Scale-up of a 100kW$_{th}$ pilot FICFB-gasifier to a 8 MW$_{th}$ FICFB-gasifier demonstration plant in Güssing (Austria)

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Abstract. The FICFB (Fast Internal Circulating Fluidised Bed) gasification process is an innovative process to produce a high grade synthesis gas from solid fuels. The gasification zone is separated from the combustion zone using two fluidised bed reactors. The bed material circulates between these two zones to serve as a heat carrier for the gasification process. The necessary heat is obtained by burning remaining charcoal or additional fuel in the combustion zone. Steam is used as a gasification agent, to yield a nearly nitrogen free product gas with high calorific value of 12-14 MJ/Nm³ dry gas. The scale-up process with the aid of a cold model for the demonstration plant is given in this paper with results on circulation rate, bed material losses as well as on leakage measurements between the combustion and gasification zone.
Key words: gasification, scale-up, cold flow model, demonstration

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. A decline can be found in some fields, like wood stoves, whereas an increase can be seen in the fields like woodchip burning and district heat supply systems.
Climatic conventions (Kyoto, Buenos Aires) and the European Union White paper demand a substantial increase in the use of biomass, which can be achieved only if new applications for the use of biomass are developed, like electric power generation from biomass. Gasification seems to have the greatest potential in this area, offering great flexibility and high electrical as well as high overall efficiencies.
These conditions led to the development of the FICFB-gasification system (Fast Internal Circulating Fluidised Bed) [1, 2, 3, 4] by the Institute of Chemical Engineering together with AE Energietechnik.
The fundamental idea of this gasification system is to physically separate the gasification reaction and the combustion reaction (Fig. 1) in order to gain a largely nitrogen-free product gas. Biomass entering the stationary fluidised bed gasification reactor is heated up, dried, devolatilised and converted to CO; CO_2; CH_4; H_2; H_2O_g as well as char (C). Simultaneously the strongly endothermic gasification reactions (reactions with water vapour) take place (1, 2).

$$CO + H_2O \rightarrow CO_2 + H_2 \tag{1}$$

$$C + H_2O \rightarrow CO + H_2 \tag{2}$$

A chute connects the gasification with the combustion section, operating as a circulating fluidised bed. Bed material together with any non-gasified carbon is transported through this chute into the combustion section, where the remaining carbon is fully combusted. The heated bed material is separated by e.g. a cyclone and fed back into the gasification section. The necessary heat required for the gasification reactions is produced by burning carbon brought along with the bed material into the combustion section. Additionally, the temperature in the combustion section is controlled by supplementary fuel, like recirculated product gas or wood. The gasification section is fluidised with steam, the combustion section with air, resulting in two different gas streams, a nearly nitrogen-free product gas with a calorific value of 12–14 MJ/Nm^3 (dry) and a flue gas from the combustion section.

The FICFB-gasification system has, in contrast to conventional gasifiers operated with 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 the proceeding of the scale-up from the 100kW$_{th}$ pilot plant to the 8MW$_{th}$ demonstration plant using a cold flow model is described.

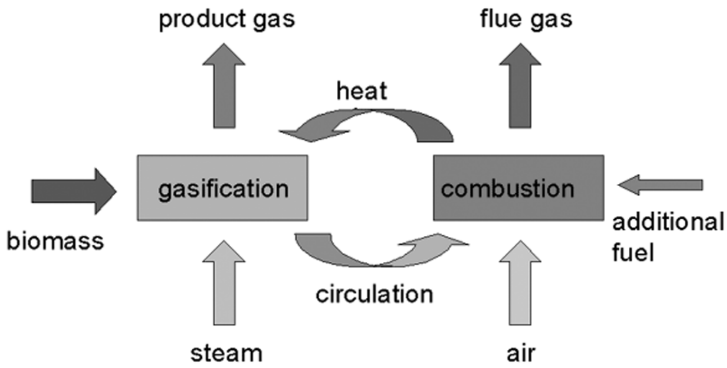

Fig. 1. Principle of FICFB-gasification process

The 100kW$_{th}$ pilot plant

In the beginning, experiments in the pilot plant were carried out with quartz sand as bed material and wood chips as fuel to investigate the optimal operation conditions [1]. In the latter different bed material and during 1997 and 1998 different fuels (rape seed grist, brown coal, wet wood chips, clover pellets, sewage sludge pellets, animal residues and barley) were tested [2,3]. During 1600 hours of operation, 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 [4]. These data obtained from the 100 kWth were expected to be nearly unchanged in a larger plant. More critical is the scale up of the fluid dynamic of the fluidised bed system shown above. To evaluate the fluid dynamic of an 8 MW$_{th}$ demonstration plant, a cold flow model according to similarity rules were used.

