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Evaluation of effective operation parameter on High Efficiency Particulate Air and Ultra Low Particulate Air filters

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Abstract

The particle penetration removal efficiency of the High Efficiency Particulate Air (HEPA) and Ultra Low Particulate Air (ULPA) filters were studied by using of mono-disperse liquid aerosols of Di-Octyl Phethalate (DOP) under vary operational conditions. The effects of different operational factors, including the particle size, the face velocity and pressure drop were investigated in this study. The results indicated that the most penetrating particle size through the ULPA and HEPA filters was approximately 0.1-0.12 µm. Brown diffusion effect is suggested mechanism for particle size removal mechanism of 0.1 µm and less while impaction and interception mechanisms are explained the behavior of HEPA and ULPA filters for removal of 0.12 µm and more particle size. The penetrations of particle through both kind of filters were increased with increasing of face velocity. Additionally, the pressure drop of filter is increased versus the rising of face velocity. The cost of energy is lower in low face velocity of filters. (DOI:**https//doi.org/10.52547/JCER.5.2.55**)

Keywords: HEPA; ULPA; Filtration; Efficiency

1. Introduction

HEPA filter is an extended-medium, dry-type filter in a rigid frame which is widely used in nuclear, microelectronic, pharmaceutical and food industries [1]. The filter is used either to treat polluted air before it is released into the environment or to admit air with very low dust concentration into a process. ULPA is a kind of super effective filter with a removal efficiency of over 99%, capable of absorbing and filtering particulates and dusts in air as smaller as 0.01µm [2].

The quality of filter is a function of particle collection efficiency and pressure which is defined by Equation 1, which is ratio of fractional capture per unit thickness (E) inside the filter to pressure drop over the unit thickness (ΔP/t) [3].

$$qf = \frac{E}{\Delta P/t} = \frac{Ln\,(\frac{1}{Pn})}{\Delta P} \quad (1)$$

where P_n is the penetration and t are the thickness of the filter medium.

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The collection efficiency depends on the structure of the filters like porosity, fiber diameter and filter thickness, the operational conditions such as filtration velocity, temperature, humidity and aerosol characteristics such as particle density and size [4], [5].

The effect of particle size and concentration and gas flow velocity on particle collection efficiency of filter was assessed in some studies. The filter collection efficiency of homogeneous fibrous media is calculated by Eq. (2) [6].

$$E = 1 - \exp\left(-\frac{4\alpha Z\eta}{\pi(1-\alpha)d_f}\right) \tag{2}$$

Where E:filter collection efficiency, α: packing fraction, Z: filter thickness, µm, η: single fiber collection efficiency, d_f: fiber diameter µm.

The single fiber collection efficiency, η is expressed as a function of the efficiencies calculated for each of the different capture mechanisms considered for a single fiber. These mechanisms are direct interception, inertial impaction and Brownian diffusion. A simple general approach, described by Kasper, Preining, and Matteson and Brown is to assume that the aforesaid mechanisms act independently [7]. Making this assumption, a fraction $(1-\eta_d)$ of particles would escape capture by Brownian diffusion if this mechanism acted alone. If the capture of particles is also subjected to the other mechanisms, a fraction $(1-\eta_d)(1-\eta_i)(1-\eta_r)$ will escape capture by these different mechanisms. This means that the total single fiber collection efficiency can be calculated as follows (Kasper, Preining, & Matteson, 1987):

$$\eta = 1 - (1-\eta_d)(1-\eta_i)(1-\eta_r) \tag{3}$$

Where: η_d is diffusion single fiber efficiency, η_i is inertial single fiber efficiency and η_r is interception single fiber efficiency (Figure 1).

Diffusion of extremely small, submicron particles is a result of Brownian motion. These particles are so small and the number of collisions with air molecules is low. Particles are moved from one gas streamline to the next by random motion. Diffusion mechanisms could be an effective collection mechanism under sufficient contact time and proper distance to the target [6].

Interception is a mechanism in which there is particles of roughly 0.1 to 1-micron diameter that are carried by the gas streamline with sufficiently close to the surface of the fiber. These particles have insufficient inertia to leave the gas streamline and are carried with the streamline [6].

