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Assessment study of an advanced gasification strategy at low temperature for syngas generation

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ABSTRACT

Low temperature gasification for solid residues is herein presented, its environmental impacts evaluated through life cycle assessment (LCA) and further compared with those from other techniques, including incineration. One tonne of municipal solid waste (MSW) was established as functional unit and investigated within defined boundaries. The environmental assessment of low temperature gasification revealed poor results for some of the evaluated impact categories, causes for the higher incineration performance being stated. Also, future perspectives on the combination of plasma and gasification were highlighted as a way to overcome the encountered weaknesses.

Introduction

The goals of waste management have changed substantially over the last few decades. At first, they were simply the treatment and disposal of residual streams created by human activity, but, as populations grew and these streams became more complex and difficult to treat, new ways of managing waste were developed. One of the proposed solutions is the waste thermal treatment, which through waste-to-energy (WtE) techniques gives rise to new benefits like heat, energy and chemicals production, among others [1,2]. Nowadays, thermal conversion is the prevalent means to recover energy from residues, enabling a more sustainable supply of the referred assets, with increasing interest due to the possible reduction on fossil fuels dependence [2–4]. WtE includes several treatment techniques, each type of residues being suitable for a specific practice, some of them leading also to material recovery which represents extra valorisation of the debris streams [5]. According to a review study from 2015 [6], WtE technologies such as gasification are less widespread when compared to more conventional ones, as incineration for instance. Still, when correctly performed, this methodology depicts advantages like higher feedstock flexibility, reduced water and oxidant consumption [1], reduced dioxin

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and aromatic emissions [2], prompter operational conditions [7] and higher gas yields [8], among others [9].

Gasification is a WtE technique able to convert solid waste fractions at temperatures that can go up to 1800 °C, in a versatile synthetic gas (also called syngas – a gaseous mixture of hydrogen, carbon monoxide, carbon dioxide and light hydrocarbons) that can later be used in the production of valuable assets [5,10]. It occurs through the reactions mentioned in Fig. 1:

Several types of reactors exist [13] and different working conditions must be applied regarding not only their configuration and operational parameters as well as the characteristics of the used feedstock [14]. The combination of the ideal experimental settings affords a more sustainable and valuable process, enhancing either the waste management efficiency and also the quality of the producer gas obtained which may further undergo distinct applications [10,15,16]. The settlement of all the operations throughout the gasification process gives rise to diverse outputs, which entail a set of environmental impacts, from exposure to emissions and natural resources depletion.

The main difference between gasification and incineration is that the first promotes the partial oxidation of solid fuels into a high energy gas while the latter occurs under an excess of oxygen to ensure complete combustion of the feedstock originating thermal, mechanical or electrical energy [17]. As most of the reactions involved in gasification are endothermic, temperature plays a major role within the overall process, affecting the possible outcomes and their absolute effects [15]. Diverse methodologies are available to the evaluation of the aforementioned impacts, life cycle assessment (LCA) constituting a very useful resource [6].

LCA is an important tool to quantify the environmental impacts caused throughout a product's life, from raw material acquisition through production, use and disposal phases [18]. Within LCA framework, there are several methodologies aiming to evaluate the contribution of each process during the overall cradle-to-grave sequence that constitutes the product life cycle. Depending on the particular area or service, each methodology is more or less suitable for this purpose, environmental activities normally making use of highly specialized models which convert input and output data into impact categories quantifying the associated damage [19]. Leiden University's Institute of Environmental Sciences (Centrum voor Milieukunde Leiden – CML) established a cornerstone in impact assessment by publishing an important LCA guide in 1992 [20]. After a series of revisions and updates, according to science developments and knowledge advances on complex phenomena, this methodology is still one of the most used nowadays under the name CML 2001, and within several appliances, it is also employed in the assessment of MSW management systems [21,22].

Oxidation reaction

Volatiles

$$CO + 1/2O_2 \leftrightarrow CO_2 \quad \Delta H = -283 kJ/mol$$

$$H_2 + 1/2O_2 \leftrightarrow H_2O \quad \Delta H = -242 kJ/mol$$

Char

$$C + 1/2O_2 \leftrightarrow CO \quad \Delta H = -111 kJ/mol$$

$$C + O_2 \leftrightarrow CO_2 \quad \Delta H = -394 kJ/mol$$

Boudouard reaction

$$C + CO_2 \leftrightarrow 2CO \quad \Delta H\ -172 kJ/mol$$

Water-Gas reaction

Primary

$$C + H_2O \leftrightarrow CO + H_2 \quad \Delta H = -131 kJ/mol$$

Secondary

$$C + 2H_2O \leftrightarrow CO_2 + 2H_2 \quad \Delta H = -90 kJ/mol$$

Methanation reaction

$$C + 2H_2 \leftrightarrow CH_4 \quad \Delta H = -75 kJ/mol$$

Water-Gas shift reaction

$$CO_2 + H_2 \leftrightarrow CO + H_2O \quad \Delta H = -41 kJ/mol$$

Steam Reforming reaction

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \quad \Delta H = 206 kJ/mol$$

$$C_nH + nH_2O \leftrightarrow nCO + \frac{(n+m)}{2} H_2$$

Dry Reforming reaction

$$CH_4 + CO_2 \leftrightarrow 2CO + 2H_2 \quad \Delta H = 247 kJ/mol$$

$$C_nH_m + nCO_2 \leftrightarrow 2nCO + \frac{m}{2} H_2$$

Fig. 1 – Main reactions occurring during gasification [11,12].

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