Stoichiometric Water Consumption of Steam Gasification by the FICFB-Gasification Process

H.Hofbauer, R.Rauch,
Institute of Chemical Engineering, Fuel and Environmental Technology
Getreidemarkt 9/159, A-1060 Vienna

ABSTRACT: The FICFB (**F**ast **I**nternally **C**irculating **F**luidized **B**ed) gasification process [1, 2, 3, 4] 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 fluidized 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 should remain separated. The circulating bed material acts as heat carrier from the combustion to the gasification zone. The design of the gasifier and the use of steam as gasification agent give this process a small heat loss and a nearly nitrogen free product gas with a high calorific value of 13 MJ/Nm³ dry gas. This process has been studied over five years and a lot of experiments were carried out in a 100kWth pilot plant. By using a natural catalyst and gasification temperatures above 800°C the tar content could be reduced below 3 g/Nm³. In former work the general behaviour of this gasification system was studied. In this paper the influence of water on the product gas composition was investigated. As known from literature the steam-fuel ratio has a high influence on the gas composition and the tar content of the product gas.

INTRODUCTION

In Austria the most common utilisation of biomass for energy is the combustion for heating applications. Gasification could become a second important route especially for power production [5]. Usually, biomass gasification is carried out using fixed or fluidised beds. As the overall gasification reactions are endothermic, the gasification process must be supplied with heat. The easiest way is to use air as gasification agent and to burn biomass partially within the gasification reactor. In this case the product gas has a low calorific value (around 4-6 MJ/Nm^3 dry gas) and a high nitrogen content of 45-55%.

A gas with a low nitrogen content and a higher calorific value (about 12 MJ/Nm^3 dry gas) can be produced with pure oxygen as gasification agent but the costs for the oxygen production are high. Another possibility is to supply heat with heat exchangers but here material problems due to the high temperature level will arise. The dilution of the product gas by nitrogen can also be avoided by using a dual fluidised bed system, realised in the FICFB-process. In this case no oxygen generator is necessary and also no serious material problems due to high temperatures will appear. A good overview about such systems is given by Bridgewater [6].

CONCEPT

BASIC CONCEPT

The basic idea of the FICFB concept is to divide the fluidized 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 should remain separated. The circulating bed material acts as heat carrier from the combustion to the gasification zone (see figure 1).

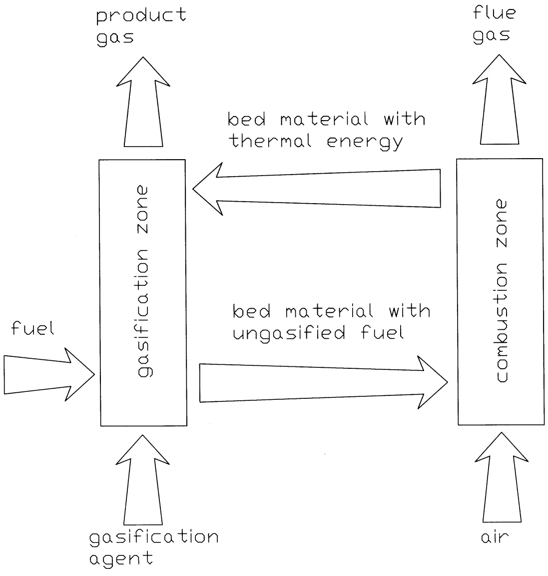


figure 1: basic concept of the FICFB-gasifier

The fuel is fed into the gasification zone and gasified with steam. The gas produced in this zone is therefore almost free of nitrogen. The bed material, together with some char coal, circulates to the combustion zone. This zone is fluidized with air and the charcoal is burned. The exothermic reaction in the combustion zone provides the energy for the endothermic gasification with steam. Therefore the bed material at the exit of the combustion zone has a higher temperature than at the entrance. The flue gas is removed without coming in contact with the product gas. With this concept it is possible to get a high-grade product gas without the use of pure oxygen. The FICFB-process has the following advantages against other existing dual fluidized bed systems:

- simple reactor design
- low investment cost because of compact design
- reduced energy losses because of efficient thermal household
- stable operation conditions, because circulation rate depends only on velocity in the riser

The gasifier produces a product gas without nitrogen, therefore the gas can be used in the following applications:

- combustion of the gas in an engine or turbine to produce electric power
- use of the gas in a fuel cell to produce electric power
- the production of synthetic natural gas
- the production of methanol
- use of the gas for direct reduction of iron ore in the steel industry
- use of the gas in the synthetic chemical industry

PILOT PLANT

The experience with a cold flow model and the 10 kWth test rig [7] was used to design the 100 kWth pilot plant. The FICFB-gasification process consists of two zones. The gasification zone is fluidised with steam and the combustion zone (riser) is fluidised with air. To avoid large amounts of gas mixing a siphon was introduced in the line from the combustion zone to the gasification zone. The bed material is splitted from the riser gas stream using a separator. The product gas and the flue gas have separated exits out of the reactor.

