TWO YEARS EXPERIENCE WITH THE FICFB-GASIFICATION PROCESS

E.Fercher*, H.Hofbauer, T.Fleck, R.Rauch, G.Veronik
*Austrian Energy / Institute of Chemical Engineering, Fuel and Environmental Technology
Siemensstraße 89, A-1211 Wien, P.O. Box 2 / Getreidemarkt 9/159, A-1060 Vienna

ABSTRACT: Based on a cold flow model and a 10 kW_{th} test rig a 100 kW_{th} pilot plant was built which has been used for experiments since May 1995. The compact construction and the use of steam as a gasification agent gives the FICFB-process (**F**ast **I**nternally **C**irculating **F**luidized **B**ed), developed in co-operation with the Austrian Energy and Environment, a small heat loss, a nearly nitrogen free product gas with a high calorific value of 13 MJ/Nm^3 dry gas. The first experiments were carried out with quartz as bed material and wood chips as fuel to find the optimal operation conditions. By using olivine and gasification temperatures above 750°C the tar content was reduced. In December 1996 a heat exchanger was installed to cool the product gas down to 200°C. After 75 hours of operation the heat exchanger surfaces showed no deposits of tar. Parallel to experimental work an energy balance of the reactor was established. With an increasing water content of the fuel the chemical efficiency decreases but the product gas quality and the lower calorific value remains constant. In July 1997 experiments with rape seed grist, brown coal and clover pellets were started. First experiments to cool down the product gas to 20°C were done successfully.

1. INTRODUCTION

1.1 Biomass Utilisation
In Europe, Austria is one of the leading countries in using bioenergy. 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 [4]. Usually, biomass gasification is carried out using fixed or fluidized 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 fluidized bed system, as used 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 over such systems is given by Bridgewater [5].

2. THE GASIFICATION CONCEPT

2.1 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 [7].

The fuel is fed into the gasification zone and gasified with steam. The gas produced in this zone is therefore nearly 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 [1,2]. The FICFB-process has the following advantages over other existing dual fluidized bed systems:

- simple reactor design
- low investment cost because of compact construction
- reduced energy losses because of efficient thermal household

2.2 The Pilot Plant
The experience with the cold flow model and the 10 kW_{th} test rig [3] was used to construct the 100 kW_{th} pilot plant. The FICFB-gasification process consists of two zones. The gasification zone is fluidized with steam and the combustion zone is fluidized 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 particles are splitted from the riser gas stream using a U-beam separator. The fuel feeding system consists of a hopper and a multi-screw-conveyor. 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 overheated by an electrical heater. The product gas, which is cooled from 700°C to 200°C by an three step heat exchanger, and the flue gas have separated exits from the reactor. They are mixed together after taking gas samples for analyses. A part of the product gas (3Nm^3/h) is cooled down with water to 20°C using a packing column to remove most of the tars. A gas burner ensures that the product gas is completely combusted before entering a cyclone and a flue gas cooler. The fly ash can be returned continuously into the gasifier with the aid of a pneumatic fly ash recycle system. In January 1998 a product gas cyclone was installed to reduce the particle content of the product gas from 20 g/Nm^3 to 3 g/Nm^3. Table 1 contains characteristic data and dimensions of the pilot plant. The reactor is manufactured with stainless steel and is isolated. The warm up is carried out with electrical preheating of all air streams.

Table 1: Characteristic data of the pilot plant

thermal output	100 kW
fuel	wood chips, biomasses, brown coal
reactor	800 x 120 mm
riser	75 x 120 mm
riser height	2500 mm
bed material	quartz, olivine
bed mass	37.5 kg
mean diameter	0.6 mm

At a bed temperature of 250°C wood chips are combusted in the raiser and gasification zone to reach the desired gasification temperature. For fuels with a higher spontaneous-ignition temperature wood pellets are combusted to reach the temperature needed. 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. Temperatures, pressures and the CO, CO_2 and H_2 content of the product gas are measured and recorded continuously.

