SIX YEARS EXPERIENCE WITH THE FICFB-GASIFICATION PROCESS

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ABSTRACT: The FICFB (Fast Internally Circulating Fluidised Bed) gasification process is an innovative process to produce a high grade synthesis gas from solid fuels. The basic idea of the FICFB concept is to divide the fluidised bed into two zones, a gasification zone and a combustion zone. Between these two zones a circulation loop of bed material is created but the gases remain separated. The circulating bed material acts as heat carrier from the combustion to the gasification zone. The use of steam as a gasification agent gives the FICFB-process, developed by TU Vienna in co-operation with AE Energietechnik, a nearly nitrogen free product gas with a high calorific value of 12 MJ/Nm^3 dry gas.
Keywords: demonstration, hydrogen, gasification,

1 INTRODUCTION

The use of biomass as a source of energy in Austria amounts to approx. 11 % of the entire primary energy demand. For the last 10 years this proportion has remained unchanged, although high priority is being given to renewable forms of energy. Some areas, like the wood stoves, are declining whereas other areas, e.g. woodchip burning and district heat supply systems, are increasing. A substantial increase in the use of biomass, as required politically by climatic conventions (Kyoto, Buenos Aires) and in the European Union White Paper, is only possible though if new applications for the use of biomass are developed. One of these areas is the generation of electric power from biomass. It was investigated in preliminary studies, that gasification has the greatest potential in this area. Gasification offers great flexibility and enables high electrical efficiency as well as high overall efficiency.

The gasification system was developed together by the Institute of Chemical Engineering and AE Energietechnik and is well known under the name FICFB-gasification system [1, 2, 3, 4].

The fundamental idea of this gasification system is to physically separate the gasification reaction and the combustion reaction in order to gain a largely nitrogen-free product gas. The endothermic gasification of the fuel takes place in a stationary fluidized bed. This is connected via a chute with the combustion section, which is operated as a circulating fluidized bed. Here, transported along with the bed material, any non gasified fuel particles are fully combusted. The heated bed material is separated in e.g. a cyclone and brought back into the gasification section. The heat required for the gasification reaction is produced by burning carbon brought along with the bed material into the combustion section. Additionally, the temperature in the combustion section can be regulated by controlling the flow of recirculated product gas or wood into the combustion chamber. The gasification section is fluidized with steam, the combustion section with air and the gas flows are separately streamed off. Thus a nearly nitrogen-free product gas with heat values of about 13000 kJ/Nm^3 (dry) is produced.

The fuel entering into the reactor is heated up, dried and devolatilies. The biomass is converted to CO; CO2; CH4; H2; H2O$_g$ as well as C as char.. At the same time the strongly endothermic gasification reactions (reactions with water vapour) take place.

$$CO + H2O \rightarrow CO2 + H2$$
$$C + H2O \rightarrow CO + H2$$

The remaining non-gasified carbon (non volatile part) crosses into the combustion section, where it is burned. The energy liberated (released) there is employed in maintaining the reaction in the gasification section.

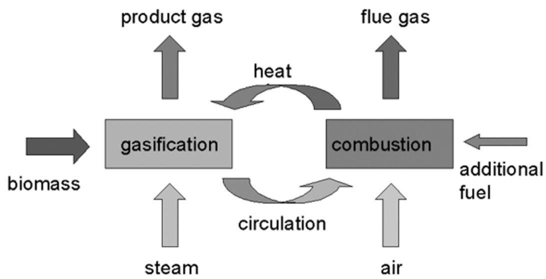

Figure 1: Princip of FICFB-gasification process

The FICFB-gasification system has, in contrast to conventional gasifiers operated with steam and air, the advantage that it produces a nitrogen-free gas, which after appropriate cleaning and treatment is usable as a synthesis gas in the chemical industry or as a source of energy.

In this paper results of the EC-project "Clean Energy from Biomass" No. ENK5-CT2000-00314 and preliminary results of the 8MW$_{th}$ demonstration plant are described.

2 THE 100KW$_{TH}$ PILOT PLANT

2.1 Description

The first experiments in the pilot plant were carried out with quartz sand as bed material and wood chips as fuel to find the optimal operation conditions. Then different bed materials were investigated. In 1997 and 1998 different fuels (rape seed grist, brown coal, wet wood chips, clover pellets, sewage sludge pellets, animal residues and barley) were tested. In 1600 hours of operation first the influence of temperature and steam fuel ratio on gas composition, tar content and cold gas efficiency with natural catalyst as bed material were studied. The gasifier was also used to explore different gas treatment systems. Especially particle separation and tar as well as ammonia removal were investigated.

