Experimental Investigation of a New Granular Filter Design

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ABSTRACT

The Panel Bed Filter is an alternative particle removal unit with the potential for high temperature filtration [1]. The filter is operating in surface filtration mode and uses sand or other granulated material as a filtration medium.

This paper presents the experimental results from laboratory investigations of a new louver design for the Panel Bed Filter. A filter unit has been built in the laboratory at NTNU using filter tray louvers [2]. Alumina spheres were used as granular media. The unit was tested using SAE-fine test dust (ISO 12103-1, dp = 12.6 μm). The results showed collection efficiency above 0.9978 for filtration velocities of 3.85 to 14.8 cm/s.

The results showed that the Panel Bed Filter can operate with higher filtration velocities compared to bag house filters while maintaining high efficiency and low residual pressure.

Keywords: granular filtration, surface filtration, cake filtration

1 INTRODUCTION

In recent years more focus has been placed on the environmental consequences of human activities. The climate change and the use of alternative energy sources as oil substitutes have attracted considerable attention. This has led to the development of EU strategies for Renewable Energy Sources (RES) that aims to increase the use of these resources from 6% (1997) to 12% (2010). In 2007 the EU states approved a proposal from the EU Council to approve a new renewable energy target equal to a 20% share of the total EU energy consumption by 2020 [3].

Substantial resources have, therefore, been used towards the development of advanced technology for highly efficient power generation from renewable energy sources. This includes the removal of particulates and other emissions into the environment from the engineering process and to protect the process-equipment from erosion and corrosion. The public awareness of the environment has also resulted in the development of stricter laws and legislation. Reducing the particle emission into the atmosphere is, therefore, of great industrial importance.

Granular bed filters that have the potential to provide both dust removal and chemical processing of the gas which makes the Panel Bed Filter a promising alternative for high temperature gas cleaning. The Panel Bed Filter utilizes the transient behavior of granular filtration and operates in the surface filtration mode. The filtration is similar to cake forming filters such as bag house filters, but they are fundamentally different from the bulk of granular filters based on deep bed filtration.

The Panel Bed filter is made up of louvered walls, somewhat resembling venetian blinds that hold the unbound granular material in place. The louvers are stacked on top of each other into tall, relatively narrow panels which create a vertical wall of granular beds. The first Panel Bed Filter concept was invented by Prof. A. Squires [4] after he discovered that a sufficient sharp reverse puff of gas, referred to as a puffback, could renew the surfaces on the gas entry side of the filter through a new mode of soil failure.

2 WORKING PRINCIPLE

Figure 1 shows the working principle of the Panel Bed Filter. The gas flows horizontally through the bed, and the dust deposits form a filter cake on the bed surface. The dust collection for cake forming filters generally takes place in four regimes: i) clean filter filtration, ii) initial depth filtration regime, iii) transition filtration regime, and iv) cake filtration regime. Under high particle loading conditions, the process will often pass through the first three regimes very quickly.

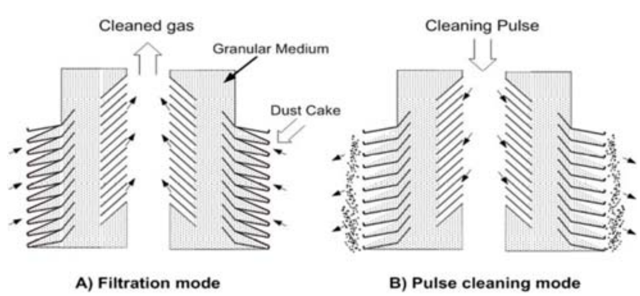

Figure 1: Working principle of the Panel Bed Filter

The filter cake is periodically removed with the relatively short pressurized pulse. During the puffback the granular medium undergoes a mass movement toward its

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free surface which removes the filter cake along with some of the granular medium. The length and intensity of the puffback are calibrated to remove the filter cake without removing the cake roots in order to start the next filtration cycle in the cake filtration regime.

2.1 Pressure drop theory

The overall pressure drop over the filter, ΔP_{TOT}, can be described as the sum of the pressure drop over the filter cake, ΔP_{Cake}, and the granular medium, ΔP_{Filter}.

