# CHARACTERIZATION OF DUST LAYER FORMED ON THIN INORGANIC POROUS MEDIA

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## ABSTRACT

In a low Reynolds number regime, the structure of dust layer formed on the filter surface generally dominates effective filtration process. The present study investigated specific resistance ($K_2'$) of dust layer and its porosity ($\varepsilon_c$) for three different inorganic filter media; a fly ash composite filter, a metal fiber filter and a stainless filter. The specific resistance ($K_2'$) of dust layer increased proportionally with the increase of filtration velocity, while the cake porosity ($\varepsilon_c$) decreased, possibly due to the compressible effect of dust layer.

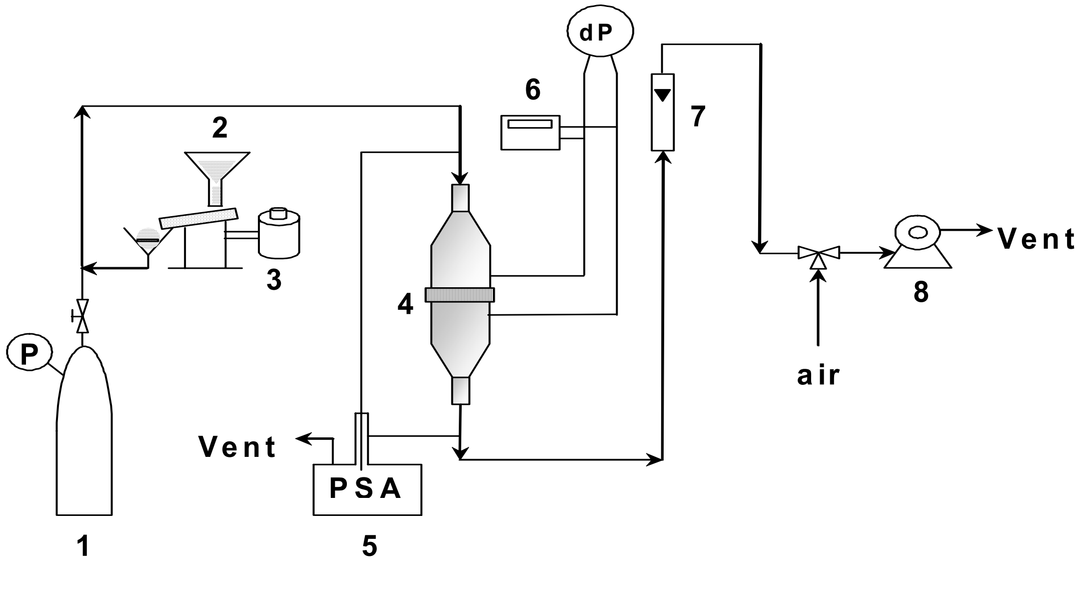
The most porous medium of metal fiber filter presented the least resistance, which ascertained that the structure of filter medium would directly influence dust deposition. The feed dust loading resulted in an adverse effect; low concentration of dust formed more dense structure. In accordance, it is more reasonable to estimate the specific resistance in order to predict the cake structure for dust filtration.

## 1. INTRODUCTION

Elimination of particulate materials from gaseous flow is of great industrial importance in recent days. Filtration is one of well known methods for gas-solid separation. In the separation of airborne dust by using porous filter media, the structure of dust layer instantaneously formed on the filter surface during the filtration directly affects the overall filtration performance by acting as an additional fixed porous medium [1]. Thus, in order to design the optimum filtration system, it is essential to understand the dust deposition mechanism. This study attempted to find the effect of dust layer on the filtration efficiency by using three different inorganic filters. In the regime of laminar flow, the structure of dust layer was verified by estimation of the cake porosity based on a modified Kozeny-Carman equation [2] and of the bulk porosity with external size of the cake.

