Gasification by O_2-enriched air and steam of two mixed plastic wastes in a large pilot scale fluidized bed gasifier

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Abstract

Advanced thermochemical technologies for plastic waste valorization represent an interesting alternative to waste-to-energy options. They promote the waste-to-hydrogen and waste-to-chemicals applications, with autothermal steam-oxygen gasification in fluidized bed reactors showing the greatest market potential. The study describes a series of experimental tests carried out at thermal and chemical steady state in a large pilot-scale fluidized bed gasifier, using steam and O_2-enriched air, with increasing fractions of oxygen, for two mixed plastic wastes (MPW). The aim was to investigate the gasification of MPW when the operating conditions gradually change from air-steam gasification to oxygen-steam gasification, with a focus on the effect of the reduced content of nitrogen, the role of steam in the reactor control, and the key process performance parameters. The tests were carried out at various O_2 molar fraction in the enriched-air stream (from 0.21 to 0.49, by keeping fixed the steam-to-carbon ratio at 0.75 mol/mol), and equivalence ratio (from 0.22 to 0.25) for two different mixed plastic waste.

Introduction

Plastic waste is a significant global issue with far-reaching environmental, economic, and social consequences [1]. Developing alternative materials to traditional plastics, improving advancing recycling technologies, and defining waste management schemes are necessary for well addressing the plastic waste problem.

Plastic waste gasification is an advanced thermochemical process that converts plastic waste in a syngas made of CO, H_2, CO_2, CH_4, and other light hydrocarbons, which can be converted into useful products, like transportation fuels and valuable chemicals [2]. One of the advantages of plastic waste gasification is that it can handle a wide variety of plastic types, including mixed or contaminated plastics that may be difficult to recycle through traditional mechanical methods. However, plastic waste gasification still presents several challenges related to the properties of plastic materials; the multi-scale nature of the process; the severe cleaning standards

required for syngas utilization; the scale-up implications [3].
The greatest techno-economic and sustainability potentials of fluidized bed plastic waste gasification [1; 2] are related to waste-to-hydrogen (WtH2) and waste-to-chemicals (WtCh) processes. In both these promising fields, autothermal gasification using steam and oxygen as fluidizing/gasifying media appears the best for a faster and efficient deployment. This is due to the numerous advantages provided by the production of a nitrogen-free syngas, including higher heating values, smaller volumes and unit operations associated, easier gas product separation, and better integration with CCS plants [4]. However, most of the industrial and experimental waste-fueled gasifiers were developed as air-blown rather than oxygen-blown, and only a limited experience exists in autothermal steam-oxygen operations, particularly on large (pilot and demonstrative scale) plants, as confirmed by recent techno-economic analyses [5]. Taking into account these considerations, the study described here reports the experimental results obtained with a large pilot scale, bubbling fluidized bed gasifier (BFBG) [4], operated with mixtures of steam and oxygen-enriched air, at increasing O_2 molar fraction, with two mixed plastic wastes. The aim was investigating the gasification of MPW when the operating conditions gradually change from air-steam gasification to oxygen-steam gasification, with a focus on the effects related to the reduced content of nitrogen, the operating criteria where steam operates as the reactor temperature moderator, and the estimate of reliable values of key process performance parameters.

Materials and methods

The pilot scale gasifier. The pilot scale BFBG employed in this study has a maximum thermal input of 400 kW, with a plastic waste capacity up to 50 kg/h, and a reactor total height (5.73 m) and internal diameter (0.489 m) that are large enough to exclude any scale-related implications [6]. This allows transferring obtained results to larger (even commercial) scale reactors, and it contributes to bridging the gap between research and industrial deployment. More details about the pilot scale gasifier can be found in Parrillo et al. [3].
The experimental procedure. The gasifier requires about 3 hours to be heated up to about 700°C by means of pre-heated blast gases and three electric heaters located along the reactor. At this temperature, the fluidizing gas and the plastic waste flow rates are set to obtain the desired values of the process parameters. Under the selected operating conditions, and without any thermal assistance of external heaters, the reactor gradually reaches thermal and chemical steady states, which are generally maintained for about 2 hours. During this time, gas and solids sampling procedures are activated and measurements of pressure, temperature, blast flow rates, and syngas composition are taken.
The plastic waste and the bed material. The bed material is made of Austrian olivine particles, having a size range of 200-400 μm, with a Sauter mean diameter of 316 μm, a particle density of 2900 kg/m^3 and a bulk density of 1600 kg/m^3. Olivine is a neo-silicate of Mg and Fe, which can be represented by the formula $(Mg,Fe)_2SiO_4$.

