Activated carbons from acrylic textile waste

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ABSTRACT

Acrylic textile waste was pyrolysed in static bed reactor in a nitrogen atmosphere in relation to different pyrolysis temperatures between 500 °C and 900 °C. Steam activation of the chars generated at 800 °C and 900 °C was carried out at three different temperatures, 800 °C, 850 °C and 900 °C to produce activated carbons. The chemical transformations of raw material and chars produced were investigated using FTIR. The FTIR spectra indicate the formation of condensed aromatic rings with nitrogen at high temperature. The pyrolysis chars and activated carbons were characterised in relation to process conditions via BET surface area, proximate and elemental analysis and surface characteristics using scanning and transmission electron microscopy. The BET surface area of the pyrolysis chars was all less than $2\,m^2\,g^{-1}$, but increased with steam activation to produce a maximum surface area of $619\,m^2\,g^{-1}$ for the activated carbon produced from the char generated at 800 °C and steam activated at 900 °C. The temperature of steam activation influenced the surface areas of the product activated carbon in that activated carbons produced from chars generated at 800 °C were significantly higher than those produced from chars generated at 900 °C. Nitrogen adsorption–desorption isotherms, micropore volume, DFT pore size distribution and electron microscopy showed that the activated carbons were mostly microporous.

1. Introduction

Activated carbon is a processed carbon material with a highly developed porous structure and a large internal specific surface area ($500–3000\,m^2\,g^{-1}$) [1]. Activated carbons are used extensively in industrial purification, waste water treatment and chemical recovery operations. They are particularly advantageous because of their high internal surface areas and active surfaces. In general, higher surface areas result in higher adsorption capacities. In addition, the pore characteristics of activated carbons are important in determining the particular application of the carbon.

Activated carbon can be made from a wide range of source materials. Theoretically, any raw material with high content of carbon could be used to produce activated carbon. In practice, coal, coconut shells, wood, peat and fruit stones are most commonly used to manufacture activated carbon. However, in laboratory scale studies, an enormous range of alternative raw materials has been used to produce activated carbons, such as fruit stones [2], tyre [3], municipal solid waste [4], synthetic polymers [5] and acrylic fibres [6]. The use of waste materials to produce activated carbon is preferable because it reduces the cost of the resultant activated carbon.

The activated carbons can be produced by physical or chemical activation. For example, physical activation via pyrolysis to produce a char followed by steam gasification, alternatively, the raw material may be treated with a chemical such as zinc chloride or phosphoric acid, followed by thermal treatment via pyrolysis to produce an activated carbon [7,8].

Whilst there have been many studies on the production of activated carbons from biomass and bio-degradable waste, there are fewer data related to textile waste. It is estimated that the generation of clothing and textile waste in the UK was of the order of 2 million tonnes per year [9]. This represents about 33 kg of clothing and textile waste per person in the UK and with a population of 500 million for the 27 countries of the European Union, this equates to approximately 16.5 million tonnes of clothing and textile waste generated per year in the EU27. Textile waste is considered as one of the fastest growing sectors in terms of household waste and the amount of waste is forecast to continue growing as sales of new textiles and clothing continue to increase. The main categories of clothing and textile waste are composed of synthetic materials such as acrylic, nylon and polyester fibres and natural materials such as wool, flax and cotton.

In addition, the fibrous nature of the textile waste material, as a feedstock precursor for the production of activated carbon, enables the production of fibrous activated carbon. Fibrous activated carbon has significant advantages over other forms of activated carbon such as granular and powder, depending on the field of application [10]. In addition, the nature of the fibrous activated carbon enables potential production as monoliths, fabrics and felt [11,12].

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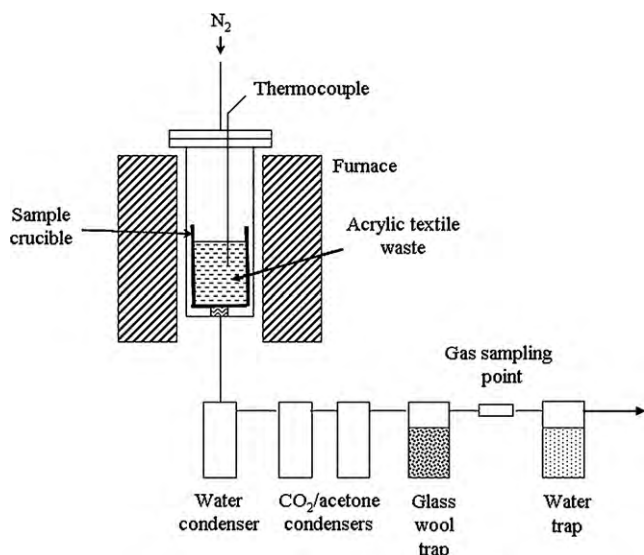
Fig. 1. Schematic diagram of the static bed pyrolysis reactor.

The main object of this study was the investigation of the thermal recycling of one category of textile waste, acrylic material, with the aim of the production of a higher value activated carbon product via pyrolysis and activation. In this respect, the pyrolysis chars and the derived activated carbons were characterised in relation to process conditions.

