CHAPTER 8

ENGINEERING APPLICATION

A fibrous filter is composed of cylindrical fibers interspersed in the path of air flow, and dust particles are collected onto these fibers by the mechanisms of interception, inertial impaction, diffusion and etc. The fibers in the fibers are loosely packed in a substantial volume, thus presenting a fairly long path along which air must pass on its way through the filter, The filter is widely used in air-conditioning and other applications where the dust loading, or particle-number concentration, is relative small and where the highest efficiency is demanded. Wider usage of this type of filter is somewhat limited by the difficulty with which fibrous filters are cleaned. Current efforts by the industry to develop effective methods for repetitive cleaning of fibrous filters are motivated by the substantial advantages of this particle-gas separation method.

The pattern of particle deposition in a fibrous filter is highly complex and intrinsically connected with the collection efficiency, loading capacity and permeability of the system. Therefore, reliable analysis of the deposition process and its effects on system parameters are required for rational design, optimization, innovation, operation and troubleshooting.

In the present work, convectional diffusional deposition of polydisperse aerosols on a dust loaded fiber was simulated stochastically.

A single fiber collection efficiency under dust loaded conditions was evaluated by using the simulation results. The η_{DIM}/η_{DI} was then be approximated by the following equation,

$$\eta_{DIM}/\eta_{DI} = 1 + \lambda m \qquad (8.1.1)$$

and the collection efficiency raising factor λ are listed in Table 7.5 for various filtration conditions.

The efficiency of a dust-loaded fibrous filter as a whole can be related to that of a single fiber η_{DIM} in the following way. Consider a filter bed consisting of a volume of fiber compressed so that they occupy a relative volume α of the bed. The crossectional area is A and the thickness h. The filtering action takes place continuously throughout the thickness of the filter as each fiber collects a fraction η_{DIM} of the particles passing by it.

At the initial stage of filtration, the collection efficiency of the filter is given by

$$E = 1 - \frac{c_e}{c_i} = 1 = \exp\left[-4\alpha\eta_{DI}\ h/\pi D_f(1 - \alpha)\right] \qquad (8.1.2)$$

where c_i is the influent concentration of aerosol and c_e is the effluent concentration of aerosol. However, under dust loaded conditions, the above equation is no longer applicable because the collection efficiency of each fiber increases with dust loads, causing, the collection efficiency of the filter to change with time and position. Yoshioka et al. (1969) derived the analytical solution for the case of combined inertial-interception and their method is adapted to the case of convective diffusion.

From mass balance, the fasic equations for the process are

$$\frac{\partial c}{\partial x} = -\frac{4}{\pi}\frac{\alpha}{1-\alpha}\frac{1}{D_f}\eta_{DIM}c \tag{8.1.3}$$

$$\frac{\partial c}{\partial x} = \frac{1}{u}\frac{\partial m}{\partial t} \tag{8.1.4}$$

where c is the mass concentration of aerosols, α is the packing density of the filter at dust loaded conditions, m is the accumulated mass of particles in unit filter volume and u is the air velocity. η_{DIM} in the equation is the only term affected by dust loads m, since its definition is the same as that in the simulation.

Since η_{DIM} can be expressed by a linear function of m, equations (8.1.3) and (8.1.4) are analytically solvable with the following initial and boundary conditions and the solution is given by equation (8.1.9) (Yoshioka et al, 1969).

$$\text{Initial condition : at } t = 0,\ m = 0$$

$$x = 0,\ c = c_i \tag{8.1.5}$$

$$x = h,\ c = c_e$$

$$E_M = 1 - \frac{c_e}{c_i} = 1 - \frac{\exp(-\lambda A\, c_i\, ut)}{\exp(-\lambda A\, c_i\, ut) + \exp(Ah) - 1} \tag{8.1.6}$$

$$\text{with } A = \eta_{DI}\frac{4\alpha}{\pi D_f(1-\alpha)}$$

Here η_{DI} is the collection efficiency of a clean single fiber given by Stechkina and Fuchs (1966), that is

$$\eta_{DI} = 2.9K^{-\frac{1}{2}}Pe^{-\frac{1}{3}} + 0.624Pe^{-1} + 1.24K^{-\frac{1}{2}}R\ Pe^{-\frac{1}{2}} \tag{8.1.7}$$

The average dust load at any instant is given by

$$\bar{m} = \frac{1}{h}\int_o^h m dx = \frac{u}{h}\int_o^h \left(\int_o^t \frac{\partial c}{\partial x} dt\right) dx \qquad (8.1.8)$$

To calculate the predicted collection efficiency by equation (8.1.6), an engineer must have the value of λ for this filtration conditions, In practical, it will be sueful if the value of λ is predictable from filtration conditions, From this standpoint, λ was plotted against Pe in Figure 8.1 - 8.4. These figures show that λ increase significantly with increasing Pe.

