Twin-Bed Gasification Concepts for Bio-SNG Production

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E.ON Sverige AB is increasing the consumption and availability of natural gas. Different alternatives for thermal gasification of biomass in order to substitute the fossil natural gas are therefore at the moment being studied. Twin-bed gasification of biomass is a technology that produces a medium heating value gas without nitrogen dilution and with high methane content. Three existing twin-bed gasifiers; SilvaGas, FICFB and MILENA with integrated gas cleaning and methanation for bio-SNG production have been studied in this final thesis. The energy efficiencies and the bio-SNG efficiencies of the processes have been calculated. Results show that if more methane in the gasifier can be produced higher bio-SNG efficiency is obtained. The bio-SNG efficiency of the twin-bed gasifiers is at the moment between 54-66%. With higher gas yield higher overall process energy efficiency is obtained. For the twin-bed gasification the overall process efficiency differs between 80-95%. The bio-SNG efficiency depends a lot on the process being optimized for bio-SNG production or not.

Introduction

E.ON Sverige AB is at the moment building a combined heat and power plant fired with natural gas in Malmö, Sweden. In order to substitute the natural gas, production of biogas with thermal gasification of biomass is being studied.

The idea is to produce a gas that can be directly introduced into the natural gas grid. The gas is called bio-SNG, Substitute Natural Gas and the properties of the gas have to meet the ones of the natural gas in the grid.

One of the technologies for thermal gasification being studied by E.ON Sverige AB is called Twin-Bed gasification. It is a type of indirect gasification that produces a medium heating value gas free of nitrogen dilution.

The aim of this master thesis is to study the existing twin-bed gasifiers with downstream gas cleaning and methanization for production of bio-SNG. To valuate the processes the bio-SNG efficiency is calculated together with the overall process efficiency.

Twin-Bed Gasification

As gasification needs heat to produce gas, this heat normally is produced by combustion of part of the fuel being gasified. With air as combustion medium direct gasification produces a low heating value gas with nitrogen dilution. Indirect gasification produces a medium heating value gas by separating the heat consumption (the gasification) and the heat production (the combustion). The only existing nitrogen in the product gas will be a result of the fuel-nitrogen or a small purge used in the gasification.

Twin-bed gasification uses two fluidized bed reactors. The biomass enters the first reactor where it is gasified with steam and the char remaining is transported to the second reactor where it is burnt with air to produce heat. The heat is transported to the gasification reactor by the bed material, normally sand. The flue gas and the product gas have two separated exits. Figure 1 shows the concept of twin-bed gasification. [1]

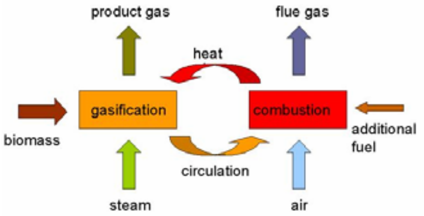

Figure 1. Concept of the twin-bed gasification. [1]

Xu *et al* (2006) have carried out a study of the most efficient combination of fluidized beds for twin-bed gasification. Their tests showed that a bubbling fluidized bed as gasifier and a circulating fluidized bed as combustor would be the best combination.

There are at the moment three existing twin-bed gasifiers; the SilvaGas, the FICFB, Fast Internally Circulating Fluidized Bed and the MILENA, Multipurpose Integrated Lab-unit for Explorative and iNovative Achievements in biomass gasification.

The SilvaGas is constructed by Battelle in the USA with support from FERCO and NREL. It consists of two circulating fluidized beds and is the most commercial available twin-bed gasifier with a gasification of about 40 MW biomass. SilvaGas is developed for IGCC, Integrated Gasification Combined Cycle at the McNeil power plant.

The FICFB is developed by Vienna University of Technology and consists of a bubbling fluidized bed as gasifier and a circulating fluidized bed as combustor. The 8 MW plant works as IGCC and part of the product gas is used for production of Fischer Tropsch diesel and bio-SNG.

