Converting wood to biogas via syngas – the SYNFERON project

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1. Introduction

In Denmark, greening the natural gas grid is developing fast. Starting in 2012 with 0%, the share of biomethane in the grid (upgraded biogas to natural gas quality) was in the start of 2020 above 10% and now in 2021 above 20%. It is still increasing and expected to be 30% in 2023, but to end at the future goal of 100% it is necessary to include other sources, which could be gasification of biomasses followed by methanation. In the SYNFERON project, a small-scale demonstration was performed of converting wood pellets to biogas.

2. Demonstration plant setup

Allothermal gasification of biomass coupled with ex situ tar removal was shown to be a viable method of producing tar-free syngas well suited for subsequent biomethanation. The gasification was performed in a fluid bed packed with olivine particles as bed material, operated at 1 barg and at isothermal conditions at 900°C furnace temperature corresponding to 800°C reactor temperature.

Steam is used as both the fluidization and gasification agent and is added from the bottom of the gasifier. A flow of wood pellets of 320 g/h, corresponding to a thermal input of approximately 1.55 kW

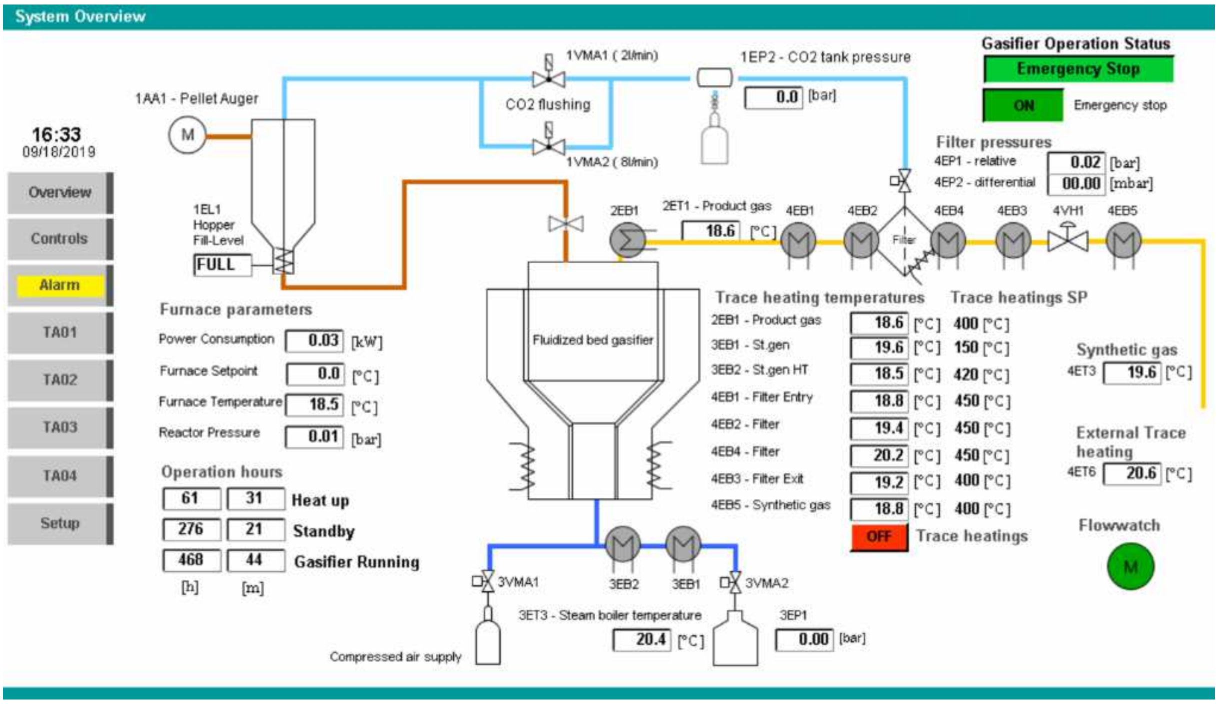

Figure 1. System overview of the gasifier (not in operation)

based on the net heating value, and a CO2 flow of 2 l/min at 1 barg are continuously added to the gasifier from the top. The gasifier uses 5.5 kW electricity, which covers the steam generation, furnace heating and losses

Figure 1 shows a system overview of the gasifier (not in operation) including fuel hopper, fluidized bed gasifier, exit filter, steam supply and CO_2 tank for filter cleaning and CO_2 flushing [1].

