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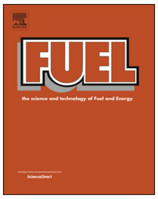

Full Length Article

Co-pyrolysis of wood and plastics: Influence of plastic type and content on product yield, gas composition and quality

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ABSTRACT

In recent years, the world has witnessed a rapid rise in waste production and energy demand, which has increased interests in waste to energy processes, particularly the co-pyrolysis of wood and plastic waste. Nonetheless, for plastic waste, most research studies narrowly focus on polyolefins because of their abundance in waste streams and their high oil yields from pyrolysis. In this paper, we study the co-pyrolysis of non-polyolefins – polystyrene (PS) and polyvinyl chloride (PVC) – and poplar wood (PW), in order to investigate the synergistic effect of PS and PVC content on product yield, gas specie yield and heating value. The experiments were performed using a fixed-bed reactor, heated to 750 °C at a rate of 20 °C/min under nitrogen atmosphere. Our results show that PVC has a large positive synergy on char yield with a maximum value of 8 wt% at 30 wt% PVC content, whereas PS only showed a slightly positive synergy (2.5 wt% maximum). Concerning oil and gas production, PS provides a small synergy. However, PVC showed a significant positive synergy on oil yield with a maximum value of 11 wt% at 50 wt% PVC content, which was linked to a strong negative synergy in gas production. Regarding gas specie yields, the addition of PS led to positive synergies in the formation of H_2, CH_4, CO and CO_2, although insignificant interactions were observed for C_xH_y compounds. Furthermore, by comparing the distribution of chloride species in the products of co-pyrolysis with PVC, using experimental and theoretical methods, we discovered that the negative synergy in HCl yield observed was mainly due to the dissolution of HCl in the water fraction of the condensed oil phase, rather than the formation of chlorinated organic compounds, as suggested in previous literature works. Our study therefore consolidates the understanding of the synergistic interactions between wood, PS and PVC co-pyrolysis, under conditions that favour gas production.

1. Introduction

The rapid growth in world population over the last century combined with industrial development and urbanization has resulted in two major issues: the sharp increase in waste production and demand for energy. In Europe, the current generation rates of wood and plastic waste are 70.5 and 26.2 Mt/yr which are accompanied by low recycling rates of 31% and 17% respectively [1]. Hence, research into opportunities for converting wood and plastic waste to energy is strongly needed. Pyrolysis is a promising technique for recovering energy inherent in combustible solid waste which involves the thermal decomposition of the waste in an inert atmosphere to yield three primary products: gas (H_2, CO, CO_2, CH_4 and light hydrocarbons), liquid hydrocarbons (tars and oils) and char (carbon material).

In recent years, co-pyrolysis of woody biomass and plastic waste has gained considerable research interest mainly due to the positive contribution of plastics to the product yield and the calorific value of the oil produced [2–6]. According to Johannes et al. [7], the interactions or synergy between biomass and plastics depends on various factors including the type and contact of the fuel components, pyrolysis duration, temperature and heating rate, and catalysts. Hence, it is not surprising that conflicting reports sometimes arise in literature concerning the differences between the actual and predicted yields of the pyrolysis products, where the predicted yields are calculated as linearly proportional to the contributions of the pure components. For example, Grieco and Baldi [8] observed insignificant interactions between low density polyethylene (LDPE) and beech wood during co-pyrolysis in a capsule at heating rates of 0.1 and 1 °C/s. However, Yang et al. [9] observed a significant synegistic effect on oil yield when LDPE and cedar wood were co-pyrolyzed at 600 °C in a dropdown tube reactor at rapid heating rates.

Research works on the co-pyrolysis of biomass and plastic waste

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Table 1
Proximate analysis (as-received basis) of wood and plastic samples.

	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	LHV (MJ/kg)
PW	8.0	2.0	85.1	4.0	17.1
PS	0.0	0.0	99.6	0.4	39.8
PVC	0.0	0.0	95.8	4.2	19.3

Table 2
Ultimate analysis (dry ash-free basis) of wood and plastic samples.

	C (%)	H (%)	O (%)	N (%)	S (%)	Cl (%)
PW	49.9	6.4	42.7	1.0	0.0	0.01
PS	92.4	7.8	0.0	0.0	0.0	0.0
PVC	38.7	4.8	0.0	0.0	0.0	56.5

have principally focused on the influence of temperature, heating rate and reaction time on product yield and quality [10–13]. Nonetheless, some authors, such as Oyedun et al. [14] have shown that the type and plastic content in the sample also play an important role. Unfortunately, the few studies on the influence of plastic content on product yield are narrowly-focused on polyolefins (polyethylene (PE) or polypropylene (PP)) because this plastic type generates high oil yields and is the most abundant in waste streams [15,8,16]. Consequently, the operating conditions chosen for these studies aim at maximising oil yields for liquid fuel production and involve low temperatures (400–500 °C), and short gas residence times (< 15 min). Furthermore, with respect to research works on the influence of plastic content in biomass on gas composition and heating value, Grieco et al. [8] and Paradela et al. [12] have observed significant interactions. However, Paradela et al. [12] conducted their experiments with a fixed plastic waste mixture of 56 wt% PE, 17 wt% PS and 27 wt% PP and Grieco et al. [8] performed theirs using only PE as the plastic type. Hence, there remains a knowledge gap in literature about the contribution of non-polyolefins such as PS and PVC on the gas composition and heating value derived from co-pyrolysis with biomass.