The main results of the pilot plant with wood pellets as fuel and natural catalyst as bed material are shown below [5].

hydrogen	30-40 vol%
carbon monoxide	20-30 vol%
carbon dioxide	15-25 vol%
methane	8-12 vol%
nitrogen	1-5 vol%

	raw gas	clean gas
tar	0,5-1,5 g/Nm³	<20 mg/Nm³
particles	10-20 g/Nm³	<10 mg/Nm³
ammonia	500-1000 ppm	<200 ppm
hydrogen sulfide	20-50 ppm	

The effect of using an artificial Ni-catalyst as bed material is described here in this paper.

2.2 Results with an artificial Ni-catalyst

This Ni-catalyst was developed within the EC-project “Hydrogen-rich Gas from Biomass Steam Gasification” JOR3-CT97-0196 by University of Strasbourg, Ecole de Chimie, Polymeres et Materiaux [6, 7]. The aim of this catalyst was to increase the hydrogen content of the product gas and to reduce the tar content. This catalyst will be used at the 500 kW_{th} pilot plant.

Within the EC-project “Clean Energy from Biomass” ENK5-CT2000-00314 this catalyst was investigated at the 100kW_{th} pilot plant. Different mixtures of catalyst with bed material were tested and the influence of the gasification temperature and the steam fuel ratio was investigated.

In Figure 2 the influence of the amount of catalyst on the hydrogen concentration is shown. These measurements were done at a steam fuel ratio of 0.5 kg steam per kg dry fuel at a gasification temperature of 850°C.

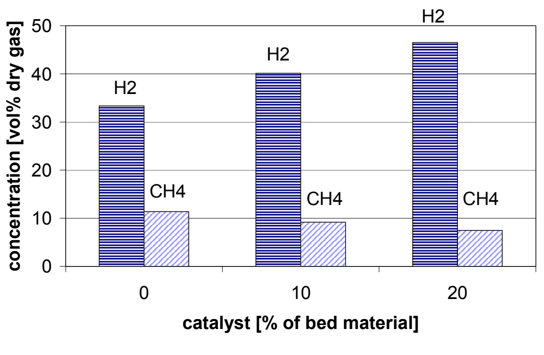

Figure 2: hydrogen and methane concentration with catalytic bed material

It is clearly shown, that this catalyst increases the amount of hydrogen in the product gas and the amount of methane decreases. This effect is well known from literature (e.g. [8]) for fixed bed catalysts after the gasifier. The new approach in this project is to develop a catalyst, which can be used inside the fluidised bed. During the experiments at the 100 kW_{th} pilot plant the catalyst showed no deactivation in a testing period of about 50 hours.

In Figure 3 the dependency of the concentration of hydrogen and methane in the dry gas on the steam fuel ratio is shown. These experiments were done with 20% catalyst in the bed material and at a gasification temperature of 850°C.

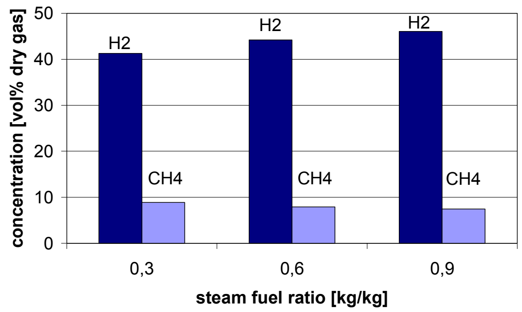

Figure 3: hydrogen concentration with 20% catalyst

With these experiments it was shown, that the influence of temperature and steam fuel ratio is the same as without catalyst [5]. With increasing temperature hydrogen increases and methane decreases and with increasing steam fuel ratio also hydrogen increases and methane decreases. In further work the influence of the catalyst on the activation energy of the gasification reaction will be investigated on basis of these experiments.

In Figure 4 the influence of the catalyst on the tar content in the dry product gas is shown. The experiments were done at a steam fuel ratio of 0.5 kg steam per kg dry fuel and a gasification temperature of 850°C.

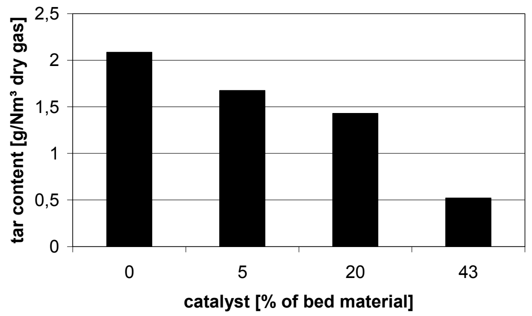

Figure 4: tar content in dependency of catalyst

As expected the tar content in the dry product gas is decreasing with a higher percentage of catalyst in the bed material. A reduction of more than 75% could be reached when 43% of the bed material consists of catalyst. This concentration is low enough, that the gas can be used in the fuel cell without any additional tar removal.

