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Washing off intensification of cotton and wool fabrics by ultrasounds

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ABSTRACT

Wet textile washing processes were set up for wool and cotton fabrics to evaluate the potential of ultrasound transducers (US) in improving dirt removal. The samples were contaminated with an emulsion of carbon soot in vegetable oil and aged for three hours in fan oven. Before washing, the fabrics were soaked for 3 min in a standard detergent solution and subsequently washed in a water bath. The dirt removal was evaluated through colorimetric measurements. The total color differences ΔE of the samples were measured with respect to an uncontaminated fabric, before and after each washing cycle. The percentage of ΔE variation obtained was calculated and correlated to the dirt removal. The results showed that the US transducers enhanced the dirt removal and temperature was the parameter most influencing the US efficiency on the cleaning process. Better results were obtained at a lower process temperature.

1. Introduction

Ultrasounds have a high potential utilization in the textile field, both in dyeing and washing [1–4]. The generation and transfer of an ultrasonic wave into a liquid medium generates localized pressure variations in the liquid that are responsible of bubbles formation and suddenly collapsing causing localized high pressure and temperatures. This phenomenon is defined cavitation. It can intensify mass transfer mechanisms in multiphase systems, such as at the liquid/solid interface [5] Intensification of mass transfer is the basis for the improvement of wet textile processes. Textiles fabrics are considered to have a dual porosity, one in the interyarn region and one in the intrayarn. During conventional wet-textile treatments, most of the flow occurs in the interyarn region, thus making the intrayarn diffusion process the rate-limiting step [6]. The intensification effect of ultrasound on various wet textile processes, such as dyeing, washing, rinsing and scouring, has been known for years even though the physical mechanism underlying this effect is not totally clear [7–10]. Several hypothesis address the increased swelling of the fibers and the reduction in the size of the dye or dirt particles [11–12]. A number of works from the literature showed that in washing operations the effect of ultrasonic cavitation improves the washing effectiveness, if compared to the traditional treatments [13–14].

At industrial level washing processes are limited by time and thermal constraints since a prolonged increase of temperature can spoil the textile. US induced cavitation allows to accelerate the processes thus obtaining results equivalent to lower temperature steps [15]. The use of ultrasound during textile cleaning can lead to chemicals, water and energy reduction thus improving the final quality product with almost no ecological impact. The introduction of new family of transducers may significantly contribute to the implementation at semi-industrial and industrial level of a number of processes [16].

In the present study the US technology has been applied to wool and cotton fabrics washing. The aim of the work was to investigate the effect that ultrasonic irradiation has on the dirt removal at short process time. Moreover it investigates if the ultrasonic irradiation can enable the use of lower cleaning temperatures. A standard methodology to dirt the fabrics was set up. Before the washing the dirty fabrics were soaked in a standard detergent solutions and subsequently washed in only water. The US washing was carried out with the fabric in close contact with the US transducers. For comparison purposes other samples were washed at identical conditions without US. The washing efficiency was evaluated through colorimetric investigation. The total color difference of the samples was measured before and after each washing. An uncontaminated sample of the same fabric was considered as color reference.

2. Materials and methods

2.1. Materials

Plain cotton woven fabrics of 144 g/m^2 and 18 micron diameter plain woven wool fabrics having a weight of 160 g/m^2, from Lanificio Cesare Gatti S.p.A., were selected for the experiments.

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Both the woven fabrics had size of 20 × 15 cm. The ECE (Economic Commission for Europe) SDC reference detergent, from SDC Enterprises Limited (UK), was used to prepare the 1 g/L water solution to soak the fabrics before the washing. The detergent has the following composition:

- Linear sodium alkylbenzenesulphonate (mean length of alkane chain: $C_{11.}5$): 8.0%.
- Ethoxylated tallow alcohol: 2.9%.
- Sodium soap (chain length: $C_{12.22}$): 3.5%.
- Sodium triphosphate (NaP_3O_{10}): 43.8%.
- Sodium silicate (Na_2SiO_3): 7.5%.
- Magnesium silicate ($MgSiO_3$): 1.9%.
- Carboxymethyl cellulose: 1.2%.
- Ethylene diaminotetracetic acid ($C_{10}H_{16}N_2O_8$): 0.2%.
- Sodium sulphate (Na_2SO_4): 21.2%.