Thus, in this work, we will investigate the influence of PS and PVC content in wood on the co-pyrolysis product yields, gas specie yields and heating value, under conditions that favour gas production: high temperature, low heating rate and long gas residence time.

2. Experimental methods

2.1. Wood and plastic samples

The materials used for the tests were poplar wood (PW), PVC and PS, whose characterstics are displayed in Tables 1 and 2. The particle size of each pure material was less than 1 mm. Several wood/plastic mixtures for each plastic type were prepared having different plastic contents: 0-5-10-30-50-100 wt% plastic.

2.2. Pyrolysis reactor and procedure

Fig. 1 gives a schematic representation of the experimental setup. For each test, 10 g of sample was placed in a quartz crucible. The sample was heated in a furnace to 750 °C at a heating rate of 20 °C/min under nitrogen atmosphere (33 mL/min) and was maintained at this temperature for 30 min before being cooled to room temperature. These operating conditions allowed a reaction time of 66 min which is sufficient for secondary cracking of volatiles to occur in order to form more gas and secondary char. At the reactor outlet, the volatile oil was condensed in an impinger bottle filled with cotton wool and cooled to 0 °C. Thus, in this case, the term 'oil' represents a mixture of bio-tar, oil, wax and small amounts of water produced from the pyrolysis process. For experiments with PVC, the oil condenser was replaced with two impinger bottles containing aqueous solutions of KOH to trap HCl gas. Next, the total amount of the non-condensable gas produced from pyrolysis was collected in a Tedlar bag. Its composition was analyzed by a micro-gas chromatograph (Micro-GC, A3000 Agilent). The quantification of HCl concentration in the aqueous phase was conducted using X-ray fluorescence (XRF, PANanalytical).

The char yield was calculated by dividing the weight loss of the sample and crucible before and after pyrolysis by the total initial sample mass. The gas yield y_{gas}, was calculated based on the following equations:

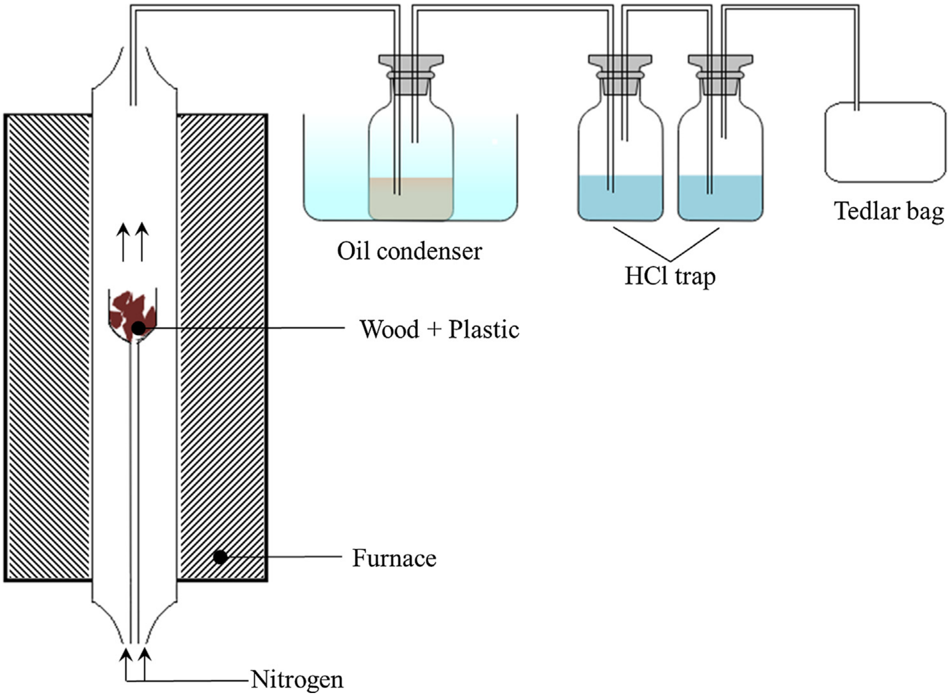

Fig. 1. Experimental setup of pyrolysis equipments.