3. Steam reforming

Post the gasification furnace, the temperature is kept above 350°C in order to avoid tar condensation in the pipes. Ex situ tar removal was performed through catalytic steam reforming at a temperature of approximately 700 to 800°C reached by internal heat exchange and external electrical heating.

Figure 2 shows the combined steam reforming and pre-methanation unit. It includes a pre-cleaning part consisting of dolomite pellets only, which also starts a WGS process and heating up syngas from about 400°C to 700°C. Then follows an endothermic steam reforming part working at 800°C heated externally by electricity and reducing tar and methane to a minimum and exchanging heat with the incoming gas. The catalyst is the "TARGET" catalyst from NEXCERIS, USA. The last part of the heat exchanger consists of catalyst, which is a mixture of dolomite pellets and methanation pellets. The methanation pellets consist of "Methanation Catalyst META-J103" from China, including >18% Ni. In this part, the concentration of H_2O is still high and there are two parallel reactions taking place here: WGS and exothermic methanation, while the temperature drops from 600°C to around 400°C by heat exchange. The gas from the tar cracker and pre-methanation then passes through an active carbon filter to remove any remaining pollutants and from there even through a water scrubber. We never found any tar in the water scrubber. The observed conversion rates were 100% for tar, 89% for ethylene and 62% for propane.

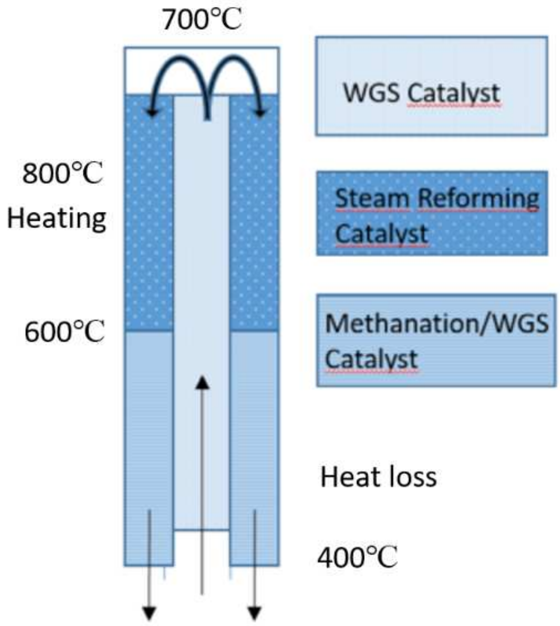

Figure 2. Steam reforming and pre-methanation unit; the tar cracker

4 Biomethanation

The thermal fuel input of 1.55 kW coupled with the electricity consumption and allothermal operations results in a gas output from the gasifier of 1.78 kW. As expected, most of the electricity is wasted as losses in this small lab-scale gasifier. According to scaling models, a full scale 20 MW plant is expected to have electricity consumption of 20-30% of fuel input in total. When adding a biomethanation unit, which has an energy conversion efficiency of 80%, calculations indicate that it is possible to produce methane with an energy efficiency of approximately 100% (based on fuel input to the gasifier).