2. Materials and methods

2.1. Waste materials

Acrylic textile fabric waste which is one of the most commonly polymers used in textile field has been investigated. Acrylic fabrics are made up of at least 85% by weight of acrylonitrile units. The remaining 15% is composed of neutral co-monomers such as vinyl acetate (VA), methyl acrylate (MA) or methyl methacrylate (MMA) which play an important role in improving the diffusion rate of dyes into acrylic fibre [13]. The acrylic textile waste fabric was obtained as clothing waste and shredded to produce small pieces of size 2 cm^2.

2.2. Thermogravimetric analysis

Thermogravimetric analysis (TGA) was applied to determine the thermal degradation characteristics of the waste sample via the weight change of the sample as a function of the temperature. A Shimadza TGA-50H analyser was used to study the thermal degradation of the acrylic fabric waste. The sample weight was 5 mg and was loaded onto the alumina pan of the TGA and suspended within the furnace. Nitrogen gas was used during the process to ensure an inert atmosphere in the unit. The waste sample was heated at a heating rate 5 °C min^{-1} to a final temperature 900 °C

2.3. Pyrolysis reactor

Pyrolysis of the textile waste was carried out in static bed batch reactor, 250 mm in length by 30 mm internal diameter and was externally heated by a tube furnace 1.2 kW (Fig. 1). The furnace was controlled to produce the desired heating rate, final temperature and final pyrolysis temperature hold time. The crucible was filled with 8 g of the shredded acrylic textile waste and heated to different final temperatures of 500 °C, 600 °C, 700 °C, 800 °C and 900 °C at a heating rate of 5 °C min^{-1} and held at each final temper-
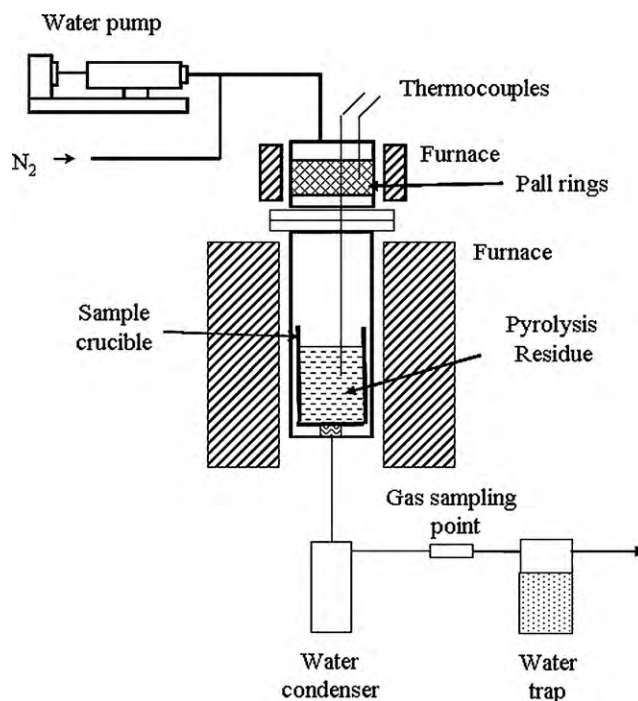

Fig. 2. Schematic diagram of the char activation reactor.

ature for 2 h. In separate experiments to determine the structural group composition of the solid product in relation to temperature of thermal degradation, the textile sample was heated to temperatures between 150 °C and 900 °C and held at that temperature for 10 min. Nitrogen was used as the carrier gas to provide an inert atmosphere and to sweep the evolved pyrolysis gases from the reactor, which also served to minimise any secondary reactions of the gases. A stainless steel sample crucible was used to hold the sample. Three condensers were used to trap the condensable products consisting of a water cooled condenser, followed by two solid CO_2 cooled condensers. A further condenser was packed with glass wool to remove any oil mist. Following this, a dreschel bottle filled with deionised water was used to dissolve water soluble gases. Gas samples were taken during the pyrolysis process at regular intervals (every 15 min) using gas syringes at the gas sampling point which was located between the last condenser and the dreschel bottle.

2.4. Activation reactor

The pyrolysis reactor was adapted to activate the chars produced from the pyrolysis experiments (Fig. 2). Two chars were investigated for activation, those produced at 800 °C and 900 °C. A steam generator was introduced to produce the activating agent for the production of the activated carbons from the pyrolysis chars. The steam generator furnace was maintained at 300 °C. A Sage instrument model 255-2-syringe pump was used to inject deionised water into the steam generator. The flow rate of the water was 2.34 cm^3/h and the activating molar flow rate per unit weight of char was calculated as 0.0325 mol g^{-1} h^{-1}. The molar flow rate of water was calculated from the flow rate of water, the molecular weight of water and the weight of char sample used for activation.

The char samples produced by the pyrolysis of the acrylic waste at 800 °C and 900 °C were ground and sieved to 211–599 μm and dried at 105 °C overnight. The sample size of char for activation was 4 g. Nitrogen was the carrier gas and the activation reactor was heated at a heating rate of 5 °C min^{-1} to different activation temperatures of 800 °C, 850 °C and 900 °C. Once the activation tem-