The MILENA is a twin-bed gasifier with a circulating fluidized bed as gasifier and bubbling fluidized bed as combustor. It is a lab-scale facility of 24 kW developed by ECN, Energy research Centre of the Netherlands. The gasifier is developed for production of bio-SNG and a pilot plant of 800 kW is planned. ECN is trying to pressurize the process in order to increase the instant methane.

Gas Cleaning and Methanation

Natural gas exists of about 90% methane. Twin-bed gasification occurs at lower temperatures, about 800°C, which causes high methane content in the product gas. Therefore twin-bed gasification is a suitable alternative for production of bio-SNG. Table 1 shows the composition of the product gas for the three twin-bed gasifiers. The H_2O, N_2 and C_2H_2 contents for the SilvaGas are not found in the literature. The 1 vol-% C_2H_4 content for MILENA includes the C_2H_2 and C_2H_6 content as well.

Table 1. Product gas composition of the twin-bed gasifiers.

Product gas [vol-%]	SilvaGas	FICFB	MILENA
H_2	22	38.2	18
CO	44.4	22.9	44
CO_2	12.2	21.9	11
CH_4	15.6	9.2	15
C_2H_2	-	0.1	
C_2H_4	5.1	2.6	1
C_2H_6	0.7	0.2	
N_2	-	5.6	4
H_2O (wet basis)	-	40	25

Both SilvaGas and MILENA produce about 15 vol-% methane while the FICFB produces less, about 10 vol-%. This due to the catalytic bed material for tar removal used by the FICFB. Catalytic tar removal favours the hydrogen content in the gas but decreases the methane content. [3]

The product gas from the gasifier has to be cleaned from particles and tar. These cleaning processes depend on what the gas is going to be used for. The most efficient technique for tar removal in production of bio-SNG with twin-bed gasification is scrubbing as it does not change the methane content and the tar can easily be returned to the combustor reactor of the gasifier. For particle removal either a cyclone or a bag house filter can be used depending on the size of the particles. [4]

SilvaGas uses a cyclone for particle removal and catalytic tar cracking for tar removal.

The FICFB gasification uses a bag house filter for particle removal and catalytic bed material for tar removal. This process also includes an oil based scrubber for removal of the remaining tar.

MILENA gasification is going to use a cyclone for the 800 kW pilot plant. For the tar removal a special scrubber technique called OLGA, OiL based GAs washer developed by ECN is going to be used.

If a catalyst is to be used in synthetization of the gas it is also necessary to clean the gas from ammonia and sulphurous compounds. This is carried out by adsorption of these compounds on zinc oxide beds.

Even though the gasifiers produce methane rich gas it is necessary to introduce a methanation step after gasification and gas cleaning to reach the required Wobbe-index. In methanation H_2 and CO reacts on a Ni-based catalyst in reaction 1. Reaction 1 and 2 are linked by the shift reaction, reaction 3.

Reaction 1:

$$CO + 3H_2 \rightarrow CH_4 + H_2O \qquad \Delta H^{\circ}_{298} = -206 \text{ kJ/mole}$$

Reaction 2:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \qquad \Delta H^{\circ}_{298} = -165 \text{ kJ/mole}$$

Reaction 3:

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad \Delta H^{\circ}_{298} = -41 \text{ kJ/mole}$$

The reactions are very exothermic which makes it important to design the methanation for heat removal. The FICFB and the MILENA gasifier are the only ones who have thought of a methanation process for their bio-SNG production. The FICFB in Güssing, Austria uses a fluidized catalyst reactor and the MILENA gasifier is going to be integrated with a three step reactor system for the methanation like that one used in TREMP, Topsø's Recycle Energy-Efficient Methanation Process.

Finally the carbon dioxide and the water formed and added to the process have to be removed. This can be carried out with the Selexol™ scrubber for the CO_2 removal and by cooling the gas for water removal.