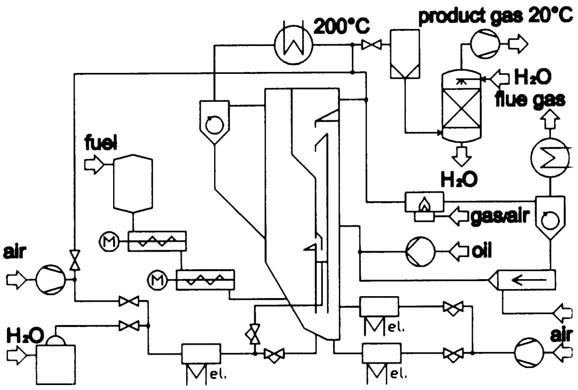

Figure 1: Flow sheet of the FICFB-process

3. RESULTS OF GASIFICATION TESTS

3.1 Composition of the product gas

In addition to the continuous analysis of the gas composition gas samples were taken and analysed with gas chromatography. A small part of the product gas is drained for analyses. This sample gas is cooled down to about 10°C where most of the condensate and tar is removed. Further gas cleaning stages are a glasswool filter and a high-grade paper filter. Until August 1997 the gasification tests were carried out using wood chips (<20 mm; water content 10-15%) as fuel. Since then, experiments with rape seed grist, brown coal, wet wood chips and clover pellets were done. The gas composition of the product gas depends on the gasification temperature and the fuel itself. With increasing temperature the hydrogen content increases, the carbon dioxide content remains nearly constant and the carbon monoxide and methane content decreases. Figure 2 shows these dependencies for wood chips. The nitrogen content of the product gas is about 5%. This is very low compared to air blown gasifiers (45-50%). The calorific value is therefore much higher and lies above 13 MJ/Nm³ dry gas. The gas samples were taken immediately after the gasification zone. The results shown in Figure 2 are calculated for nitrogen free basis.

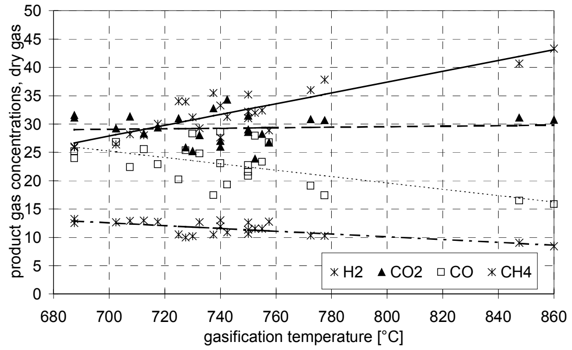

Figure 2: Gas composition of the nitrogen free product gas versus gasification temperature

For the calculation of the energy balance, linear regressions for the dependencies shown in table 2, were calculated. In the equations the gasification temperature t is given in degrees Celsius.

Table 2: Linear regressions of the gas composition

hydrogen	=0.0952*t - 38.79	vol.%
carbon dioxide	=0.0046*t +25.83	vol.%
carbon monoxide	=-0.0563*t +64.63	vol.%
methane	=-0.0247*t +29.83	vol.%

The gas composition for other fuels is shown in table 3. As in Figure 2 all concentrations in vol.% are calculated for nitrogen free basis. These are measurements after the heat exchanger was installed and therefore the gas samples were taken after the heat exchanger. The gas composition especially for CO and CO_2 is slightly different to Figure 2 because of the longer residence time. As the product gas composition is temperature dependent, the gasification temperature is also listed. The rest to 100% are higher hydro carbons. It can be seen, that fuels with the same carbon to oxygen ratio have similar product gas compositions. The steam gasification of fuels with a low oxygen content like brown coal leads to a lower carbon monoxide and a higher hydrogen content in the product gas.

Table 3: gas composition for different fuels

fuel	t	H_2	CO	CO_2	CH_4
wood chips	780°C	29.97	31.54	20.23	12.88
(w=12%)	800°C	31.76	29.14	22.54	11.70
	840°C	35.56	28.85	19.98	10.90
wet wood chips	700°C	30.14	31.42	20.63	11.83
(w=40%)	780°C	36.55	25.30	22.83	10.51
rape seed grist	720°C	25.42	27.85	22.57	13.94
	760°C	27.44	27.36	23.34	13.39
	800°C	31.93	25.14	22.38	12.66
clover pellets	720°C	42.41	13.63	29.93	8.45
brown coal	770°C	54.02	13.49	23.30	7.00
	840°C	54.24	17.22	20.55	6.16

The gasification of clover pellets in a fluidized bed at temperatures over 800°C leads to the same problems as in fluidized bed combustors. The sintering point of the ash is so low, that the U-beams and the siphon are blocked after some hours of operation. All other fuels were gasified in the FICFB-system without problems.

