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FLUID-DYNAMIC INVESTIGATIONS IN A COLD MODEL FOR A DUAL FLUIDIZED BED BIOMASS STEAM GASIFICATION PROCESS: OPTIMIZATION OF THE CYCLONE

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ABSTRACT

Gasification of biomass is an attractive technology for combined heat and power production. Although a great deal of research and development work has been carried out during the past decade the commercial breakthrough for this technology is still not in sight. The optimisation of the operation costs influences significantly the economic efficiency. Especially bed material consumption constitutes a major part of expenses in fluidised bed systems. Thus, cyclones for circulating fluidized beds need to be designed properly. A dual fluidized bed steam gasifier is in commercial operation at the biomass CHP (combined heat and power plant) in Güssing, Austria since 2002. Some erosion and caking in the cyclone of the CHP plant could be observed with increasing hours of operation. The influences of these effects as well as the influence of the solid circulation rate between the two units on the separation efficiency were investigated by fluid-dynamic investigations using a cold model. The results show that due to erosion and caking elutriation rates are increased, especially for smaller particles. However, the cyclone achieves fractional separation efficiencies of more than 99.9%.

INTRODUCTION

Biomass as energy source is politically required by climatic conventions. Electricity generation is possible in new applications like biomass gasification. This technology is an efficient and environmentally friendly method for heat and power production. A dual fluidized bed system for steam gasification, developed jointly by the Institute of Chemical Engineering and an Austrian supplier of thermal energy generation systems, is currently demonstrated in Güssing/Austria at a scale of 8MW (fuel power). The plant uses wood chips from forestry as fuel and more than 6000 hours of CHP operation could be achieved for the year 2005 (more than 17500 hours of CHP operation since commissioning in 2002) (1).

Of particular interest for the economic efficiency of the plant is the bed material consumption. While high solid circulation rates are required, high separation efficiencies of the cyclone must be ensured. A cold model on basis of established fluid-bed scaling laws has been constructed to develop the process prior to the erection of the CHP plant. The optimization of the cyclone has been done recently by fluid-dynamic investigations using this cold model.

Some erosion and caking in the cyclone of the CHP plant could be observed with increasing hours of operation. The influences of these effects on the separation efficiency were investigated and significant results are presented in the following. According to Hugi and Schlieren (2) dip tubes can be omitted in highly loaded cyclones of circulating fluidized beds. The cone of the cyclone should be slender and the entrance duct should be inclined downwards. To investigate this assumption different dip tube geometries and their influence on the elutriation were tested.

The maximal achievable separation efficiency of cyclones increases with higher solid loads due to the formation of solid strands in the cyclone inlet area (3). The theory of critical loading ratio is suitable for the calculation of separation efficiencies (4). Any material in excess of this critical load is instantaneously separated and classified at the cyclone entrance (strand separation) whereas the solids remaining in the gas are separated in the cyclone barrel (inner separation) as if the cyclone is operated at low solid loads (5). Unacceptable high solid losses of fine particles with the cyclone off-gas as well as erosions of the cyclones due to unsuitable geometric design are frequent problems in industrial applications (6).

DESCRIPTION OF THE DEMONSTRATION PLANT

At the demonstration plant in Güssing a dual fluidized bed reactor is installed to gasify wooden biomass with steam. The basic idea of this concept is to divide the reactor in two zones, a gasification zone fluidized with steam and a combustion zone fluidized with air. A circulation loop of the bed material is created between these two zones to deliver the heat for the gasification process via the circulating bed material. The flue gas remains separated from the product gas (7). This results in a nearly nitrogen-free, hydrogen-rich product gas with a lower heating value of 10-14 MJ/m³$_N$ (8). The principle of the process is displayed in Figure 1