Illustration

A filtration defined by the parameter in Table 8.1 is chosen to demonstrate how the collection efficiency of a filter can be estimated from that of a dust loaded filter. Assume log-normal particle size distribution. Also assume that the polydisperse aersols may be represented by a single Peclet number, namely that corresponding to mean particle size. The diffusion coefficient was obtained from Table 13, pp. 148 of Fuchs (1966), and the collection efficiency of a clean fiber η_{DI} was calculated from equation (8.1.7).

The values of E_M, m and α are calculated from equation (8.1.6) and (8.1.8) and listed in Table 8.2. Calculation of the integral of the right hand side of equation (8.1.8) is performed routinely with standard numerical methods (quadrature, Simson's rule etc.).

From the above results we see that the overall collection efficiency E_M of filter increases markedly with dust loads within a few hours, E_M rises from 99.98633 to 99.99999% . Furthermore the collection

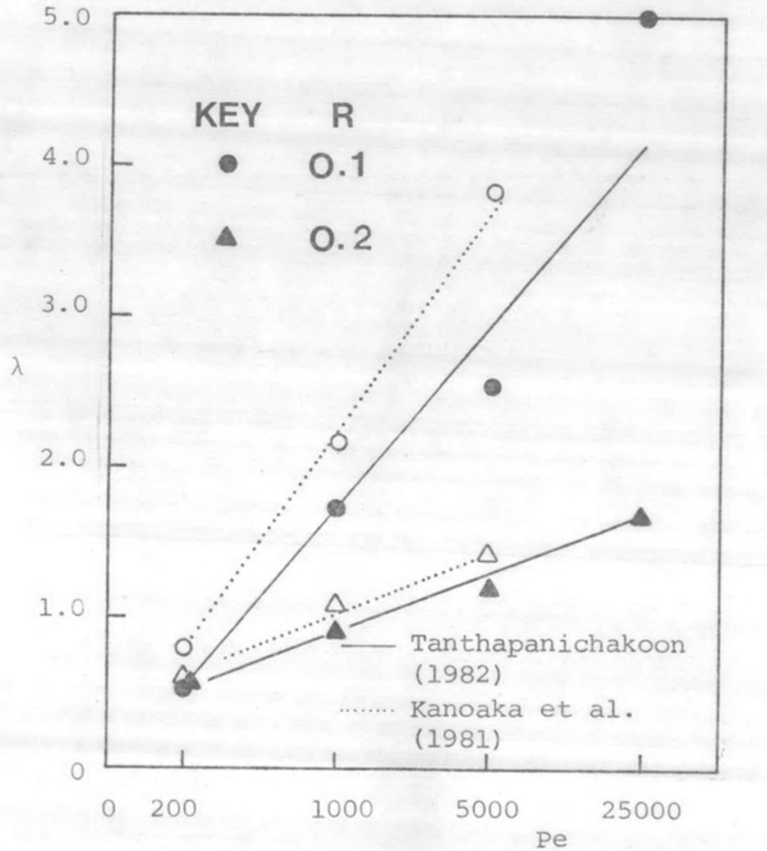

Figure 8.1 Relationship between collection efficiency raising factor λ and Peclet number Pe for the case of $\sigma_g = 1.0$