Process Calculations

In order to valuate the processes for bio-SNG production with the three twin-bed gasifiers the energy efficiencies were calculated. The energy content of each step in the process is calculated by material balances based on carbon (1), by equation (2) and by energy balances (3).

$$\sum n_i(C)_{in} = \sum n_i(C)_{out} \tag{1}$$

$$E_y = \sum m_i \cdot \left(H_i + Cp_{m,i} \cdot T_y \right) \tag{2}$$

$$\sum E_{y,in} = \sum E_{y,out} \tag{3}$$

The efficiencies of the processes are determined by the key parameters carbon conversion (4), gas yield (5), biomass to SNG efficiency (6) and overall process energy efficiency (7).

The carbon conversion is calculated by mole carbon in product gas divided by mole carbon in biomass.

$$\eta_{\text{Carbon conversion}} = \frac{\text{n}_{\text{Carbon in product gas}}}{\text{n}_{\text{Incoming biomass carbon}}} \tag{4}$$

The gas yield is measured in Nm^3 product gas per kg biomass.

$$Gasyield = \frac{F_{gas}}{m_{Biomass}} \tag{5}$$

The energy amount of the bio-SNG given by the lower heating value divided by the amount of energy of the gasified biomass also given by the lower heating value is the biomass to SNG efficiency.

$$\eta_{\text{Biomass-to-SNG}} = \frac{m_{\text{SNG}} \cdot \text{LHV}_{\text{SNG}}}{\text{m}_{\text{Biomass}} \cdot \text{LHV}_{\text{Biomass}}} \tag{6}$$

The E_{heat} in (7) is the energy in form of heat that can be provided to the district. For the energy content of the bio-SNG and the biomass the lower heating value is used as in equation (6).

$$\eta_{process} = \frac{E_{heat} + E_{SNG}}{E_{Biomass}} \tag{7}$$

Results

For the SilvaGas gasification heat loss was found at the demonstration operations and a maximum carbon conversion of 60% was reached. Figure 2 shows an energy diagram of the gasification with the SilvaGas with heat loss and without methanation.

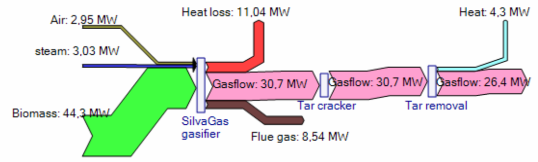

Figure 2. Energy diagram of the existing SilvaGas gasification with heat loss and 60% carbon conversion.

Assuming that the heat loss problem was solved and that the SilvaGas was operated with the COSYMA methanation developed in Güssing for the FICFB, the energy diagram would be as in figure 3 with a carbon conversion of 70%.

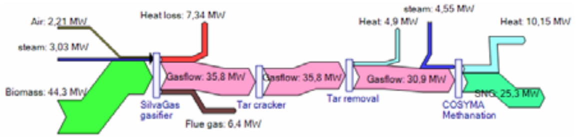

Figure 3. Energy diagram of the SilvaGas process with COSYMA methanation and 70% carbon conversion.

For bio-SNG production with FICFB gasification and COSYMA methanation, the carbon conversion is 70% and the energy content of the streams are shown in figure 4.

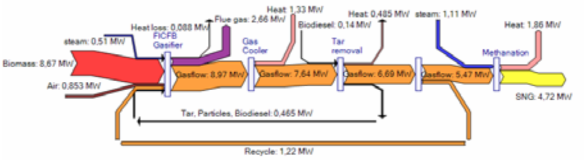

Figure 4. Energy diagram of the bio-SNG process with FICFB gasification and COSYMA methanation.

Figure 5 shows the MILENA gasification process with bio-SNG production. A carbon conversion of 80% is reached.

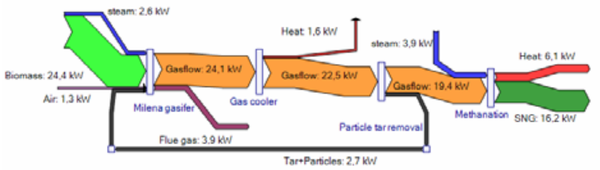

Figure 5. Energy diagram of the bio-SNG process with MILENA gasification and three stage methanation.