The fuel feeding system consists of two screws. The first is controlled by a frequency converter to adjust the amount of fuel, the second one is a fast rotating screw direct into the fluidised bed. Air is supplied by blowers into the riser and during the start up period also into the gasification zone. Steam is produced by an electrical steam generator and superheated by an electrical heater. The product gas is cooled by a three step heat exchanger and is afterwards cleaned from dust and partly from tar by a bag filter or a sand bed filter. Additives can be fed into the product gas stream in front of the bag filter, to improve the dust and tar separation efficiency. After the particulates are removed the tar is separated by a scrubber. In the scrubber the gas is also cooled down to a temperature of 25-55°C. After these cleaning steps the product gas is burned in a cyclone burner (see figure 2).

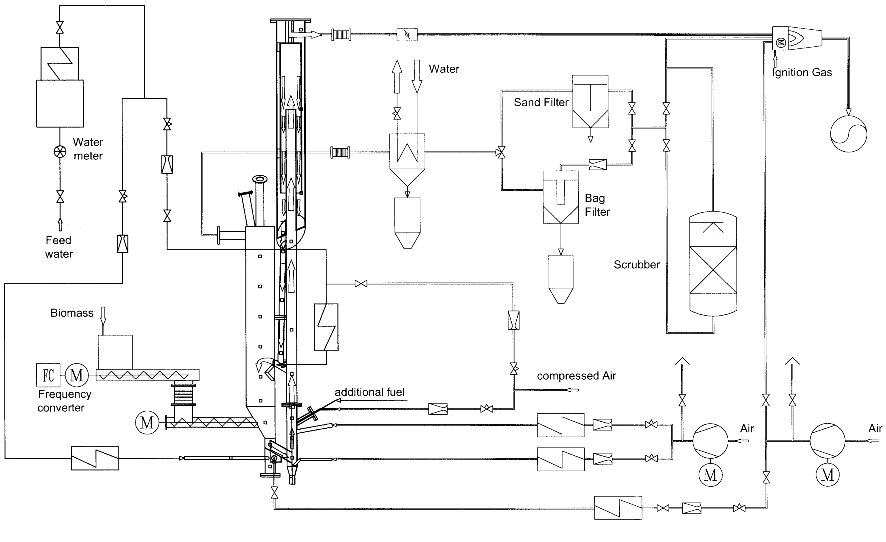


figure 2: Flow sheet of the FICFB-process

Table 1 contains characteristic data and dimensions of the pilot plant. The reactor is manufactured with stainless steel and is insulated. The warm up is carried out with electrical preheating of all air streams and by combustion in both zones. The whole warm up lasts about 4 hours. An oil feeder was installed into the riser, which gives the possibility to change the temperature level of the system without varying other operation parameters. With this installation parameter studies can be carried out very easily.

Table 1: Characteristic data of the pilot plant

thermal output	100 kW
fuel	wood pellets, wood chips, biomass residues
reactor diameter	300 mm
riser diameter	100 mm
riser height	4250 mm
bed material	quartz, natural catalyst, catalyst
bed mass	70kg
mean diameter	0.5 mm

Temperatures, pressures and CO, CO_2 and H_2 content of the product gas are measured and recorded continuously. Gas samples are taken and analysed by gas chromatography to measure the concentrations of H_2, CO, CO_2, hydrocarbons, N_2 and O_2 in the product gas. CO, CO_2, NO, NO_2 and O_2 from the flue gas are measured and recorded continuously. Dust, tar, H_2S and NH_3 content of the product gas is measured in front and after the heat exchanger, after the filter and after the scrubber. So all separation efficiencies can be determined.