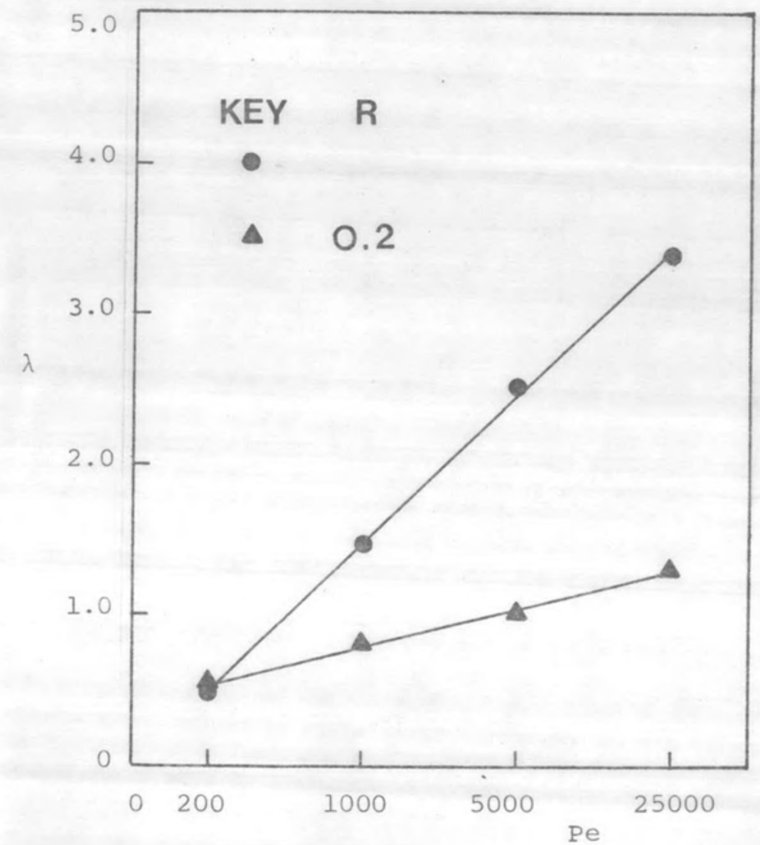

Figure 8.2 Relationship between collection efficiency raising factor λ and Peclet number Pe for the case of $\sigma_g = 1.1$

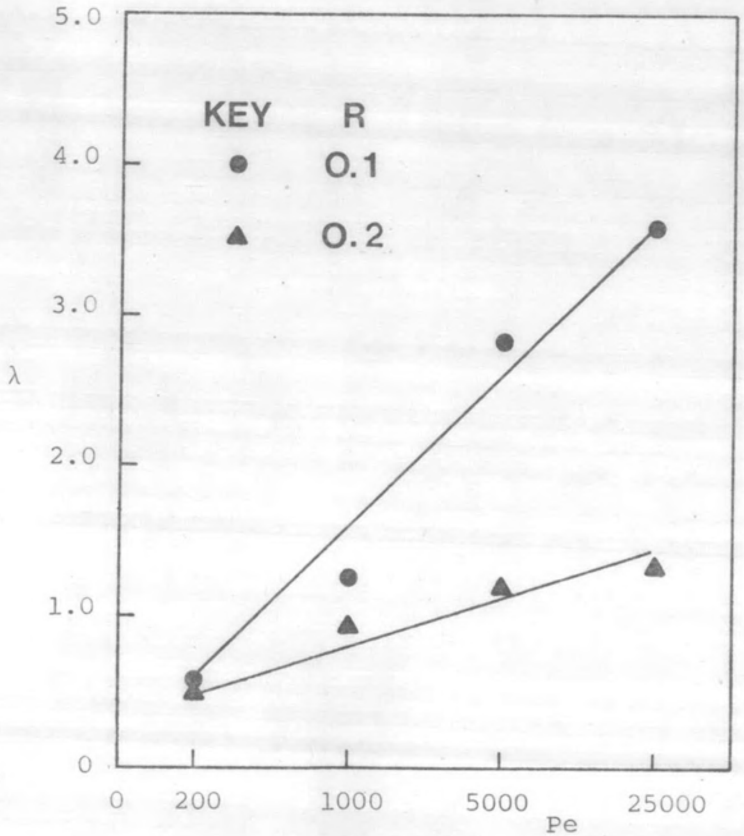

Figure 8.3 Relationship between collection efficiency raising factor λ and Peclet number Pe for the case of $\sigma_g = 1.2$

