

## GASIFICATION OF BIOMASS IN A CIRCULATING FLUIDIZED BED FOR THE GENERATION OF POWER AND HEAT

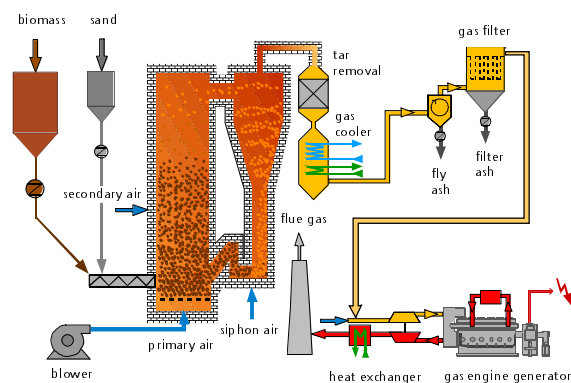
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**ABSTRACT:** Energy from biomass is one of the most important strategies for a clean future based on substitution of fossil energy by renewable energies and lowering global CO<sub>2</sub>-emissions. Since biomass predominantly is suitable for decentralized energy production efficient conversion technologies below 10 MW<sub>el</sub> are needed. Due to the high efficiency one of the most promising technologies in this context is the gasification of biomass combined with IC engine application. Therefore a pilot plant for air-blown biomass gasification in an atmospheric circulating fluidized bed is in use for process development at the Fraunhofer-Institute for Environmental, Safety and Energy Technology UMSICHT. The plant with a capacity of 0.5 MW fuel input is connected to a block heat and power plant (BHPP) with IC engine. Primary aim of the development project, sponsored by the German Federal Minister for Nutrition, Agriculture and Forests (FKZ 94 NR 140-F and 98 NR 075), is to demonstrate the feasibility of the process in order to establish an economically successful biomass conversion-technology to the market. One of the major research tasks is to solve the tar problem. Using the described technology the tar content of the gas can be kept below the critical limit for engine operation. The article gives a technical description of the plant and its main features and it presents results of 150 h continuous operation of the whole plant including the IC engine. (See also poster V8.73)

### 1 NOTION AND TECHNICAL CONCEPT

Utilization of biomass for energy recovery has an enormous potential worldwide and it is an effective way for lowering global CO<sub>2</sub>-emissions. Since biomass predominantly is suitable for decentralized energy production, efficient technologies for plant below 5 MW<sub>el</sub> are needed.

An innovative plant concept for electricity and heat production from biomass is given by figure 1. It is based on the transformation of solid biofuel into a flammable gas in an atmospheric circulating fluidized bed (CFB). After gas reforming, cooling, and dust removal, the gas is fed into a Block Heat and Power Plant (BHPP) with internal combustion engine (IC engine). This technology enables very efficient electricity production from a biomass capacity of 7,000 - 50,000 t/a (1-10 MW<sub>el</sub>). Simultaneous use of the process heat is possible at various plant locations for different temperature ranges [1]. CFB-gasification processes have already been employed in several types of commercial plants [2] into a low tar containing gas, whose exhaust fumes need not be scrubbed prior to atmospheric emission. However gas engine application requires gas temperatures at which residual tar components would condense. Therefore an additional tar reduction system is necessary [3]. Due to profitability of the whole plant any kind of wet gas scrubbing system for tars should be avoided. Experimental investigations at the pilot plant present a suitable solution for the tar problem which is based on a catalytic gas cleaning device operating at high temperatures between the gasifier and the gas cooler.



**Figure 1:** CFB-gasifier with Block Heat & Power Plant.

Since the technology requires a certain capital investment and since the CFB-reactor must reach a minimal height for acceptable gasification, the application of this process to a plant with a fuel capacity below 5 MW is not practical. The feedstock should have a particle size between a few millimeters to 3-5 cm and a maximum content of 25% moisture.

BHPP with IC engine for non-standard gases are state-of-the-art and reach a high electrical efficiency. The generators are commercially available as standard, free-standing modules with electrical capacities from 30 kW<sub>el</sub> to a few MW<sub>el</sub>. The expected electrical efficiency of the complete plant is 26-30 %, which is considerably more efficient than biomass combustion followed by a steam cycle process [4].