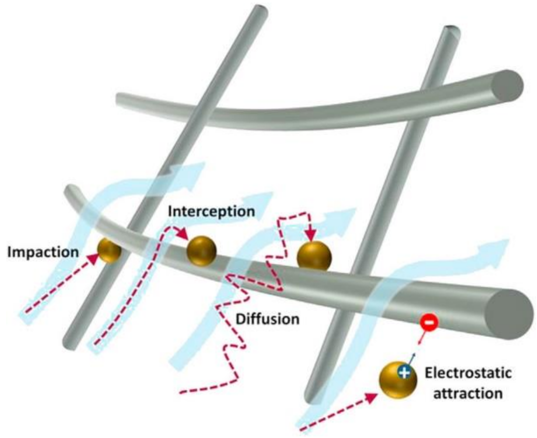


Figure 1 Basic particle collection mechanisms [8]

The diffusion and direct interception efficiencies, η_d and η_r, can be calculated by Eq. (4) and (5) respectively [9]. In these equations, the parameters Cd and Cr were later included by Liu and Rubow [10] to account for the slip flow effect.

$$\eta_d = 1.6\left(\frac{\varepsilon}{Ku}\right)^{1/3} Pe^{-2/3} Cd \tag{5}$$

$$\eta_r = 0.6\left(\frac{\varepsilon}{Ku}\right)\frac{R^2}{(1+R)} Cr \tag{6}$$

$$C_d = 1 + 0{,}388 Kn_f \left(\frac{\varepsilon Pe}{Ku}\right)^{1/3} \tag{7}$$

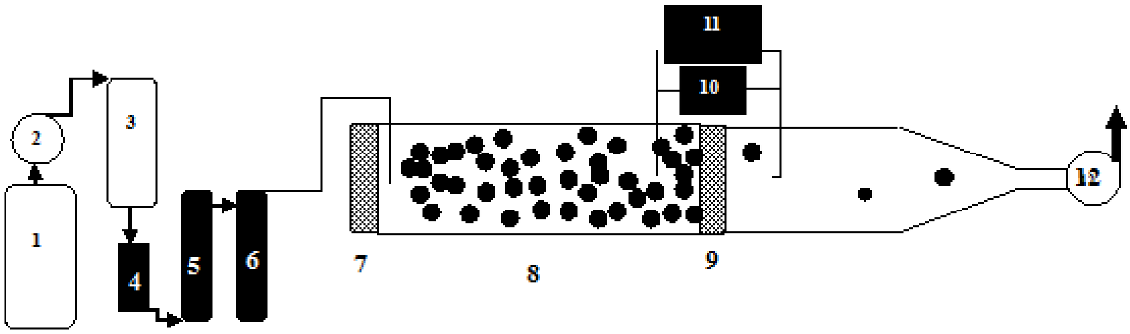
$$C_r = 1 + \frac{1.996 Kn_f}{R} \tag{8}$$

In these equations Pe, K_{nf}, R and Ku that are given in following equations, are P`eclet number, fiber Knudsen number, interception parameter and Kuwabara number receptively.

In the mechanism called impaction, large particles moving toward the target have mass, and therefore momentum, which causes each particle to travel in a straight line toward the target. The particle leaves the streamline as the streamline bends to move around the

Table 1.
Characteristics of tested filter in the study

No. of filter	Kind of filter	Dimension (L×W×h) cm	Nominal efficiency (%)	Pressure lost (Pa.)
1-6	ULPA	305 × 305 × 150	99.999	220
7 -9	HEPA	305 × 305 × 150	99.997	180



(1) compressed air	(2) Pressure regulator	(3) High efficiency drier	(4) High efficiency filter
(5) Constant Output Atomizer		(6) Evaporation-Condensation aerosol conditioner	
(7) ULPA filter	(8) Test Tunnel	(9) test filter	(10) micro manometer
(11) CNC	(12) Fan	(13) Air out put	

Figure 2. diagram of the Setup for this study

target. The greater mass of the particle, the more likely that it will travel in a straight line. Also, as the velocity difference between the particle and the target increases, the particle will have increased momentum and will be more likely to be carried into the target. Impaction of a fiber can be calculated by [6]:

$$\eta_I = 0.0334STK^{3/2}\left(1+0.0334STK^{3/2}\right)^{-1} \qquad (8)$$

Where STK is Stock's Number.