2.2. Contamination procedure

Wood combustion soot was crushed in a ceramic mortar from Carlo Erba and then sieved with a 50 μm certified test sieved from Giuliani Tecnologie s.r.l.. A 10% (w/w) emulsion of this sieved soot in corn seed oil, from Carapelli S.p.A., was prepared. It was then sonicated for 10 min in an laboratory US bath, from UR Ultrasonic. A micro-syringe was employed to soil the samples: 8 stains of 25 μL volume each were deposited on the fabric.

2.3. Apparatus

Experiments were carried out in a stainless steel ultrasound vessel (prototypal equipment constructed by Obem S.p.A.). It allows to carry out dyeing and washing operations on textile materials. The vessel is equipped with a centrifugal pump and an electrical resistance to implement circulation and heating of the treatment bath. A flat SONOPLATE® ultrasound emitting device by Weber Ultrasonic's GmbH, working at 25 kHz frequency and supplied with 600 W power generator was used in this work.

It is positioned at the bottom of the vessel and it is constituted of 8 cone-shaped transducers, mounted on a stainless steel plate.

The vessel is equipped with rectangular bars at the top of the sonicator plate as dummy volumes to reduce the amount of water necessary for the experiments.

A stainless steel frame (height: 10 cm width: 15 cm length: 20 cm) was set up to hold and fix the fabric with a proper tension during the operations. The frame is composed of moving bars with grooves to fix the fabric frame at the desired distance from the sonicator plate. (Figs. 1 and 2).

Mechanical agitation was achieved by circulating water by the help of a centrifugal pump.

2.4. Washing conditions

The samples were soaked for 3 min in the 1 g/L solution prepared with the ECE detergent. Afterwards the washing experiments were carried out at different temperatures and time. The temperature was set at 25 °C and at 60 °C; the process times were 10, 30 and 60 s. During washing the samples were fixed on the frame, described above. The US were switched on as soon as the frame with the fabric was immersed into the water. The time was controlled through a chronometer. The frame was then removed from the vessel. Afterward the samples were washed with only water. To evaluate the effect of the transducers/fabric distance on the washing efficiency, the frame holding the sample was set at 1 and 15 mm distance from the sonicator plate. For comparison, other samples were washed at identical conditions without US.

2.5. Washing efficiency evaluation

The traditional method to quantify the washing efficiency in textile research is to measure the change in the colorimetric parameters of the fabric and relate it to the soil removal. This technique is quite useful mainly with textile samples of small size [17–18]. In this study the total color difference of the samples was measured before and after each washing cycle by a Datacolor Check II type instrument. The reflectometer converted the reflectance measurement into L (lightness), a (color shift between green and red), b (color shift between blue-yellow), h (hue) and E (total color difference) values according to the CIELab system. The measurements were carried out on each stain of the fabric and the mean value of the 8 stains was considered. The LAV (larger aperture view) module was employed to completely cover each stain during the measurements.

The total color differences, ΔE, of the samples were measured before and after each washing cycles. A wool and a cotton fabric without any stain were considered as the reference sample ($\Delta E = 0$). To evaluate the washing effectiveness the ΔE percentage variation were calculated as follows:

$$\Delta(\Delta E)\% = \frac{\Delta E_i - \Delta E_f}{\Delta E_i} * 100 \quad (1)$$

where ΔE_f is the ΔE of the washed samples, with and without ultrasounds and ΔE_i is the ΔE of the unwashed samples.

2.6. Anova statistical analysis

The general linear model of the Anova analysis was chosen to fit our results. US/fabric distance, contact time and process temperature were chosen as the fixed factors for the model. The washing

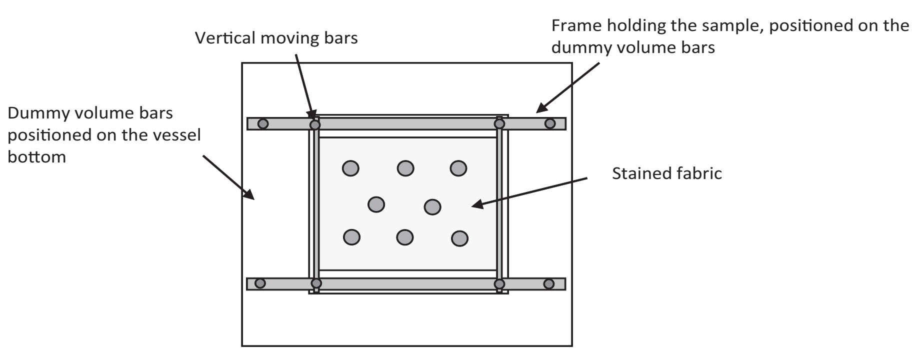

Fig. 1. Top-view of the washing vessel with the frame holding the soiled fabric.