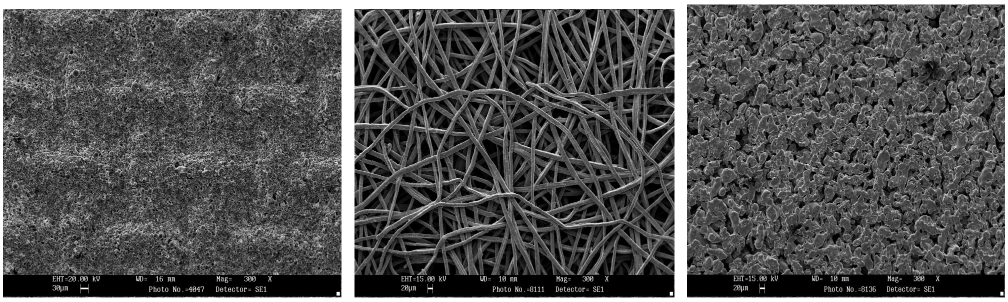
## 2. EXPERIMENTAL

Test set-up for filtration is described in Fig. 1. Compressed dry air (1) was used to create a simulate flue gas stream. Fly ash particles ($dp_{50}$ = 8 ㎛) classified through a 26 ㎛ stainless sieve was fed into the gas stream through a vibrating feeder (2). Dust feed loading was adjusted by the vibration intensity of the electric power slidax (3). The filtration system includes a filter module (4), an electronic micro-manometer (6) or a mercury manometer (dP) and a rotameter (7). The pressure drop across the filter media was measured as a function of air flow velocity and dust concentration at the ambient room temperature (20~27℃). Filtration velocities varied from 0.10 to 0.19 m/s. The effective diameter of dust collection area was designed to be 3.2 cm. Surface appearance of the porous filters was as shown in Fig. 2: fly ash composite filter (FA filter), metal fiber filter and stainless filter.




1. Air cylinder 2. Vibrating feeder
3. Slidax 4. Filter module
5. Particle size Analyzer 6. Micro-manometer
7. Gas rotamer 8. Vaccum pump

**Fig. 1.** Schematic diagram of apparatus for dust filtration.



(a) FA filter (b) Metal fiber filter (c) Stainless filter

**Fig. 2.** Surface observation of test filters indicating structural difference.

The FA ceramic composite filter was prepared by dip-coating of coal fly ash particles on the stainless steel woven mesh substrate (#Tyler standard #100). The spherical ash particles are filled in between wire and wire of the mesh, showing a solid packed bed structure [3]. The metal fiber filter was the fabricated fiber of Fe-Al-Ni alloy under the vacuum. Thus it gives a very porous 3-dimensional assemblage. The stainless filter was commercially made of thin compressed stainless wire by vacuum sintering at the high temperature, and micro-pore channels are quite uniformly distributed through out the filter.

The pores of the filter media was analyzed by Capillary flow porometer (USA, CFP-1100-AEL, PMI), and filter porosity (ε) was calculated as the following definition:

$$\varepsilon = 1 - \frac{\text{solid weight made of filter medium}}{\text{solid weight of the same volume with filter medium}} \tag{1}$$

The estimated pore characteristics are summarized in Table 1.

**Table 1.** Mean flow pore diameter and porosity of three filter media

| | FA filter | Metal fiber filter | Stainless filter |
|---|---|---|---|
| Mean flow pore diameter (μm) | 3.37 | 30.47 | 1.86 |
| Porosity (%) | 54.3 | 82.4 | 46.8 |

The test dust, coal fly ash, was classified with a stainless sieve (Tyler standard #500) of which aperture size was 26μm, and then size analyzed through a laser diffraction method by Malvern Mastersizer (UK, Version 2.19). It revealed about 8 μm of median diameter with a mono dispersive distribution. The visual observation by using SEM indicated the dust particles mostly spherical and not much aggregated by themselves. It may be good for the dust filtration study.