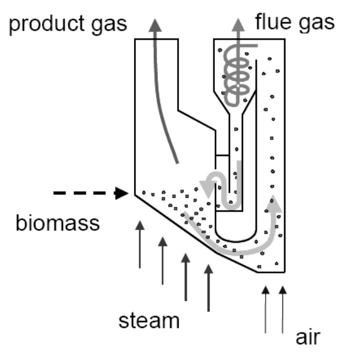

Fig. 1: Principle of the dual fluidised bed gasification process

The fuel power of the demonstration plant is 8 MW, the electrical output is 2 MW and the thermal output 4.5 MW. A flowchart of the plant is given in Figure 2. Wood chips with a water content of 20 – 30 % are used as fuel and transported via screw conveyors into the fluidised bed reactor. The producer gas is cooled and cleaned by a two stage cleaning system. A water cooled heat exchanger reduces the temperature from 850°C – 900°C to about 160°C – 180°C. The first stage of the cleaning system is a fabric filter to separate the particles and some tar from the product gas. These particles are returned to the combustion zone of the gasifier. In a second stage the gas is liberated from tar by a scrubber. Spent scrubber liquid saturated with tar and condensate is vaporized and fed for thermal disposal into the combustion zone of the gasifier. In addition, the scrubber is used to reduce the temperature of the clean product gas to about 40 °C which is necessary for the gas engine. The clean gas is finally fed into a gas engine to produce electricity and heat.

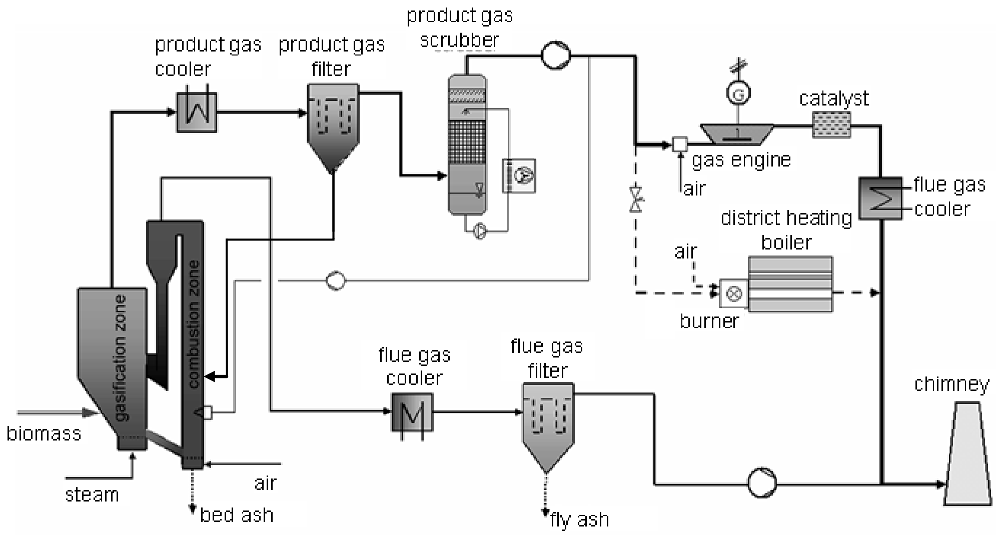

Fig. 2: Simplified flow sheet of the biomass CHP Güssing, Austria (9)

EXPERIMENTAL

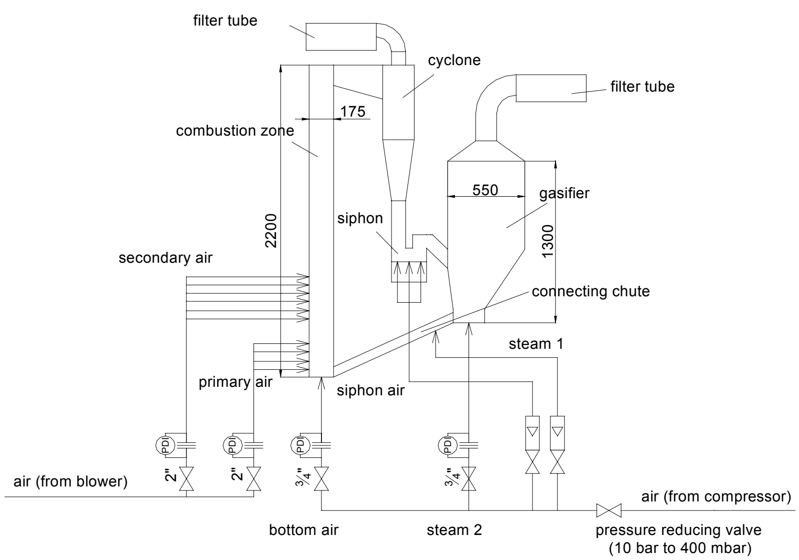

Fig 3: Dual fluidized bed cold model (dimension in mm)

