STEAM GASIFICATION OF BIOMASS AT CHP PLANT GUESSING – STATUS OF THE DEMONSTRATION PLANT

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ABSTRACT: Biomass gasification offers the possibility to produce heat and power at a high efficiency. In Guessing (AT) a biomass CHP is demonstrated, where a gasifier is coupled to a gas engine to produce electric power and heat. As gasification technology a steam blown fluidised bed gasifier is used, which produces a nitrogen free gas with a high calorific value (12 MJ/Nm^3) and only a low amount of tar. A cooling and two stage gas cleaning system makes sure that the gas engine gets a cool and clean gas. In this paper the main results of a two years demonstration program are described. Until the end of March 2004 about 9700 hours of operation with the gasifier and 7100 hours with the gas engine could be reached, which demonstrates the smooth functionality of the CHP plant. The favourable characteristics of the product gas (low nitrogen content, high hydrogen content) allow also other usages of this gas. Research projects concerning the production of SNG (synthetic natural gas), Fischer-Tropsch Diesel and electricity in a SOFC (solid oxid fuel cell) have been started.
Keywords: gasification, demonstration, operating experience

1 INTRODUCTION

In the year 1991 the district of Guessing (AT) developed a new energy concept, where all energy demand should be covered by renewable energy. Therefore a biodiesel plant and a district heating system, based on biomass, were installed. In this way 95% of the heat demand and more than 100% of the fuels, which are needed in the region are produced from renewables. As a result of these efforts in the area of renewables, an “European Center for Renewable Energy” was established in Guessing.

The latest plant of this successful row was a 8 MW_{fuel} CHP plant, based on a steam blown gasifier, producing heat and power (4.5 MW_{th}, 2 MW_{el}) with a gas engine, with the capacity to cover the total electricity demand in Guessing. At the end of 2001 this demonstration plant for combined heat and power production (CHP) from biomass started operation. So Guessing has changed the energy supply during the last decade totally to renewable sources.

2 DESCRITPION OF CHP GUESSING

In Guessing an innovative process for combined heat and power production based on steam gasification is demonstrated [1]. Biomass is gasified in a dual fluidised bed reactor. The producer gas is cooled, cleaned and used in a gas engine. A detailed flow sheet is shown in Figure 1, characteristic data of the demonstration plant are summarized in Table I.

As biomass wood chips from forestry are used. The wood trunks are dried naturally by storage of about 1-2 years in the forest. Then they are delivered to the CHP-plant and chipped there. When the biomass is used, it has a water content of about 25-40%.

The heat produced in the process is partly used inside, e.g. for air preheating, steam production, etc., and the rest is delivered to the district heating system. The net electricity produced is delivered to the grid. The feed in rate in Austria is regulated by law and depends on the type of biomass used and on the size of the plant.

Table I: characteristic data of Biomass-CHP

Start up of gasifier	November 2001	
Start up of gas engine	April 2002	
Fuel:	wood chips	
Fuel Power	8000	kW
Electrical output	2000	kW
Thermal output	4500	kW
Electrical efficiency	25.0	%
Thermal efficiency	56.3	%
Total efficiency	81.3	%

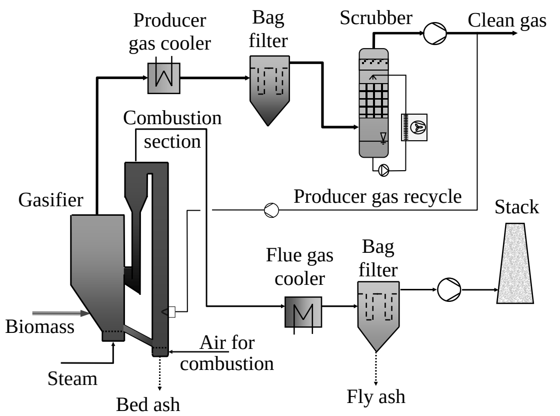

Figure 1: schema of the Biomass-CHP

Biomass chips are transported from a daily hopper to a metering bin and fed into the fluidised bed reactor via screw feeders. The fluidised bed gasifier consists of two zones, a gasification zone and a combustion zone. The gasification zone is fluidised with steam which is generated by waste heat of the process, to produce a nitrogen free producer gas. The combustion zone is fluidised with air and delivers the heat for the gasification process via the circulating bed material.

