LANDFILL SOLID WASTE-BASED SYNGAS PURIFICATION BY A HYBRID PULSED CORONA PLASMA UNIT

Gomez Rueda Y.[1] , Nuran Zaini I.[2], Yang W. [2], Helsen L.[1, 3]
[1] Department of Mechanical Engineering, KU Leuven , Kasteelpark Arenberg 1, Leuven, 3001, Belgium
[2] Department of Materials Science and Engineering, KTH Royal Institute of Technology, Brinellvägen 23, Stockholm, SE-114 28, Sweden
[3] EnergyVille, Thor Park, Waterschei, Genk, Belgium

ABSTRACT: Gasification of excavated Municipal Solid Waste (MSW) for energy and materials recovery has been seen as a solution for current energetic, environmental and land availability issues. However, it poses many technological challenges, and among them the most difficult is to obtain of a tar-free syngas. In this work, two set of experiments were performed in order to obtain a syngas from MSW with a low tar content. In the first stage, MSW gasification was performed in order to identify the tar yield and composition at different temperatures using air and steam. After that, the most representative tar compound, naphthalene, was selected to perform tar cracking experiments in a pulsed corona plasma reactor able to operate from ambient temperature up to 1200°C. The results of these experiments show that the pulsed corona plasma can enhance the tar thermal cracking reactions, reducing by 200°C the temperature at which 100% of the naphthalene is converted.
Keywords: tar, tar removal, gasification cleaning, clean synthesis gas, pulsed-corona plasma

1 INTRODUCTION

Enhanced Landfill Mining (ELFM) is a novel concept which sees landfills not as final waste disposal sites, but as new mines where hidden energy and materials can be recovered. However, the heterogeneity of buried MSW, its relatively low LHV with respect to other solid fuels, and the high tar yield obtained during its gasification makes the energy recovery from buried MSW a great challenge.

Although in the industry there are currently many options for syngas tar cleaning, very few of them are able to fulfill the stringent requirements for gas engines, gas turbines and fuel cells, which tolerate tar levels up to 50, 5 and 1 mg Nm-3 respectively .

Among the solutions proposed, physical methods like OLGA (which consist on a train of scrubbers) have been able to reach tar levels low enough to allow the syngas to be fed to gas engines, however its operation is limited to temperatures of 400°C . This limits the utilization of such scrubbing systems to low-temperature gasifiers, otherwise the gas exiting the gasifier would need to be cooled-down, which reduces the efficiency of the gasification process.

Other solutions, such thermal and catalytic tar cracking have been demonstrated to work at high temperatures, but the need of high thermal resistant materials in one site and the lack of long-run test in the other side, gives them limited performances.

The use of cold plasma for tar removal purposes has been limited to low temperatures, usually below 400°C. In this temperature range, cold plasma technologies have been able to crack tar model molecules such as toluene, benzene and naphthalene either alone or in combination with catalysts. However in order to be scaled-up, cold plasma technologies need to be operated at the temperatures of the gas exiting the gasifier.

The lack of data published of cold plasmas at high temperatures is mainly due to the technology used. Most of the lab-scale cold plasmas explored in literature are Dielectric-Barrier Discharge (DBD) plasmas. This type of plasmas have the advantage of being easy to operate, but its biggest flaw is that it needs a dielectric material around one or two of the electrodes. This dielectric material can either be degraded by high temperatures or high-voltages or both. Therefore DBD plasmas have been demonstrated at low temperatures.

The use of other type of corona plasma, called corona plasma, would allow to surpass this limitation. However the operation of such systems is more complex, since it needs an additional unit to generate pulses to avoid its transition towards an arc. Evaluating this unit at high temperatures is fundamental to allow cold plasmas to be scaled-up.

2 AIM AND APPROACH

The aim of this project is first to study the tar yield and composition of the MSW gasification at two different temperatures using steam and air. After analyzing the different tar compounds, one of these was selected in order to be cracked in a secondary pulsed-corona plasma reactor in order to evaluate the performance of such reactor at different temperatures. These temperatures represent the gas exit temperature of different gasifiers.

3 SCIENTIFIC INNOVATION AND RELEVANCE

Tar is known as the Achilles' Heel of gasification , and although there is a wide range of tar abatement methods most of them produce secondary undesirable effects. For instance partial oxidation reduces the LHV of the syngas, scrubbing requires syngas cooling, catalysts can be quickly deactivated and do not allow long-term running processes, etc.

Corona plasma is then one of the most attiring alternatives, since it overcomes all the aforementioned issues, while reducing tars and particles producing a syngas suitable for IC engines, turbines and fuel cells. However, its high energy input together with the difficulty to operate in a high-temperature reactor makes it unsuitable for the industry.

In this work we present a modified pulsed corona plasma that can operate within a high temperature reactor. This device could be potentially used at the exit of a gasifier, and allow to study the link between plasma and thermal cracking reactions.

