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Granular bed filtration of high temperature biomass gasification gas

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Abstract

High temperature cleaning of producer gas from biomass gasification has been investigated with a granular filter. Field tests were performed for several hours on a single filter element at about 550 °C. The results show cake filtration on the granular material and indicate good filtration of the biomass gasification producer gas. The relatively low pressure drop over the filter during filtration is comparable to those of bag filters. The granular filter can operate with high filtration velocities compared to bag filters and maintain high efficiency and a low residual pressure.

This work is a part of the BioSOFC-up project that has a goal of utilizing the producer gas from the gasification plant in a solid oxide fuel cell (SOFC). The BioSOFC-up project will continue to the end of 2007.

Keywords: Panel bed filter; High temperature; Gas cleaning; Biomass gasification; Granular filter

1. Introduction

Granular bed filters with the possibility to provide chemical processing of the gas make the panel bed filter (PBF) promising for high temperature cleaning of gasification producer gas [1]. This cleaning concept utilizes the transient behavior of granular filtration and operates in surface filtration mode. The concept was invented in the United States [2] and further developed in Norway.

The purpose of the research is to clean a slipstream from a steam gasification reactor (the fast internally circulating fluidized bed (FICFB) gasifier at Biomasse Kraftwerk Güssing in Güssing, Austria) so the gas can be utilized in a solid oxide fuel cell (SOFC). The solid drawn boxes in Fig. 1 shows what has been tested in Güssing, Austria, while the dotted boxes indicate equipment tested in the laboratory.

The particle sensitive membranes in the SOFC, combined with the need of a minimum inlet gas temperature of 800 °C to start the reactions create a challenging filtration process. This is a part of the ongoing research project BioSOFC-up that is funded by the Research Council of Norway and Norwegian and Austrian industry. The project will continue to the end of 2007 [3].

2. The working principal of the panel bed filter

The PBF is a granular bed filter, in which particles are removed from a gas passing through a bed of unbound granular medium. In the PBF, the granular medium is supported by louvered walls that hold the granular material in place. The louvers are placed in relative compact panels. The gas flows horizontally through the bed, and the dust deposits forms a filter cake on the bed surface. The louver design creates approximately twice the filtration surface (calculated with a 32° angle of repose in the granular material [4]) compared to the frontal projected area of the filter.

The PBF differs from other granular filters in that filtration takes place on the surface. The formation of a filter cake increases the cleaning efficiency of small particles as compared to deep bed filtration. Tests have shown that cake filtration with the PBF yields high efficiencies for both low and high temperatures [5,6]. Cake filtration occurs when the deposit layer becomes thick enough so that the properties of the dust cake, rather than the granular medium, determine the filtration characteristics. The properties of the dust cake are influenced by the geometry of the filter and the gas properties as well as the particle properties and forces. The filter cake build-up generally goes through three different stages starting from clean conditions: (i) initial depth filtration, (ii) transition filtration regime, and (iii) dust cake filtration [2,7]. Filtration with high particle concentration makes the filter cake build-up go through the two first stages in a very short time [5].

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Nomenclature

C	dust concentration in flue gas (kg/m^3)
d_p	average particle diameter (m)
K_1	residual resistance of filter (m/m^2)
K_2	specific resistance of dust cake (m/kg)
K_1^*	residual resistance of filter normalized by the gas viscosity (kg/m^2 s)
K_2^*	theoretical specific cake resistance (s^{-1})
P_{Tank}	pressure in reservoir for pulse cleaning (Pa)
ΔP_{Cake}	pressure drop in the filter cake (Pa)
$\Delta P_{\mathrm{Filter}}$	pressure drop in the granular medium (Pa)
ΔP_{TOT}	total pressure drop over the filter unit (Pa)
ΔP_0	pressure drop over a clean filter (Pa)
Q	volume flow (m^3/s) (used in Figs. 4 and 5a)
t_{valve}	total open time for pulse valve during pulse cleaning (s)
T	temperature (K)
v_f	superficial gas velocity through filter cake (m/s)
$\bar{W}_A$	average accumulated mass of dust per filter area (kg/m^2)
X	median particle size for a given percentages given as subscript (in Table 1) (m)

Greek letters

μ	gas viscosity (Pa s)
ρ_{pb}	particle bulk density (kg/m^3)

Low and stable total pressure drop over the filter, ΔP_{TOT}, is maintained throughout the filtration process. Fig. 2 shows a cross-section of a filter element and the principles in: (A) filtration mode and (b) pulse cleaning mode.