The producer gas is cooled and cleaned by a two stage cleaning system. A water cooled heat exchanger reduces the temperature from 850°C – 900°C to about 150°C – 180°C. The first stage of the cleaning system is a fabric filter to separate the particles and some of the tar from the producer gas. These particles are recycled to the combustion zone of the gasifier. In a second stage the gas is liberated from tar by a scrubber.

Spent scrubber liquid saturated with tar and condensate is vaporized and fed for thermal disposal into the combustion zone of the gasifier. The scrubber is used to reduce the temperature of the clean producer gas to about 40 °C. The clean gas is finally fed into a gas engine to produce electricity and heat. If the gas engine is not in operation the whole amount of producer gas can be burned in a backup boiler to produce heat. The flue gas of the gas engine is catalytically oxidised to reduce the CO emissions. The sensible heat of the engine's flue gas is used to produce district heat. The flue gas from the combustion zone is used for preheating air, superheating steam as well as to deliver heat to the district heating grid. A gas filter separates the particles before the flue gas of the combustion zone is released via a stack to the environment.

3 RESULTS OF CHP GUESSING

The start-up of the biomass-CHP was done in two steps. First the gasifier and the gas treatment was started in November 2001 and after extensive measurements on the gas quality, the gas engine was started in April 2002.

The hours of operation are shown in Table II. The total hours of operation are from November 2001 till end of March 2004.

Table II: hours of operation

	2001	2002	2003	total
Gasifier	120	3182	4695	9792
Gas engine	0	1251	4152	7111

3.1 Energy and Mass Balance

The energy and mass balances were solved with the software tool IPSE$_{pro}$®. IPSE$_{pro}$® is an equation-oriented stationary simulation software developed for power plant simulation. This software can also import measured data (temperatures, concentrations, mass flows, etc.) and after defining a confidence interval for each measurement, the energy and mass balance is solved. Based on the balanced data, for different conditions (gasification temperatures, steam fuel ratios, etc.) a parameter variation model was established. With this model the optimal operation parameters were defined.

The main results of the energy and mass balances are shown in Table III and Figure 2.

In Table III the results of the measured mass and energy balances for two different gasification temperatures are shown. It can be clearly seen, that with a higher gasification temperature the electric efficiency is lower and the bed material circulation rate had to be more than doubled.

Table III: comparison of different parameters

Parameter:	11th Dec. 03	21st Feb. 04
Gasification temp. [°C]	900	800
Water content Biomass [%]	27.5	25.2
Steam fuel ratio [kg/kg$_{fuel}$]	0.73	0.61
Cold gas efficiency [%]	60.8	64.2
Electric efficiency [%]	18.4	20.9

In Figure 2 the influence of different process conditions on the efficiency of the gasification plant are shown. The bars belong to the left y-axes and show the electric efficiencies, if the optimisation is done by one measure after another. The dots belong to the right scale and show the increase of efficiency from each single measure.

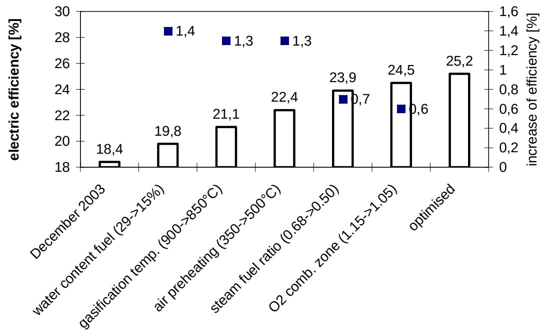

Figure 2: influence of process conditions

It can be clearly seen, that the water content of the biomass has the strongest influence on the electric efficiency. Also the preheating of the air for the combustion zone and the gasification temperature has a strong influence on the efficiency. Other operating parameters like steam-fuel ratio or the ratio of air to fuel in the combustion zone has a minor influence on the efficiency, than the parameters mentioned before.

