Conversion of sorted municipal solid wastes into syngas in an updraft fixed bed gasifier

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Introduction

Europe's energy demand increases. Highly unstable fossil fuel energy prices, the lack of local energy sources, and its inhomogeneous distribution across Europe demonstrates that there is a need of alternative energy source. At the same time, the quantity of wastes in landfills increases annually. The EU Action Plan emphasizes the importance of the utilization and valorization of Municipal Solid Waste (MSW) (Martínez, 2020). This correlation between wastes generation and energy demand shows that this energy source alternative should be seriously considered. One of the most promising options which could provide a significant amount of energy could be a gasification of MSW. Process of gasifying is a more advanced way compared with incineration (Waste-to-Energy) because it additionally allows to produce a valuable products (Waste-to-Value and Waste-to-Chemicals) which could be used for new products generation e.g. H_2, CO, NH_3, synthetic gas (syngas), etc. Moreover, syngas is oxygenated fuel which can be used in internal combustion engines (Cerone, 2020) and reduces emissions. Converting MSW into the syngas partially solves the energy storage and distribution problem which is a common problem with incineration plants.

This topic examines the energy potential of municipal solid waste syngas products which could allow to reduce the landfills emitting CH_4 which is more than 25 times potent greenhouse gas than CO_2. Research of municipal solid wastes ultimate, proximate, thermogravimetric, tar, and syngas analysis is conducted in this paper. The comparison of syngas and tars composition and other parameters of different types of MSW under a similar equivalent ratio (ER) is provided.

Materials and methods

Feedstock samples were taken from Vilnius mechanical-biological waste treatment plant, located in Lithuania. Samples were divided into three categories according to its origin, i.e. solid recovered fuel (SRF), fraction after wastes sorting drum separator (FDS), and sorted plastic packaging mixture (PPM). These kinds of MSW were shredded and pelletized into 6 mm diameter pellets. The proximate and ultimate analysis of these wastes were determined. The calorific value were analyzed by using an IKA C5000 calorimeter according standard EN ISO 21654:2021, moisture and ash content determined according CEN/TS 15414-1:2010 and EN ISO 21656:2021 respectively and chemical composition determined with a Flash 2000 CHNS analyzer. MSW samples properties were determined with Netzsch Jupiter STA 449 F3 thermogravimeter. Gasification process gaseous (syngas) and liquid (tars) products were analyzed with Agilent 7890A and Varian GC-3800 chromatographs respectively.

MSW excels with the specific behavior compared with coal or wood chips i.e. because of plastics residues low glass transition (melting) point. Because of this reason, an updraft fixed bed gasification reactor was used (see Figure 1). The gasification process takes place under isothermal (800 °C) conditions. MSW from the fuel hopper is fed by a screw conveyor through a water-cooled inlet jacket at the top of the reactor. Once in the reactor, MSW pellets fall to the bottom of the reactor covered with 5 - 10 mm fraction of crushed chamotte grains which increases the combustion area of the molten fuel samples and ensures air distribution and mixing with the fuel.

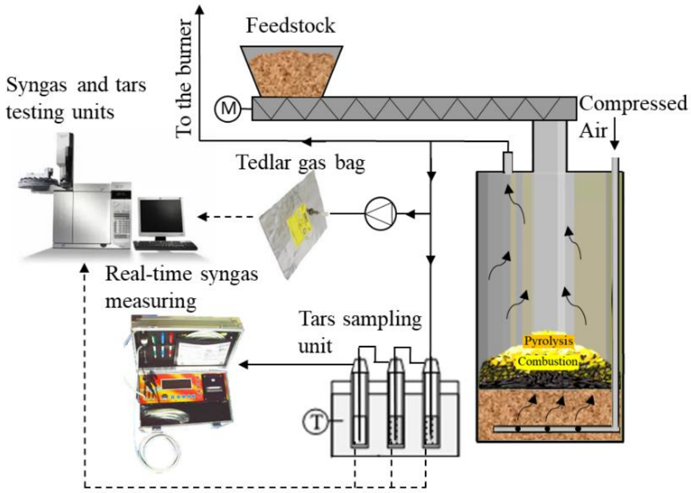

Fig. 1. Schematic view of the experimental rig for the MSW gasification

Fuel supply rate and air quantity were controlled according to real-time syngas measurements with a VISIT 03H analyzer. When the composition of the syngas has stabilized, "Tedlar" gas bags were filled with extracted samples. Two gas bags were filled for each measuring point. At the same time a liquid gasification product – tars were collected in a sampling unit containing six bottles filled with isopropanol. This solution was then analyzed and tars composition and quantity were calculated.

