Gasification of RDF in two-stage reactor unit, comparison of two reactor configurations

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Introduction

Gasification and pyrolysis are attractive methods of municipal solid waste (MSW) utilization. The purpose of gasification and pyrolysis is to produce synthesis gas for fuels and chemicals production. Solid feedstock is converted by gasification or pyrolysis to combustible gas containing hydrogen, carbon monoxide, carbon dioxide, water, methane, higher hydrocarbons, inert gas originating from the gasification agent and various contaminant such as ammonia, hydrogen chloride, hydrogen sulfide and tar (Bosmans et al., 2013). Among them, the formation of tar represents main drawback of both technologies. Tar is a mixture of aromatic hydrocarbons with molecular weight higher than benzene (Ahmadi et al., 2011). Due to its physical and chemical properties, tar tends to condensate or polymerize at high temperature which cause serious problems such as blockages in pipelines (Blanco et al., 2012). Enormous effort is put into research of tar removal technologies. These technologies can be divided into physical and chemical. From the physical technologies, tar absorption is interesting method. Main disadvantage of physical methods is production waste stream contaminated by tar. The chemical technologies are in this direction preferable. Especially, catalytic tar decomposition is popular method where tar is decomposed to lighter molecules up to hydrogen and higher conversion of feedstock to gaseous product can be achieved. The presence of catalyst allows to reduce temperature in the reactor, thus lower material requirements are demanded. Deactivation of catalyst is the weak spot of catalytic tar decomposition. Namely, coke formation, catalyst poisoning and catalyst sintering are main disadvantages of this technologies. Catalysts based on nickel are reported as very effective catalyst for tar decomposition (Blanco et al., 2013; Šuhaj et al., 2019). The configuration of gasifier has also big impact on tar content and gas composition. There are many works concerned on studying different gasifying units consisted from 2 and more reactors (Haydary, 2017; Gadsbøll et al., 2019).

Due to low heating value, high moisture content and heterogeneity, MSW is not very suitable feedstock for gasification or pyrolysis. A utilised form of MSW is commonly used as feedstock. So-called refuse-derived fuel (RDF) is produced from MSW by mechanical-biological treatment (MBT). RDF is mixture of paper, plastic, textile and wood with more uniform particle size distribution and higher heating value.

In this work, placement of input for gasifying agent into two-stage reactor unit was examined. The two-stage reactor unit consisted of 2 reactors. In the first reactor, RDF was gasified/pyrolised and volatiles were fed to the secondary catalytic reactor. The air was used as gasifying agent and in the first configuration, air was fed to the first reactor. In the second configuration, nitrogen was fed to the first reactor and volatiles were mixed with air before entering to the secondary catalytic reactor. As catalyst was used clay mineral enhanced by NiO. The gas composition, tar yields at different reactor temperatures were studied.

Material and methods

Two-stage reactor unit was constructed from 2 steel pipes with the inner diameter 17 mm and the length 466 mm and 400 mm. The heat supply for both reactors was provided by 2 electric furnaces. In every experiment, 10 g of RDF was loaded into the first reactor. In the second reactor was placed 10 g of prepared catalyst from mineral clay enhanced by NiO (Šuhaj et al., 2019). Simplified scheme of apparatus is shown in picture Fig. 1.

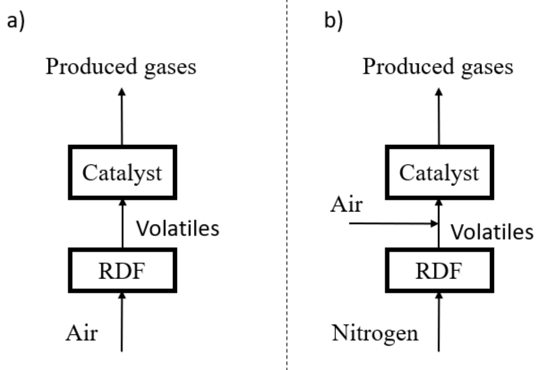

Fig.1: Simplified scheme of apparatus.

