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Use of ultrasonic energy in the enzymatic desizing of cotton fabric

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ABSTRACT

Enzyme process and ultrasound power are the two important clean technologies which have potential use in the textile industry like desizing, scouring, dyeing and so on. In the present work, the feasibility of introducing ultrasonic energy in enzymatic desizing process of cotton to improve the desizing efficiency is investigated. The results indicate that ultrasonic power value and cavitation effect were the two most important factors for improving the enzymatic desizing efficiency. The obvious saved treatment time show that the overall reaction rate between enzyme and starch could be accelerated by ultrasonic energy. Comparing with the conventional enzymatic desizing process, the ultrasound assisted system can save half the processing time and improve about 5 percent point in desizing efficiency.

1. Introduction

The concept of cleaner production (CP) has been practiced for many years in many countries. At its heart, the concept is about the prevention rather than the control of pollution (Tanapongpipat et al., 2008). The application of enzymes in the textile industry is becoming increasingly popular because of the mild conditions of temperature and pH that are required and the capability of enzymes of replacing harsh organic chemicals. Also important is that wastewater from enzymatic treatments is readily biodegradable and, accordingly, does not pose any environmental hazard (Yachmenev Val et al., 1998). At present, the typical applications of enzymes for treatment of cotton can be summarized as desizing (Öner and Sahinbaskan, 2011), scouring (Preša and Tavčer, 2008; Hebeish et al., 2009), bleaching cleanup, bio-finishing, bio-stoning, garment laundering (Yachmenev Val et al., 2004) and dyeing (Padma et al., 2007; Meksi et al., 2012).

Enzymatic processing of cotton, like any wet processing system, involves mass transfer from the processing liquid medium across the surface of the textile substrate. In general, large enzyme molecules (120,00–150,000 Da) have low diffusion rates and tend to react with external cellulose fibers in cotton yarn. Mechanical agitation of an enzyme processing solution usually improves the transport of bulky enzyme molecules toward the surface of the cellulose fabric and into the interior of the cotton yarn, but it is well known that mechanical agitation is not a very effective stirring mechanism for the immediate border layer of liquid at a solid/liquid interface where the enzymatic reaction actually occurs (O'Neill et al., 2007; Cortez et al., 2001).

Ultrasonic-based approaches have long been studied as an alternative to the conventional methods to accelerate mass transfer during some textile processing steps such as desizing (Sahinbaskan and Kahraman, 2011), scouring (Yachmenev Val et al., 2004; Yachmenev Val et al., 2001), bleaching (Abou-Okeil et al., 2010; Hebeish et al., 2011), mercerizing and dyeing of cotton fabrics (Duran et al., 2009; Akalin et al., 2004). Ultrasonic waves are vibrations with frequencies above the human audible range of 16 kHz. Ultrasound may be broadly classified according to frequency range as power ultrasound (20–100 kHz) and diagnostic ultrasound (Mohammad Mahmoodi et al., 2010; Sivakumar et al., 2009). Introducing ultrasonic energy into liquid causes two major phenomena: heating and cavitation. Formation and collapse of bubbles formed by ultrasonic waves are generally considered responsible for most of ultrasound's physical and chemical effects in solid/liquid or liquid/liquid systems. And the powerful agitation of the liquid border layer cased by cavitation could substantively improve the transport of bulky enzyme molecules toward the fiber surface and increase the overall reaction rate (Yachmenev Val et al., 2001; Abou-Okeil et al., 2010).

A thorough research of the available literature did not yield any direct data related to the application of ultrasonic energy to the enzymatic desizing of cotton. To move toward a more eco-friendly textile wet processing and cleaner production, the present work is to optimize the enzymatic desizing process of cotton fabrics in the

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presence of ultrasonic energy. The end goal of this research is to find milder conditions that the cotton fabrics could be effectively and efficiently desized. Various factors namely ultrasonic power, enzyme concentration, temperature, pH value and time which may affect the enzymatic desizing process were thoroughly investigated.

2. Experimental

2.1. Materials

Plain-weave cotton fabric of 100% (130 g/m^2) was used in this study. The fabric was sized with phosphate modified starch. Commercial amylase KW-40 was used as the desizing agent, which was kindly provided by Shanghai KDN Biotechnology Group, China. Sodium chloride and acetic acid were purchased from Zhejiang Zhongxing Chemical reagent Co., Ltd., China. Potassium iodate, potassium iodide and perchloric acid were purchased from Tianjin Damao Chemical Reagent Factory, China. All the applied chemical reagents in this study were AR grade.

2.2. Desizing process

Enzymatic processing of all samples was carried out in an SK3310HP KUDOS ultrasonic cleaner with a frequency of 53 kHz. The aqueous desizing solution was prepared with different enzyme concentration (viz. 1–3 g/L) and sodium chloride 5 g/L, and the pH was adjusted to different values (viz. 5–9) using acetic acid. Then the solution was preheated to the designed temperature (viz. 20–60 °C) by the ultrasonic cleaner machine. And then the fabric was kept in the solution for different times (viz. 10–50 min) with fiber to liquor ratio 1:30. After the treatment, the fabric was washed twice with hot water, then with cold water and finally dried for desizing efficiency testing.

