Carbohydrate Polymers 186 (2018) 310–320

Contents lists available at ScienceDirect

Carbohydrate Polymers

journal homepage: www.elsevier.com/locate/carbpol

Nanosilver leverage on reactive dyeing of cellulose fibers: Color shading, color fastness and biocidal potentials

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ARTICLE INFO

Keywords:
Viscose
Immediate AgNPs
Color shading
Release
Biocidal properties

ABSTRACT

The current approach focuses on studying the leverage of nanosilver (AgNPs) incorporation on the dyeing process of viscose fibers by blue reactive dye. Nanosilver was straightway incorporated into viscose fibers using sodium citrate as nanogenerator. Owing to AgNPs incorporation, color of fibers was turned to greenish-blue and darker greenish color was observed with low Ag content (< 1 g/kg). Regardless to the processes sequencing, color strength of fibers was magnified by increasing in Ag content. The constancy of fibers color was not affected by AgNPs inclusion, whatever the processes sequencing and Ag content. Release property of Ag from fibers into water was considerably depended on the processes sequencing. By incorporation of AgNPs firstly, the lowest Ag release value was estimated (0.25 g/kg after 24 h). Antimicrobial activities were significantly improved by AgNPs incorporation. Reduction in bacteria and fungi was reached 92.4% and 67.9% after 24 h contact time, respectively.

1. Introduction

Textile industrialization is one of leading industries in which nanotechnology is being implemented with full enthusiasm (Ahmed & Emam, 2016; Emam, Mowafi, Mashaly, & Rehan, 2014; Emam, Rehan, Mashaly, & Ahmed, 2016; Emam, Saleh, Nagy, & Zahran, 2015, 2016; Mowafi, Rehan, Mashaly, Abou El-Kheir, & Emam, 2017; Rehan, Mashaly, Mowafi, El-Kheir, & Emam, 2015). Nanotech-textiles become one of the most popular textiles with their multi-functional properties, as one of the most important advantageous properties of nanotech-textiles is their protective properties. The characteristic properties of different metal nanoparticles and their applications in manufacturing functional textiles were extensively studied in literatures (Ahmed, El-Rafie, & Zahran, 2015; Ahmed & Emam, 2016; El-Rafie, Ahmed, & Zahran, 2014; Emam, El-Hawary, & Ahmed, 2017; Emam, El-Rafie, Ahmed, & Zahran, 2015; Emam et al., 2013; Emam, Mowafi et al., 2014; Emam, Rehan et al., 2016; Emam, Saleh et al., 2015, 2016; Emam & Zahran, 2015; Junyan, 2003; Mowafi et al., 2017; Qian, 2004; Qian & Hinestroza, 2004; Rehan et al., 2017; Rehan, Hartwig, Ott, Gätjen, & Wilken, 2013; Rehan et al., 2015; Smith & Block, 1982; Trotman, 1984; Zahran, Ahmed, & El-Rafie, 2014).

Nowadays, numerous researches are interested in reducing or inhibiting those infections caused by antibiotic-resistant bacterial species which survived on hospital textiles (Neely & Maley, 2000; Slaughter et al., 1996). Consequently, these demonstrate a great demand for antimicrobial textiles and materials (quaternary ammonium compounds, chitosan, triclosan, metals/metal oxides nanoparticles and bioactive plant-based extracts) that are capable of protection against major pathogens (Ahmed et al., 2015; Ahmed & Emam, 2016; Alemdar & Agaoglu, 2009; Ali, Joshi, & Rajendran, 2011; El-Rafie et al., 2014; Emam, El-Hawary et al., 2017; Emam, El-Rafie et al., 2015; Emam, Manian et al., 2014; Emam et al., 2013; Ilić et al., 2009; Jeong, Hwang, & Yi, 2005; Joshi, Ali, & Rajendran, 2007; Kalyon & Olgun, 2001; Ki, Kim, Kwon, & Jeong, 2007; Liang et al., 2006; Pinto, Vale-Silva, Cavaleiro, & Salgueiro, 2009; Sójka-Ledakowicz et al., 2009; Sun, Li, Qiu, & Qing, 2005; Worley & Sun, 1996; Worley, Williams, & Crawford, 1988; Zahran et al., 2014). Silver nanoparticles (AgNPs) have been widely used due to its broad spectrum of antimicrobial activities and low toxicity toward mammalian cells (Gaonkar, Sampath, & Modak, 2003; Kim et al., 2009).