Table 2 shows the key parameters for the bio-SNG process with SilvaGas, FICFB and MILENA gasification. The column to the left with SilvaGas shows the efficiency for the process without production of bio-SNG and with heat loss.

Table 2. Key parameters for the bio-SNG process with the three twin-bed gasifiers.

	SilvaGas	SilvaGas	FICFB	MILENA
Carbon conversion [%]	60	70	70	80
Biomass to SNG efficiency [%]	-	57	54	66.3
Overall process efficiency [%]	75	83	97	82
Gas yield [Nm^3/kg]	0.66	0.77	1.02	0.82

As table 2 indicates, the overall process efficiency of the FICFB gasifier is much higher than that of MILENA gasification and SilvaGas gasification. This result is obtained because of the higher gas yield with the FICFB gasifier. It is also shown that for gasification with higher instant methane content, as in the MILENA gasification compared with FICFB gasification, a higher biomass

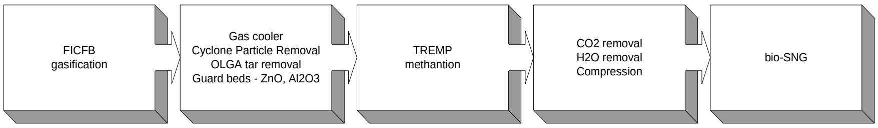

Figure 6. Suggested pressurized bio-SNG plant.

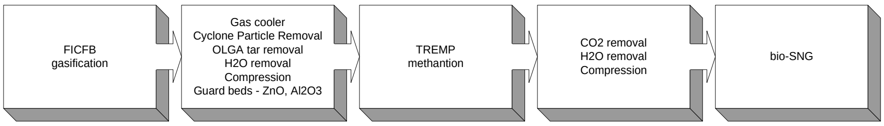

Figure 7. Suggested bio-SNG plant operated at atmospheric pressure.

to SNG efficiency is reached.

Seemann *et al* (2005) calculated a biomass to SNG efficiency of 60% for bio-SNG production with the FICFB gasifier on larger scale in their study. According to Deurwaarder *et al* (2005) a biomass to SNG efficiency of maximum 70% can be reached with the MILENA gasifier.

Discussion and Conclusions

For the most efficient bio-SNG production a gasification technology producing a gas with high methane content is preferred. Twin-bed gasification produces a nitrogen free gas with high methane content because of the low temperature and is therefore a suitable technology. To increase the methane content the twin-bed gasifier could be pressurized but this has still not been tested with twin-bed gasification. The great challenge with bio-SNG production from twin-bed gasification of biomass is that these gasifiers are still not available on larger scale.

High instant methane content increases the biomass to SNG efficiency, which makes it important to otimize the entire process for high methane content. This can be fulfilled by increasing the pressure, gasify at lower temperatures (although tar production is also favoured by lower temperature) and by scrubbing the gas instead of thermal or catalytic cracking for tar removal. Figure 6 shows a suggestion of an efficient bio-SNG plant with pressurized FICFB gasification, OLGA tar removal and the methanation process called TREMP™.

If the twin-bed gasification process would not be able to pressurize the bio-SNG plant would have an additional water removal step before compression and methanation of the product gas shown in figure 7.

Further Investigation

In this thesis the total energy efficiency with integrated drying of the biomass has not been concluded. This should be seen as subject of further investigation.

Further Research & Development of a possible bio-SNG plant with twin-bed gasification should concentrate on evaluation of a pressurized process compared to the atmospheric gasification process with pressurized methanation. A follow up of the MILENA pressurized gasification for evaluation of pressurized twin-bed gasification should be conducted.

Further research of the planned methanation system for MILENA gasification and follow up of the 1 MW COSYMA methanation by Paul Scherrer Institute, Switzerland is suggested.

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