The plastic waste are polyolefin blends, named Blu-L and Blu-C, provided by Corepla (Italian Consortium for Plastic Packaging), and prepared by the I.Blu-Company [7] from non-recyclable residues of separated collection of plastics packaging. Table 1 reports its ultimate and proximate analysis (obtained via a LECO Truspec CHN/S), together with low heating value (LHV). Blu-C has a lower carbon content and calorific value than Blu-L and a higher ashes content.

Table 1. Plastic waste characterizations of the plastic waste granules.

	Blu-L	Blu-C
Ultimate analysis, %wt		
C	81.5	76.00
H	12.4	8.2
N	0.29	0.4
S	0	0.30
O	1.56	6.98
Moisture	0.52	0.9
Ashes	3.41	7.6
Proximate analysis, %wt		
Volatile matter	96.0	89.21
Fixed carbon	0.07	2.31
LHV, MJ/kg_{fuel}	38.7	31.1

Results and discussion

The tests with Blu-L and Blu-C were carried out by increasing the oxygen molar fraction (from 21% to 39% for Blu-L and from 21% to 49% for Blu-C) in the enriched-air, by keeping fixed the equivalence ratio value (ER=0.22) and the Steam to Carbon (StC=0.75 mol/mol). The ER value, considered relatively low compared to the typical ranges of autothermal gasification, was established to avoid the risk of overheating the reactor. The fluidization velocity is at constant values (0.5 m/s), able to ensure a good fluidization quality of the bed. A further series of tests was carried out with Blu-C to study the role of the steam in the control of reactor temperature, by increasing ER (in the range 0.21-0.26) and StC (in the range 0.88-1.41 mol/mol). Figure 1 shows the bed temperature obtained by varying the O_2 molar fraction, with Blu-L and Blu-C.

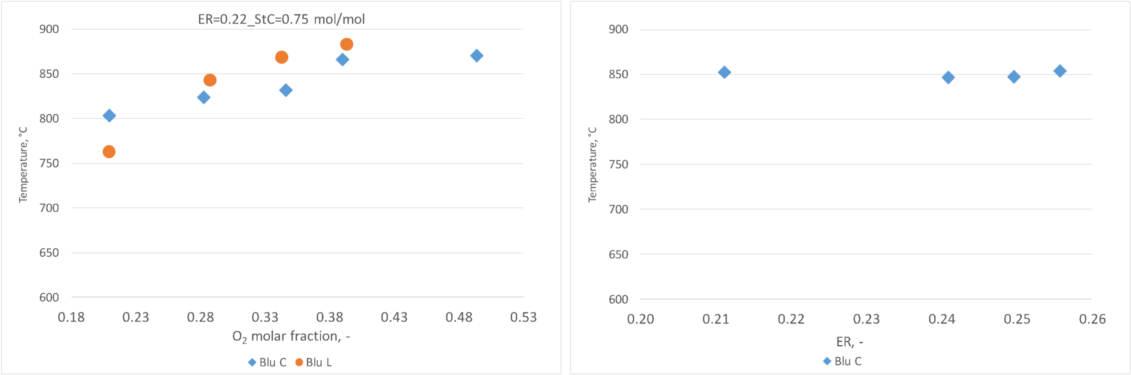

Figure 1. Bed temperature obtained i) by varying the O_2 molar fraction, with Blu-L and Blu-C (left); ii) by varying the ER and the StC to keep the reactor temperature at a constant value (right).