Experiments were performed under ambient conditions with the cold model (see Figure 3). A blower provides the air for primary combustion air (primary air) and secondary combustion air (secondary air). The primary air injection is about 175 mm over the sieve distributor bottom in the combustion zone, the secondary air injection is about 250 mm over the primary air. To fluidize the bottom of the combustion zone (bottom air), the siphon (siphon air), the connecting chute (steam 1), and the gasification part (steam 2) a compressor is used. The fluidization of the connecting chute, siphon and gasification zone in Güssing happens by means of steam. The necessary total amount of fluidization air for the cold model amounts approximately 500 Nm³/h. The distribution of bottom air over the fluidized bed cross section (siphon, combustion zone, gasification zone) is reached with a sieve insert as gas distributor bottom. The measurement flow rates are measured by of orifice plates and rotameters.

To start the experimental procedure all air flows are increased slowly. After reaching the terminal settling velocity in the riser, circulation of the bed material takes place. Steady state conditions can be ascertained immediately after adjustment of the volume flows to the desired values. The measurements start when all pressures as well as the temperatures of the air flows are constant which needs usually less than one minute. Each experiment lasted for 0.5 h and after the experiment the bed material, collected in the filter tubes, is weighed and sieved.

Obviously chemical reactions cannot be reproduced in cold flow models. Thus, the air flows for the combustion part as well as for the gasification part are calculated taking the gasification and combustion reactions into account. In Table 1 relevant data and operating temperatures of the cold model as well as of the biomass CHP Güssing are represented. Additionally, volume flows, average gas velocities, and the solid flow rate per area in the combustion zone are listed. The pressure loss in the cold model should be 90 % of the hot rig (10).

Table 1: Defaults of the CHP in Güssing and calculated values of the cold model

parameter	symbol	CHP Güssing	cold model	dimension	ratio
medium		flue gas	air		
temperature	T_c	950	40	°C	
density	ρ_F	0.29	1.05	kg/m³	3.62
dynamic viscosity	η_F	$46.82 \cdot 10^{-6}$	$19.9 \cdot 10^{-6}$	Pa·s	
pressure drop gasification zone	$\Delta p_{gasifier}$	108	97	mbar	0.9
volume flow	Vc	4900	450	Nm³/h	0.09
average gas velocity	u	12	6.25	m/s	0.52
solid flux	G_S	68	120	kg/m²s	1.76

The defaults of the plant Güssing and the results of the computation regarding the bed material of the cold model are displayed in Table 1. Olivine, a natural mineral, has proven to be a suitable bed material with enough resistance to attrition and moderate tar cracking activity (11). The calculated density ratio is slightly different to the actual one due to lack of alternatives to bronze. According to scale criteria (12) a density ratio of 3.62 should be adjusted. The actual density ratio from olivine to bronze is displayed in Table 2. Since the actual density is smaller than calculated the specific circulation increases. Nevertheless, the results gathered from the measurements have to be seen as trends, since abrasion of the bed material and ash from the biomass cannot be simulated in a cold model. Moreover, the bronze used has a spherical shape in contradiction to the olivine used at the demonstration plant.

Table 2: Physical characteristics of the bed material

parameter	symbol	CHP Güssing	cold model	dimension	ratio
		olivine	bronze		
density	ρ_P	2900	8730	kg/m³	3
average particle diameter	d_P	530	125	µm	0.24
particle size ditribution	-	100 - 800	40 - 280	µm	
particle sphericity	ψ	0.87 - 0.9	1	-	