## 3. RESULTS AND DISCUSSION

### *3.1 Specific resistance ($K_2'$)*

Specific resistance ($K_2'$) for a dust layer could be defined from the filter drag model [4]. In Eq. (2), $S_E$ represents the drag of the clean fresh filter medium, and the second term ($K_2'\mu W$) is the resistance arisen from dust deposition.

$$S = \frac{\Delta P}{u} = S_E + K_2^{'}\mu W \tag{2}$$

In this work, $K_2'$ was evaluated in terms of filtration velocity and dust feed concentration. The values of $K_2'$ for three test filters increased with the increase of velocity as seen in Table 2. The absolute value of $K_2'$ was the largest in the cake on the stainless filter, but the increasing rate with velocity was the steepest in the FA filter. Thus, the structure of the cake should depend closely on the structure of substrate filter media. More shift dust flow impaction, in general, might form more compact the previously formed dust layer on the filter media. Amongst three test media, the metal fiber filter with the largest pore and porosity had the least value of specific resistance. It may be because as fine particles would not migrate with the main flow stream, they would be dominated by Brownian motion rather than inertia and infiltrated inside pore channels of the cake, ultimately reducing open size of pores.

Table 3 shows that on the whole, low concentration of feeding brought high resistance for all filters as could be predicted from the reference [5]. Increase in the feed concentration results in simultaneous arriving more particles at the pore channels, and the particles may bounce against the medium surface or on the particles already be there. The following dust particles may then penetrate into the accumulated dust layer finding a more stable position. In accordance, the dust layer deposited close to the medium surface plays a role of depth filtration as like another filter medium and forms a further compact dust layer. However, in the view of overall specific resistance of average dust cake, as increasing the concentration, the blocking of the pores must be basically decreased.

FA composite filter is composed of granular bed and excellent in permeation of fluid flow. Dust collection is made mainly by dust layer rather than filter itself. Thus, as the concentration increased, the porosity of the filter cake was increasing and the resistance relatively decreased.

The most porous metal fiber filter does not form the bridge of particles, so that quite a large amount of dust would deposit in the inside of pore channels and penetrate the medium at the same time, thereby decreasing the collection efficiency and the resistance. The drop of specific resistance of the metal fiber filter does not seem to be by increase of cake porosity, but due to frequent collapse of fragile dust layer.

**Table 2**. Specific resistance ($K_2'$) of dust layer with filtration velocity (feed dust concentration: 5 $g/m^3$)

| Filtration velocity (m/s) | $K_2'$ (m/kg) | | |
|---|---|---|---|
| | FA filter | Metal fiber filter | Stainless filter |
| 0.10 | $3.50 \times 10^9$ | $1.21 \times 10^9$ | $8.51 \times 10^9$ |
| 0.15 | $5.89 \times 10^9$ | $1.57 \times 10^9$ | $9.13 \times 10^9$ |
| 0.19 | $8.07 \times 10^9$ | $1.87 \times 10^9$ | $10.95 \times 10^9$ |

**Table 3.** Specific resistance($K_2'$) of dust cake with feed concentration (filtration velocity: 0.1 m/s)

| Dust concentration ($g/m^3$) | $K_2'$ (m/kg) | | |
|---|---|---|---|
| | FA filter | Metal fiber filter | Stainless filter |
| 5 | $3.50 \times 10^9$ | $1.21 \times 10^9$ | $8.51 \times 10^9$ |
| 10 | $1.79 \times 10^9$ | $1.13 \times 10^9$ | $3.93 \times 10^9$ |
| 15 | $1.38 \times 10^9$ | $1.03 \times 10^9$ | $3.24 \times 10^9$ |
| 20 | $1.21 \times 10^9$ | $0.94 \times 10^9$ | - |