Particulates and tar are measured with a method similar to the tar protocol, which was developed by the IEA-gasification group. Gas is sampled isokinetically and filtered in a glass fibre filter at 150°C to remove particulates and heavy tars. Afterwards the gas is cooled in gas washing bottles, filled with toluene at 0°C, to separate the light tars. The glass fibre filter is extracted with dichlormethane in a Soxhlet-Extractor, and then the burnable particles are combusted. So the amount of heavy tars, fly coke and unburnable part can be determined. The condensables of the gas washing bottles are extracted, the amount of water is measured to calculate the steam content of the product gas and the amount of light tars is determined gravimetically.
For this paper the tar content was measured after the heat exchanger and presents the sum of heavy and light tars.

RESULTS

EXPERIMENTAL RESULTS

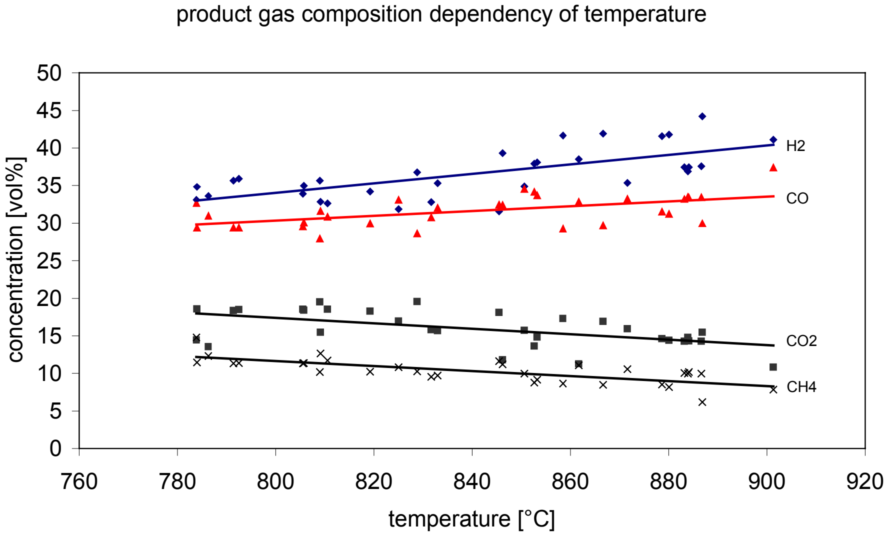
In 1999 a new gasifier was installed at the Institute. This gasifier has the same basic design as mentioned above, but an improved operation performance as the previous one. The experiments, shown in this paper, were carried out in the old pilot plant as well as the new one. As fuel for the experiments wood pellets were used. These have the advantage, that the water contents is very low (<10%) and it is a standardised fuel with nearly the same composition over the whole year. The steam-fuel ratio was varied from 0.18-0.8 kg steam per kg dry fuel). The steam-fuel ratio is calculated in the following way:

$$\text{steam} - \text{fuel ratio} = \frac{\text{sum water input}\,[\text{kg/h}]}{\text{dry fuel input}\,[\text{kg/h}]}$$

Sum water input is the sum of steam, which is used in the gasifier (for fluidisation of the gasification zone and siphon) and the water content of the fuel.
As bed material a natural catalyst was used and the gasification temperature during the experiments was varied from 750 to 900°C.

gas composition

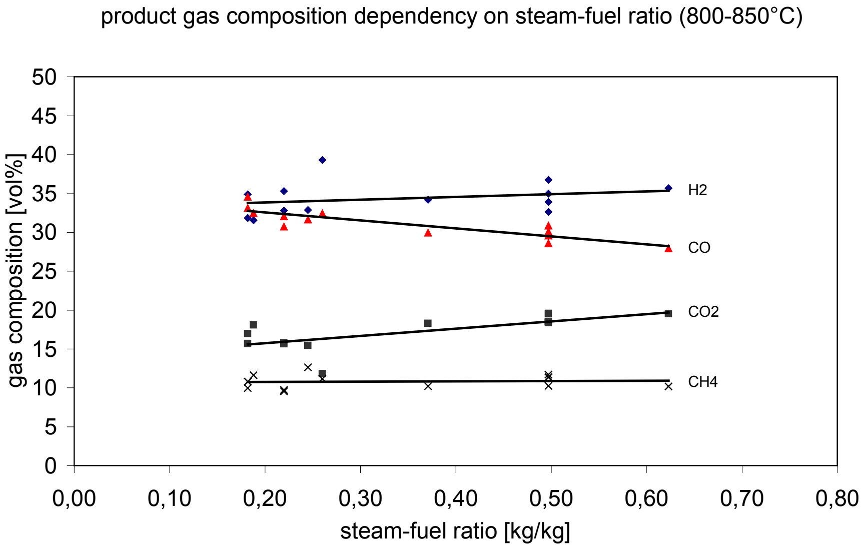
As known from literature, the gas composition depends mainly on the used fuel, on the temperature and on the steam-fuel ratio [4,8,9]. The gas composition depends also on the residence time, but in all experiments the residence time was kept as constant as possible. Therefore in the following diagrams the dependency of the dry product gas composition to these parameters is shown. The nitrogen content for all experiments was below 5 vol% and is not shown in the diagrams. The rest to 100 % is nitrogen and higher hydrocarbons. From the gaschromatographic analysis it can be seen, that the main component of the these hydrocarbons is ethene.

