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Effect of polyethylene co-feeding in the steam gasification of biomass in a conical spouted bed reactor

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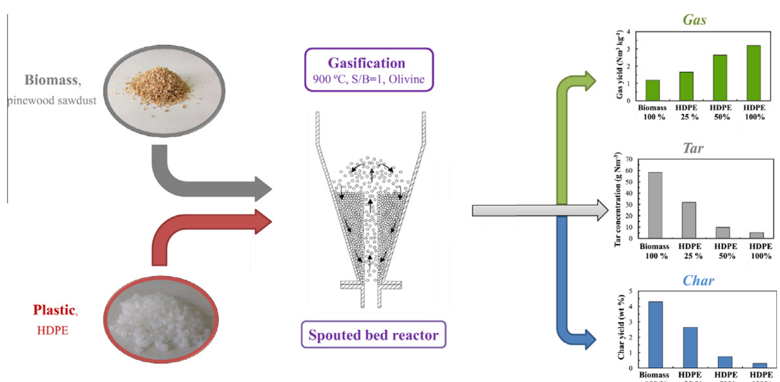
HIGHLIGHTS

- The spouted bed reactor performs well in the cogasification of biomass and HDPE.
- The hydrodynamic performance of spouted bed reactor avoids operational problems.
- HDPE cofeeding has a significant synergetic effect on tar and char yields.
- The gas yield corresponds to the ratio of the biomass/plastic mixture in the feed.
- HDPE cofeeding augurs good perspectives for this valorisation route.

GRAPHICAL ABSTRACT



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ABSTRACT

The steam gasification of different mixtures of biomass and high density polyethylene (0 wt%, 25%, 50% and 100% of HDPE) has been carried out in continuous mode in a conical spouted bed gasifier, and the results have been compared with those obtained feeding pure biomass and HDPE. The experiments have been carried out at 900 °C and using a steam/(biomass + plastic) mass ratio of 1. Olivine has been used as primary catalyst in order to minimize tar formation. The cofeeding of HDPE has given way to an interesting synergetic effect involving the reduction of both tar and char yields. Thus, the tar content in the gaseous product was reduced from 58.23 g Nm^{-3} in the gasification of pure biomass to only 9.74 g Nm^{-3} when a mixture made up of 50% of each feedstock was in the feed. These promising results evidence the interest of the cogasification strategy apart from contributing to increasing feedstock availability.

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1. Introduction

One of the main advantages of tertiary thermal treatments and especially of gasification is the possibility to treat jointly different residues. Thus, the separation cost is reduced and feedstock availability is considerably improved, avoiding seasonal problems and increasing the runtime of gasification units [1]. Moreover, the cogasification of different wastes is a combined strategy boosting the construction of big plants, with lower unit operating costs, higher efficiency and better control of emissions [2].

The co-feeding of different residues pursues synergies of great interest, such as increasing the heating value of the gaseous product, as occurs in the cogasification of coal/biomass [3–5] and coal/petroleum derivates [3,4,6]. Moreover, the co-feeding of biomass and pet coke has revealed a positive effect on the mixture reactivity, reducing both the reaction time and emissions of CO_2, NO_x and SO_x [7–9]. The presence of alkali metals (particularly

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potassium) in the biomass has a positive catalytic effect on the gasification process [10].

The cogasification of biomass/plastic mixtures has been proposed as a strategy for avoiding the operational problems involving plastic gasification, such as plastic feeding, or for reducing the amount of solid by-product (fine dust) produced due to the incomplete gasification of waste plastics [11]. The better results obtained in the cogasification process can be explained by the improvement in the plastic pyrolysis step prior to gasification.

Furthermore, the reactor design plays a critical role in gasification. Thus, the hydrodynamic features of the reactor should be suitable for handling residues of different density and granulometry, minimizing the segregation problems in the bed. Arena et al. [12] recently reviewed the reactors used in the gasification of municipal solid wastes (MSW). In previous studies, the excellent performance of the conical spouted bed reactor has been proven for the steam gasification of biomass [13,14] and HDPE [15]. The conical spouted bed reactor (CSBR) is especially suitable for the treatment of materials of different density and granulometry as it can operate with low segregation due to the vigorous and cyclic movement of the particles and the role played by the spout region to avoid defluidisation problems [16]. Moreover, the high heat and mass transfer rates enhance the kinetics of the pyrolysis step [17] prior to gasification. Although the short residence time in the CSBR is interesting to minimize secondary reactions in biomass pyrolysis, it is not enough for the complete gasification of the tar fraction [14].