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

By defining K_1 as the specific resistance of the filter medium, K_2 as the specific cake resistance and applying Darcy's law, the overall pressure drop can be defined as:

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

μ is the gas viscosity, v_f is the gas velocity across the exposed filter surface and $\overline{W}_A$ is the mass of dust cake per unit area. Replacing the specific resistance and viscosity with K^* while combining *Equations 1 and 2* gives:

$$K_2^* = \frac{\Delta P_{Cake}}{v_f \overline{W}_A} \tag{3}$$

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

3 LOUVER DESIGN

The original filter concept described by Squires [5] consisted of two sets of louvers defining a single bed of thickness about 25 mm. Later louver designs have increased the filter surface per louver in order to reduce the number of louvers per filter unit, simultaneously enhancing the overall filter surface. The work has increased the filter competitiveness through cost effective production and plant compactness.

Figure 2 shows the Wishbone louver and the L10-56 louver. The Wishbone louver [6] was the first louver used in a demonstration plant [7] and the louver performance has been used as a reference for later designs. The L10-56 louver is the latest louver design that has been experimentally studied prior to the present work.

The filter tray is a new louver design [2] that had not been experimentally tested before the present work. Theoretical estimates show that the filter tray design significantly increases the filtration surface area compared to the L10-56 louver and has the potential to operate at high filtration velocities [8].

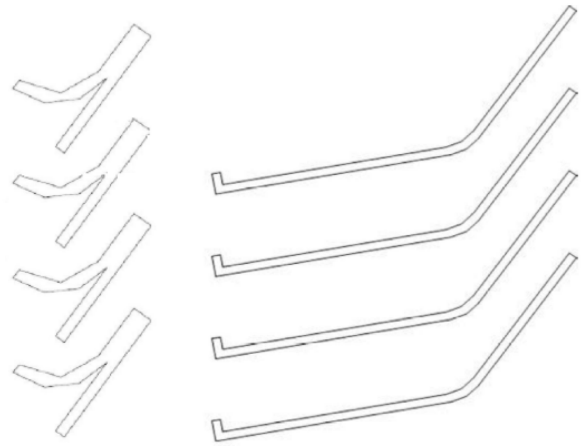

Figure 2: Wishbone and L10-56 louver designs

4 EXPERIMENTAL SETUP

4.1 Filter tray louver design

Figures 3 and 4 show the filter tray design that was built at NTNU. The filter was modified from its original design described by Squires [2][8] in order to use spheres of alumina as granular material (Sintred Bauxite 20/40, Saint-Gobain Proppants). Figure 3 shows the 300 μm meshed grid that supported the bed and the plate at the bottom of the clean gas volume. The plate was used to adjust the clean gas volume to achieve uniform spill during the calibration of the puffback. Figure 4 shows the geometry of the 80 mm vide louver.

