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Modification of cotton fabric with a dendrimer to improve ink-jet printing process

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ABSTRACT

In this study, the cotton fabrics were modified with different polyamidoamine (PAMAM) dendrimer concentrations to yield antimicrobial and efficient polymeric materials for ink-jet printing. PAMAM dendrimer has been covalently grafted on cotton fabric via the reaction of cellulosate anion with the cynuric chloride. The obtained modified cotton fabrics were characterized by FTIR and TGA. The morphology and yellowness of modified cotton fabrics were analysed by SEM and UV spectroscopy. The ink-jet printing onto modified cotton fabrics were evaluated at different pHs. The results at optimum pH indicated that by increasing the PAMAM dendrimer concentration in modified cotton fabric not only the colour strength of reactive ink-jet printed fabric increased but also the antimicrobial cotton fabric produced. A comparision between printing modified and unmodified cottons suggest that the PAMAM dendrimer has the potential for using in single-phase ink-jet printing. The yielded prints demonstrate excellent colour fastness for washing and dry/wet crocking properties.

1. Introduction

In the near future, it is expected that the traditional flat or rotary screen printing and roller printing techniques were superseded by digital printing technologies, which have found an increasing number of applications in printing textile (Chapman, 2002; Eckman, 2004; Ervine, Siegel, & Siemensmeyer, 2000; Gupta, 2001; Siemensmeryer, Siegel, Ervine, & Bullock, 1999; Stefanini, 1995; Ujiie, 2006).

Cotton fabric can be printed on with reactive dye based inks (Aston, Provost, & Masselink, 1993; Kumbasar & Bide, 2000; Petrinic, Andersen, Sostar-Turk, & Le Marechal, 2007). Commercial ink-jet reactive inks are based on dyes with low to moderate fixation properties. Therefore, maximizing the dye fixation for economic and environmental reasons is considered to be very important. Generally, reactive dyes are applied to cellulosic fabrics in the presence of an alkali to promote the fixation of the dye to the fabric through covalent bond formation via the reaction of the cellulosate anions with the reactive groups of the reactive dye molecule. In ink-jet printing, none of the conventional printing chemicals, such as alkali, urea and thickener can be directly incorporated into the ink formulations (Fan, Kim, Lewis, & Perruzi, 2003). If reactive dyes based ink formulations incorporate an alkali, then not only the ink can cause corrosion of the print head nozzle, but also would have an extremely limited storage life, as the dye rapidly hydrolyzes to a non-reactive form leaving behind a precipitate that will block the nozzle. In order to prevent dye hydrolysis, a stable ink formula containing purely dye should be prepared and applied to cotton substrates that have been pre-treated prior to ink-jet printing with a print paste, which contains an alkali, urea and thickener (Hauser, 2011; Walters, Santillo, & Johnston, 2005).

Application of the pre-treatment process is felt to be disadvantageous in practice, because the pre-treatment process is environmentally unfriendly, energy-intensive and time-consuming. In addition, the print pastes have a short shelf life due to their pH.

Previous studies have detailed the increase of reactive ink fixation through the modification of reactive dyes (Li & Tincher, 1999), fabrics (Eltz, Schrell, & Russ, 1994; Hutter & Matzinger, 2000; Kaimouz, Wardman, & Christie, 2010; Kanik & Hauser, 2003; Zhang, Westland, Cheung, Burkinshaw, & Blackburn, 2009) and ink formulation (Soleimani-Gorgani & Shakib, 2013), as well as the use of fixation-enhancing chemicals in the pre-treatment process. (Yuen, Ku, Choi, & Kan, 2008).

Although, the modification of cotton fabric was used to improve the printability back in last century, however, in recent years, the

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chemical modification offers a possibility to enhance ink fixation and allowing the printing process to be carried out through the reduction of the chemical amount and energy consumed (Ahmed, 2005; Abo Farha, Gamal, Sallam, Mahmoud, & Ismail, 2010; Prabu & Sundrarajan, 2002).

Recently, some dendrimers have been used as exhausting and fixing agent for dyeing cotton with reactive dye to improve the fixation of dye, which offered the potential of lowering costs through the reduction of the chemical amount and energy consumed.

Polyamidoamine (PAMAM) dendrimers are water-soluble, non-immunogenic, biocompatible compounds (Cheng, Ma, & Xu, 2008; Roseita & Tomalia, 2001; Winnicka, Bielawski, Rusak, & Bielawska, 2009) and their highly-branched nature could provide enormous surface area that generates great reactivity to cynuric chloride.

Basically, in commercial anionic reactive dye (Procion Red H-E3B), the sulphonate group is anionic, which causes electrostatic repulsion with anionic cellulose groups. Therefore, modification of cotton fabrics with amino groups of PAMAM dendrimer may decrease the negative charge build-up on the fibre surface, thereby assisting the absorption of the dye onto the fabric. Under these conditions, the electrostatic repulsion between dye and fibre would be minimized and the available nucleophilic groups (cellulose anions and amino groups) will be reactive towards electrophilic reactive groups.

The aim of this work was to determine, whether the modification of cotton fabric with a PAMAM dendrimer could enhance the printability of the fabric with reactive dye based ink. For this purpose the functional groups of PAMAM dendrimer contained primary amino groups were used because, as mentioned above, such functional groups could theoretically be able to react with reactive groups under neutral pH conditions.