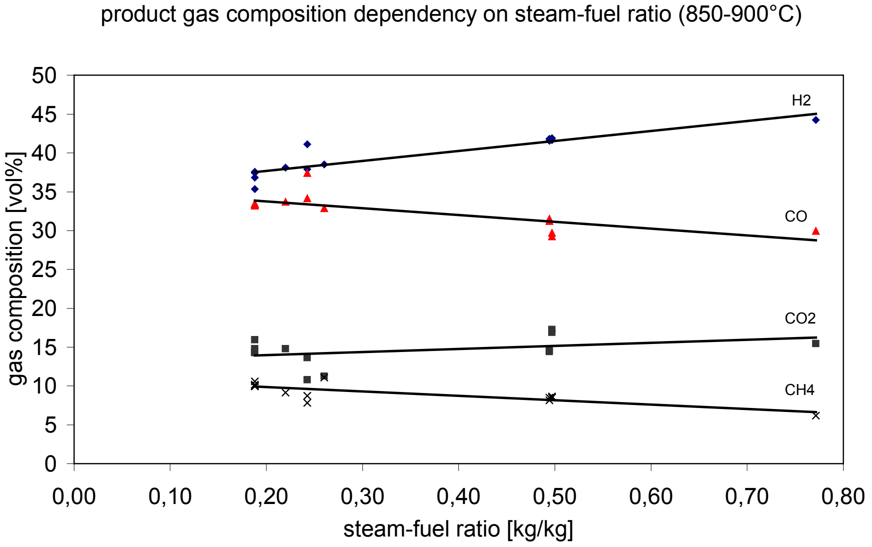


From the diagram "product gas composition dependency of temperature" it can be seen, that with increasing temperature the hydrogen and carbon monoxide concentrations are increasing and the carbon dioxide and methane concentrations are decreasing with increasing temperature. The reasons for these dependencies are, that the reactions at higher temperatures are faster and the gas composition is nearer to equilibrium.

In the next two diagrams the gas composition in dependency on the steam-fuel ratio is shown. For temperatures between 800 and 850°C the hydrogen and carbon dioxide contents are increasing with a higher steam-fuel ratio. Carbon monoxide is decreasing and methane is almost constant. In the temperature area between 850 and 900°C the same tendencies can be seen, the only difference is, that the gradient of hydrogen is higher and methane is decreasing with higher steam-fuel ratio.

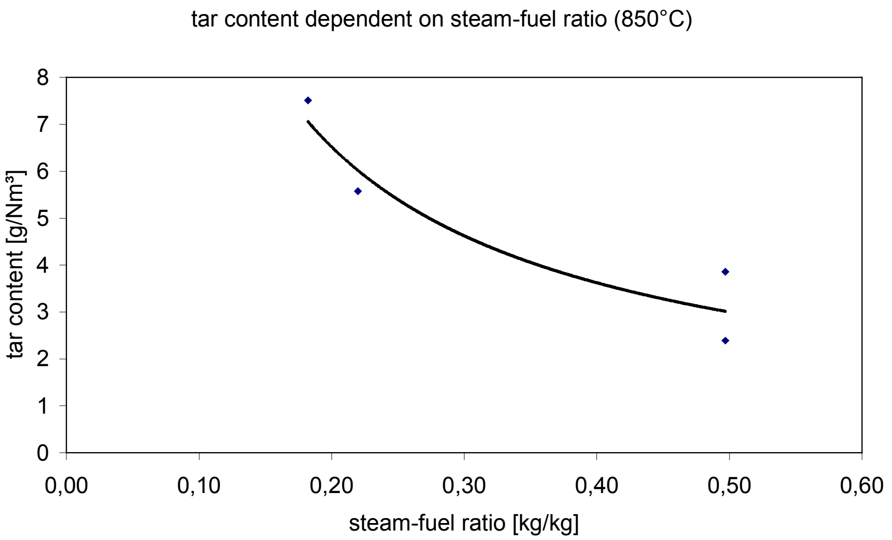
With the results of these measurements the gas composition of the product gas can be calculated for different steam-fuel ratios and temperatures. The next step will be to improve the model of the gasifier on basis of this measurements.