When a filter cake has built up and the total pressure drop over the filter has reached a desired maximum value, the filter is cleaned by sending a short pressure pulse in the reverse direction of the flow. The pressure pulse fluidizes the granular medium and moves it slightly horizontally outwards between the louvers [8]. The dust cake, together with some of the granular medium, falls from the filter element and then the filter surface is clean.

The pressure pulse duration is a matter of milliseconds and must be calibrated so it removes the dust cake, but not the "roots" in the outside layer of the granular medium [2]. There are two parts to this problem. First, the geometry of the pulse system and the pulse reservoir pressure must be selected to deliver the required conditions for dust cake removal. This is solved through calculations and laboratory experiments. Secondly, the magnitude of the cleaning action which is necessary to detach the cake must be known. This depends on the dust properties and is calibrated on site in the field.

3. Theory of filter cake and pressure loss

The overall pressure drop over the filter, ΔP_{TOT}, is the sum of the pressure drop over the filter cake, ΔP_{Cake}, and the granular medium, $\Delta P_{\mathrm{Filter}}$:

$$\Delta P_{\mathrm{TOT}} = \Delta P_{\mathrm{Filter}} + \Delta P_{\mathrm{Cake}} \tag{1}$$

Using Darcy's law and applying K_1 as the specific resistance of the filter medium and K_2 as the specific cake resistance Eq. (1) is rewritten [9] as:

$$\Delta P_{\mathrm{TOT}} = \mu K_1 v_f + \mu K_2 v_f \bar{W}_A \tag{2}$$

where μ is the gas viscosity, v_f the gas velocity across the exposed filter surface and $\bar{W}_A$ is the mass of dust cake per unit

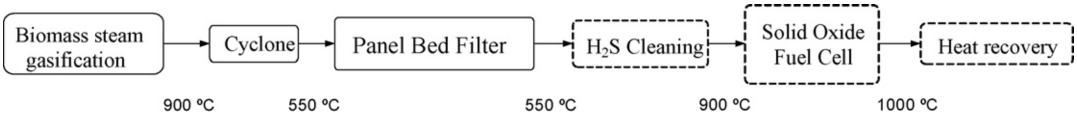

Fig. 1. Schematics of the tests.

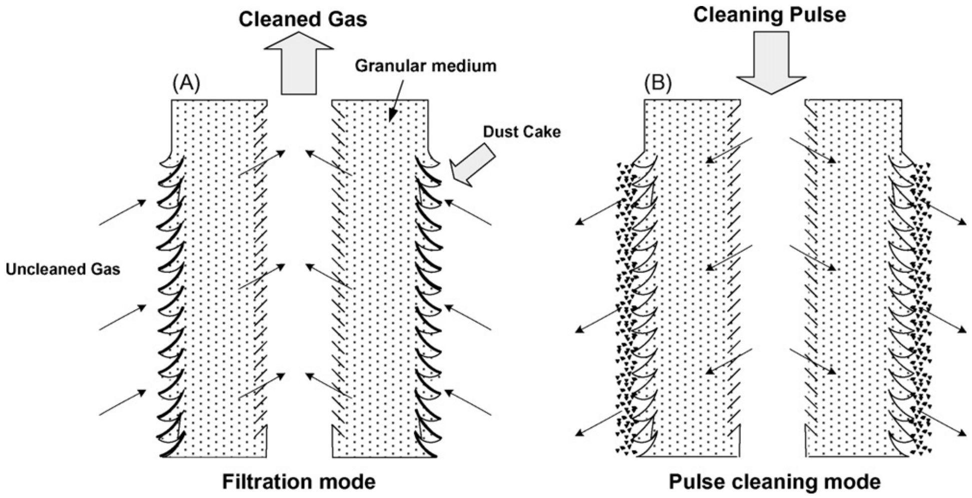

Fig. 2. Working principle of the panel bed filter.