In Figure 5 the dependency of the tar content on the gasification temperature is shown.

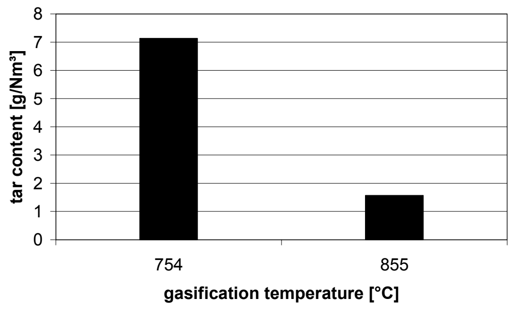

Figure 5: tar content in dependency of gasification temperature

Here 20% of catalyst in the bed material and a steam fuel ratio of 0.5 kg/kg at a gasification temperature of 850°C were used. Also here the catalyst showed the same tendencies as the bed material without catalyst. Only the reduction of the tar content with the gasification temperature is much higher as without catalyst.

3 THE 500KW$_{TH}$ GASIFICATION PLANT

3.1 Description

The aim of the EC-project JOR3-CT97-0196 was the development of a fluidised bed gasification process for the production of a hydrogen rich gas from biomass. To achieve this aim a 500kW$_{th}$ plant was built and tested, a catalyst for fluidised beds was developed and fundamental research on the fluid dynamics were done.
In general the results of this project are:

- The first experiments showed that the necessary circulation rate can be reached easily and the nitrogen content in the product gas is below 5%.
- During the work on the cold flow model a new scaling parameter was introduced
- A new catalyst for fluidised beds was developed and tested. This catalyst showed high activity in reducing tars and increasing hydrogen content.

The aim of the following EC-project "Clean Energy from Biomass" No. ENK5-CT2000-00314 is biomass-gasification and fuel-cell coupling via high-temperature gas clean-up for decentralised electricity generation with improved efficiency.

To prove the technical feasibility of this integration, the 500 kW gasifier plant was assembled and will be operated, which includes catalytic biomass steam-gasification, hot gas clean-up and a 125 kW$_{el}$ molten carbonate fuel cell.
The partners in this project are:

- University of L'Aquila – Italy - Chemical Engineering Department
- Technical University of Vienna - Austria - Institute of Chemical Engineering, Fuel and Environmental Technology
- University College London - United Kingdom - Chemical Engineering Department
- University of Strasbourg - France - Ecole de Chimie, Polymeres et Materiaux
- Ansaldo Ricerche SpA - Genova – Italy
- Schumacher Umwelt- und Trenntechnik GmbH – Crailsheim – Germany
- Italian National Agency for New Technology, Energy and the Environment - Italy

The Institute of Chemical Engineering at University of Technology Vienna developed a model of the gasifier to simulate the biomass gasification process and a model of the MCFC; the models were integrated into the flow sheeting simulation tool IPSE$_{Pro}$ in order to simulate the pilot plant.

3.2 Results of simulation

In order to simulate the biomass gasification process, a model of the gasifier, suitable to be used within the flow sheet simulation tool IPSE$_{pro}$, had to be developed. Therefore, a model based on equilibrium calculation in the gas phase, but also considering the composition of the volatiles emitted directly by the biomass particles, was designed [9]. This model can be adapted to the gas composition measured at the pilot plant at TU Vienna. A detailed model of the reaction kinetics, which cannot be integrated into the flow sheeting tool owing to its high complexity, has also been developed. The results of these simulations will serve to improve the flow sheeting model. Furthermore, a model of the MCFC was established which consists the energy and mass balance of anode and cathode side, as well as basic equations of the electrochemical process in the fuel cell. For the polarisation losses in the fuel cell, the model of Arato [10] was used, which was obtained from a fuel cell of Ansaldo.

The models mentioned above are implemented into the flow sheeting tool to simulate the pilot plant which is used in this project. About 190 m³/h (NTP) of product gas are produced by the 500 kW gasifier and 320 m³/h (NTP) of flue gas are formed at combustion side. The product gas passes the cooling and cleaning facilities. Finally the product gas is cooled in a quench to about 375°C to reach the temperature required by the fuel cell (650°C) after compression to 3,5 bar. Because of the water added and evaporated in the quench, a gas stream of 211 m³/h (NTP) enters the fuel cell on anode side. The product gas is converted in the MCFC with an assumed fuel utilization of 50%. So an electrical output of the fuel cell of 142 kW will be reached.