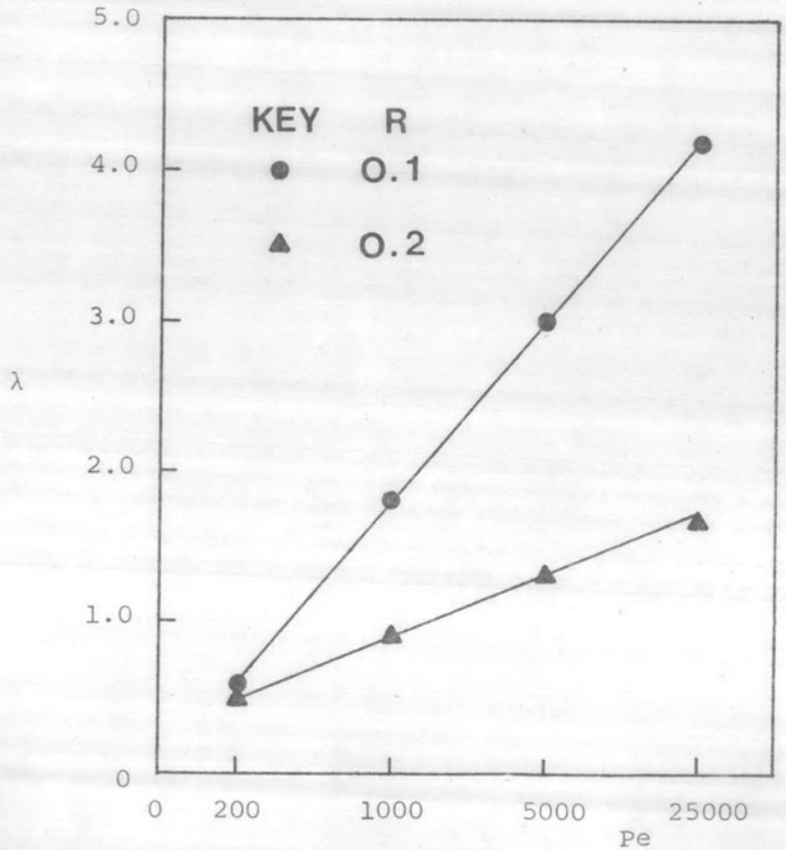

Figure 8.4 Relationship between collection efficiency raising factor λ and Peclet number Pe for the case of $\sigma_g = 1.4$

Table 8.1 A typical filtration system

D_f	$= 0.94\ \mu m^*$
α	$= 0.112^*$
d_p	$= 0.1\ \mu m$
c_i	$= 5.0\times10^{-8}\ g/cm^3$
U_∞	$= 72.5\ cm/s$
u	$= \frac{U_\infty}{1-\alpha} = 81.64\ cm/s$
η_{DI}	$= 0.025589$ Eqn. (8.1.7)
σ_g	$= 1.2\ cm$
D	$= 6.82\times10^{-6}\ cm^2/s$
Pe	$= D_f\ U_\infty\ /D = 1000$
R	$= 0.1$
h	$= 1.436\ cm$
ρ_p	$= 1\ g/cm^3$
ρ_f	$= 2.50\ g/cm^{3*}$
A	$= 1\ cm^2$
λ	$= 1.6$ (Figure 8.3)

*Filter mat type Cambridge 0115E

Table 8.2 Calculated Values of E_M, $\bar{m}$ and α at various filtration time t.

t (min)	E_Mx100(-)	$\bar{m}$x10^4 (gm/cm^3)	α
0	0.99986076	0.0	0.112000
1	0.99986327	1.7053357	0.112170
2	0.99986574	3.1406756	0.112341
3	0.99986816	5.1160198	0.112512
4	0.99987054	6.8213680	0.112682
5	0.99987287	8.5267202	0.112853
10	0.99988393	17.053539	0.113705
20	0.99990325	34.107439	0.115411
30	0.99991935	51.161641	0.117116
40	0.99993278	68.216094	0.118822
50	0.99994397	85.270756	0.120527
60	0.99995330	102.32559	0.122233
90	0.99997296	153.49088	0.127349
120	0.99998434	204.65694	0.132466
150	0.99999094	255.82345	0.1375823
180	0.99999476	360.99023	0.142699
210	0.99999697	358.15715	0.147816
240	0.99999825	409.32416	0.152932
270	0.99999900	460.49122	0.158049
300	0.99999943	511.65831	0.163166
330	0.99999967	562.82542	0.168282
360	0.99999982	613.99254	0.173399
390	0.99999990	665.15966	0.178516
420	0.99999995	716.32678	0.183633
450	0.99999997	767.49389	0.188749
480	0.99999999	818.66100	0.193866

efficiency of the air filter is very high even in the inital period. Consequently, this filter is sometimes called HEPA Filter (High Efficiency Performance Air Filter). On the other hand the packing density α shows very slow increase with time from its initial low value.