Solid recovered fuel gasification in sliding bed reactor

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Abstract

Waste generation is omnipresent, not only in inhabited locations. Each country deals with this issue differently, often ignoring the fact, that waste materials usually have interesting energy content, which can be utilised in order to decrease the use of fossil resources. According to Kaza et al. (2018), 3.4 billion tons of waste will by generated by 2050. Nowadays we generate over 2.01 billion tons out of which, more than one third is not managed in an environment-friendly way. Only 30.4 % of global waste is recycled or energetically utilised (Kaza et al., 2018).

The increasing energy demand and the fossil resources restriction trends also put pressure on the society. The utilisation of energetical compounds of waste material helps to solve both issues, waste cumulation and energy consumption. Apart from conventional incineration, other principles, such as pyrolysis (Santamaria et al., 2021) or gasification (Arena et al., 2014; Valin et al., 2019) may be used for SRF utilisation. The latter one brings an alternative approach of waste energy storage in form of synthetic gas.

In this study, specific SRF material was used. A mixture of municipal (unrecyclable plastics and paper) and industrial (unrecyclable plastics, wood, paper and textile) waste was produced in form of a fluff with particle size 1-25 mm. Lower heating value of this SRF is 19.1 MJ/kg. Because of the safety reasons concerning transport and proper utilisation, the SRF was mixed with plain softwood pellets in the rate of 3:2 in this study.

The process of gasification was carried out a unique cross/updraft reactor of medium scale with sliding bed over circular grate and tangential oxidiser (air) intake. The process of gasification was performed in four experimental rounds, each time with different material and oxidiser flows and process temperature. The influence of these parameters on producer gas quality and purity was examined. The analyses of the raw producer gas were realised through sampling probe and sampling track, situated immediately at the reactor outlet. Molecular composition, energy content and polluting agents (particulate matter (PM) and tar compounds (TC)) within producer gas were analysed using thermogravimetric and mass spectra principles.

Table 1. Parameters of the gasification process.

Experiment	[#]	**1**	**2**	**3**	**4**
Temperature	[K]	938.8	941.9	1005.4	935.8
Relative pressure	[kPa]	-0.1	-0.2	-0.3	-0.1
Fuel flow	[$kg\cdot h^{-1}$]	48.5	48.6	50.3	14.2
Air flow	[$m^3\cdot h^{-1}$]	7.2	11.8	14.6	7.8
Equivalence ratio	[-]	0.22	0.23	0.24	0.28
Cold gas efficiency	[%]	42	27	25	68
Hot gas efficiency	[%]	48	37	35	93

The results of the gasification performances show nonlinear dependency of gas efficiencies on other gasification parameters. The efficiencies (HGE and CGE) seem to have their depressions around λ=0.24, however, fuel flow parameter affects the course of the efficiency much. As it is seen in table 1, the fourth case when only 14.2 $kg\cdot h^{-1}$ were used and λ=0.28, the CGE was equal to 68 % and HGE was as high as 93 %. Chiemchaisri et al., (2010) defined in their study CGE=66 % for landfill-mined SRF gasification in small-scale downdraft application. However, the LHV was very poor – only 1.6 $MJ\cdot m^{-3}$. Another downdraft reactor, described by Sobolewski et al., (2014), reached 62 % of CGE for SRF/wood biomass mixture. The LHV was quite promising in this case: 3.05 $MJ\cdot m^{-3}$. Vonk et al., (2019) described an experimental stand of downdraft reactor capable of plastic SRF gasification (SRF/wood 1:4). In two experiments with λ=0.23 and 0.28, the CGE=35 and 39 % were obtained. In both cases, technical issues in form of bridging and clogging were observed. However, LHV was in both cases very promising: 5.1 and 4.1 $MJ\cdot m^{-3}$, respectively. The dependency of CGE and HGE on equivalence ratio is evident in the graph in Figure 1.

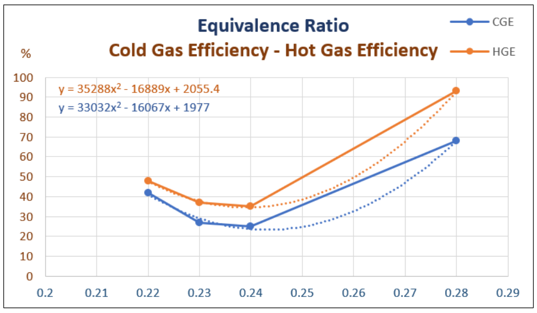

Fig. 1 Equivalence ratio vs. conversion efficiency

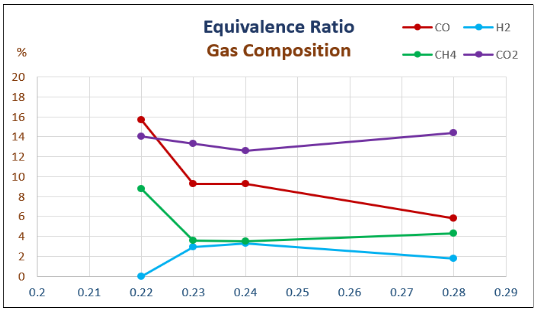

Fig. 2 Equivalence ratio vs. producer gas composition

The fuel load in the reactor seems to be much more important than, for instance, gasification temperature. As seen in the graph in figure 2, the gas composition does not differ as much in case of λ=0.23 (T=941.9 K) and λ=0.24 (T=1005.4 K) as it does in case of low fuel load (λ=0.28 and T= 935.8 K). The best energetic parameters of the producer gas were obtained in the first case, when LHV=5.0 MJ·m^{-3} was reached during production of 67 m^3·h^{-1} of producer gas, generated out of 48.5 kg·h^{-1} of fuel, on average. In this case, the producer gas consisted of CO=15 % vol. An absolute lack of H_2 was compensated by rich content of CH_4=8.8 % vol. The content of PM within the producer gas was ranging from 0.5 g·m^{-3} in case of fourth experiment in low fuel load, to 5.0 g·m^{-3} in case of third experiment, when H_2 content and conversion efficiency were the lowest and LHV=2.7 MJ·m^{-3}.

The results achieved in this study underline the output from SRF gasification in specific conditions. Those included variable temperature (935.8-1005.4 K), equivalence ratio (0.22-0.28) and fuel flow (14.2-50.3 kg·h^{-1}). The examined parameters included producer gas content and energy value, conversion efficiency and content of polluting agents, namely particulate matter and tar compounds.

The highest conversion rate (HGE=93 %) was accompanied by relatively low LHV, equal to 2.7 MJ·m^{-3}. This was influenced by low CO content equal to 5.8 % vol. On the other hand, LHV of 5.0 MJ·m^{-3} and CO=15.7 % vol. along with CH_4=8.8 % vol. seem promising. However, this scenario operated with HGE and CGE as low as 48 and 42 %, respectively. In these two cases, the value of equivalence ratio λ was 0.22 and 0.28, respectively. An interesting correlation between conversion efficiency and producer gas LHV is evident, outlining two distinct approaches of combined gasification of SRF and biomass: The way of efficient production of less energetic gas and the way of producing good quality gas with worse efficiency. The hydrogen yield may also be considered in some applications, nowadays. Its highest content equal to 3.3 % vol. was measured in case of λ=0.24.

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