4 EXPERIMENTAL

The first experimental stage consists of gasification experiments using MSW as feedstock. These experiments were done using a small scale fixed-bed reactor at KTH, using two types of MSW issued from mechanical sorting of excavated waste. The two types of waste are labelled as 2D and 3D which represent light plastics and dense plastics respectively. These two types of MSW were exposed to steam and air and to two gasification temperatures. The composition of these two types of MSW is presented in table. Tar yield was determined using a cold tar trap of 5 bottles, two of them filled with isopropanol, and the tar composition was determined by the SPA/SPE method. The setup is shown in figure 1. The goal of this first experimental stage is to determine the tar yield, tar composition and tar dew point during MSW gasification at different temperatures.

The second stage of experiments consist of model tar cracking tests using a hybrid plasma reactor. The hybrid plasma reactor consists of a tubular reactor that is heated through a convection oven up to 1200^{o}C on where a pulsed electrical corona discharge is introduced thanks to a wire installed alongside the radius of the tube, as shown in figure 2. The power source can produce 60kV of voltage, but a maximum of 24kV was kept during all the experiments. The thermal effect of the plasma is negligible. The main goal of these experiments is to find the influence of the plasma and temperature into the cracking of the most representative tar model molecule obtained from the first set of experiments.

Table I: MSW composition used during gasification tests

Fraction (wt.%,db)	Landfill waste fractions	
	3D	2D
Wood	21%	1%
Paper	3%	4%
Textile	1%	9%
2D Plastics	2%	39%
3D Plastics	17%	5%
Other combustible	13%	11%
Fines	43%	32%

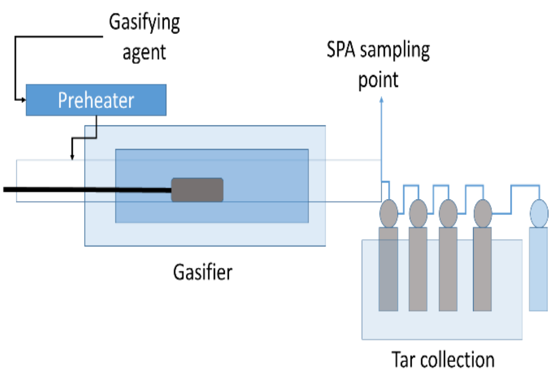

Figure 1: Fixed-bed gasifier.

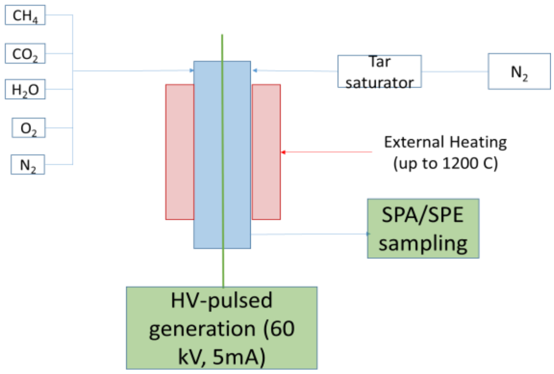

Figure 2: Hybrid plasma unit.

5 PRELIMINARY RESULTS AND CONCLUSIONS

After the first stage experiments it was evident that higher temperatures reduced the tar yield, however the tar dew point is simultaneously much higher (up to 30 degrees) as it can be seen in Figure 3. This was caused mainly by the increase of Class 5 tar produced by the polymerization of lighter components of Class 2, which are more abundant at low temperatures.

The most representative tar compounds at low temperatures were xylene, toluene and naphthalene. But at high temperatures, naphthalene is by far the most stable compound. This can be seen in the 3D steam gasification results shown in figure 4. In general, polyaromatic compounds (PAHs) proportion increases while heterocyclic aromatics are reduced. This is an indication that a degree of polymerization takes place during thermal cracking of tar, which also can explain the increased tar dew point.

During the second stage experiments, naphthalene was chosen as tar model molecule. The experiments consisted of cracking naphthalene under a nitrogen atmosphere by thermal cracking alone and by a combination of thermal cracking with plasma cracking.

The naphthalene initial concentration was maintained at 1.6 g/Nm3, and it was fed to the reactor thanks to a tar saturator that was kept around 70°C. A nitrogen stream passes through the saturator and is combined with a nitrogen stream free of naphthalene before entering the reactor. The residence time of the naphthalene inside the reactor was around 1min.

The results show that naphthalene can be fully cracked at 800^{o}C using a combined corona discharge – thermal cracking (at 24kV feed voltage) while it needs a temperature of 1000^{o}C when no plasma is used. This results demonstrate the synergetic effect of corona plasma cracking – thermal cracking, under a nitrogen atmosphere.

However this synergy is not the same for all the temperatures. The effect increases with temperature up to 800C, point on which the thermal cracking reactions start to be predominant. The contribution of plasma to naphthalene cracking drastically drops after this point. This is an indication that the plasma removal efficiency does not increase linearly with temperature, and its limit is dictated by the temperature at which the tar compound can be removed.

