Production efficiency and safety assessment of the solid waste-derived liquid hydrocarbons.

J. Čespiva[1], J. Skřinský[1]

[1]VSB – Technical University of Ostrava, Centre for Energy and Environmental Technologies, Energy Research Centre, 17. listopadu 2172/15, 708 00, Ostrava, Czech Republic
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Presenting author email: jakub.cespiva@vsb.cz

Introduction

Solid waste materials have a certain potential. From the energetical point of view, so-called solid recovered fuel (SRF) is an interesting alternative in numerous material/energy conversion systems, such as combustion gasification or pyrolysis. Apart from waste-to-energy principles, which are the domain of waste utilisation, other approaches, such as waste-to-liquid (WtL), may be utilised in connection with the above-mentioned thermochemical conversion principles.

The production of hydrocarbon (HC) liquid materials, forming a wide range of individual components, is important for future production processes in terms of de-fossilisation and material demand, especially liquid fuels and organic chemicals. The composition of the synthetic gas from the SRF gasification process can be modified by means of physical and chemical environments, increasing its usability in the catalytic synthesis units. For such units, H_2 and CO are the most valuable components. The course of their synthesis into higher HC chains is then strongly dependent on the inner conditions within the synthesis reactor.

In this paper, the course of the WtL process is evaluated from the efficiency and safety points of view, outlining the possibilities of improving the modification in terms of different process parameters, used catalysts, and the quality of the source gas.

Materials and Methods

Synthetic gas generation

The input synthetic gas produced from solid recovered fuel (SRF) contained a mixture of sorted fractions of plastic, paper, textile and wood components, which could not have been feasibly recycled. This certified SRF fuel was delivered by OZO a.s. company (The Czech Republic) in the form of fluff with a bulk density value equal to 109 kg/m^3, and the individual particle size was in the range of 0.2 to 25 mm. The lower heating value (LHV) of this fuel was 19.1 MJ/kg (EN 18125).

The gasification technology, utilised for the thermochemical conversion of the SRF into producer gas and solid, carbonaceous residue, was defined by the cross/updraft reactor with a sliding bed over a circular grate. This technology works in an autothermal regime and utilises atmospheric air as the oxidising media. The maximum input power of this reactor is approx. 250 kW. The construction and the working principle of the reactor appear to be especially beneficial for the utilisation of the SRF material, as was previously evaluated (Čespiva et al., 2023)

Table 1. Parameters of the input synthetic gas.

CO (%)	CH_4 (%)	H_2 (%)	LHV (MJ/m^3)	Q l/min	T (K)
6.5	14.2	4.8	6.33	2.2	298,15

F-T Technology

The Fischer-Tropsch synthesis unit with micro catalyst bed is of laboratory scale with a maximum flow of the four-compound gas equal to 40 l/h (10 l/h for each entry gas). The synthesis reactor is tubular with a stationary bed of the catalyst, placed in the maximum volume of 9,4 cm^2. The maximum allowed tested pressure is 70 bar (tested with He), and the maximum reactor temperature is 530 °C. The catalysts used for the purpose of this research were of cobalt base, impregnated on Al_2O_3 bearer of spherical shape (1 mm diameter).

Performance evaluation methodology

There are many ways to the synthesis process evaluation. In this study, the parameter of conversion efficiency was examined. This parameter is a tool for simple comparison of the individual process, and its determination is based on the examination of the masses in [kg], which enter the system in the form of gas and leave the system in the form of liquid. Another crucial parameter is the share of lower and higher quality fractions within the produced liquid mixture. Usually, the sample of the HC mixture contains a heavier fraction with up to 99% wt. of water, and a lighter fraction, which consists of HC chains where the content of water is only in trace amounts. Determining this share is also possible by measuring the weight rate after precise separation.

The determination of the content of the individual samples was performed through gas chromatography with a mass spectrometer (GC-MS). The 7820-A chromatograph with A5977B MSD electron ionisation mass spectrometer attached (both Agilent, USA) was used in order to determine the exact composition of the HC chains.

Safety parameters estimation

In order to determine the parameters of the produced synthetic liquids in terms of safety, the autoignition test (AIT) experiments were performed. The AIT characteristics of synthetic liquid-air mixtures were prepared using both the EN 14522:2005 and the ASTM E659-78:2005 methods. The experiments were conducted in two different experimental arrangements: a 500 ml spherical vessel and a 250 ml conical vessel-for different liquid equivalence ratios between 50 µl and 300 µl. The initial temperatures were between 25 and 700°C.

The AIT for fuel/air mixtures shows a large inconsistency due to various physical-chemical factors which affect its values as the chemical composition, concentration, volume, and shape of the flask. The novelty of the article is the investigation of the effect of the fuel phase on its combustion properties with no change in the fuel´s physical-chemical properties.

Results and discussion

The setup of the gasification technology, described in the previous chapter, sufficed for the stabilised production of the gas parameters, which are summarised in Table 1. below. The producer gas was rich in CH_4 (4.8 % vol.), and despite the relatively high content of N_2 (69.8% vol.), the LHV = 6.33 MJ/m^3 is sufficient and very promising, compared to similar studies on fixed bed gasification reactors. On the other hand, high CH_4 is compensated by a much lower content of CO and H_2, which is only 6.5 and 4.8 % vol, respectively. The presence of CO_2 is a natural consequence of the partial combustion of the fuel.

The synthesis showed variable results, influenced by reactor temperature and used catalyst. In the case of cobalt catalyst without any promoters, the conversion efficiency was measured to be 20% in the 280 °C environment, while the 250 °C environment reached only 12% in the stable state. The examination of the fraction content showed 67% of heavier (watery) fraction while the 250 °C regime reached 72%. The simplified results are seen in the table 2.

Table 2. Synthesis parameters.

Catalyst	Temperature regime	
Cobalt	250 °C	280 °C
Pressure (bar_g)	15	15
Conversion efficiency (%)	12	20
Heavier fraction (%)	72	67
Lighter fraction (%)	28	33
Off-gas flow (l/h)	8	6

Conclusion

In this study, the influence of catalyst and synthesis reactor parameters on the solid-recovered fuel-derived gas synthesis was examined. The basic conversion efficiency was determined, and the characteristics of the produced hydrocarbon liquid were investigated. The results showed that 20% conversion efficiency could be reached while the Co catalyst is used and the physical conditions in the reactor are set at 280 °C and 15 bar_g. Moreover, the detailed composition analysis of this product mixture was performed on gas chromatography equipment, showing mainly groups of C4 – C30 in the form of alcohols, alkanes and waxes. Safety assessment of the synthetic liquid mixtures was determined through autoignition tests (flash point analysis).

References

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