Gasification of plastic waste to syngas in thermal CO_2 plasma

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Introduction

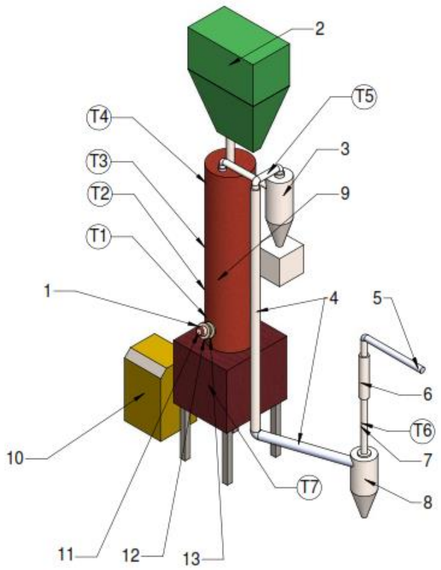
Due to ambitious EU goals on fossil carbon footprint reduction and waste management promotion as well as striving to reduce the dependence on fossil fuels, alternative sustainable fuels have gained high interest. Energy recovery from non-recyclable plastic waste has been extensively investigated during the past few years, especially after the COVID-19 pandemic.

In this regard, the objective of this experimental study was to investigate the possibility of gasifying plastic waste, i.e., FFP2 face masks, to synthesis gas (syngas) by direct current (DC) thermal arc plasma technology using carbon dioxide as a plasma-forming gas, a heat carrier, and a reactant.

Experimental setup and Methodology

The experimental plasma gasification system was designed and built at the Plasma Processing Laboratory of the Lithuanian Energy Institute and is shown in Fig. 1. The 140 kW_{th} input plasma gasifier with reactor length of 1.3 m and inner diameter of 0.2 m was used to carry out the experiments.

Figure 1. Plasma gasification system.



The main parts of the system consist of: 1 – an atmospheric pressure DC arc plasma torch, 2 – a feedstock hopper with a screw feeder, 3 – a cyclone, 4 – a gas cooling, 5 – a gas burner, 6 – a rotameter, 7 – a gas and tar sampling point, 8 – a condenser, 9 – a plasma-chemical reactor, 10 – an ash-char hopper, 11 – a power supply, 12 – plasma-forming and shielding gas supply, 13 – a plasma torch cooling, T1, T2, T3, T4, T5, T6, T7 – thermocouples.

Shredded into peace FFP2 face mask material was pelletized into 8 mm diameter pellets, which were used as a feedstock material for syngas production. The FFP2 pellets were fed from the hopper through a screw feeder controlled by a frequency controller. Carbon dioxide simultaneously was used as a plasma-forming gas, a heat carrier, and a reactant.

To determine the performance of the plasma gasifier, it was quantified in terms of H_2 and CO yield, H_2/CO ratio, lower heating value (LHV_{syngas}), carbon conversion efficiency (CCE), energy conversion efficiency (ECE), and a specific energy requirement (SER) according to the methodology described by (Albarelli *et al* 2011; Tamošiūnas *et al* 2016).

Results and Discussion

Feedstock characterization

Full proximate and ultimate analysis of the FFP2 face mask pellets used as a feedstock material for the thermal plasma gasification to syngas is described in Table 1.

Table 1. Proximate and ultimate analyses of the FFP2 pellets.

Parameter	Wood pellets
Ultimate analysis (wt.%)	
Carbon	85.19±0.68
Hydrogen	14.58±0.07
Nitrogen	<0.01
Sulphur	0.027±0.008
Oxygen (by difference)	n.d
Chlorine	0.008±0.004
Proximate analysis (wt.%)	
Volatile matter	96.7±1.05
Fixed carbon (calculated)	n.d
Ash	3.06±0.09
Moisture	0.15±0.01
HHV, MJ/kg	51.54±0.16
LHV, MJ/kg	48.44±0.16

Effect of CO_2 as a plasma-forming gas and gasifying agent on the gasification process performance

Plasma gasification of FFP2 pellets to syngas was performed at the constant FFP2 pellets mass flow rate of 10.62 kg/h, CO_2 flow rate of 11.55–21.13 kg/h, and the plasma torch power of 40.6–68.4 kW. The main reaction products at the optimally determined experimental conditions (FFP2/CO_2 ratio – 2.0, plasma torch power – 68.4 kW, thermal efficiency of the plasma torch, $\eta_{plasma\ torch}$ = 73.1) are summarized in Table 2.

Table 2. Concentrations of the producer gas.

FFP2 pellets (kg/h)	CO_2 Flow Rate (kg/h)	H_2 (vol.%)	CO (vol.%)	CO_2 (vol.%)	CH_4 (vol.%)	C_2H_2 (vol.%)	C_2H_6 (vol.%)	C_3H_8 (vol.%)	N_2 (vol.%)
10.62	21.13	24.62	55.84	7.67	5.83	2.86	0.09	0.04	3.04

At the FFP2/CO_2 ratio of 2.0, the highest H2/CO ratio obtained was 0.44. The LHV of the produced syngas was around 14.0 MJ/nm^3 and did not depend much on the CO_2 mass flow rate and the plasma torch power. The highest yield of producer gas was 3.20 Nm^3/kg_{FFP2}. The tar content measured in the producer gas was 23.04 g/Nm^3, with major constituents being benzene and toluene comprising more than 56% of the total compounds detected. The CCE was close to 100% with some carbon (1–2%) left in the ash/char as a by-product. The highest ECE was 48.8%, which is still lower than conventional gasification (up to 80%). At the same time, the lowest SER required to produce one kilogram of syngas under these experimental conditions was 6.78 MJ (or 1.88 kWh/kg_{syngas}).

Conclusions

In conclusion, it was demonstrated that syngas can be successfully produced from the used FFP2 face masks in the ambient of CO_2 plasma. However, additional research must be conducted to maximize plasma gasification process efficiency at lower energy costs. These studies are foreseen in the future.

Acknowledgments

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