The biomethanation unit developed at the Technical University of Denmark (DTU) was installed, and the exit gas composition from the tar reformer is exactly suited for the subsequent methanation. It consists of a trickle bed reactor with a total electronic control system for addition of nutrients, pH-control, etc. A part stream of the syngas from the gasifier and tar cracker is added to the bioreactor, which converts all gasses to a biogas only containing CO_2 and CH_4. The input gas to the biomethanation unit contains around 48% CO_2, 11% CO, 31% H_2 and 10% CH_4, while the output gas contains around 64% CO_2 and 36% CH_4 (dry basis). The high output CO_2 is due to the CO_2 flushing.

Figure 3 shows the composition of the main components throughout the total system from the gasifier to the biomethanation output; all values were measured except the tar. Figure 4 shows the steam consumption, the tar reduction and the energy content in the gas flow throughout the system [2].

5 Tar modelling and mass balance

Tar from the gasifier is represented by Naphthalene ($C_{10}H_8$). According to literature, Naphthalene contributes to a large part of all the compounds in tar from

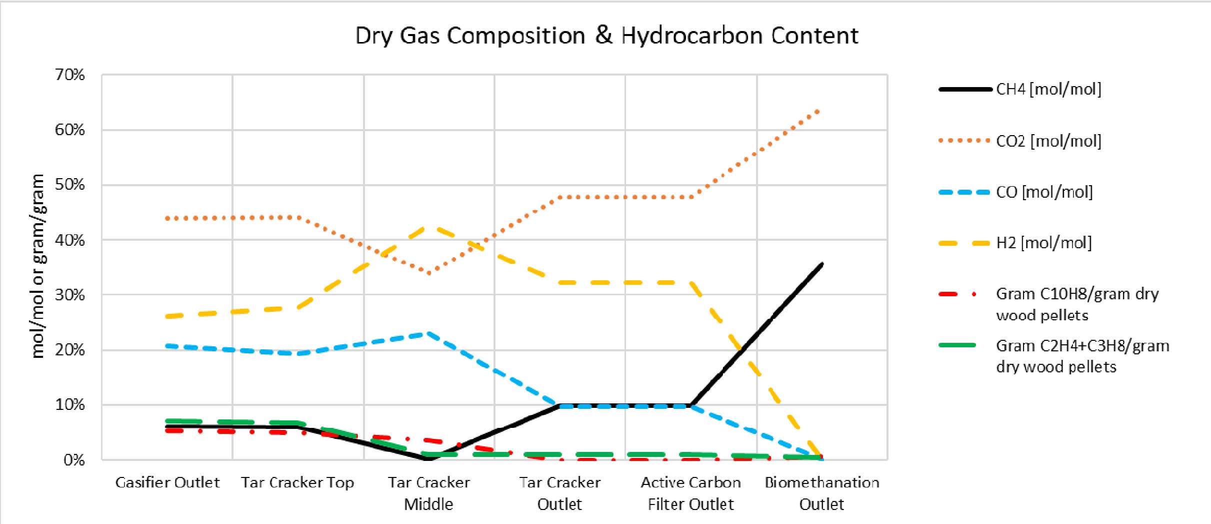

Figure 3. The composition of the main components throughout the total reactor system