Cold flow model for the 8MW$_{th}$ demonstration plant in Güssing

To manage a scale-up by a factor of 80 from the 100kW$_{th}$ pilot plant to the 8MW$_{th}$ demonstration a fundamental study in terms of fluid dynamic had to be carried out. To optimise the two-phase fluid dynamic in the FICFB-reactor a cold flow model made of Plexiglas was set up. The experimental simulation was designed according to the model theory of Glicksman [5], keeping the parameters Fr, Re, ρ_p/ρ_f and L/d_p constant (Table 1).

Table 1: Technical data of the demonstration plant and the cold flow model

Parameter	Symbol	Demonstration plant	Cold flow model	Dimension
Bed material		quartz sand	bronze	
Particle density	ρ_P	2500	8750	kg/m³
Bulk density	ρ_S	1440	5380	kg/m³
Average particle diameter	d_P	440-600	110-150	µm
Shape factor	ψ	0,9 – 0,95	1	
Fluidisation medium		Steam/Air	Air	
Temperature	T	800 - 900	20	°C
Density	ρ	0,3243 – 0,2967	1,1881	kg/m³
Viscosity	μ	45,48 *10^{-6}	18,24 *10^{-6}	Pas
Length	L	L	0,25 * L	m
Area	A	A	0,0625 * A	m²
Velocity	U	U	0,5 * U	m/s
Volume flow	V	V	0,03125 * V	m³/s
Circulation rate	M_S	M_S	0,109 * M_S	kg/s
Specific circulation rate	G_S	G_S	1,75 * G_S	kg/m²s

Performed measurements

The cold flow model has been used to carry out measurements of the bed material circulation rate, which is important to ensure the heat exchange between the combustion and the gasification zone (Fig. 2). Measurements have been carried out using different bed material diameters, different fluidisation media volume flows and distribution as well as different angles of the chute and different inlet geometries of the cyclone.

Gas leakage through the chute from the combustion to the gasification zone was measured as well as the bed material loss from the gasification and the combustion zone. Further on using flaps in the air streams of the gasification and combustion zone different pressures and its result on the stability of the system were investigated.

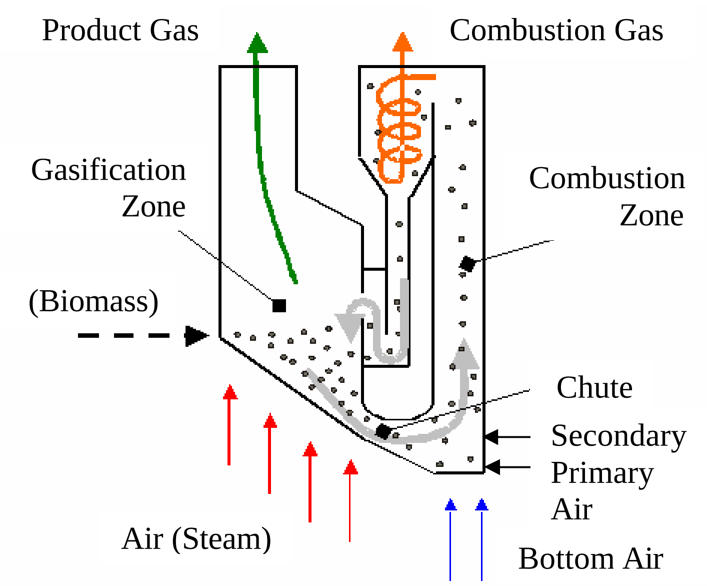

Fig. 2. Cold Flow Model

Results of the cold flow model

Figure 3 on the left shows the influence of different air distributions in the combustion section. The total volume flow and the bottom air were kept constant while the ratio of secondary to total volume flow was varied. By increasing the volume flows in the lower part of the riser (bottom and primary air) the circulation rate could be significantly raised. Also an increase of the circulation rate through different improvements can be clearly seen. A change of the bed material mean particle size from 0.13mm (E1) to 0.11mm (E2) nearly doubled the bed material circulation rate. Further increase (E3, E4) was archived by optimisation of the cyclone geometry and the angle of the chute. These improvements lead to a bed material circulation rate far above the necessary circulation rate for successful operation of the gasifier.

In Figure 3 on the right hand side the influence of different quantities of bed material in the system can be seen. These experiments were carried out with a mean bed material diameter of 0.11mm, optimised cyclone geometry and the same flow conditions as mentioned above. It is clearly shown, that a higher amount of bed material, which is equivalent to the pressure drops of the fluidised bed, results in higher circulation rates. Again an increase of the volume flows in the lower part of the riser leads to higher circulation rates.