## 2 THE PILOT PLANT AT FRAUNHOFER UMSICHT

The pilot plant, based on the scheme given by figure 1, was set up in 1996 at Fraunhofer UMSICHT. The project's goal is to optimize the operation of the process and to interpret data, which will be used for the construction of a commercial demonstration plant. The efforts, especially in the field of tar minimization will help to develop this technology into a commercially applicable process.

The illustration in figure 2 shows the whole installation of the plant. From left to right there are gasifier building, combustion chamber, biomass dryer, and the BHPP-container unit. Inside the gasifier building biomass hopper of 10 m<sup>3</sup>, feeding system, the CFB-gasifier, the reformer, the heat exchanger and the fabric filter are placed.



Figure 2: 0.5 MW-Pilot plant at Fraunhofer UMSICHT.

The pilot plant is designed for a fuel consumption of 80-100 kg/h dry weight, which corresponds to a heat capacity of 400-500 kW. The produced gas can be burned in a combustion chamber with a natural gas incinerator or be fed to a BHPP. The process is operated by a PC-based process control system. In order to obtain a maximum amount of data, the pilot plant is equipped with a multitude of measuring instruments for pressure, temperature, gas flow, and also on-line gas analysis for CO, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub>, H<sub>2</sub>O and O<sub>2</sub>. Biomass feedstock moisture and tar content of the gas are analyzed after discontinuously sampling. The lean gas from air blown biomass gasification reaches heating values of approximately 5 MJ/m<sup>3</sup> (s.T.p., dry). Technical and operational data of the pilot plant have been described previously [5].

## 3 EXPERIMENTAL INVESTIGATIONS

The following data belong to an 150 h test run, in which continuously approx. 220 Nm<sup>3</sup>/h of gas were produced, reformed, cooled and filtered. Main operational parameters conditions are shown in figure 3 and figure 4.

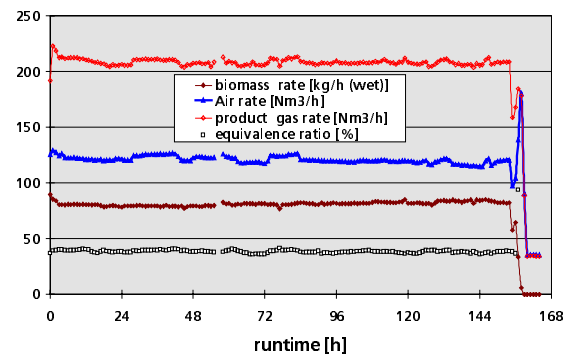


Figure 3: Main process parameters for the gasification of wood vs. time. Operating average temperatures CFBG reactor 905 °C, reformer 880 °C.

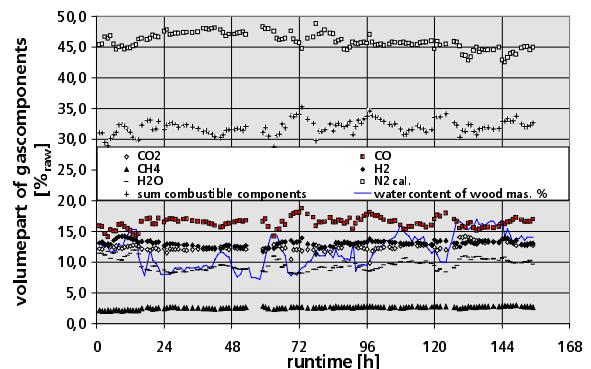


Figure 4: Gas composition behind the reformer on wet basis vs. Time.

The composition of the produced gas shows 32 % of the volume to consist of combustible components namely carbonmonoxid, methane and hydrogen. The yielded heating value was approximately 4,5 MJ/m<sup>3</sup> (s.T.p. wet).

### Tar content

For proper IC engine operation especially the tar content the gas should be constantly below 50-100 mg/Nm<sup>3</sup> [6]. Figure 5 shows this target being achieved with acceptable, variations.