3.2 Tar content of the product gas

Tars are the non-aqueous condensables, soluble in organic solvent (toluene or diethyl ether), when the product gas is cooled down to 20°C. The amount of tar is measured by gravimetric method after drying the tars with rests of solvent. The following 3 steps are used for collecting the tars:

(1) The product gas is hot filtered (200°C) with glass wool to remove heavy tars together with dust particles. The glass wool is then extracted with toluene. The toluene is distilled out and the rest is dried at 115°C and is weighted.
(2) In the next step the product gas is cooled down to 20°C removing all the condensables and the water. The condensables are then extracted with diethyl ether, before the diethyl ether is distilled out and the rest is dried at 105°C.
(3) The dry product gas is passed through toluene to collect the rest of the tars. The toluene from the absorption bottle is also distilled and the rest is dried at 115°C

The three tar fractions are weighted and added together. The tar content of the dry product gas is calculated from the total amount of tars in gram divided by the volume measured. Figure 3 shows the tar content of the product gas for different fuels. Solid symbols show experiments with quartz as bed material, outlined symbols show experiments with olivine as bed material.

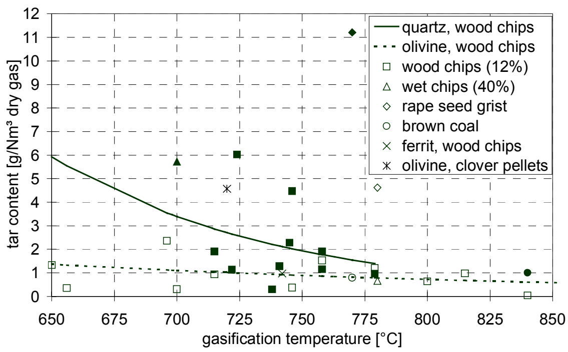

Figure 3: Tar content of the product gas for different fuels

Generally the use of olivine as bed material reduces the tar content compared to quartz. The tar content of the product gas decreases with increasing gasification temperature. Wood chips and brown coal have similar tar contents, while rape seed grist and clover pellets give higher tar contents. Because of the gasification with steam, the water content of the fuel has nearly no influence on the tar content. Compared to air blown fluidized bed gasifiers the tar content for wood chips and quartz as bed material, of about 2g/Nm³ dry gas, is quite low. These results corresponds with measurements published by Corella [6].

3.3 Cleaning and cooling the product gas

The first step of the product gas cleaning is a cyclone, which is installed between the gasifier and the heat exchanger. This cyclone reduces the particle content from 20 g/Nm³ to about 3 g/Nm³. The particles collected after the cyclone consists to 90% of fly coke. After the cyclone the product gas is passed through a heat exchanger and cooled down to 200°C. After 75 hours of operation no deposits of tars were found on the heat exchanger surface. A possible explanation could be the high steam content (above 40%) of the product gas. After the heat exchanger a part of 3 Nm³/h of the product gas is passed through a filter to remove the rest of the particles. The clean product gas is afterwards cooled down to 20°C with a packing column. In this counter flow column water is used to cool and clean the product gas. Almost all of the tars are removed in this step.

4. ENERGY BALANCE OF THE FICFB-PROCESS

4.1 Experimental results

To calculate the energy balance of the FICFB-process all wood chips experiments were analysed and dependencies for the product gas composition (see table 2), the product gas amount, the amount of carbon transported into the riser and the amount of water necessary for the gasification reactions (see table 4) were calculated using statistic methods. The equations in table 4 contain the specific values for one kilogram dry wood (m_{Btr}).

Table 4: Equations calculated from experimental results

product gas amount = $33.333/(71.375-0.05207*t)*m_{Btr}$
carbon into riser = $0.11 * m_{Btr}$
$H_2O = (12.57*t-3378.48)/(71375-52.068*t)*m_{Btr}$

4.2 The energy balance

The balance was made for the pilot plant with one exception. Instead of oil, product gas itself is assumed to be recycled into the riser. Figure 4 shows the energy streams considered in the energy balance. Besides the energy in the fuel (E_f), in the steam (E_s), in the air (E_a), in the recycled gas (E_r), in the product gas (E_{PG}) and in the flue gas (E_{FG}), the heat loss of the gasification zone (E_{GZ}), the heat loss of the combustion zone (E_{CZ}) and the energy loss through the fly coke (E_{FC}) are included.

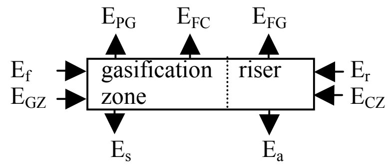

Figure 4: Energy balance of the FICFB-process

To solve the energy balance of the whole process it is necessary to solve the balances of the gasification and combustion zones first. The circulating bed material, working as heat carrier between these two zones, combines these two balances. Although the chemical reactions occurring in the gasification zones are not known, it is possible to solve the energy balance for this zone using the experimental results described in table 4. In the riser carbon and recycled product gas are combusted, as the chemical reactions for these processes are well known, the energy balance can be calculated.