Nano-silver as one of the different nanomaterials used to impart antimicrobial activities in textile materials, can impart antimicrobial properties as well as characteristic colors such as brown, cream, yellow, dark green or purple according to the size and shape of AgNPs incorporated in textile matrices. Chattopadhyay and Patel reported that treatment with AgNPs could improve the tensile strength and color

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https://doi.org/10.1016/j.carbpol.2018.01.074
Received 1 October 2017; Received in revised form 20 December 2017; Accepted 20 January 2018

depth on cotton, wool and silk fabric (Chattopadhyay & Patel, 2009; Gulrajani, Gupta, Periyasamy, & Muthu, 2008). Recently, the efficiency of AgNPs direct synthesis in multi-functionalization of natural and synthetic fibers/fabrics was investigated, as all the treated fabrics acquired new decorative color, antimicrobial and UV-resistance properties (Ahmed & Emam, 2016; Emam, El-Hawary et al., 2017; Emam, Mowafi et al., 2014; Emam, Rehan et al., 2016; Emam, Saleh et al., 2015, 2016; Mowafi et al., 2017; Rehan et al., 2015).

The authority of nanosilver incorporation on the textile dyeing process was previously studied for dispersed dye, sulfur dye, vat dye, acid dye and direct dye (Gorenšek & Recelj, 2009; Gulrajani et al., 2008; Ki et al., 2007; Maneerung, Tokura, & Rujiravanit, 2008; Perelshtein et al., 2008; Saengkiettiyut, Rattanawaleedirojn, & Sangsuk, 2008). Disperse dyeing of cotton and cotton/polyester blend fabrics in the presence of AuNPs was reported by using a binder, and the treated fabrics were exhibited excellent antimicrobial activity against *E. coli*, *S. aureus* and the fungus of *C. albicans* (Perelshtein et al., 2008; Saengkiettiyut et al., 2008). Additionally, the laundering durability and changing in color of fabrics were monitored. A combination treatment of wool fabric with sulfur dye and AgNPs was studied to produce moth-proofing, antimicrobial and antistatic fabrics (Ki et al., 2007; Maneerung et al., 2008). Inspiration of AgNPs on cotton and wool fabrics dyed with vat dye were demonstrated through antibacterial activities and color differences (Gorenšek & Recelj, 2009). Pretreatment of wool fabrics with nanosilver composites was shown to increase the acid dye up-take (Mashaly, Moursy, Kamel, Taher, & Farahat, 2014). Additionally, the presence of nanosilver was showed to effect on the color strength and manifest the antimicrobial properties of cotton, silk and wool fibers which were finished with direct dyes (Chattopadhyay & Patel, 2009).

Cellulosic based textiles are shown to be mostly dyed with reactive dyes, as reactive dyes are characterized by production of a wide range of bright colors with excellent wash fastness. Herein, the leverage of nanosized silver on color shading, color fastness and augmentation of biocidal properties of reactive dyed viscose fibers was systematically studied. AgNPs were directly synthesized using citrate as a reducing agent. The effect of silver salt concentration, dye percentage in reaction liquor and the reaction sequences were monitored. SEM images and EDX data were represented to confirm the successive incorporation of nanosilver on the treated fibers. Absorbance spectra, color coordinates, color strength and the color fastness were all estimated for treated fibers to check the influence of AgNPs incorporation on the coloration process. Release behavior of silver ions and biocidal properties of treated fibers were both evaluated to measure the effect of dyeing on the application of fibers incorporated silver.