The experimental tests with Blu_L (which has the higher LHV) at increased oxygen content resulted in a progressive increase of bed temperature, since the amount of nitrogen removed was not counterbalanced by a sufficient additional amount of steam. Test with Blu-C (which has the lower LHV) showed a rather similar trend in the bed temperature, but the latter was more easily managed, even with O_2 molar fractions as high as 50%. The role of moderator played by the steam in substitution of the nitrogen appeared crucial: Figure 1 (right) shows that an appropriate increase in the steam flow rate, i.e. an increase of the StO2 ratio, allowed to keep constant the bed temperature, even under higher values of ER.

Figure 2 shows the syngas composition for the comparable tests with Blu-L and Blu-C (top) and for those with Blu-C at a fixed bed temperature (bottom). The reported dry and nitrogen free syngas compositions avoid trends linked to the dilution of the two moderators (nitrogen and steam). For the tested MPWs (Figure 2, top), the higher O_2 percentage in the enriched air indirectly enhances the endothermic reactions involving steam, especially Water Gas and Steam reforming of CnHm, due to the related reactor temperature increase. This explains the increase in terms of CO_2 and H_2, against the reduction of CnHm. Methane and BTX are apparently less influenced by the variations of the involved parameters. The diagram at the bottom of Figure 2, related to test at an almost constant temperature, indicates that ER affects syngas composition mainly in the content of carbon dioxide. The constant temperature along the reactor determines a limited variation of the syngas concentrations of other components.

Figure 3 shows H_2/CO ratio and LHV_{syngas} of the syngas obtained in the comparable tests with Blu-L and Blu-C (top) and by keeping fixed the reactor temperature with Blu-C (bottom). H_2/CO ratio is close to the values of interest for hydrogen and SNG production [2].

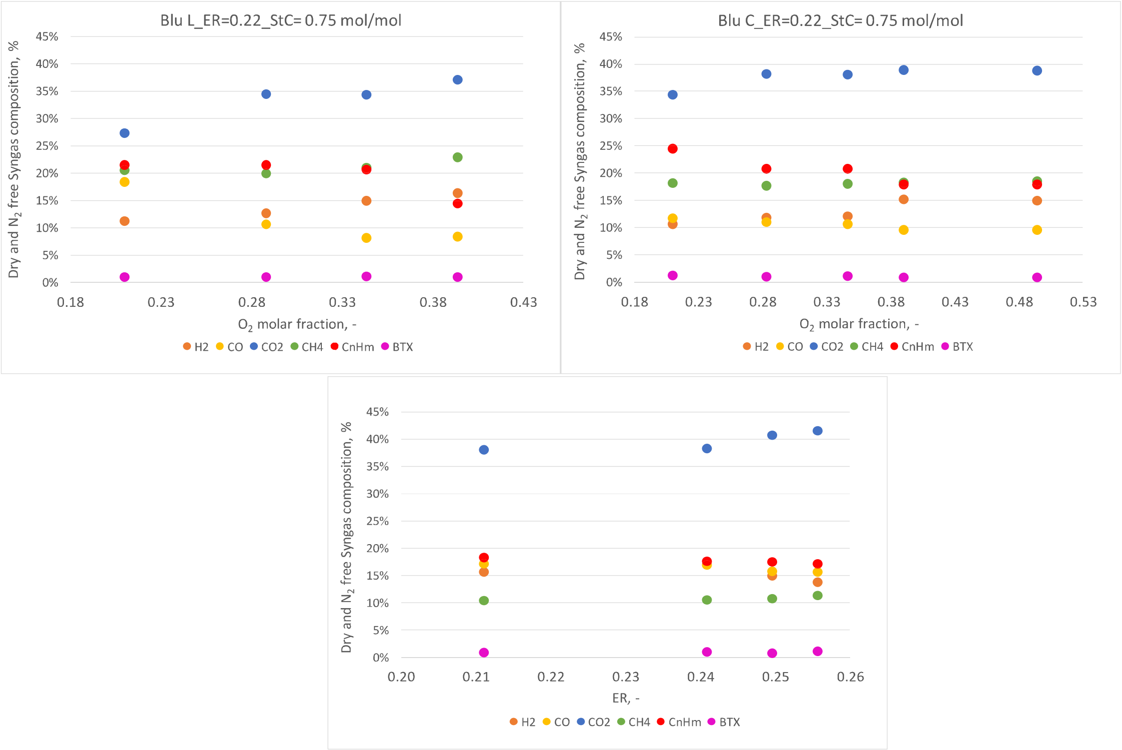

Figure 2. Syngas composition obtained by varying the O_2 molar fraction, with Blu-L (top-left) and Blu-C (top-right), and by keeping bed temperature constant by appropriate variation of ER and StC, with Blu-C (bottom).