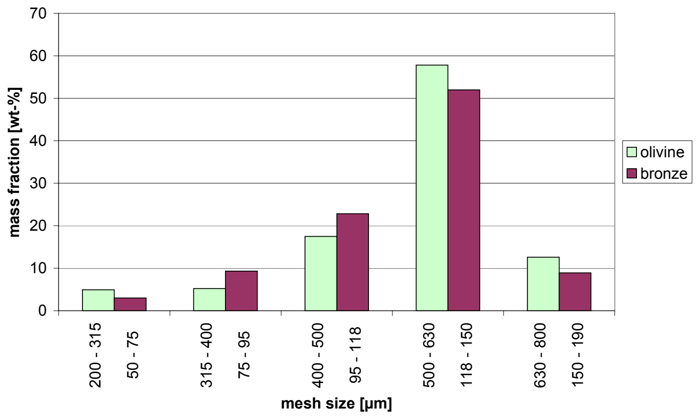

Fig. 4: Comparison particle size distribution olivine/bronze

Based on sieve analysis of the olivine the needed particle size distribution of the bronze particles was calculated using the Glicksman criteria. Figure 4 shows a comparison of the particle sizes of olivine and bronze. The numbers in the first line of the mesh size axis are gained from the sieving of olivine. This particle size distribution represents a typical bed material mixture in the gasifier. The plant is in commercial operation, which means that fresh bed material is added continuously to compensate the loss of bed material due to abrasion as well as due to elutriation. Based on the olivine particle size distribution, the particle size distribution of the bronze was adapted to the calculation. The mean particle diameter of the bronze of 125 µm fits sufficiently to the required value of 126 µm, which is important for the calculation of geometry ratios.

The matter in hand deals with investigations about elutriation out of the combustion zone and separation efficiency of the cyclone. As mentioned above, the bed material consumption is of particular interest for the economic efficiency of the plant. It could be observed, that with increasing hours of operation the elutriation of bed material increases, i.e. the separation efficiency of the cyclone decreases. Two possible reasons are suspected: caking in the corner of the cyclone (Figure 5) and erosion on the cyclone wall, which caused a strip in the region after the cyclone entrance duct (Figure 6).

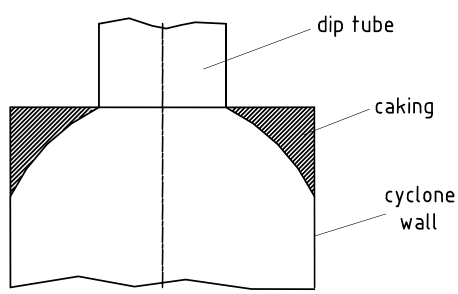

Fig. 5: Cross section of the caking

In the cold flow model the caking was simulated with a glass fibre model (according to Fig. 5; called ´cake´) and the erosion of the cyclone wall with a strip of Plexiglas (called ´strip´). Additionally, dimensions of the cyclone are given in Figure 7.

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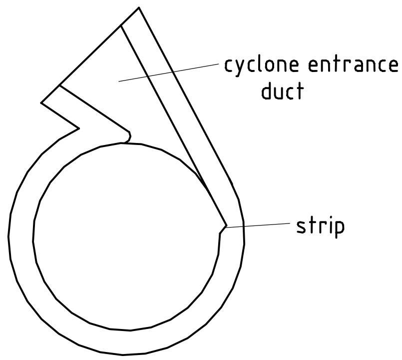

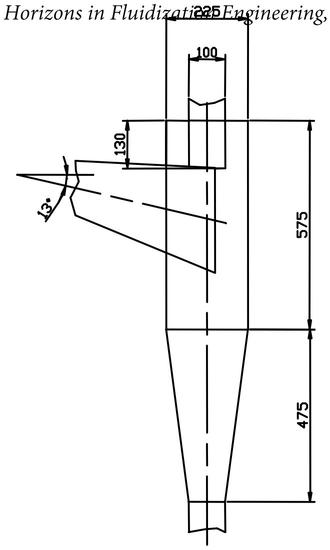

Fig. 6: Erosion of the cyclone wall

Fig. 7: Cyclone dimension

EXPERIMENTAL RESULTS

In general, increased solid flow rates leads to increased bed material losses (Fig. 8). Surprisingly, the elutriation during the experiment with no fixtures (cake and strip) is lower than in ´no fixture, with dip tube´. The separation efficiency with dip tube is worse than without dip tube at highly loaded circulating fluidized bed recycle cyclones as observed by Hugi and Reh (2).

By the simulation of caking in the upper range of the cyclone and washing out after the cyclone entrance duct a substantially larger elutriation can be recognized. This could be decreased enormous by the use of a dip tube. However, if no caking appears the elutriation is about 2-3 times higher than without dip tube.