Davies' law describes the pressure drop evolution (ΔP) of a clean fibrous filter with filtration velocity (U_o) [5].

$$\frac{\Delta P}{Z} = 64\mu U_0 \frac{\alpha^{3/2}(1+\alpha^3)}{d_f^{\ 2}} \qquad (9)$$

The aims of this study are experimental evaluation of effective particle collection mechanisms on HEPA and ULPA air filters.

2. Materials and Methods

In this study the efficient parameters in collection of particles were tested on 6 HEPA filters and 3 ULPA filters by DOP method (Table 1).

The lists of instruments used in this study are as followed:

1. Compressed air generator: Production of mono size aerosol of DOP needs to 35 PSI and 3.5 liter.
2. High efficiency drier: TSI manufactory and model 3074
3. Constant Output Atomizer: TSI manufactory and model 3076 that can produce aerosols from liquids. In this study DOP was used for production of aerosols.
4. Evaporation-Condensation aerosol conditioner: TSI manufactory and model 3072
5. Test Tunnel: the function of the tunnel is creative a specified air flow rate and defined DOP aerosol concentration. Dimension of the tunnel is length 350 cm, area section 30 × 30 cm. A qualified ULPA filter that install in inlet of tunnel, removed 99.999% of atmospheric particle of entry air into the tunnel.
6. Fan: a fan with 287 rpm can produced air flow 0-600 m3/hr.
7. Air flow meter: Air flow manufactory model TA2 that has measured of gas flow rate.
8. Micro manometer: head loss of filters in test condition was determined by micro manometer model AMP 50K, Air Flow manufactory.
9. Condensation Nuclei Counter (CNC): This device is made by TSI manufactory and its model is 3022 A and has ability to count of particles in before and after of filter under test.
10. Impactor: the distribution of generated particle was determined by ten-stage Andersen Impactor that its model was 2740.

DOP was used as particulate matter. The DOP was dissolved in ethyl alcohol. This solution, fed to the aerosol generator, was atomized in the particle-free air. Different particle diameters could be obtained by changing the DOP concentration in the solution. In experimental section of this study, seven particle diameters were produced, including 0.04, 0.07, 0.1, 0.12, 0.3, 0.5, 0.7 and 1 nanometer at a concentration of 107particles/cm3. The diameter of the particles was controlled by Andersen Impactor. The efficiencies of the filters were obtained by counting the particles before and after the filter by using a TSI CNC. The tests were accomplished at gas velocities varying from 1.58 to 4.9 cm/s. Also, the pressure lost through test filter was measured as function of air flow rate. Each test was triplicate.

3. Result and Discussion

The filters efficiency was evaluated in 8 gas velocities between 1.58 and 4.9 cm/s. Figure 3 shows typical results of filter efficiency as a function of particle size, at Uo = 2.42 cm/s. It can be noticed that the minimum collection efficiency or maximum penetration for both filters was obtained in dp. 0.12 mic. Diffusion collection mechanisms causes of removing of smaller particle and Interception and Inertia impaction are effective mechanisms for collection of bigger particles.

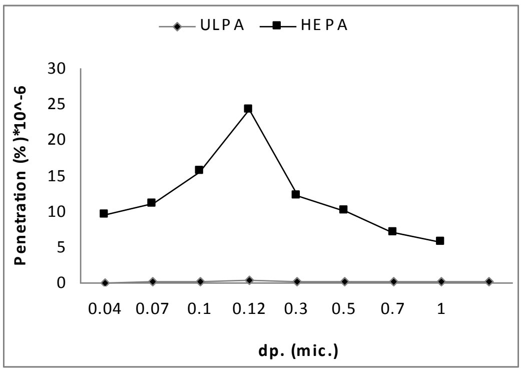


Figure 3. Comparison of penetration of HEPA and ULPA filter as function of particle diameters

As figure 4 and 5 show, the efficiency was decreased with increasing gas velocity. In this study defined conditions, the dp:0.12 mic. has maximum penetration and dp:1 mic. has maximum removal due to increasing of effect of inertia impaction mechanism.