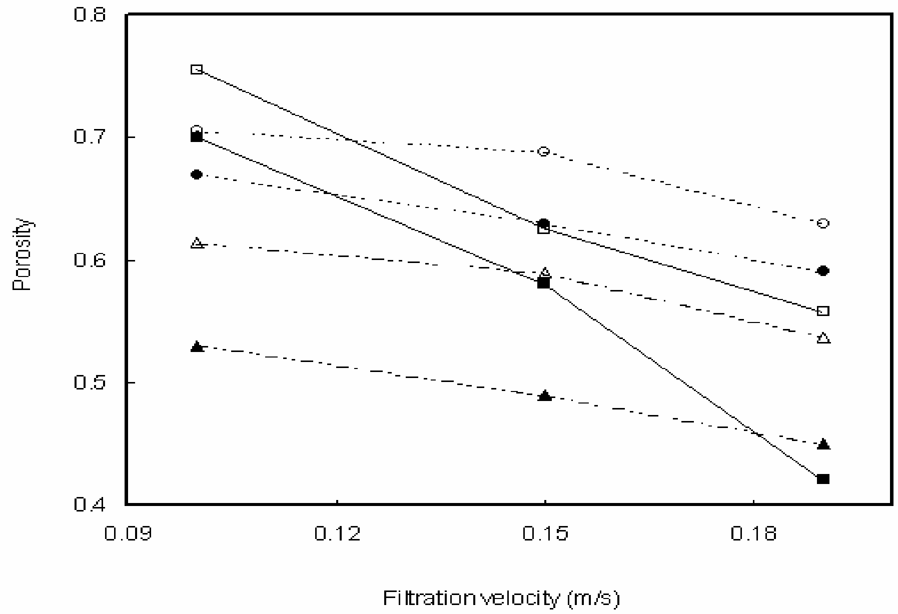
*3.2 Cake porosity ($\varepsilon_c$)*

The porosity of dust layer during filtration is important because it determines flow resistance and dust detachment by regeneration. Nevertheless it is almost impossible to determine the porosity by measuring devices because the dust layer formed on the filter media is apt to be easily broken and its compressibility must be considered. Thus, this study regarded the dust layer as a solid granular bed, and the cake porosity ($\varepsilon_c$) have been calculated from the modified Kozeny-Carman equation (Eq. (3)). It then was compared with bulk cake porosity ($\varepsilon_b$) described in Eq. (4). Fig. 3 shows the effect of velocity and dust feed concentration on the porosity of three filters. The porosities, $\varepsilon_c$ and $\varepsilon_b$ are decreasing with increasing the filtration velocity, which may indicate more compact structure of the cake at high velocities. On the whole, the bulk porosity ($\varepsilon_b$) was estimated larger than $\varepsilon_c$. It may be in the evaluation of $\varepsilon_b$ due to skip of consideration of potential mechanisms including particles' interaction and flow condition in practical filtration process. Despite the same height and mass density of dust, high filtration velocity may compact the cake more effectively resulting in a denser structure, and dust particles in a low dust concentration would flow along the fluid stream and infiltrate through the pore paths, ultimately changing the pore distribution. Therefore, in the analysis of dust layer, the porosity obtained from the experimental specific resistance should be more reliable than bulk prosity.

$$K_2{}' = \frac{180 L_c}{D_{c.p}{}^2 W} \frac{(1-\varepsilon_c)^2}{\varepsilon_c{}^3} \tag{3}$$

$$\varepsilon_b = 1 - \frac{W}{\rho_p L_c} \tag{4}$$

As a result of the experiment in a constant filtration velocity and feed concentration, the flow resistance against the filter media was relatively low in FA filter, a thin porous membrane filter. Thus, the surface dust layer was seldom affected by filter medium and formed a highly porous fixed bed. The cake structure of metal fiber filter depends greatly on how dense lump and bridging of dust particles on the filter surface occurs. More or less thick (1.65 mm) stainless filter showed high flow resistance because fine dust blocks the filter pores since initial stage of filtration. In the long run, the dust layer has been consistently compacted resulting in a low porosity.