Results and discussion

Thermogravimetric analysis show, the temperature threshold for the release of volatile substances of SRF, FDS and PPM are similar (see Figure 2.). When MSW samples were heated to 250 °C, moisture was released. The samples were already dried before thermogravimetric analysis, so the change in mass doesn't exceed 5 %. The release of organic matter begins at the same (250 °C) temperature. Nevertheless, the end of the organic matter release phase differs according to the origin of the waste. The end of volatile matter release phase for FDS is 510 °C, SRF - 520 °C, and PPM - 550 °C.

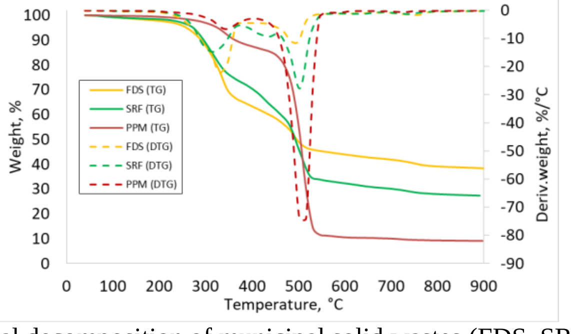

Fig. 2. Thermal decomposition of municipal solid wastes (FDS, SRF and PPM)

FDS, SRF, and PPM waste samples were gasified in fixed bed updraft gasifier under same conditions - temperature of reactor 800 °C and equivalent ratio (ratio between actual and stoichiometric air) (ER) 0.12 – 0,25 and results were compared. PPM accounted for the largest share of volatile matter – 90 %, and the volatiles of SRF and FDS reached 61 and 49 %, respectively. PPM wastes can be described with the fastest volatile release. With the temperature increase by 100 °C (450 - 550 °C), the gasification process of the plastic packaging mixture was particularly intense and 74 % of the material entered the gas phase. By comparison, in the same temperature range, 28 % of SRF and 13 % of FDS volatiles were released.

It was determined that FDS syngas mostly contains of CO (9.6 ± 3.1 %), H_2 (5.2 ± 2.2 %) and CH_4 (4.0 ± 1.5 %). The calculated calorific value of FDS syngas 3.5 ± 1.2 MJ/m^3. SRF syngas contains higher levels of H_2 (7.5 ± 2.5 %) and CH_4 (7.4 ± 3.0 %), and CO (13.9 ± 6.1 %) compared with FDS. The calculated calorific value of SRF – 5.9 ± 2.4 MJ/m^3. PPM syngas can be described with the highest concentrations of methane (9.3 ± 3.7 %) and hydrogen (9.9 ± 1.6 %), but lowest concentrations of carbon monoxide (8.7 ± 1.6 %). PPM higher combustible gas concentration increases syngas calorific value, which was 6.3 ± 1.6 MJ/m^3.

FDS tars contains highest amount of benzene (7.0 ± 0.5 g/m³), toluene (2.3 ± 0.4 g/m³), naphthalene (3.0 ± 0.3 g/m³) and acenaphthylene (1.3 ± 0.1 g/m³) organic compounds. The average tar quantity in FDS syngas was 16.2 ± 0.8 g/m^3. SRF tars also contain a high amount of benzene (18.1 ± 7.9 g/m³), toluene (5.5 ± 3.0 g/m³), naphthalene (4.9 ± 2.0 g/m³) and acenaphthylene (2.1 ± 0.9 g/m³). The average tar quantity in SRF syngas determined was as twice as large as FDS and reached 34.7 ± 15.1 g/m^3. PPM syngas composition was similar to SRF, containing benzene (14.8 ± 3.0 g/m³), toluene (3.7 ± 1.5 g/m³), naphthalene (5.7 ± 1.5 g/m³) and acenaphthylene (2.8 ± 1.3 g/m³). The average tar content in PPM syngas was 32.4 ± 9.3 g/m^3.

Conclusion and discussion

Gasification of municipal solid wastes in an updraft gasifier shows that the highest energy potential of synthetic gas can be obtained from the gasification of plastic packaging mixture (PPM) wastes. The average calorific value of synthetic gas from PPM waste was 6.25 MJ/m^3. The calorific value of solid recovered fuel (SRF) was 5.87 MJ/m^3, and the fraction after the wastes sorting drum separator (FDS) was 3.52 MJ/m^3. SRF and PPM had the highest concentrations of tars in synthetic gases. The concentration of tars in SRF syngas reaches 34.7 g/m^3, PPM - 32.4 g/m^3, FDS - 16.2 g/m^3. The use of a syngas cleaning system in order to convert MSW to valuable products may be required.

References

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