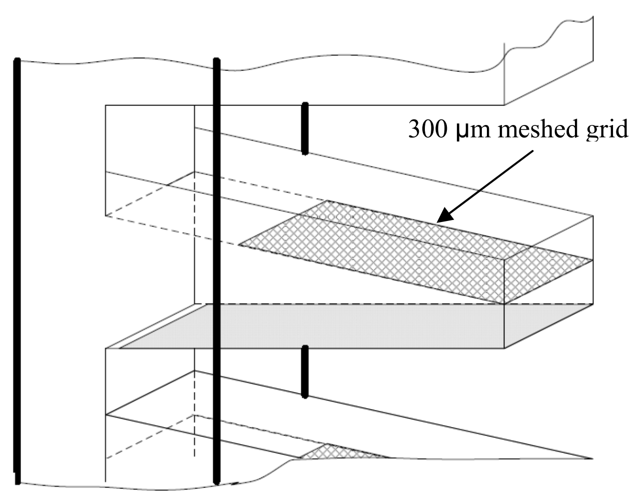

Figure 3: Principles of the filter tray louver design

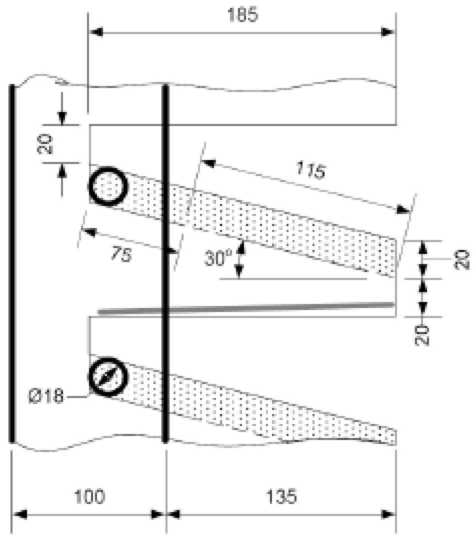

Figure 4 Side view of the filter tray louver

4.2 Laboratory setup

Figure 5 shows the experimental setup. Compressed air at approximately 7 bar passes through three Domnick Hunter filters whereby oil and moisture, coarse particles and fine particles are removed respectively. The pressure is reduced in a reduction valve before entering the particle dispenser (Palas gmbh, RBG 2000). The filter inlet cone was built out of 3mm Lexan, so the cake build up could be seen during the filtration (at S.T.P.) of the dust laden gas. A total filter (Pall, Type A/E Glass Fiber) was placed after the Panel Bed Filter to gravimetrically determine the dust concentration in the cleaned gas. The gas flow was manually controlled by two parallel valves and measured with a calibrated nozzle before going through the fan. A LabVIEW program was made to log the temperatures, pressures and flow rate.

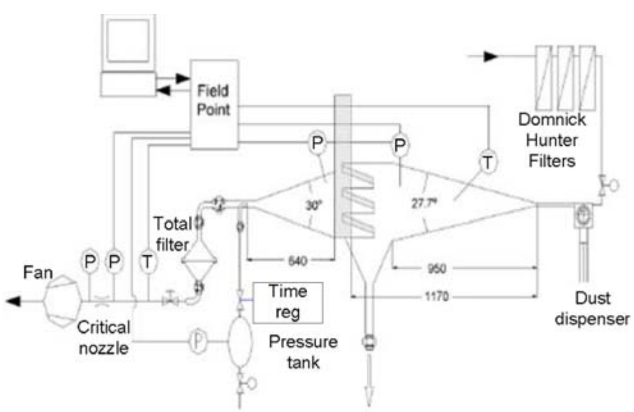

Figure 5: Laboratory setup

5 RESULTS AND DISCUSSIONS

Table 1 presents an overview of the results of the present study. The superficial velocity is defined as the rate of gas flow divided by projected vertical frontal area of the panel [panel height x panel width]. The length of each filtration test varied from a few hours to several days.

Test number	Filtration velocity	Superficial velocity	Dust concentration	Efficiency
#1	5.03 cm/s	5.07 cm/s	6.87 g/m^3	0.99786[a]
#2	4.97 cm/s	5.01 cm/s	5.72 g/m^3	0.99951
#3	4.99 cm/s	5.03 cm/s	3.53 g/m^3	0.99999
#4	3.85 cm/s	3.87 cm/s	7.01 g/m^3	0.99999
#5	6.92 cm/s	6.98 cm/s	5.58 g/m^3	0.99927
#6	14.8 cm/s	14.9 cm/s	5.42 g/m^3	0.99979

a) Started filtration without filter cake roots (clean bed)

Table 1: Overview of experiments

Figures 6 and 7 shows the pressure buildup, the filtration velocity and the specific cake resistance of test #6.