2.3. Determination of the desizing efficiency

For determination of the desizing efficiency, samples were taken to determine the starch content on fabric. The starch content on fabric was analyzed by referring to a perchloric acid method. The absorbencies were converted to starch concentration using calibration chart (Fig. 1), and the desizing efficiency was calculated using Eq. (1):

$$\text{Desizing}(\%) = \frac{w_0 - w_1}{w_0} \times 100\% \quad (1)$$

where w_0 (mg/g fabric) and w_1 (mg/g fabric) are the amount of starch on per unit weight of fabric for control and desized fabric, respectively (Dong et al., 2009).

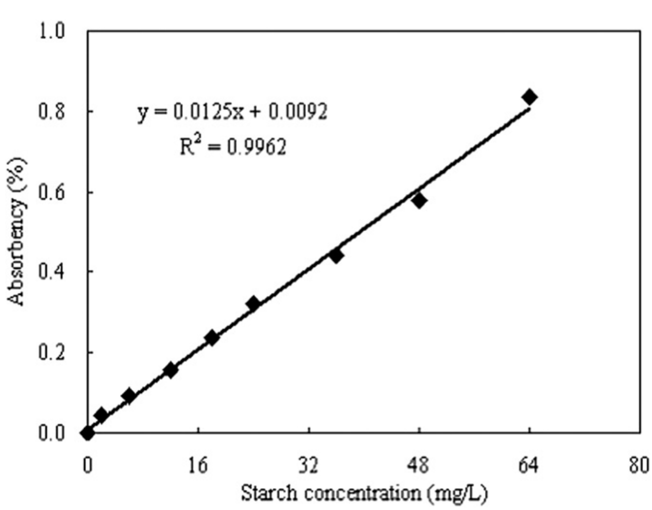

Fig. 1. Calibration chart for the relationship between starch concentration and absorbency.

3. Results and discussion

3.1. Effect of ultrasonic power on the desizing efficiency

The controlled fabrics were treated under different ultrasonic power levels (viz. 0–180 W) to investigate the effect of ultrasonic and its power value on the enzymatic desizing process. The aqueous solutions were prepared with amylase KW-40 2 g/L and sodium chloride 5 g/L at pH 7. Then, all the samples were kept at 50 °C for 15 min with liquor ratio 1:30. The desizing efficiency of the treatments was shown in Fig. 2.

It can be seen from Fig. 2 that the desizing efficiency could be significantly improved when ultrasonic energy was applied in the enzymatic desizing process. Fig. 2 also indicated that desizing percentage increased with the increasing of ultrasonic power, and the maximum desizing percentage value was obtained at the rated power (180 W) of the applied ultrasonic cleaner machine. It was possible because that the starch film on the fiber surface became unsmooth even broke under ultrasonic energy (Wang et al., 2006), then more starch exposed to the amylase and broke down. Furthermore, ultrasonic energy could effectively remove the starch hydrolysis products from the fabric surface which could inhibit the action of amylase on starch (Apar and Özbek, 2004). So the rated power 180 W was applied in the subsequent discussions.

3.2. Effect of enzyme concentration on the desizing efficiency

The concentration is one of the most important factors for enzymatic treatments. The samples were treated under ultrasonic power of 180 W with different amylase KW-40 concentration (viz. 1–3 g L^{-1}) to investigate the effect of enzyme concentration on the desizing percentage value. The aqueous solutions were prepared with sodium chloride 5 g/L at pH 7. And the samples were kept at 50 °C for 15 min with liquor ratio 1:30. The desizing percentage values of the treated fabrics with different enzyme concentration were presented in Fig. 3.

The results in Fig. 3 showed that desizing percentage values remarkably increased when enzyme concentration increased from

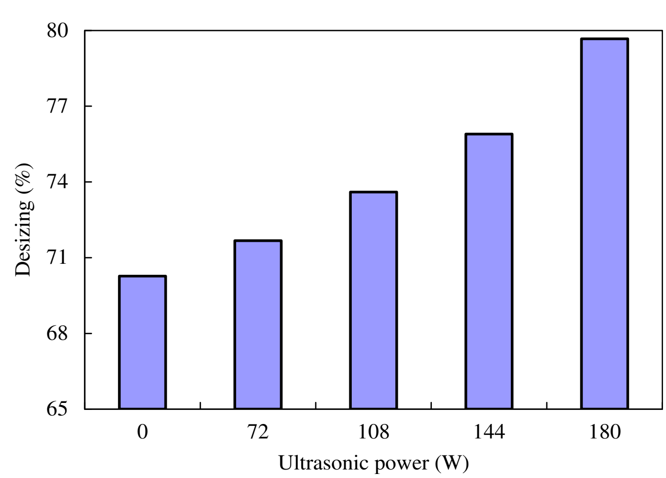

Fig. 2. Effect of ultrasonic power on the desizing efficiency.