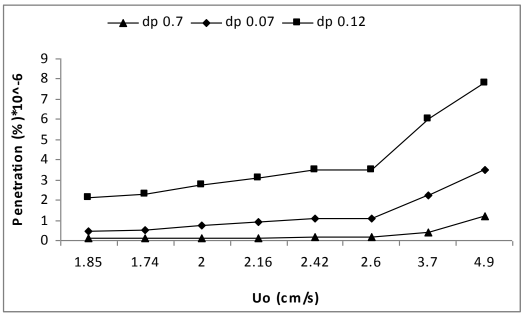


Figure 4. Variation of penetration of filter No 1 as a function of gas velocity for three particle size

As figure 5 shows, increasing of gas velocity from 1.85 cm/s to 4.9 cm/s causes of increasing penetration from 1.6×10-6 to 4.4×10-6 for dp. 0.12 mic, another hand if the gas stream velocity will be increases to 264 percent, the penetration increases to 275 percent of initial penetration.

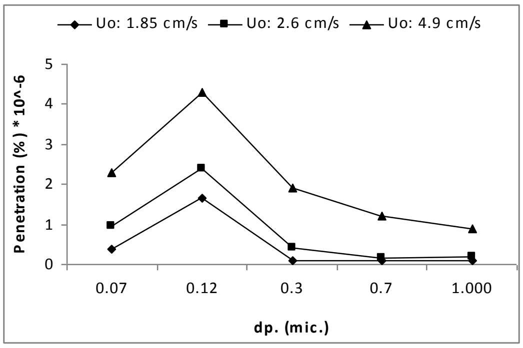


Figure 5. Variation of penetration of filter No 1 as a function of particle size diameter for three gas velocity

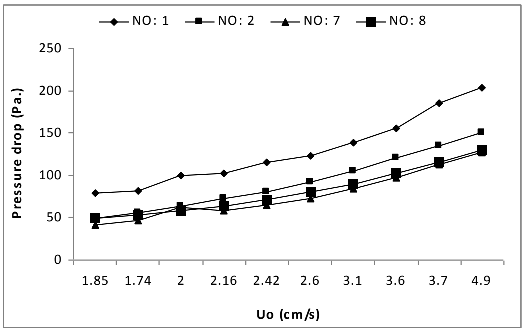


Figure 6. Comparison of variation of pressure drop of HEPA and ULPA filter as a function of gas velocity

Pressure drop of fiber filter directly increase with increasing of gas stream velocity (Eq.9). In this study pressure drop of 4 filters were determined as a function gas stream velocity. Increasing of velocity from 1.58 cm/s to 4.9 cm/s in filter No:1 lead to increasing of pressure drop from 70 pa. to 200 pa. Also, pressure drop in ULPA filter is higher than HEPA.

4. Conclusion

In design of a dedusting projects for industrial or operation of clean room, identification of distribution of particle size and selection of best gas collection velocity are two important data. Although, the removal efficiency of sub-micro particles via ULPA and HEPA filters are decreased with increasing of gas face velocity, for the particle with bigger than 1.2-micron size, increasing of gas face velocity leads to increasing of removal efficiency. Experimental results of this study show that:

- The penetration of HEPA filter is higher than ULPA filter. For example, penetration of a tested HEPA filter is greater than 55 times to ULPA filter.
- Maximum penetration of the ULPA and HEPA filter is funded in 0.1- 0.12 mic. particle size.
- Penetration of these fiber filters are increased by increasing of gas velocity. For example, increasing of gas velocity from 1.85 cm/s to 4.9 cm/s, lead to increases of penetration from 1.65×10-6 to 4.3×10-6 percent.
- Pressure drop of filter has direct relationship with gas velocity. For example, decreasing of gas velocity to third of its initial value cause to increase pressure drops to 2.6 time.
- All of experimental results of this study is supported by correlations from the literature.

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