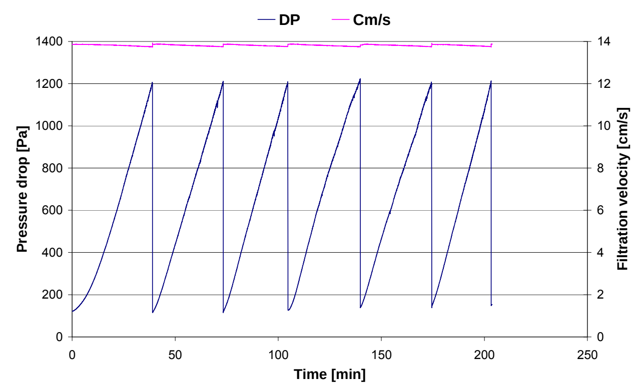

Figure 6: Pressure buildup of test #6

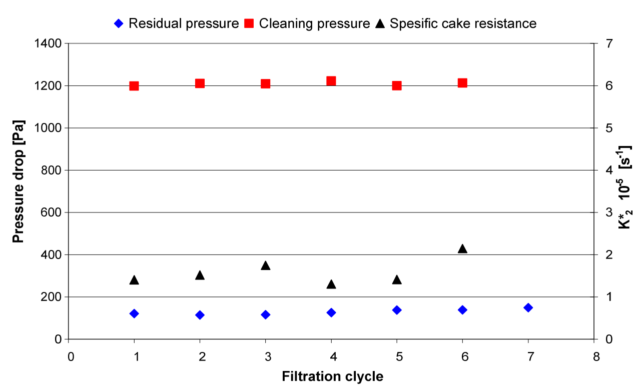

Figure 7: Cycles and K^*_2 value of test #6

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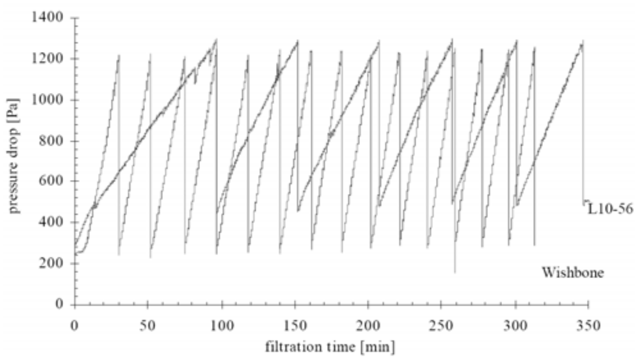

Figure 8: Comparison of Wishbone louvers (high frequency curve) and L10-56 louvers (low frequency curve) [9]

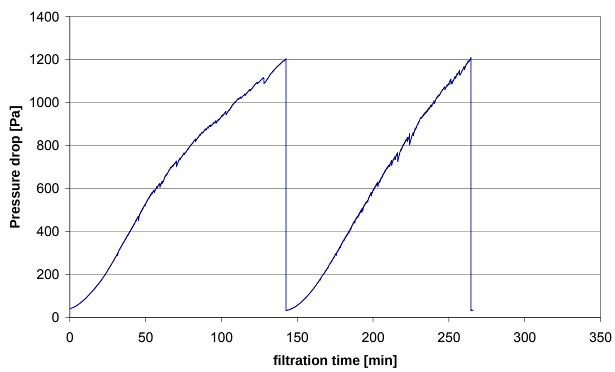

Figure 9: Pressure build up of test #2

Figure 8 shows the pressure build up of the Wishbone louver and L10-56 louver using SAE-fine dusts with a concentration of 5 g/m^3 and a superficial filtration velocity of 5 cm/s.

Figure 9 shows the pressure buildup of the filter tray louver (test #2), using the same dust at a concentration of 5.72 g/m^3 and a superficial filtration velocity of 5.01 cm/s.

The filtration tests with the wishbone and L10-56 louvers were made with the same dust and experimental setup as was used for the present study [9]. The approximately equal specific cake values also indicate equal filtration conditions with similar cake properties.

A comparison of figures 8 and 9 clearly shows the lower residual pressure of the filter tray design compared to the wishbone and L20-56 louvers. The time between each filtration cycle of the filter tray design is about twice that of the L10-56 louver and approximately seven times that of the wishbone louver. The increased time of the filtration cycles allows for longer operation in the cake filtration regime where the collection efficiency is highest.

6 SYMMARY AND CONCLUSIONS

The experimental study of filter tray louvers for the Panel Bed Filter showed high collection efficiency for filtration velocities up to 14.9 cm/s. The applied velocities are extremely high compared to bag house filters which normally operate in the area of 1.0 to 2.5 cm/s. The residual pressure drop over the filter has been significantly reduced with the new design. The length of the filtration cycle was increased compared to previous designs which allows for longer filtration in the cake filtration regime where the collection efficiency is highest.

7 ACKNOWLEDGMENTS

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