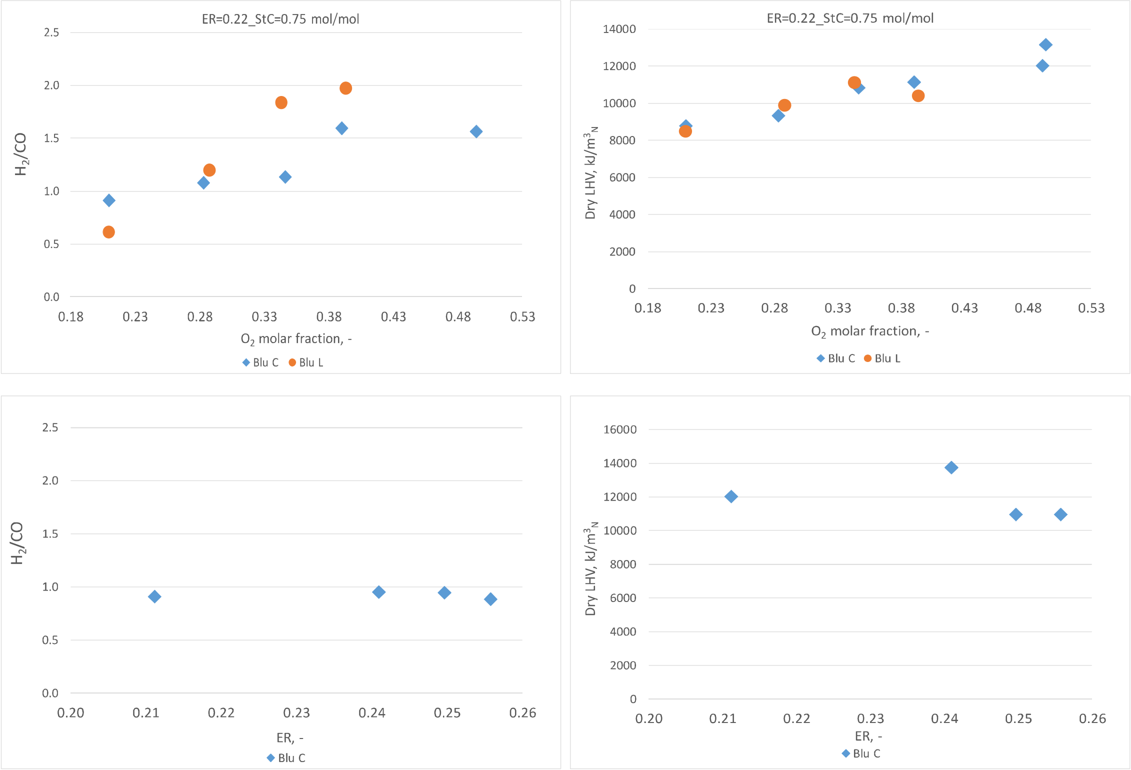

Figure 3. H2/CO ratio and the LHV_{syngas} by varying the O_2 molar fraction, with Blu-L and Blu-C (top), and by varying the ER and the StC with Blu-C (bottom).

Conclusions

The autothermal MPW gasification was investigated by means of pilot-scale experiments in a large bubbling fluidized bed reactor. The gasifier was operated with steam and O2-enriched air, at increasing fractions of oxygen, keeping fixed the equivalence ratio, steam-to-carbon ratio, and steam-to-oxygen ratio. The results indicate that the reactor can be operated as an oxygen-steam gasifier for MPW of moderate-high calorific value, only if an appropriate flow rate of steam can be injected in the reactor. Steam has the key role of moderator of the reactor temperature, whereas it has a limited influence on the syngas composition. The equivalence ratio is an important operating parameter since it largely affects the reactor temperature, which appears the variable that, in turn, more affects the syngas composition.

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