In the configuration a), the air was fed to the first reactor. In the configuration b), the air was mixed with volatiles and was fed to the catalytic reactor and nitrogen was fed to the first reactor. Experiments for configuration

a) were carried out at temperatures 700, 750 and 800 °C in the catalytic reactor and the same temperature was set in the first reactor. Volume flow of air was set to 10 dm^3h^{-1}. In the configuration a), the temperature in the first reactor was set 550 °C while in the catalytic reactor were used temperatures 700, 750 and 800 °C. Volume flow of air and nitrogen was set to 10 dm^3h^{-1} and 15 dm^3h^{-1}. The produced gases were fed to the scrubbing system filled by isopropanol for capturing tar. After it, gas sample was analysed by gas chromatography. The isopropanol with captured tar was used to determine amount of produced tar by standard procedure (Kamp et al., 2006).

Results and discussion

It was expected, that elevated temperature of volatiles caused by partial oxidation by added air will lead to better tar decomposition. Results of tar yields showed in Tab. 1 indicate that higher temperature in the first reactor has better impact on tar decomposition. However, at the temperature 800 °C, slightly lower tar yield was achieved for configuration b).

Tab. 1: Comparison of tar yields

Temperature [°C]		700	750	800
Tar yield [mg/g of RDF]	Configuration a)	8.1	6.2	7.6
	Configuration b)	15.5	14.4	5.61

Composition of produced gases showed in Tab. 2 indicates drop of hydrogen content when air feed was redirected between reactors. However, the hydrogen has growing trend with elevated temperature. It can be expected at temperatures above 800 °C a higher hydrogen content can be achieved by configuration b).

Tab. 2: Comparison of gas composition (nitrogen free), hydrocarbons represent volume content of ethane, ethylene, propane and propylene

Apparatus	Configuration a)			Configuration b)		
Temperature [°C]	700	750	800	700	750	800
CO_2 [vol. %]	15	8.0	11.0	40	27.1	17.3
H_2 [vol. %]	46.6	54.1	43	23.2	31.2	41
CO [vol. %]	22.8	23.3	23	24.9	17.0	34
CH_4 [vol. %]	7.9	8.4	11.1	7.9	11.1	4.6
Hydrocarbons [vol. %]	8.1	6.3	12	4.5	13.7	2.9

Conclusions

Results proved that feeding air into the first reactor under temperature 800 °C has better impact on tar yield and gas composition. Better results for second configuration can be expected above this temperature. Experiments with different operating conditions will be performed in the future work. It is necessary to find optimal temperatures, volume flows of air and nitrogen for both configurations. Also impact of operating condition on catalyst will be studied.

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References

Ahmadi, M., Brage, C., Sjöström, K., Engvall, K., Knoef, H., Beld, B.V., 2011. Development of an on-line tar measurement method based on photo ionization technique. Catal. Today 176, 250–252.

Blanco, P.H., Wu, C., Onwudili, J.A., Williams, P.T., 2012. Characterization of tar from the pyrolysis/gasification of refuse derived fuel: influence of process parameters and catalysis. Energy Fuels 26, 2107-2115.

Bosmans, A., Wasan, S., Helsen, L., Waste to clean syngas: avoiding tar problems. In *Second International Enhanced Landfill Mining Symposium*, Houthalen-Helchteren, Belgium. (October 14-16, 2013).

Gadsbøll, R. Ø., Clausen, L. R., Thomsen, T. P., Ahrenfeldt, J., Henriksen, U. B., 2019. Flexible TwoStage biomass gasifier designs for polygeneration operation. Energy. 166, 939-950.

Haydary, J., 2017. Modelling of two stage gasification of waste biomass. Chem. Eng. Trans. 61, 1465–1470.

Kamp, W.L., Wild, P.J., Knoef, H.A.M., Neeft, J.P.A., Kiel, J.H.A., 2006. Tar measurement in biomass gasification, standardisation and supporting R&D. ECN report ECN-C-06-046, ECN, Petten, The Netherlands.

Šuhaj, P., Haydary, J., Husár, J., Steltenpohl, P., Šupa, I, 2019. Catalytic gasification of refuse-derived fuel in a two-stage laboratory scale pyrolysis/gasification unit with catalyst based on clay minerals. Waste Manage. 84, 1-10.