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Preparation of activated carbon fibers from mixtures of cotton and polyester fibers

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ABSTRACT

Activated carbon fiber (ACF) is a novel material that is attracting increasing research attention. Specifically, ACF production from fiber mixtures is considered as a useful approach to reuse waste cloth and fibers. However, extant studies did not thoroughly investigate the use of the fore-mentioned mixtures in ACF preparation. In the present study, we describe ACF preparation from mixtures of cotton and polyester fibers and discuss solutions for a problem encountered during preparation. We attempted to determine a non-destructive method by using gray-scale intensities of the ACF images. The method is potentially promising, and we expect that it can be used for adsorption evaluations after further improvements.

1. Introduction

Activated carbon fiber (ACF) is attracting significant attention [1–3] because pores on its surface possess the potential to adsorb and retain undesired substances. Consequently, ACF is considered as a potential alternative to activated carbon that is conventionally used as a filter to remove waste products. Common evaluation methods for adsorption on activated carbon fibers include methyleneblue (MB), mercury infiltration, or nitrogen adsorption methods [4–6]. The MB method is simple and requires very less time.

In most studies, ACF is prepared from only a single material [7,8]. Sugumaran et al. reported on ACF produced from banana empty fruit bunch (BEFB) and Delonix regia fruit pod (DRFP) [7], and a group reported on ACF prepared from silk [8]. However, ACF production from a mixture of fibers is expected to constitute an ecologically friendly approach that reuses waste cloth and fiber materials. In a previous study, we determined that the adsorption ability of ACFs derived from fiber mixtures does not effectively increase [9]. The melting point of polyester is 260 °C [10], and this is lower than the temperatures used in the present study. Therefore, polyester liquefies during the thermal treatment and results in polyester fibers that close the pores generated in cotton, rayon, and other fibers. Thus, the pore structure generated from non-polyester fibers exhibits a lower propensity for adsorption. The ACFs produced by using a one-step thermal treatment exhibited higher methylene blue (MB) adsorption when compared with those produced by using a two-step thermal treatment. This suggests that the pore structure of carbonized fibers closes with repeated heating in the presence of polyester.

The present study involved preparing ACFs from mixtures of cotton and polyester fibers, characterizing the products, and measuring their adsorption abilities. The results of the MB adsorption experiments revealed that treatment at 600 °C under carbon dioxide produced ACF derived from cotton and polyester mixtures with good adsorption ability. The results may be useful in better understanding the adsorption abilities of ACFs derived from mixed fiber wastes that include materials with low melting points such as polyester.

2. Materials and methods

2.1. Material

Cotton (single fiber cloth No. 670101) and polyester (single fiber cloth No. 670110) were purchased from the Japanese Standards Association. Methylene blue (MB), potassium dihydrogen phosphate, and disodium hydrogen phosphate were purchased from Kanto Chemical (Japan). Activated charcoal made from palm (ACP) was purchased from Taihei Chemical (Japan).

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2.2. Thermal treatment

Samples were carbonized at various temperatures in a tubular furnace (ISUZU, KRO-14) that was equipped with a temperature control unit (CHINO, MODEL-SU) under a flow of nitrogen or carbon dioxide gas.

2.3. Sample treatments

The sample treatments were as follows: untreated cotton (C), cotton heat-treated under nitrogen at 200 °C (C-200N), cotton heat-treated under nitrogen at 400 °C (C-400N), cotton heat-treated under nitrogen at 600 °C (C-600N), cotton heat-treated under carbon dioxide at 200 °C (C-200C), cotton heat-treated under carbon dioxide at 400 °C (C-400C), and cotton heat-treated under carbon dioxide at 600 °C (C-600C); untreated polyester (P), polyester heat-treated under nitrogen at 200 °C (P-200N), polyester heat-treated under nitrogen at 400 °C (P-400N), polyester heat-treated under nitrogen at 600 °C (P-600N), polyester heat-treated under carbon dioxide at 200 °C (P-200C), polyester heat-treated under carbon dioxide at 400 °C (P-400C), and polyester heat-treated under carbon dioxide at 600 °C (P-600C); untreated cotton–polyester mixture (CP, 1:1 vol ratio), CP heat-treated under nitrogen at 200 °C (CP-200N), CP heat-treated under nitrogen at 400 °C (CP-400N), CP heat-treated under nitrogen at 600 °C (CP-600N), CP heat-treated under carbon dioxide at 200 °C (CP-200C), CP heat-treated under carbon dioxide at 400 °C (CP-400C), and CP heat-treated under carbon dioxide at 600 °C (CP-600C) (Table 1).

