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Combustion of textile residues in a packed bed

Changkook Ryu *, Anh N. Phan, Vida N. Sharifi, Jim Swithenbank

Sheffield University Waste Incineration Centre (SUWIC), Department of Chemical and Process Engineering, The University of Sheffield, Mappin Street, Sheffield S1 3JD, United Kingdom

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Abstract

Textile is one of the main components in the municipal waste which is to be diverted from landfill for material and energy recovery. As an initial investigation for energy recovery from textile residues, the combustion of cotton fabrics with a minor fraction of polyester was investigated in a packed bed combustor for air flow rates ranging from 117 to 1638 kg/m^2 h (0.027–0.371 m/s). Tests were also carried out in order to evaluate the co-combustion of textile residues with two segregated waste materials: waste wood and cardboard.

Textile residues showed different combustion characteristics when compared to typical waste materials at low air flow rates below 819 kg/m^2 h (0.186 m/s). The ignition front propagated fast along the air channels randomly formed between packed textile particles while leaving a large amount of unignited material above. This resulted in irregular behaviour of the temperature profile, ignition rate and the percentage of weight loss in the ignition propagation stage. A slow smouldering burn-out stage followed the ignition propagation stage. At air flow rates of 1200–1600 kg/m^2 h (0.272–0.363 m/s), the bed had a maximum burning rate of about 240 kg/m^2 h consuming most of the combustibles in the ignition propagation stage. More uniform combustion with an increased burning rate was achieved when textile residues were co-burned with cardboard that had a similar bulk density.

Keywords: Burning rate; Combustion; Ignition front; Packed bed; Textile residues; Municipal waste

1. Introduction

The waste management policies in many developed countries including the UK are rapidly moving towards material and energy recovery from the conventional disposal method – landfill. The UK disposed of three quarters of the municipal waste (29 million tonnes) directly by landfill and about 10% by incineration in 2002/2003 [1]. A further 79 million tonnes of waste was generated from commerce and industry, which has similar composition to the municipal waste. A recent study shows that the energy from the total residual waste (municipal, industrial and commercial) after material recovery could account for as much as 17% of total UK electricity consumption in 2020 [2].

An increasing proportion of waste is segregated either at source or by dedicated facilities after waste collection, in order to enhance material recovery. Typical segregated materials include paper/cardboard, plastics, textile, glass and metals. Some of the segregated streams contain material that cannot viably be re-used or recycled but can be used for energy recovery.

The amount of textile in municipal waste generated in England was about 1000 kilo-tonnes in 2002 which comprised about 3% of municipal waste [3]. Approximately 75 kilo-tonnes of textile waste were collected for recycling mostly at civic amenity sites and bring banks. However, a much larger amount of the post-consumer textile is recovered by charity-operated textile banks, direct donation and door to door collection. The recovered textile is reused for second hand clothing, filling material, wiping cloths and

* Corresponding author. Tel.: +44 114 222 7523; fax: +44 114 222 7501. *E-mail addresses:* c.ryu@sheffield.ac.uk, c.ryu@shef.ac.uk (C. Ryu).

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fibre reclamation. 7% of the recovered textile waste is rejected and enters the waste stream [4]. The textile waste is a mixture of natural and synthetic fibres such as cotton, wool, silk, nylon, olefin and polyester. Cotton and polyester are the most commonly used. Although their chemical compositions vary, they all have a high energy content.

Combustion in a moving bed furnace is commonly used in industry for energy recovery from waste. Although various types of furnaces and grates are available, the fundamental feature of the combustion in the moving bed is the propagation of the ignition front. In the moving bed furnace, the feed material forms a bed on the grate through which the primary air is supplied. The top of the bed ignites by external heat sources such as radiation from the hot environment. Then, the ignition front progresses into the bed by the downward transfer of the heat released from the reactions of volatiles and char from pyrolysis of the material. The combustion is usually aided by the grate movement that induces solid particle mixing.