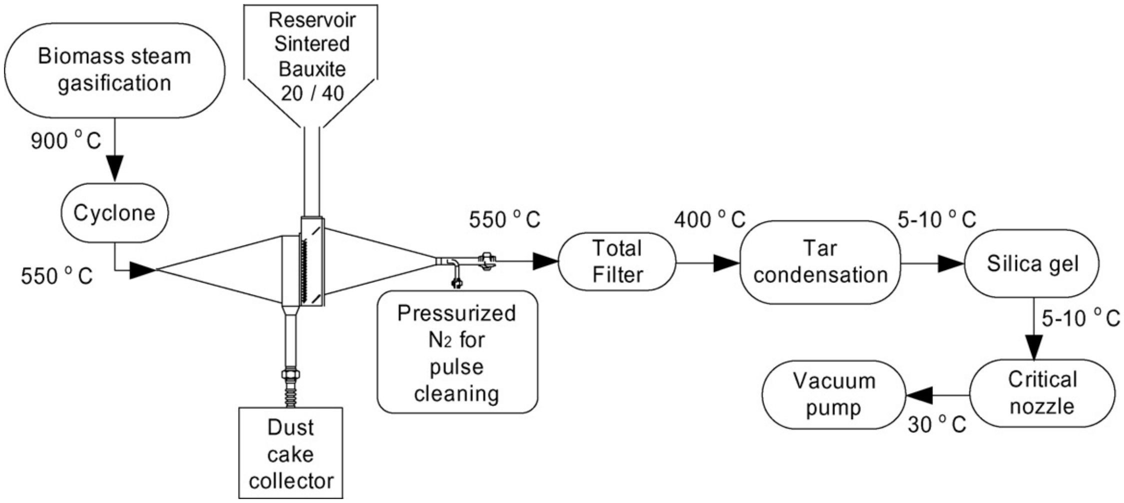

Fig. 3. Setup in Güssing.

area. Replacing the specific resistance and viscosity with K^* while combining Eqs. (1) and (2) gives:

$$K_2^* = \frac{\Delta P_{\mathrm{Cake}}}{v_{\mathrm{f}}\bar{W}_{\mathrm{A}}} \tag{3}$$

K_2^* is a function of the filter cake structure and physical parameters of the filtration process.

4. Experimental apparatus and methodology

Field tests were conducted on the gasifier at Biomasse Kraftwerk Güssing in Güssing, Austria. The gasifier is an indirectly fired steam gasification unit with a thermal input to the plant of 8 MW using wood chips as fuel. The electric efficiency is about 20% in addition to heat generated for a district heating system. The producer gas has a content of hydrogen of up to 45 vol.%, CO of up to 30 vol.%, CO_2 of about 20 vol.% and methane of up to 12 vol.% based on dry conditions. Small amounts of nitrogen are also found in the producer gas, about 2 vol.%. Burning wet wood chips as received, the H_2O content of the producer gas is about 40 vol.%, giving a lower heating value of about 9 MJ/kg [10].

In the present experiments, a slipstream was taken from the gasifier freeboard at isokinetic conditions. A cyclone was used to reduce the dust concentration from 40–60 g/m^3 (S.T.P.) in the gasifier to 2–3 g/m^3 (S.T.P.). The producer gas was cooled down from 900 to 550 °C. The temperature reduction reduces the alkali and chlorine content in the gas. This leaves H_2S and tars as the potentially most difficult compounds. Further cooling might introduce operational problems due to tar condensation on the filter. However, the critical temperature limit is highly dependent upon gasifier operation.