Process simulation represents a powerful tool to find out about the energetic behaviour of the whole system. Weak points were localized and an optimization of the operating parameters is performed permanent during the demonstration program. Modelling generally helps understanding the complex behaviour of chemical installations.

3.2 Sulphur, Chlorine and Fuel-Nitrogen balance

During summer 2003 the sulphur, chlorine and fuel-nitrogen balance were measured to find out the behaviour of these components during steam gasification in a dual fluidised bed. At about 25 points of the plant, samples were taken and analysed. Sampling and analysis of these samples was done according to Austrian, or European norms. If no norm was applicable a measurement method was developed.

Sulphur is introduced into the plant mainly by the biomass, other inputs as precoatmaterial, RME are very small compared to the input with the biomass. The Sulphur is converted inside the gasification zone mainly to H_2S and also to a small amount to mercaptans. These products are transported as gas through the product gas filter and also through the scrubber. The concentration of H_2S is in the clean gas about 100ppm. In the gas engine these sulphur components are oxidised and leave the plant through the chimney.

Chlorine acts completely different to sulphur. Here the input is, similar to all other components, also from the biomass. As the concentration of Chlorine in biomass from forestry is very low (normally <0.01m%), also the input from the precoat material has to be taken into account. The chlorine concentration in the product gas is very low (< 5ppm) and almost all chlorine is found in the ash (about 95%).

The nitrogen, which comes with the biomass into the gasification zone, is converted to about 60% to ammonia. The ammonia passes the product gas filter without separation and is partly removed by the product gas scrubber. This separation is caused by condensation of water, which occurs inside the scrubber and depends mainly on the operating temperature of the scrubber and on the water content of the product gas at the entrance of the scrubber. The remaining ammonia is converted in the gas engine to NO_x and leaves together with some thermal NO_x, which are also produced in the gas engine, the chimney. The emissions of NO_x are below the emission limit of 500mg/Nm³.

3.3 Comparison of Bed Materials

One essential parameter for the gasification system is the type of bed material, which is used. For fluidised bed gasifiers different bed materials are described in literature. Silica sand is often used as bed material, but it has no catalytic activity. Dolomite, calcite and magnesite are the most investigated bed materials in relation to their catalytic activity in tar destruction [2]. Also chemical compounds of iron, nickel and other metallic elements were studied to obtain their potential on tar reduction [3]. In the FICFB-gasification system the bed material was selected by applying the following criteria:

(1) attrition resistance
(2) catalytic activity in hydrocarbon and tar reforming

In previous work different bed materials were investigated and olivine (iron and magnesium orthosilicate) was selected as bed material for the demonstration plant because of its attrition resistance and its catalytic activity.

In spring 2003 the olivine, which was used successful in the demonstration period, was no longer available. So the following alternatives were investigated on their behaviour in the dual fluidised steam gasifier:

(1) silica sand / dolomite
(2) olivine from another source
(3) magnesite (as additive)
(4) limestone (as additive)
(5) magnetite (as additive)
(6) iron ore (as additive)
(7) ash (as additive)

To investigate to activity of other materials in tar reforming, these materials were tested in a small scale fixed bed reactor. Here toluene was used as reference substance for the tars and the activity of the conversion of toluene was measured in a hydrogen, steam, helium atmosphere. The main results are shown in Figure 3.

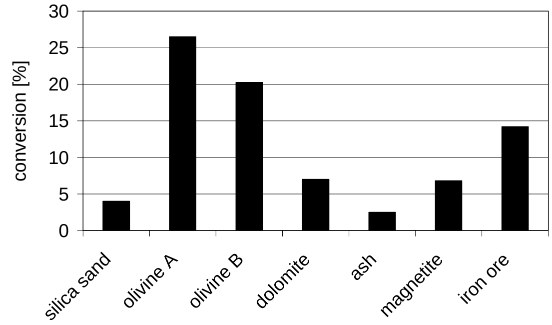

Figure 3: conversion of toluene

As it can be seen olivine A (original bed material) is the most active in tar reforming. Olivine B is, after activation, the second. The activation of olivine is done by heating it for more than 100 hours above 900°C.