The moving bed combustion is often studied using a batch-type packed bed. It has an analogy with the cross-current moving bed as the time elapsed corresponds to the fuel residence time i.e., the location along the grate. The packed bed combustion of wastes has been investigated by several researchers for simulated mixtures [5–7] and for individual waste materials such as cardboard and waste wood [8]. These studies presented the effects of fuel properties (particle size, moisture content, calorific value, etc.) and operating conditions (flow rate and preheated temperature of air) on the progress of combustion. However, very little work has been carried out on the combustion of textile residues. Co-combustion of textile residues with other fuels such as coal and propane has recently been studied in other types of furnaces [9,10].

Another topic regarding textile combustion is the flammability of textile material treated with flame retardants. Flame retardants which can be inorganic, halogen-containing or phosphorus-containing are physically mixed or chemically bonded to the polymer in order to meet fire safety regulations for certain textiles including toys, nightwear and upholstery. Their end effect is to reduce the heat transfer to the polymer once ignition occurs [11]. Among the extensive studies on the effects of flame retardants on various fabrics, Price et al.'s [12] and Zhu et al.'s [13] studies provide comparison for pyrolysis of cottons untreated and treated with flame retardants.

This paper presents the combustion characteristics of textile residues and their mixtures with other waste materials, as a preliminary investigation for energy recovery from segregated waste materials. The ignition and burning rates of textile residues in a packed bed are derived from experimental results at different air flow rates in order to evaluate their combustion performance. The irregular trend of ignition rate is explained from observation in a glass tube reactor. Co-combustion tests with other waste materials investigate a way to achieve more controllable and efficient combustion of textile residues.

2. Experimental methods

2.1. Materials

The textile residues samples were collected from a local workshop. They were a mixture of cotton and polyester from cloths in which the polyester fraction ranged from 0% to 35% (the average of polyester fraction was calculated to be about 5%). The samples were cut into 30×50 mm rectangles after separating thick cloths. The cardboard and waste wood samples were used for co-combustion tests in this study, representing typical segregated materials from municipal wastes. Table 1 shows the results of standard fuel analysis for the samples. The textile residues had a high volatile matter content and virtually no ash. The calorific values of all the samples were about 16 MJ/kg which is about twice the value for typical municipal wastes and half that of high rank coals. The bulk densities of the textile and cardboard samples were much lower than that of waste wood.

Fig. 1 compares the thermogravimetric analysis using a Mettler-Toledo TA8000 TGA and differential thermogram curves of the three materials. The mass loss of textile residues which are mostly cotton (i.e., cellulose) had a narrow peak with a maximum at 364 °C. It was very similar to pure cellulose pyrolysis [14] and, therefore, the effect of flame retardants is not significant in textile residues. Waste wood and cardboard had a wider peak with maxima at 372 °C and 357 °C respectively, as they contain lignin and hemicellulose. The rapid pyrolysis stage ended before 400 °C for all the samples.

Although these materials are lignocellulosic, the cardboard and waste wood samples used for co-combustion tests represent two categories of waste materials in terms of thermal thickness and surface area to mass ratio. Cardboard is thermally thin and has a high surface area to mass ratio, which leads to a smaller temperature gradient inside and a relatively short burn-out time during combustion.

Table 1
Properties of the waste samples

		Textile residues	Cardboard	Waste wood
Proximate analysis	Moisture (wt %)	3.6	2.7	6.9
	Volatile matter (wt%)	89.0	80.4	71.7
	Fixed carbon (wt%)	6.9	11.2	18.5
	Ash (wt%)	0.5	5.7	2.9
Ultimate analysis	Carbon (wt%)	43.3	41.7	44.9
	Hydrogen (wt%)	6.2	6.4	6.7
	Oxygen[a] (wt%)	46.4	43.5	38.6
Gross calorific value (MJ/kg)		16.0	15.7	16.0
Particle size and shape		30×50 mm rectangle	20×20 mm square	20 mm, cube
Bulk density of bed (kg/m^3)		90	76	308

[a] By difference.