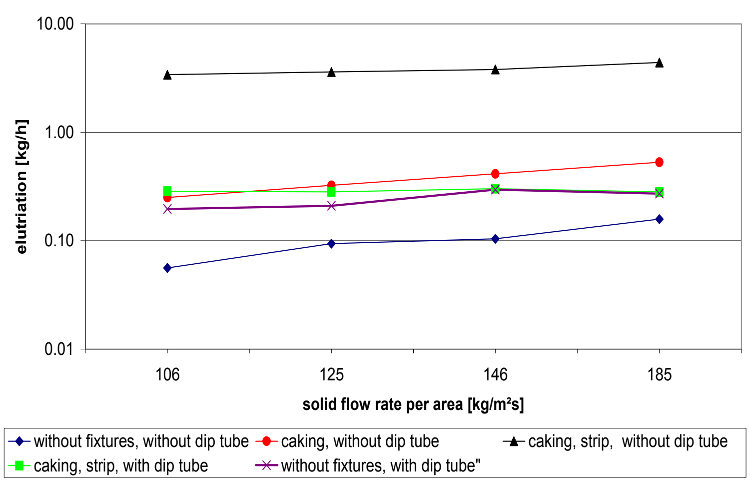

Fig. 8: Comparison elutriation

Fig. 9 shows the separation efficiency of the most important investigations. The separation efficiency is in all cases more than 99.9%.

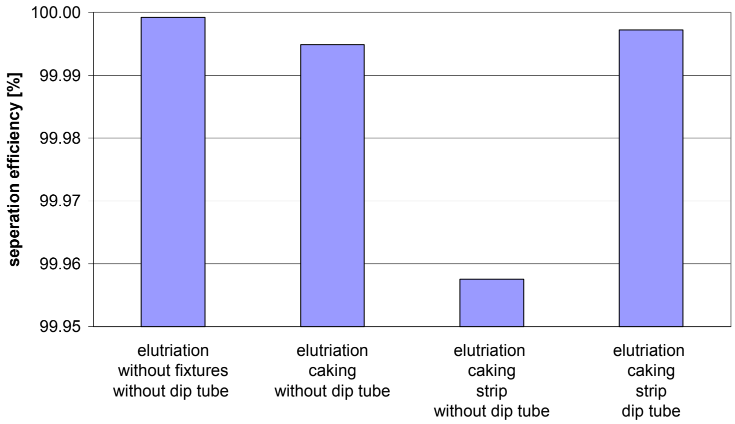

Fig. 9: Separation efficiency

The fractional separation efficiency increases with the particle diameter (Figure 10). Thus, the particle size distribution of the bed material is of big importance for the separation efficiency of the cyclone. In the investigations ´big caking, strip, dip tube´ and ´without fixtures, without dip tube´ is for each particle size greater than 63 µm the fractional separation efficiency more than 99.9%. In the investigation ´big caking, strip´ is it for particle diameters > 80µm more than 99.9%.

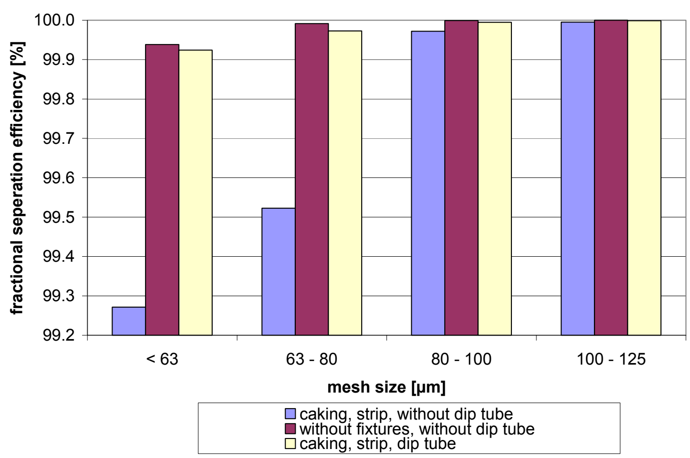

Fig. 10: Fractional separation efficiency

SUMMARY

As expected, the particle size distribution in the elutriated bed material after the cyclone is shifted to smaller sizes. This could be seen throughout all experiments. However, fractional separation efficiencies of not less than 99 % could be observed. In case of caking in the corner of the cyclone and at the same time erosion on the cyclone wall most significant decrease in the separation efficiency occurs obviously. This effect could be compensated by the use of a dip tube, although highly loaded hot gas cyclones are usually built without dip tubes.

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Summarizing, it can be stated that highly loaded cyclones for circulating fluidized beds need to be designed properly to avoid erosion in the entrance duct. Assuming the caking and erosion of the entrance duct are prevented, separation efficiency of more than 99.99 % can be expected.

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