2.4. Adsorption of methylene blue

In order to determine the adsorption of methylene blue (MB) by the ACF samples, we used test methods for activated carbon as per the Japan Industrial Standard K-1474 [11]. Briefly, we commenced the study with a 1200 mg/L aqueous MB solution that was diluted to concentrations corresponding to 120 mg/L, 24 mg/L, 12 mg/L, 2.4 mg/L, 1.2 mg/L, 0.24 mg/L, and 0.12 mg/L by using a phosphate buffer prepared from potassium dihydrogen phosphate, disodium hydrogen phosphate, and Milli-Q pure water. The optical absorbance of these solutions was measured by using a spectrophotometer (U-3210, HITACHI, Japan) to obtain a calibration curve. Subsequently, we measured the absorbance of the 120 mg/L MB solution after adding 1 g of ACF or ACP sample as a positive control. We determined the adsorption ability of the samples as the amount of MB (mg) adsorbed by the activated carbon (ACF or ACP, g) based on the optical absorbance of the solution and the obtained calibration curve.

2.5. Adsorption performance of activated carbon fibers

The adsorption abilities of the ACFs were also evaluated by using images captured by a digital camera (Ricoh, caplio R5 lens focal length 4.6–33 mm), and this was followed by processing using Image J software (National Institutes of Health, USA). The samples were photographed at a camera-to-sample distance of 30 cm. This method was previously used to evaluate liquid crystals [12–14] and ACFs [8]. The color images were converted to gray-scale intensities (GI) with pixel values ranging from 1 to 255 by using Image J software, and the average GI value was used to quantify changes in the optical absorbance [14]. The average intensity was calculated based on more than 100 points from each gray-scale image.

Table 1
Summary of heat treatment processes for activated carbon fibers derived from cotton and polyester. Each process and sample names are listed.

Heat treatment		Cotton	Polyester	Cotton:polyester blend
Nitrogen gas	R.T-200 °C	C-200N	P-200N	CP-200N
Nitrogen gas	R.T-400 °C	C-400N	P-400N	CP-400N
Nitrogen gas	R.T-600 °C	C-600N	P-600N	CP-600N
Nitrogen gas	R.T-200 °C	C-200C	P-200C	CP-200C
CO_2 gas	200 °C			
Nitrogen gas	R.T-400C	C-400C	P-400C	CP-400C
CO_2 gas	400C			
Nitrogen gas	R.T-600C	C-600C	P-600C	CP-600C
CO_2 gas	600C			

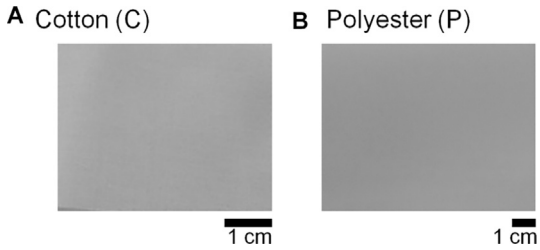

Fig. 1. Images of (A) untreated cotton and (B) untreated polyester.

3. Results and discussion

3.1. Thermal treatment for carbonization and activation

Typical images of the untreated cotton (C) and polyester (P) samples are shown in Fig. 1. A summary of the heat-treatment processes employed are listed in Table 1.

First, we consider treatment under nitrogen. Typical images of the ACFs prepared from cotton, polyester, and cotton–polyester under nitrogen are shown in Fig. 2A, B, and C, respectively. At temperatures exceeding 400 °C, ACF derived from cotton corresponds to a fragile black cloth (Fig. 2A). ACF derived from polyster corresponds to a white cloth at 200 °C, a white cloth mixed with yellow powder at 400 °C, and a yellow powder at 600 °C (Fig. 2B). The characteristics of both cotton and polyester are observed for ACF derived from the mixture of cotton and polyester (Fig. 2C).

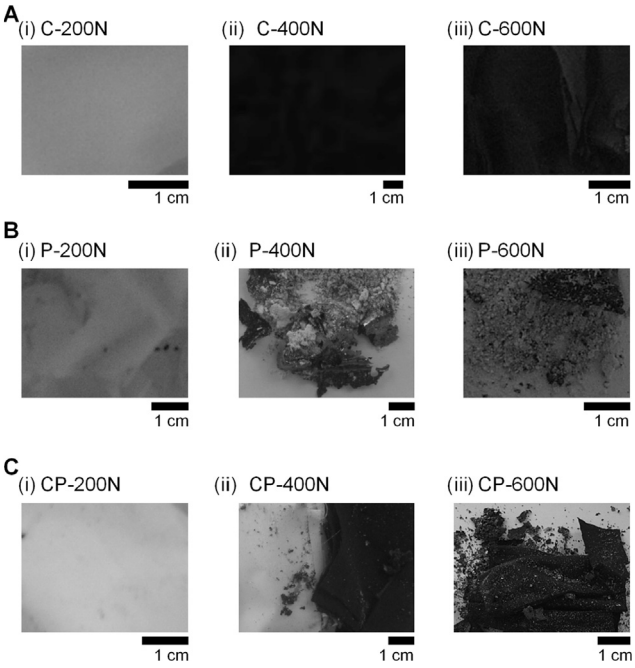

Fig. 2. Images of the carbonized fibers derived under nitrogen at several temperatures from (A) cotton (i) C-200N, (ii) C-400N, and (iii) C-600N); (B) polyester (i) P-200N, (ii) P-400N, and (iii) P-600N); and (C) cotton–polyester (i) CP-200N, (ii) CP-400N, and (iii) CP-600N.