Downstream the PBF, a total filter, a tar condensing box immersed in an ice/water mixture, a silica gel container for water removal, a valve for flow adjustment, a critical nozzle for flow measurement, a suction pump, and a long tube for cleaned gas venting above the plant roof were used. The experimental setup is shown in Fig. 3.

The PBF used in this project was a heated module with a width of 80 mm and a height of 300 mm (240 cm^2). Actual filtration surface is up to twice this area due to the geometrical design of the louvers. Sintered Bauxite 20/40 (alumina-oxide spheres) from Norton Proppants Inc. was used as the granular filtration medium during the tests. The alumina-oxide spheres have an average diameter, d_{p}, of 662 μm and a bulk density, ρ_{pb}, of 2020 kg/m^3 [11]. Filter regeneration was conducted with on-line pulsing with nitrogen. Temperatures, pressures and filter pressure drop build-up were logged, and the mass flow and filtration velocity were calculated in real time.

5. Results and discussion

Fig. 4 illustrates the influence of filtration velocity on the pressure build-up and cycle time. The pressure fluctuations over the filter are due to pressure fluctuations in the gasification process. Fluctuations in the gasification process also influenced the dust concentration. The dust concentration was calculated gravimetrically after separating dust and Sintered Bauxite by a cascade sieve. Therefore, the results only give an approximate value of the dust concentration. The dust concentration was

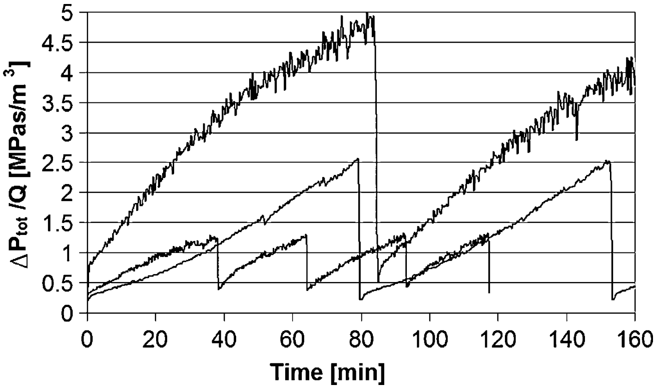

Fig. 4. Comparison of the pressure build-up at three different operating conditions 0.5 m^3/h (top curve), 1 and 2 m^3/h (bottom curve) (S.T.P.).

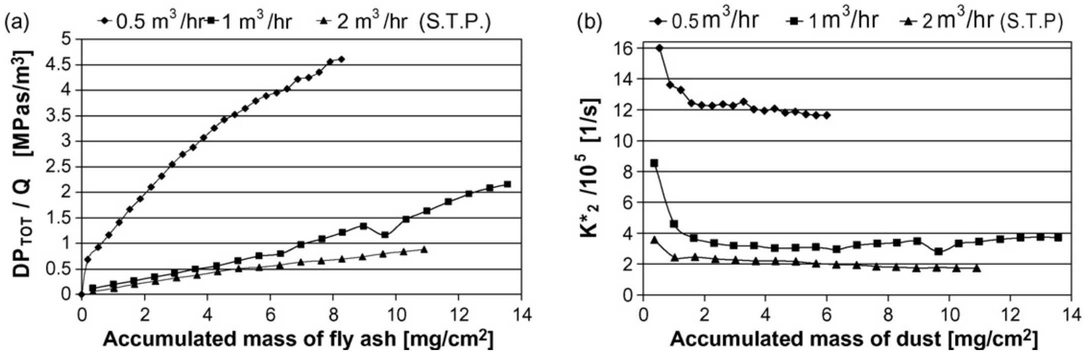

Fig. 5. (a) Pressure build-up and (b) calculated specific cake resistance at operating conditions.