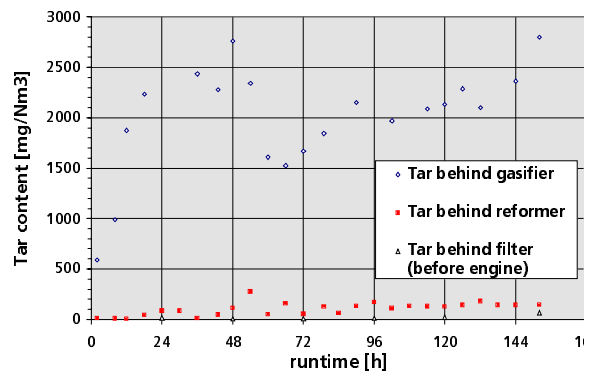


Figure 5: Tar content at the gasifier exit, at the catalytic reformer outlet and after dust removal vs. time.

Tar was sampled every 6 hours simultaneously behind the gasifier and behind the reformer. Sampling conditions

were the same as described earlier [7]. The level of all PAH heavier than naphthalene was significantly below 50 mg/Nm<sup>3</sup> corresponding to a conversion rate of 98-99%. The gentle increase of the tar component naphthalene with time after the catalyst must be seen as result of reversible plugging of some of the channels in the catalyst by dust, caused by a not optimized in situ cleaning system for the catalyst. This can be shown by comparing tar content and pressure drop over the catalyst. Additional tar samples were taken behind the filter for a period of 24 h. Naphthalene was the only detectable tar component behind the filter with concentrations below 30 mg/Nm<sup>3</sup>. The remaining tar content did neither cause any problems to the fabric filter nor to the engine. No increase of filter plugging could be detected neither of the pressure drop nor from the cleaning cycle rate (figure 6).

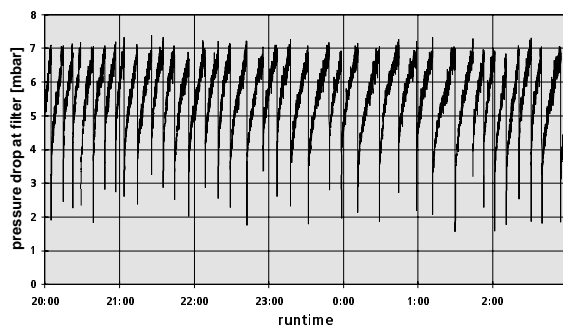


Figure 6: Constant pressure drop and cleaning cycles of the fabric filter.

The wet gas can be directly fed into the engine without any tarry waste water. For investigation purposes the gas was temporarily cooled down below the steam condensing temperature. In this condensed water no residual hydrocarbons such as tars were detectable. The table 1 gives an overview of the composition of the condensate.

Table 1: Analysis of the condensed water from upgraded gasification gas.

analytical parameter	
pH	8,6
el.ectrical conductivity	6,4 mS
Hydrocarbons including tars	below detection limit (S < 2 mg/l)
ammonia	1,3 g/l
other kations	S < 0,25 mmol/l
carbonate, hydrogencarbonate	3,2 g/l
other anions	S < 0,1 mmol/l

### Efficiency of the process

The combustion heat performance (thermal feedstock power) and the chemical power output behind gasifier and behind reformer are shown as a function of time in figure 7.

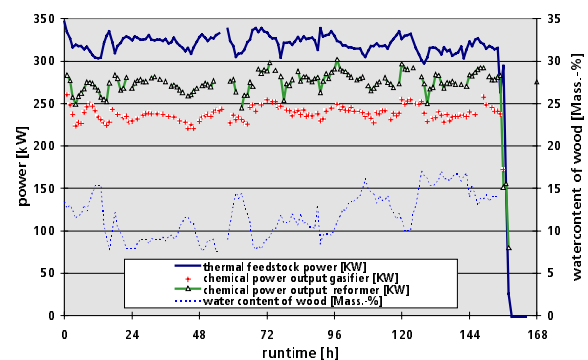


Figure 7: Power in- and output at different steps of the process vs. time.

The variations in the data are only caused by the water content of the input. The average efficiencies for the different process steps are shown in table 2.

Table 2: Efficiencies of the process.

efficiency	value [%]	comments
thermal eff. of CFB-gasifier (based on cold gas)	74	
thermal eff. gasifier + reformer (based on cold gas)	86	incl. partial oxidation, reforming and gas shift
electrical eff. of whole process	27	without internal needs

The overall efficiency reaches the expected level of 26-30%. The reformer does not only enable the operation of an IC engine by keeping the tar low, but it also increases the gas yield by reforming tar, char, and methane. As a result from ash analysis and mass balance calculations the carbon conversion rate of the gasification process is higher than 98%.