4.3 Results calculated using the energy balance

To make it easier to examine several operation conditions a program to solve the energy balance was written. One of the most important results is the dependency between the chemical efficiency and the water content of the wood chips. Figure 5 shows, that with increasing water content the chemical efficiency decreases, and the flue gas temperature and the amount of product gas recycled into the riser increases. Compared to other gasifiers the water content of the fuel has no influence on the product gas composition as mentioned before, but a great influence on the chemical efficiency. Figure 5 is calculated for a constant gasification temperature of 800°C and a specific circulation rate of 50kg bed material per 1kg dry wood .

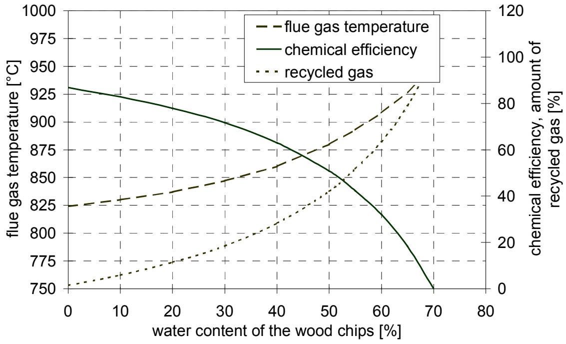

Figure 5: Chemical efficiency, flue gas temperature and amount of recycled gas versus water content

In an internally circulating fluidized bed reactor the circulation rate of the bed material is very important. As figure 6 shows, a low circulation rate leads to high combustion temperatures in the riser. To get a temperature difference below 50°C between the gasification zone, which consumes energy, and the raiser, which supports the energy through combustion of char coal and recycled product gas, a circulation rate of 50kg bed material per 1kg dry wood chips is necessary. Figure 5 is also calculated for a gasification temperature of 800°C.

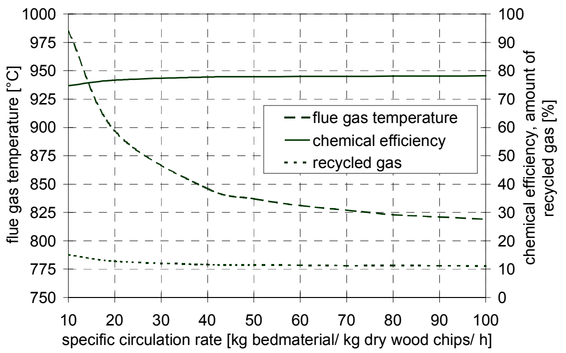

Figure 6: Chemical efficiency, flue gas temperature and amount of recycled gas versus circulation rate

If the amount of water consumed by the gasification reactions is compared to the amount of water fed into the reactor, it can be seen, that there is about 3 times more water than needed. This excess water has a positive influence on the tar content of the product gas. The influence of the heat loss of the reactor, the energy loss of the reactor through fly coke and the influence of preheating the combustion air was also investigated using the energy balance. The results are, that the water content of the fuel has the greatest influence on the chemical efficiency and that the gasification temperature should be as high as possible, to reduce the tar content of the product gas. For wood chips it is no problem to gasify at such high temperatures, because the thermal ash behaviour is good. For other biomass, like clover pellets, this is not the case and the gasification temperature is limited by the softening temperature of the ash.

The results published here are calculated for the pilot plant, but it is no problem to use the energy balance for bigger plants.

5. CONCLUSION

The main results of the two year experience with the FICFB process are that the composition of the product gas depends on the gasification temperature, the residence time and the elementary analysis of the fuel, especially the C, H and the O contents. Fuels with a high C content and a low O content, like brown coal, lead to a hydrogen rich product gas.

The tar content of the product gas is quite low compared to air blown gasifiers. It is lower than for other fluidized bed systems. One reason for this low tar content is the excess of water in the gasification zone. The tar content depends on the gasification temperature and the fuel itself. With olivine as bed material the tar content can be decreased.

It was proved that the product gas can be cooled down to 20°C without any problems. After 75 hours of operation no traces of tar could be found on the heat exchanger surfaces.

A program to solve the energy balance of the FICFB-process was calculated to investigate the influence of several parameters. The water content of the fuel has the greatest influence on the chemical efficiency of the process. But experiments showed that it had no influence on the product gas composition as long as the temperature was kept constant. The chemical efficiency is hardly dependent on the gasification temperature. Therefore the gasification temperature should be as high as possible to get a low tar content. The upper limit is the maximum combustion temperature in the riser or the softening temperature of the ash.

The next step will be to design and built a larger plant (1-5 MW_{th}), which is integrated in a district heating system.

6. REFERENCES

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