Table 1
Comparison with literature values

Dust	d_p (μm)	C (g/m^3)	v_f (cm/s)	T (°C)	K_2 ($\times 10^{-5}$ s^{-1})
Present work		2.8	1.8–8.5	550	1.9–12
Fly ash from bark boiler (PBF) [2]	$X_{50.3} = 12.3$, $X_{953} = 62.2$	1	9	200	0.65
Steinkohle-Flugasche [fly ash from hard coal] (ceramic filter element) [12]	$3 \leq d_p \leq 100$		3	600	1.9
NaCl, NH_4Cl, Al_3O_2 (HEPA filter, surface filtration mode) [13]	0.5–2		2.45–3		2–20
Silica (metal fiber fleece) [14]	$X_{50.0} = 0.53$, $X_{90.0} = 1.66$	1	2.5	600	0.18
Quartz (ceramic fiber fleece) [14]	$X_{50.0} = 0.7$, $X_{90.0} = 2.74$	25	2.5	600	0.18

used to calculate the accumulated mass of dust with time and the specific cake resistance.

In Fig. 5a the pressure build-up is plotted against the accumulated mass of dust for the different filtration conditions while in Fig. 5b the calculated specific cake resistance is plotted.

Fig. 6 shows the pressure before and after the pulse cleaning of the filter and the variation in the specific cake resistance. The 8 h of operation show a steady residual pressure after the cleaning cycle which indicates that the pressure pulse used for the regeneration of the filter is satisfactory. The pressure pulse (P_{Tank} 1 bar and t_{valve} 109 ms) were within the range of earlier tests conducted with horizontal pulse cleaning [2,5,7].

Bag house filters operate normally with superficial velocities in the range of 0.1–2 cm/s. The PBF can operate at higher temperatures and velocities with comparable pressure loss and filtration efficiency. No detectable weight increase on the total filter (in mg) was measured after the tests so the dust concentration after the filter could not be calculated.

The calculated specific cake resistance is found within the higher range of published values, Table 1. Note the high values of the filtration velocities for the PBF.

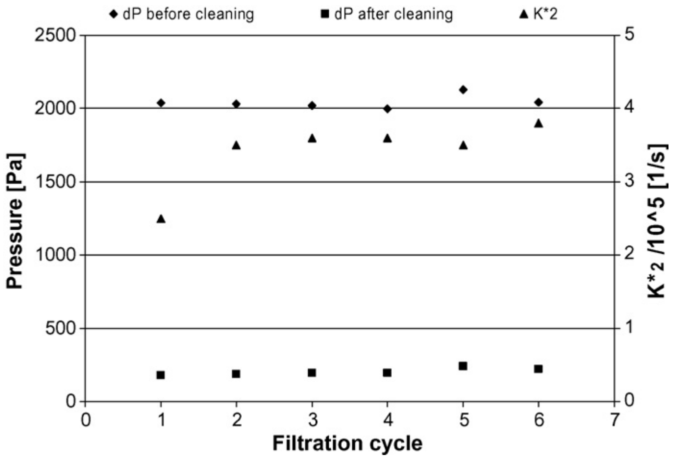

Fig. 6. Variations in specific cake resistance and residual pressure loss during a filtration cycle with a volumetric flow rate of 1 m^3/h (S.T.P.).

6. Conclusions

Field tests were performed for several hours on a single filter element at about 550 °C. These tests show that dust cake is being formed on the granular surfaces and indicate good efficiency for the cake filtration. The tar in the producer gas did not condense, inflict the dust filtration, or the filter cleaning.

The results indicate good dust removal from the biomass gasification producer gas with a relatively low pressure drop over the filter. The pressure drop over the PBF is competitive to those of bag filters even with considerable higher filtration velocities. The specific cake resistance is in the higher range compared with literature values of other high temperature filters.

Plans for further work in 2007 include the construction and testing of a larger PBF designed for 10 m^3/h. This panel bed filter unit will be used in tests together with an H_2S removal unit to clean the gasification producer gas in Güssing at 500 °C before heating the gas and utilizing it in an SOFC.

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