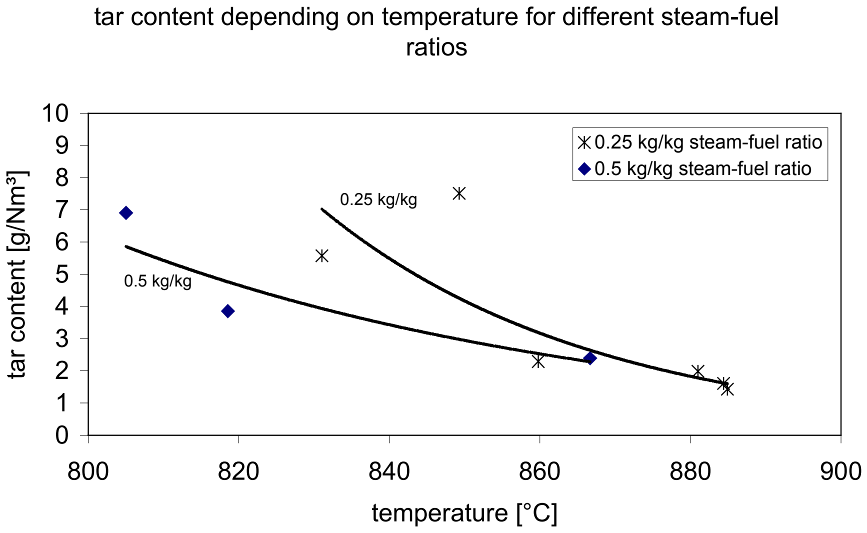


tar content

As known from previous experiments the tar content depends strongly on the gasification temperature. Here the dependency of the tar content to the steam-fuel ratio was studied. In the first diagram the dependency of the tar content on the steam-fuel ratio is shown. It can be seen, that with increasing steam-fuel ratio the tar content is decreasing.



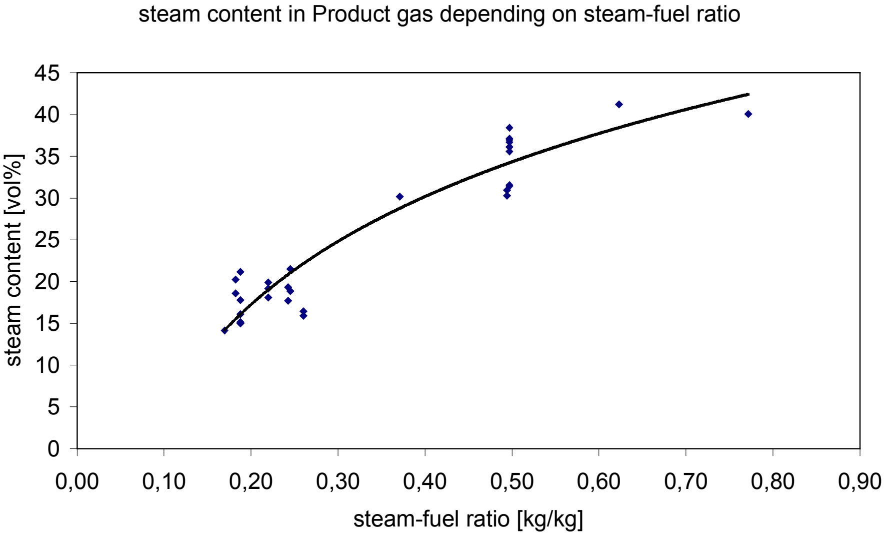
In the next diagram the tar dependency on the temperature is shown at different steam-fuel ratios. For this diagram two steam-fuel ratios were used to show the dependency of the tar content on the temperature.