## 4 ECONOMIC PROSPECTS

A favorable process concept for combined heat and power production in a medium power range is a combination of air blown CFB-gasification and a BHPP with gas engine (IC engine) or diesel engine (see fig. 3). As mentioned before this technology enables efficient electricity production from a biomass capacity of 7,000-50,000 t/a (5-30 MW). This corresponds with an electrical output in the range of 1-10 MW<sub>el</sub>. The investment costs e. g. of an 18 MW CFB-gasification plant with a 5 MW<sub>el</sub>-BHPP is estimated to be less than 2500 EURO/kW<sub>el</sub> [6]. This estimation includes the complete plant costs including facility construction costs, fuel drying and the block-type BHPP investment. Costs for land and for long term fuel storage facilities are not included.

The diagram given in figure 8 depicts the maximum economically feasible fuel price versus the investment costs for different plant sizes. An 8% interest rate for 15 years on the capital investment was used in the calculations.

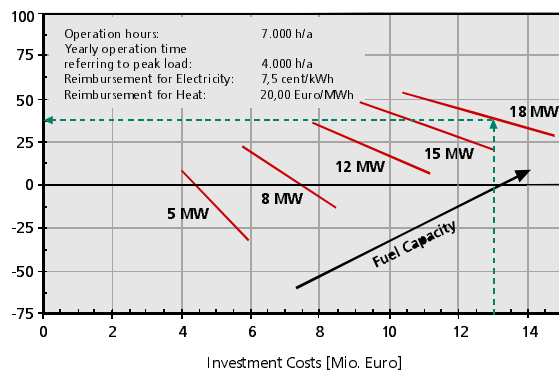


Figure 8: Economic prospects of the process depending on the plant size

Based on a 7.5 cent/kW<sub>el</sub> reimbursement for renewable energy production (was given by law in Germany until april 2000, nowadays 9 cent), plants under 5 MW fuel input capacity are hardly profitable. Although the length of the bars reveals an uncertainty of the estimation the cost projections demonstrate that energy production from biomass is economically feasible e. g. for plants with a fuel capacity of 12 MW and for fuel prices up to 20 EURO/t dry weight. The investment costs of this plant size is estimated to be in the range of 9 million EURO then.

## 5 CONCLUSIONS

The production of power and heat by CFB-gasification of biomass combined with BHPP can be economically successful and technically feasible. Catalytic reforming is suitable to solve the tar problem. The technical concept has successfully been demonstrated at a pilot scale plant of 0.5 MW<sub>th</sub>. Further process development at commercial plants is necessary to achieve a standard available technology for high efficient biomass conversion.

## 6 REFERENCES

- [1] Ising, M., Hölder, D., Backhaus, C., Althaus, W. (1998): Holzvergasung in der zirkulierenden Wirbelschicht. Brennstoff-Wärme-Kraft Bd. 50 (1998), No. 1/2, p. 59-62
- [2] Ståhl, K., Neergaard, M. (1996): Das Kombi-Kraftwerk mit integrierter Biomassen-Vergasung in Värnamo/Schweden. VGB Kraftwerkstechnik 76 (1996), No. 4, p. 327-330
- [3] Simell, P. A., Bredenberg, J. B.-son (1990): Catalytic purification of tarry fuel gas. Fuel, Vol. 69 (1990), October, 1219-1225
- [4] Schönberg, I., Hölder, D., Althaus, W. (1997): New Applications for Cogeneration. UTA International (1997), No. 2, p. 199-203
- [5] Ising, M., Unger, C., Balke, U.: Energetische Nutzung von Holz und Biomasse durch Vergasung in der zirkulierenden Wirbelschicht. Abschlußbericht für das Bundesministerium für Ernährung, Landwirtschaft und Forsten (BML) (FKZ 94 NR 140-F) (1999)
- [6] Ising, M., Gil, J., Unger, C.: Gasification of biomass in a circulating fluidized bed, 1st World conference and Exhibition on Energy and Industry, 5-9 June 2000; Sevilla, Spain
- [7] Ising, M., Hölder, D., Backhaus, C., Althaus, W.: Fluidized Bed Gasification of Biomass for Cogeneration. Proceedings „Biomass for Energy and Industry“, p. 1549-1551, 10th European Conf. 8-11 June (1998), Editor: C.A.R.M.E.N, Germany