2. Experimental

2.1. Materials

The fabric used was 100% singed, desized, scoured and bleached cotton plain weave fabric (98 g/m^2), which was supplied by the Broojerd Textile Company, Iran. Sodium alginate, sodium carbonate and cyanuric chloride at the highest purity were provided by Sigma-Aldrich Company, USA. The PAMAM G2 dendrimer used was a derivative of Polyamidoamine (Fig. 1); the preparation of the dendrimer is described in the literature (Esfand & Tomalia, 2001). The dye (Procion Red H-E3B) used for printing cotton was kindly provided by DyStar Company, Germany (Fig. 2). A non-ionic detergent, Synperonic BD 100, Univar, UK, was used in the wash-off process. Other chemicals used were received from Merck Company, Germany.

2.2. Equipment and instrumentation

A laboratory padder (Kimia Behris Company, Tehran, Iran) was applied to the pre-treatment solutions onto the fabrics, after which they were then dried in an Ecocell oven (Munich, Germany). The prepared ink was filtered through 0.45 and 0.2 μm Sartorius Minisart filter (Göttingen, Germany). The modified and unmodified cotton fabrics were ink-jet printed using a HP DeskJet 5150 printer. Fixation was performed using a laboratory steamer supplied by Kimia Behris Company, operating in the atmospheric pressure. The dye concentration in the washing baths was determined by absorbance measurements at λ_{max} using UV Ikon 923 Double Beam UV/Visible spectrometer (Saint-Quentin-Yvelines, France). The reflectance measurements of the prints were determined using a GretagMacbeth Spectrophotometer ColorEye7000A (New York, USA) with d/8 measurement geometry under the following conditions: measurement wavelength range from 400 to 700 nm, measurement area of 10 mm in diameter, and the specular component included (SCI) measurement mode. The CIELAB values were computed under D65 illuminant and SCI 1964 (10) standard observer. The Fourier transformed infrared spectroscopy in attenuated total reflection mode (ATR-FTIR) spectrums of unmodified and modified samples were recorded on Bruker (IFS-48) (Bruker Optik GmbH, Germany), in the range 400–4000 cm^{-1}. The pH, surface tension and viscosity of inks were characterized using 827 pH Metrohm meters (Herisau/ Switzerland), Tensiometer K100MK2 (Hamburg, Germany) and Brookfield DVII (New Jersey, USA), respectively. The colour fastness to light and washing of the ink-jet printed fabrics were determined by AATCC Test Methods 16-2001 and AATCC Test Method 61-2001. The yellowness index was defined by ASTME313 method in which the multiple samples were measured and the readings averaged were used. The antimicrobial test of modified and unmodified cotton fabrics was evaluated using a quantitative antimicrobial test according to AATCC100-2004. Thermal behaviours of the unmodified and modified samples were analysed by using Thermo Gravimetry/Differential Thermal Analyzer (Seiko Exstar 6000, TG/DTA 6100) in a nitrogen atmosphere at a heating rate of 10 °C/min. The surface morphology of the unmodified and modified cotton samples was determined through the use of a Scanning Electron Microscope (SEM).

2.3. Preparation of modified cotton fabrics

The modification was occurred by the route depicted in Fig. 3.

In this procedure, the cyanuric chloride was used for the covalent grafting of dendrimer on cotton fabrics. Polyamidoamine PAMAM G2 dendrimer, which was synthesized according to classical methods (Esfand and Tomalia, 2001), used as a nucleophile agent to react with cyanuric chloride. A suspension of freshly cyanuric chloride (4 mg, 1.2 equiv) in acetone (20 ml), which was cooled in an ice bath was added dropwise with stirring into a solution of polyamidoamine PAMAM G2 dendrimer (5%, 10% and 15% omf), at below 5 °C and pH 4.5–5. After 30 min, at 0 °C and pH 5, the mixture was stirred for 15 min at 25 °C, controlling by TLC to yield PAMAM-triazine derivatives in solution. The product was essentially homogenous as judged by TLC. Then, cotton fabric (3.5-3.5 cm, 0.27 g), previously soaked in 100 mL of 0.5 M NaOH during 24 h, was introduced and the temperature was raised to 30–40 °C with stirring at 5.5–6 for 2 h. When the reaction was complete, the solution was allowed to stand at 80 °C and pH 5 for 24 h under reflux and stirring. The modified cotton was collected and thoroughly washed with acetone (100 ml), water (100 ml) and methanol (100 ml). To determine the optimum application of PAMAM, a series of modified fabric samples 2, 3 and 4 were obtained with 5%, 10% and 15% omf, respectively.

2.4. Fabric pre-treatment

The pre-treatment paste was prepared using 150 g sodium alginate made from a stock sodium alginate solution, which was made ready by dissolving sodium alginate (50 g) in de-ionized water (0.95 dm^3), sodium bicarbonate (8 g) and urea (10 g). Then, the paste was made up to a weight of 200 g with de-ionized water (Ahmed, 2005; Fan et al., 2003; Yuen, Ku, Choi, & Kan, 2004a, 2004b) which was subsequently mixed thoroughly. The pre-treatment was padded onto the cotton fabric using a padding machine with an even pressure of 2.6 kg/m^2 and a constant padding speed of 2.5 r/min until a pick-up of 80% was achieved. The pre-treated fabrics were dried in an oven at 80 °C, and then conditioned before ink-jet printing.