both satisfied, and the resulting dyestuffs are larger, more stable molecules, with better fastness properties than the original acid dyes from which they are formed, as had been reported by Lewis (1992) and Nasau (1998).

Corona treatment is a contemporarily alternative process that uses ionized air to increase the surface modification of the wool fibres (Čelan Benkovič, 2005). The presence of high amounts of oxygen and nitrogen species in the plasma gas induces chemical and physical changes on the surface through oxidation, grafting and adhesion, by the formation of carbonyl, carboxylic, hydroxyl, amino, nitro, etc. groups. Numerous investigations have indicated that chemical changes on wool surface, caused by a low-temperature plasma treatment, improves processing and performance characteristics of wool fibres, depending on treatment time, pressure and nature of the plasma gas, because of the progressive hydrocarbon chains oxidation and removal of the fatty-acid upper layers (Molina et al., 2005). Kan and Yuen (2006) studied the adsorption rate (hydrophylicity) of low-temperature plasma-treated wool fibre using three plasma gases, i.e. oxygen, nitrogen and 25% hydrogen/75% nitrogen mixture, respectively, by spectrophotometric measurements. Ratetić (2004) reported the significant reduction of wool shrinkage and pilling behaviour after oxygen plasma treatment, although frictional and topographical changes negatively influenced the wool handle (harsh and stiff). Molina et al. (2003) described the improved shrink resistance and wettability of wool even at short treatment time (10 s) using water vapour plasma. The obtained values of the advancing contact angle provide an evidence of the hydrophilic group formation on the wool surface. Kan et al. (1998a, 1998b) studied the effect of low-temperature plasma modified surface on the wettability and dye-bath exhaustion rate during chrome dyeing. Reported results proved that plasma treatment could accelerate the hydrophilicity and surface electrostatic properties as well as enhancing the overall dyeing process, depending greatly on selection of appropriate plasma gas and treatment time. The above-listed properties are related to human comfort and well-being, leading to the manufacture of end products with high added value.

Due to an increase of ecological problems in wet finishing of wool fabrics, the purposes of this research are, firstly, to investigate the surface chemical composition of the untreated and Corona/plasma-treated wool fabrics using various analytical techniques and, secondly, to study the influence of plasma treatment on the sorption characteristic of wool fabric during dyeing with metal-complex and acid dyes, in order to optimize different dyeing systems.

2. Experimental

2.1. Materials

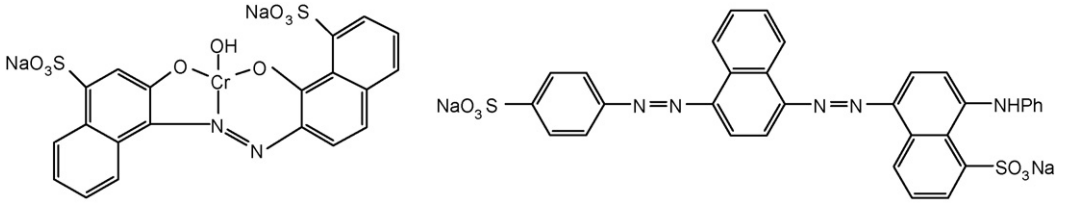
Experiments were carried out on woven wool fabric with mass/unit area 160 g/m^2, vertical density of 21 threads/cm and horizontal density of 19 threads/cm. The source fabric was washed at 40 °C for 20 min using a neutral non-ionic washing agent, and afterwards rinsed in warm and then cold water, and dried at temperature of 60–70 °C. Both sides of the fabric were treated with low-temperature plasma using Corona pilot-apparatus (DWI Aachen) at a constant output power of 2.5 kW and a feeding velocity of 7 m/min, respectively. In the reaction chamber atmospheric gas with 78% nitrogen and 21% oxygen content was applied. Treatments were repeated four times to ensure a satisfying surface effect. Constructional and operational parameters of Corona reactor are depicting in patents DE19731562 and NZ526178.

2.2. Dyeing process

Two different pre-treated fabrics (untreated and Corona-treated) were dyed under 80 °C or 98 °C temperature, and at a liquor ratio 1:20, using two dyes of differing chemical constitution, according to the standard dyeing procedures by means of Turby laboratory apparatus (W. Mathis) with medium bath circulation. Dyeing was carried out using Bemaplex 1:1 metal-complex dye – C.I. Acid Blue 158 and Bemacid acid dye – C.I. Acid Blue 113 supplied by Bezema. The chemical structures of the applied dyes are presented in Fig. 1.

The metal-complex dyeing process was started at 45 °C, when 1% of amphoteric levelling agent (Keriolan A2N – Bezema), and 4% of sulphur(VI)acid (96%) were added for pH 2 adjustment. 1% of the metal-complex dye was appended 10 min after starting the process. Afterwards, the dye-bath was heated to 80 °C or 98 °C (2 °C/min), maintained for 60 min and then reduced to 60 °C.

The initial acid dye-bath contained 0.5% of amphoteric levelling agent (Keriolan A2N-Bezema), 0.5 mL/L of pH-regulator



C.I. Acid Blue 158 C.I. Acid Blue 113

Fig. 1 – The chemical structure of used dyes.