Porosity
0.8
0.7
0.6
0.5
0.4
0.09
0.12
0.15
0.18
Filtration velocity (m/s)

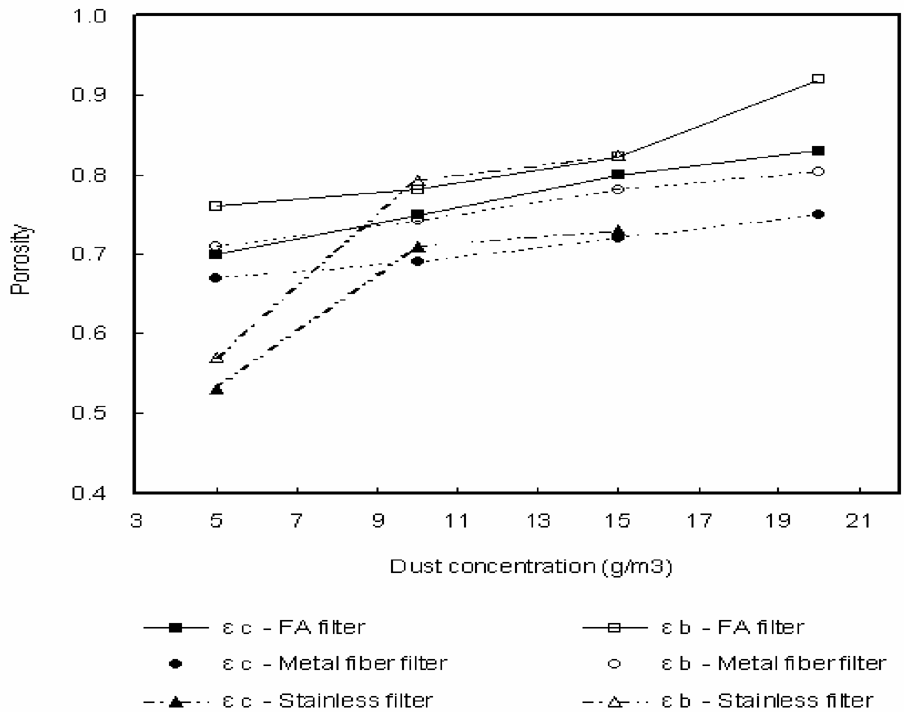

Porosity
1.0
0.9
0.8
0.7
0.6
0.5
0.4
3
5
7
9
11
13
15
17
19
21
Dust concentration (g/m3)
ε c - FA filter
ε b - FA filter
ε c - Metal fiber filter
ε b - Metal fiber filter
ε c - Stainless filter
ε b - Stainless filter

**Fig. 3**. Comparison of dust cake porosity ($\varepsilon_c$) and bulk cake porosity ($\varepsilon_b$) with filtration velocity (at the dust conc. of 5 g/m$^3$) and dust concentration(at the filtration vel. of 0.1 m/s).

## 4. CONCLUSIONS

This work presents partial experimental results on the cake formation and its structure according to the filtration velocity in laminar flow region and dust concentration for three different porous filters. It was found that the specific resistance ($K_2'$) and the porosity of the dust layer would be closely affected by filtration velocity and dust feed concentration for all kinds of filter media. As for estimation of cake structure, the structural porosity evaluated from the modified Kozeny-Carman relation might be better to understand the practical filtration mechanism.

## NOMENCLATURE

| | | |
|---|---|---|
| $D_{c.p}$ | Particle diameter of dust layer | m |
| $K_2'$ | Specific resistance of dust layer | m/kg |
| $L_c$ | Dust layer thickness | m |
| $\Delta P$ | Pressure drop | N/m$^2$ |
| t | Filtration time | s |
| S | Filter drag | N-min/m$^3$ |
| $S_E$ | Clean filter drag | N-min/m$^3$ |
| u | Superficial fluid velocity | m/s |
| W | Areal mass density | kg/m$^2$ |
| $\varepsilon$ | Porosity of medium | |
| $\varepsilon_b$ | Bulk porosity of dust layer | |
| $\varepsilon_c$ | Real porosity of dust layer | |
| $\rho_p$ | Particle density | kg/m$^3$ |
| $\mu$ | Viscosity | Ns/m$^2$ |

## ACKNOWLEDGEMENT

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