It can be seen from the diagram, that the dependency on the temperature is higher at a low steam-fuel ratio. It is also shown in this diagram, that a higher steam-fuel ratio causes a lower tar content in the product gas. From these results it was realised, that the optimal steam-fuel ratio for a low tar content is higher than 0.5 kg steam per kg dry fuel. The optimal temperature for a low tar content is higher than 850°C.

water consumption

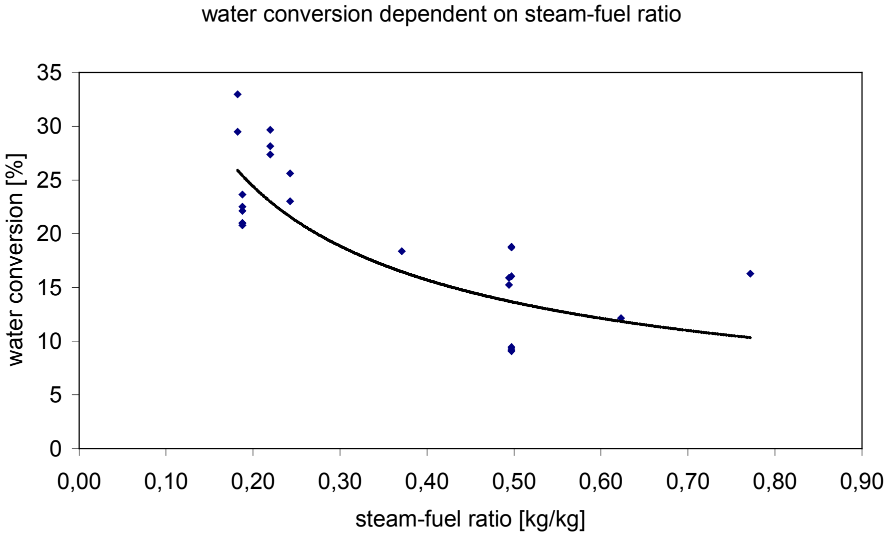
In the next diagram the dependency of the steam content in the product gas on the steam-fuel ratio is shown. It can be seen, that the steam content in the product gas increases with increasing steam-fuel ratio. It can be also seen, that there is no linear dependency. At a steam-fuel ratio of about 0.1 kg/kg all steam would be used by the gasification reactions. This steam-fuel ratio could not be investigated by experiments, because the lowest steam-fuel ratio, which is possible at the $100kW_{th}$ gasifier is 0.15 kg/kg.



In the next diagram the water conversion is shown in dependency on the steam-fuel ratio. The water conversion is a important figure to estimate the efficiency of the steam gasification system. The water conversion was calculated in the following way:

$$water\ conversion = \frac{sum\ water\ input\ [kg/h] - sum\ water\ output\ [kg/h]}{sum\ water\ input\ [kg/h]} * 100 \quad [\%]$$

It can be seen, that the water conversion decreases with increasing steam-fuel ratio. Also the influence of the temperature on the water conversion was investigated. As estimated before, the water conversion increases with increasing temperature. From these results it can be estimated, that the optimal steam-fuel ratio is below 0.5 kg steam per kg dry fuel. Above this ratio the water conversion is almost constant and more steam causes only more steam content in the product gas, without shifting the reactions to the desired side.



CONCLUSION

It was shown in this work, that the product gas composition, the tar content and the water conversion depends strongly on the steam-fuel ratio. The dependency of the product gas composition on the temperature and on the steam-fuel ratio was investigated. With this results the model of the gasifier will be improved and a basis for scaling up was created. Also the dependency of the tar content on the temperature and the steam-fuel ratio was investigated. By using a low steam-fuel ratio a high tar content was produced. Increasing the steam-fuel ratio the tar content could be reduced essentially. As known from previous experiments a high gasification temperature causes a low tar content in the product gas. The influence of the steam-fuel ratio and temperature on the water conversion were also investigated in the experiments. It was shown that a steam-fuel ratio above 0.5 kg/kg has only minor influence on the water conversion. Above this steam-fuel ratio only the steam content in the product gas increases, without a major influence on the equilibrium on the gasification reactons.

In the $100kW_{th}$ pilot plant two steam-fuel ratio for all further experiments could be defined. One is 0.25 kg/kg, which causes a high tar content, but also a low steam content in the product gas, the second is 0.5 kg/kg, which causes a lower tar content, but also a higher steam content in the product gas than the first one. With this two steam-fuel ratios all further experiments will be done and the separation efficiencies of the gas treatment system will be investigated.

In this work all necessary investigations referring the temperature and steam-fuel ratio were done to improve the model of the FICFB-gasifier and to have a basis for the scaling up the pilot plant to demonstration plant.

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