The interest of co-feeding high density polyethylene (HDPE) together with biomass lies in the possibility to decrease tar formation, which is one of the main challenges in the biomass gasification process, particularly in the steam gasification [18]. The literature regarding the cogasification of plastics and biomass is very scarce and the studies have been carried out using different gasification agents and reactor technologies. Moreover, limited information of the materials used is provided in these studies, which hinders the interpretation of the results. Pinto et al. [11] studied the steam cogasification of polyethylene (PE) and pine wood wastes in a downdraft gasifier in order to minimize PE gasification problems in this reactor. Ahmed et al. [19] used a batch fixed bed reactor for the steam cogasification of PE and wood. Wilk and Hofbauer [20] carried out the steam cogasification of PE and soft wood pellets in a dual fluidised bed reactor at 850 °C using olivine as catalyst. Alvarez et al. [21] studied the batch pyrolysis of biomass/polypropylene mixtures and the on line steam gasification of the pyrolysis products at 800 °C. They observed that the addition of plastics caused a positive effect on both the gas yield and the hydrogen concentration.

Other authors have also worked in continuous regime in fluidised bed reactors using air or pure oxygen as gasifying agent in order to provide totally or partially the energy required for the cogasification of biomass and different plastics. Thus, Pinto et al. [22] gasified mixtures of coal, biomass and PE with steam and air. Likewise, Aznar et al. [6] gasified mixtures of coal, sawdust and heterogeneous plastics with air and different equivalence ratios, using dolomite as tar cracking catalyst. Mastellone et al. [4] also studied the air cogasification of plastics, coal and biomass in a fluidized bed gasifier. Ruoppolo et al. [1] studied the gasification of PE with sawdust or olive stones using steam and oxygen as gasifying agents under isothermal conditions. Moreover, the same authors recently studied under similar conditions the cogasification of polyethylene terephthalate (PET)/biomass and waste tyre/biomass mixtures [23].

This paper deals with the effect the mass ratio of HDPE/pine wood sawdust in the feed has on the steam gasification process in a conical spouted bed reactor. The runs have been carried out in continuous regime at 900 °C using a steam/feed ratio of 1. Olivine has been used as in situ primary catalyst. The results have been compared with those obtained in the gasification of single materials and the synergies regarding gas yield and composition and tar content in the gaseous stream have been analyzed. The interest of the study carried out lies in the CSBR capability for handling materials with different physical properties, such as pine wood and plastics, without operational problems. The solid circulation flow rate attained in this reactor avoids agglomeration and defluidization problems caused by the melting of plastic and biomass ashes. The low segregation is another interesting feature of conical spouted beds for both the joint valorisation of biomass/plastic mixtures and the operation with catalysts in situ for tar cracking or reforming [13]. Furthermore, this technology has been successfully scaled up for biomass pyrolysis process. Thus, a 25 kg/h plant has been constructed and is currently operative [24]. The use of a draft tube of optimized geometry in the pilot plant allows for operating under stable conditions with vigorous movement and good mixing, low pressure drop, low fluidizing gas requirements and high heat transfer rates (up to 220 W m^{-2} k^{-1}) [17,25]. These features make the spouted bed reactor an interesting technology for large-scale thermochemical processes.

2. Experimental section

2.1. Feedstock properties

The HDPE was provided by Dow Chemical (Tarragona, Spain) in the form of chippings (4 mm), with the following properties: average molecular weight, 46.2 kg mol^{-1}; polydispersity, 2.89; and density, 940 kg m^{-3}. The higher heating value, 43 MJ kg^{-1}, has been determined by isoperibolic bomb calorimetry (Parr 1356).

The biomass used in this study is forest pinewood waste (Pinus insignis), which has been crushed and ground to a particle size below 4 mm. The sawdust has been sieved to obtain a particle size between 1 and 2 mm. This material has been dried at room temperature to a moisture content below 10 wt%. Ultimate and proximate analyses have been carried out in a LECO CHNS-932 elemental analyzer and in a TGA Q500IR thermogravimetric analyzer, respectively. The higher heating value (HHV) has been measured in a Parr 1356 isoperibolic bomb calorimeter. The thermal degradation behavior of this biomass was reported in a previous study [26]. The main features of both the raw biomass and the HDPE are summarized in Table 1.

2.2. Catalytic materials

The experiments were carried out using olivine as catalyst, which is an inexpensive magnesium iron silicate with tar cracking properties. This material was provided by Minelco, Lulea (Sweden). It has been ground and sieved to the desired particle diameter,

Table 1
Characterization of the biomass and HDPE used in this study.

	Biomass	HDPE	Method
Ultimate analysis (wt%)			
Carbon	49.33	85.71	ASTM 5373
Hydrogen	6.06	14.29	ASTM 5373
Nitrogen	0.04	0	ASTM 5373
Oxygen	44.57	0	ASTM 5373
Proximate analysis (wt%)			
Volatile matter	73.4	99.7	UNE 32019
Fixed carbon	16.7	0.3	–
Ash	0.5	–	UNE 32004
Moisture	9.4	–	ASTM 3302
HHV (MJ kg^{-1})	19.8	43.1	UNE 32006

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