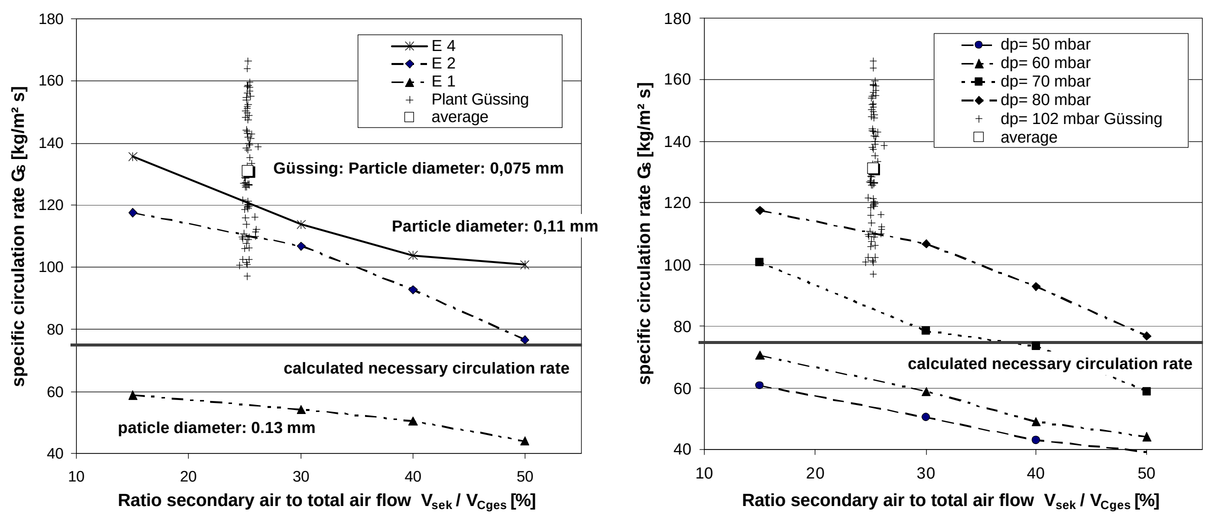

Fig. 3. Specific circulation rate in dependency of fluidisation distribution and amount of bed material

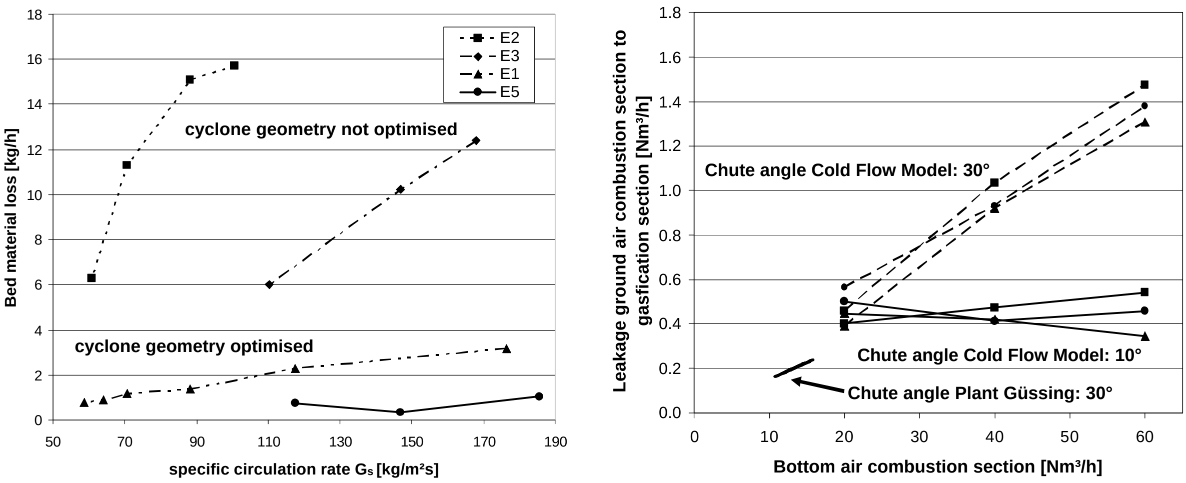

Fig. 4. Bed material loss in dependency of the specific circulation rate and leakage between the combustion and gasification part in dependency of the bottom air volume stream

In figure 4 on the left hand side the effect of the optimisation of the cyclone geometry can be seen. Using the standard arrangement, the bed material loss was far too high, which would result in high costs for bed material replacement in the demonstration plant. Through a change in the inlet geometry of the cyclone a separation efficiency of over 99.99% could be achieved. The so obtained geometry was used to construct the cyclone of the demonstration plant.
The different leakages from the combustion to the gasification zone in dependency of the ground air flow can be found in figure 4 on the right hand side. The increase in the angle of the chute in order to raise the bed material circulation rate results also in an increase of the leakage through the chute, though even with this increase the leakage does not exceed 3% of the ground air.

Conclusion

The cold flow model served as important tool to scale-up the FICFB process by a factor of 80. The information obtained from the investigations from the cold flow model was used for the design of the 8 MW_{th} gasification plant. Preliminary results from the demonstration plant show good agreement with the results obtained from the cold flow model in terms of circulations rates and gas leakage (Figure 3 & 4) as well as with the results from the 100 kWth pilot plant (product gas composition, tar content, etc.).

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