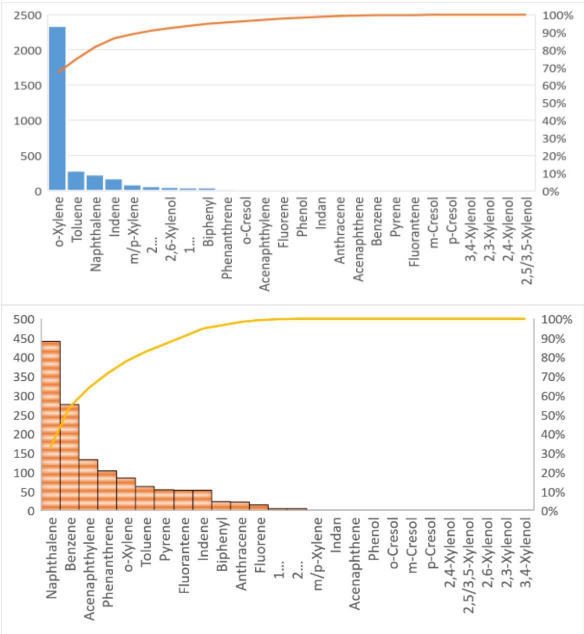

Figure 3: Tar composition for 3D MSW steam gasification. Concentrations are expressed in µg/100 ml Top: at 800°C, Bottom: at 1100°C

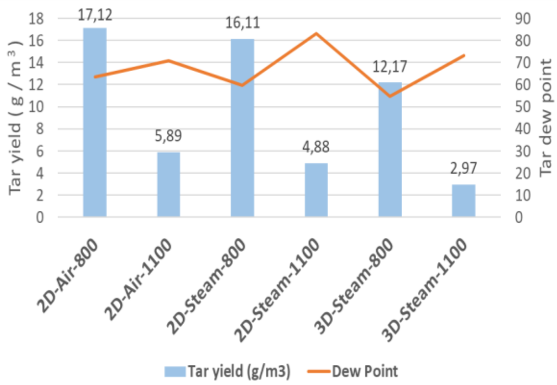

Figure 4: Tar yield and tar dew point in gasification experiments. Tar dew point is expressed in Celsius degrees.

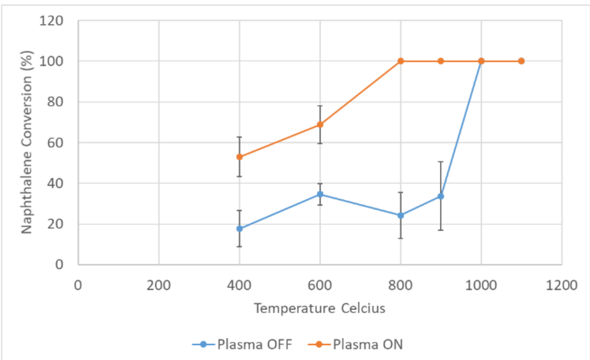

Figure 5: Naphthalene tar cracking using thermal-cracking only (blue line) and thermal-plasma cracking (red line)

6 REFERENCES

[1] Jones, P. T. et al. Enhanced Landfill Mining in view of multiple resource recovery: A critical review. J. Clean. Prod. 55, 45–55 (2013).

[2] Claude, V., Courson, C., Köhler, M. & Lambert, S. D. Overview and Essentials of Biomass Gasification Technologies and Their Catalytic Cleaning Methods. Energy and Fuels 30, 8791–8814 (2016).

[3] Abdoulmoumine, N., Adhikari, S., Kulkarni, A. & Chattanathan, S. A review on biomass gasification syngas cleanup. Appl. Energy 155, 294–307 (2015).

[4] Sikarwar, V. S. et al. An overview of advances in biomass gasification. Energy Environ. Sci. 9, 2939–2977 (2016).

[5] Nair, S. A. et al. A high-temperature pulsed corona plasma system for fuel gas cleaning. J. Electrostat. 61, 117–127 (2004).

[6] Milne, T.A.; Evans R.J. Biomass Gasifier Tars: Their Nature, Formation and Conversion. National Renewable Laboratory. (1998)

[7] Fjellerup et al. Formation, Decomposition and Cracking of Biomass Tars in Gasification. Technical University of Denmark. (2005)

[8] Koytsoumpa E; Karellas S.; Kakaras E. Modelling of Substitute Natural Gas production via combined gasification and power to fuel. Renewable Energy. (2018)

[9] Tao K. et al. Plasma enhanced catalytic reforming of biomass tar model compound to syngas. Fuel 104, 53-57. (2013)

[10] Liu et al. Hybrid plasma-catalytic steam reforming of toluene as a biomass tar model compound over Ni/Al2O3 catalysts. Fuel processing technology 166, 269-275. (2017)

7 ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Community's Horizon 2020 Programme under Grant Agreement No. 721185 (MSCA- ETN NEW-MINE).

8 LOGO SPACE