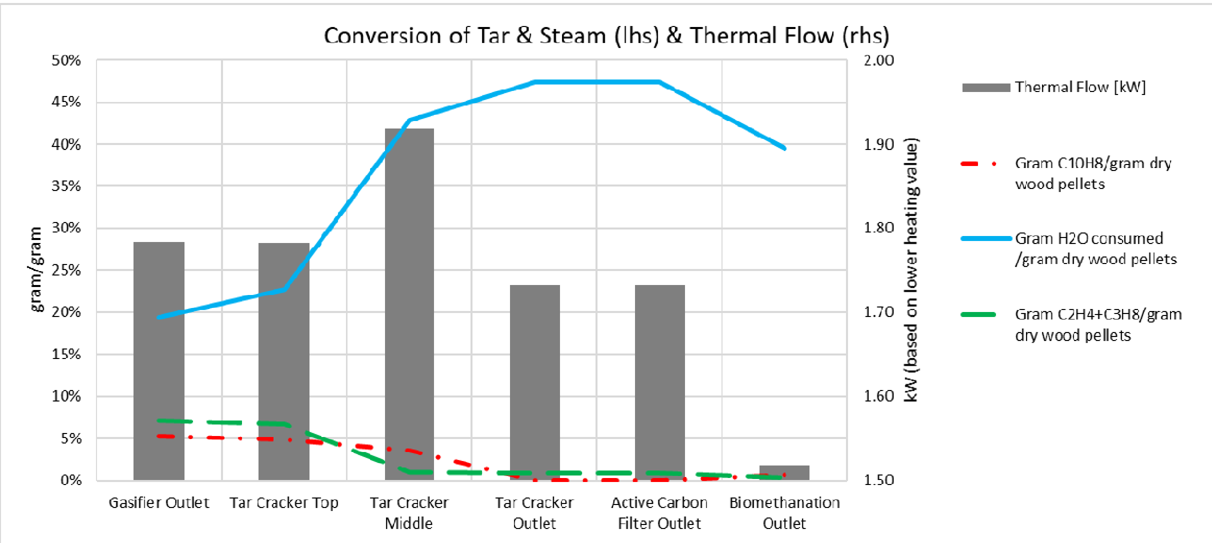

Figure 4. The steam consumption, tar reduction and energy content in the gas flow

gasification, and furthermore taking the average C/H ratio in tars it usually ends at 10/8 [3,4]. Hence, in this work we assume Naphthalene to represent all tars. We did not measure the tar, and we used the following method of modelling the tar content:

The empirical stoichiometric mass balance was done based on the stoichiometric molar flow of fuel and gases at inlet compared to outlet gases and balance was made as shown in equation (1), which is developed into eq. (2)

$$\text{Fuel} + \text{flushing } CO_2 + \text{converted } H_2O = \text{measured gas components out} + \text{tar} \quad (1)$$

$$x(C_{13}H_{19}O_8 + bH_2O + aCO_2) + yH_2O = \%CO + \%CO_2 + \%CH_4 + \%C_3H_8 + \%H_2 + \%C_2H_4 + zC_{10}H_8 \quad (2)$$

Equation (2) is explained as follows:
$C_{13}H_{19}O_8$ represents wood that gives the correct relation of masses of C, H and O. The known amount of moisture in the fuel is represented by bH_2O and "b" is a calculated variable. The relation between flushing CO_2 and fuel is known, which determines variable "a". The inflow of CO_2 flushing was measured using a flowmeter. The fluid bed of the gasifier is fluidized by steam and yH_2O represents the amount of steam converted to other gases during the gasification process. Only a part of the H_2O is converted. "x" is the stoichiometric factor of fuel in inlet.
On the right side of the equation, all the measured molar concentrations of the output gases are assumed to be the arbitrarily chosen stoichiometric factors. As mentioned, in this work we assume Naphthalene to represent all tars. "z" is then the stoichiometric factor of $C_{10}H_8$ in the outlet. With these assumptions it is possible to calculate the three unknowns, x, y and z from the three elemental balance equations for C, O and H using Problem Solver in Microsoft Excel.

The calculations were made based on measurements of gas compositions measured at points throughout the whole system from gasifier to biomethanation outlet.

6 Conclusion

In a small-scale demonstration plant, we succeeded in converting wood pellets into biogas (CO_2 + CH_4).
The gasifier was an electrically heated lab-scale fluid-bed and the conversion efficiency of the biomass was about 100% caused by the added electricity.
The tar was converted 100% to syngas in a steam reformer. The syngas from the gasifier and tar cracker was converted into biogas in a biomethanation unit.
We have shown that instead of measuring, it is possible to calculate the steam conversion and the tar content from the gasifier based on measurements of input mass flows and output composition of the gasses.

7 References

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