The best illustration for the activity of the bed material is the temperature of the product gas after the heat exchanger. With olivine A the heat transfer is constant from the start up of the plant. This shows that from the beginning of operation the tar content is low enough and no tars deposit inside the heat exchanger. Using olivine B as bed material the tar content at the beginning is higher and there are some tars deposits inside the heat exchanger. With silica sand / dolomite the plant could not be operated, because of the high tar content in the product gas.

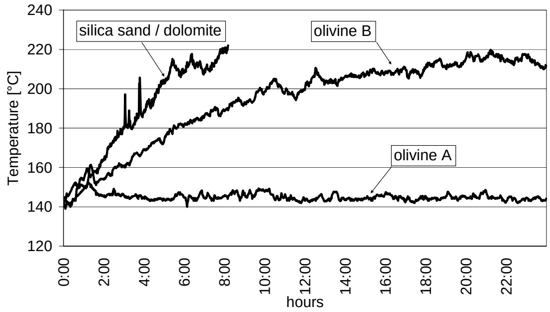

Figure 4: temperature after heat exchanger

Olivine has proven its suitability in biomass gasification in a dual fluidised bed reactor. It combines on the one hand the attrition resistance as bed material for fluidised beds and on the other hand the catalytic activity for tar reforming.

4 FURTHER PROJECTS

The favourable characteristics of the product gas (low nitrogen content, high hydrogen content, H_2:CO ratio of 1.6 – 1.8) allow also other usages of this gas. Research projects concerning the production of SNG (synthetic natural gas), Fischer-Tropsch Diesel and electricity in a SOFC (solid oxid fuel cell) have been started.

4.1 Fischer Tropsch Synthesis

Within the EC-project RENEW (Renewable Fuels for Advanced Power Trains) in the 6th Framework programme a bypass flow of about 10Nm³/h will be converted via Fischer-Tropsch synthesis into diesel. The design of the Fischer-Tropsch reactor is at the moment going on. The gas will be taken after the existing gas treatment, compressed to 20-25bar, cleaned from sulphur and chlorine components and converted in a slurry reactor to waxes. From these waxes the diesel will be produced via hydrotreating. The FT-reactor should be finished till end of 2004 and in spring 2005 first results are expected.

4.2 Methanation

This work is done partly under the EC-project RENEW and partly financed by national funds from Switzerland and Austria. The main work is done by the Paul-Scherrer Institute from Switzerland and presented in an own paper.

A test rig for methanation was designed to perform experiments in a 2 kW scale. The tendency of catalysts towards coking was tested at PSI with model compounds of light biomass gasification tars. The most promising catalyst then was used in a -term experiment with a slip stream of the FICFB gasifier in Guessing. After more than 120 h on stream the catalyst still showed an outstanding performance. Under the heaviest conditions more than 98% CO-conversion and 99% tar-conversion to methane was achieved. The chemical efficiency of the process is depending strongly on the load of tars in the syngas; 83% for “tar-free” syngas and 85% for “tar-loaded” syngas.

Based on these results from the experiments in Guessing in May 2003 the next step is to run long term experiments of more than 1000 h under pressurized operation conditions.

4.4 SOFC

This work is performed together with the Austrian Bioenergy Center and with the Department of Energy and Process Engineering, NTNU in Trondheim.

Coupling of a solid oxide fuel cell (SOFC) with a biomass gasifier gives electric efficiencies up to 43% and overall efficiencies of more than 80%. These high efficiencies can only be reached, if the gas cleaning is done at high temperatures. Therefore the work programme focuses on the removal of dust, chlorine and sulphur components in a temperature area of 500-800°C. At the moment fundamental research is going on.

5 CONCLUSION

With the help of this system the scale up of the pilot plant (100 $kW_{fuel\ input}$) at TU Vienna, to a large-scale, commercial installation is achieved and at the same time the R&D by the partners has been completed to an extend, that allows the industrial partner [Repotec] to bring an economical and commercially viable biomass driven CHP process to the market.

Due to the favourable characteristics of the product gas research projects beyond electricity production were started. First results were achieved with the methanation of product gas to produce synthetic natural gas (SNG). From the other projects the first results can be expected at the beginning of 2005.

5.1 Acknowledgement

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5.2 References

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