2. Experimental

2.1. Materials and chemicals

Silver nitrate (99.5%, from Panreac, Barcelona – Spain), Trisodium citrate (99% from Sigma, Aldrich – Germany), CI Reactive Blue19 (RB19) ($C_{22}H_{16}N_2Na_2O_{11}S_3$, DyStar Colours, Frankfurt – Germany), sodium hydroxide (99%, from s.d. fine Chemical Limited, Mumbai – India), Sodium sulfate anhydrous (99%, El Nasr Pharmaceutical Chemicals, Cairo – Egypt) and Sodium carbonate anhydrous (97%, El Nasr Pharmaceutical Chemicals, Cairo – Egypt) were used as received.

Viscose as regenerated cellulose fibers (Lenzing Viscose®) with length of 38 mm and linear density of 1.3 dtex, was kindly supplied from Lenzing AG (Lenzing, Austria). Fibers did not have been spanned and were used without further treatment.

2.2. Procedure

The current study concluded three different process carried out for viscose fibers to acquire green color based on combination of AgNPs incorporation and blue reactive dye. These processes are represented in direct incorporation of AgNPs followed by dyeing, dyeing followed by incorporation of AgNPs and concurrently combination of AgNPs incorporation and dyeing. The experimental conditions of the fibers treatment were summarized in Table 1. The treated samples are named as Ag – Dye, Dye – Ag and Dye/Ag, respectively. Each process can be described briefly as follows:

Table 1
Experimental conditions for treatment of viscose fibers.

Samples	Ag Conc. (mg/L)	Dye Conc. (%)	Process ordering
Blank	0	0	
A	0	1%	Dyeing
B	0	5%	Dyeing
1	40	0	AgNPs
2	200	0	AgNPs
3	800	0	AgNPs
4	40	1%	AgNPs followed by dyeing
5	200	1%	AgNPs followed by dyeing
6	800	1%	AgNPs followed by dyeing
7	40	5%	AgNPs followed by dyeing
8	200	5%	AgNPs followed by dyeing
9	800	5%	AgNPs followed by dyeing
10	40	1%	Dyeing followed by AgNPs
11	200	1%	Dyeing followed by AgNPs
12	800	1%	Dyeing followed by AgNPs
13	40	5%	Dyeing followed by AgNPs
14	200	5%	Dyeing followed by AgNPs
15	800	5%	Dyeing followed by AgNPs
16	40	1%	Concurrently
17	200	1%	Concurrently
18	800	1%	Concurrently
19	40	5%	Concurrently
20	200	5%	Concurrently
21	800	5%	Concurrently

2.2.1. Incorporation of AgNPs

5 g of viscose fibers were submerged in $AgNO_3$ solution (40, 200 and 800 mg/L) using 1:50 material to liquor ratio and then the mixture was heated till boiling under continuous stirring. A 10 mL from 3% tri-sodium citrate as reducer was drop wisely added to every 100 mL of silver nitrate solution. The reaction mixture was kept at boiling temperature under constant stirring for 30 min and then the fibers were removed and rinsed twice by tap water. The treated fibers were then dried at 80 °C prior to analyses/characterizations and dyeing process.

2.2.2. Dying process

Dyeing with the reactive dye was performed for fibers and AgNPs-fibers using the CI reactive blue19 dye. The dyeing was carried out by dissolving of dye (1% and 5% (owf)) in distilled water then 5 g viscose fibers was added to dye solution using material to liquor ratio of 1:50. To this dye bath, 30 g/L sodium sulfate was added at 40 °C and after 30 min, 20 g/L sodium carbonate was drop wisely added. Then the temperature was raised to 60 °C and dyeing process was preceded for a further 60 min. At the end of dyeing, the dyed samples were rinsed with tap water and then dried on air prior to analyses/characterizations and/or AgNPs incorporation.

2.2.3. Concurrently combination process

In this process, combination between fibers dyeing and AgNPs incorporation was concurrently performed. $AgNO_3$ was added in the solution mixture during the dyeing operation. A 5 g viscose fibers was added to dye solution (1% and 5% (owf)) using 1:50 material to liquor ratio and then sodium sulfate (30 g/L) was added at 40 °C. After 30 min sodium carbonate (20 g/L) was drop wisely added to dye bath, followed by addition of $AgNO_3$ solution (40, 200 and 800 mg/L) and tri-sodium citrate (10 mL, 3%). The temperature of mixture was then raised to 60 °C and the process was performed for further 60 min under