In further work the simulation will be used to optimise the pilot plant.

4 THE 8MW$_{TH}$ DEMONSTRATION PLANT

4.1 Description

In the frame of industrial centers and networks of competence „K$_{IND}$/K$_{NET}$" of the Austrian Ministry of Economic and Labour "RENET Austria" was founded by the partners AE Energietechnik, EVN, Guessinger Fernwaerme and Institute of Chemical Engineering, Vienna University of Technology. Within this network an 8 MW$_{th}$ demonstration plant was build and the start up was in September 2001. Out of a fuel input of 8 MW 4,5 MW$_{th}$ for the district heating system and an electric output of 2 MW$_{el}$ – first in a demonstration period of two years, later in commercial operation– will be produced.

At the end of April 2002, 1500 hours of operation of the gasifier including the gas treatment system were counted. After extensive measurements of the gas quality the gas engine was started in April 2002.

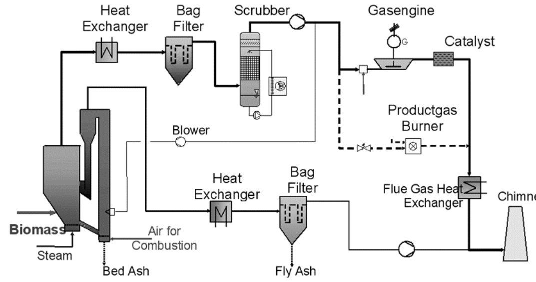

Figure 6: schema of demonstration plant

4.2 Results

The gasifier was till end of April 2002 more than 1500 hours in operation and the results are quite convincing. The gasifier and the biomass feeding system are operating like designed. Also the gas treatment system operates quite well. Problems with deposits, which occurred at the product gas heat exchanger are now solved. First results with the gas engine show that the designed electrical power can be reached.

The temperature difference between gasification and combustion zone is very low, which is a sign for a high circulation rate of bed material. In the Figure 7 the temperature difference is shown.

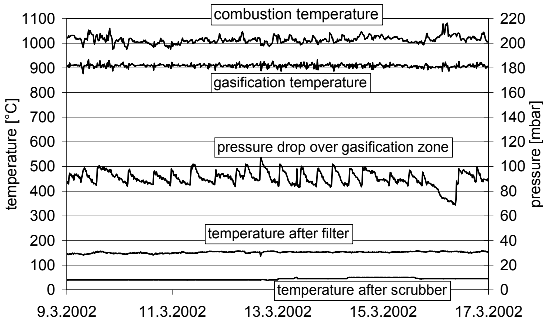

Figure 7: temperatures and pressures at the demonstration plant

During the 1500 hours of operation extensive measurements of temperatures, pressures, gas composition, etc. were done. From these data the efficiency of the gasifier and the separation efficiencies of the product gas treatment system were calculated. In Figure 8 the chemical efficiency of the demonstration plant is shown in dependency on the steam fuel ratio as one example.

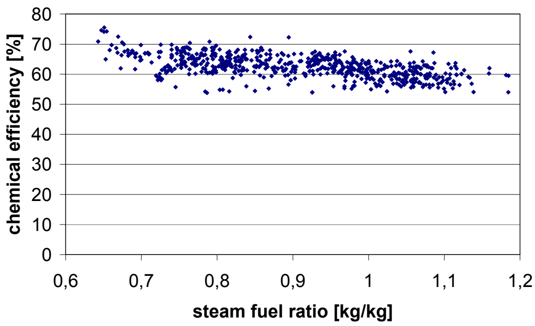

Figure 8: chemical efficiency of the demonstration plant

The product gas treatment system operates as designed. The separation efficiency of the product gas bag filter is for particles over 99% and for tar between 20 and 30%. The separation efficiency of the scrubber for tar is about 98-99% and for ammonia between 30 and 70% (depends mainly on amount of water condensed in the scrubber). With this gas quality it was possible to integrate the gas engine which was operated for 50 hours until now.

The further steps will be:

- Further optimisation of gas cleaning system
- Optimisation of operation costs
- Extension of Availability

5 CONCLUSION

The FICFB-gasification system has been developed in the recent years to a status, so that a demonstration plant was built. With this plant on the one hand the necessary scale up from the pilot plant (100 kW_{th}) at Vienna University of Technology to a commercial biomass CHP-plant is realised on the other hand RENET Austria does the necessary R&D, that the industrial partner AE Energietechnik can introduce a marketable and economic biomass CHP on the market. Aim of this development is a CHP-plant with a high electric efficiency and a large range of capacity.

5.1 Acknowledgement

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