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Drawing the Optimal Design Factor of a Metal Filter for Capturing Radioactive Aerosol Using Particle Collection Modeling

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1. Introduction

The HEPA filter made up with the typical glass fiber has problems that its heat and pressure resistance are lower than the metal fiber filter in the condition of high temperature and high pressure, and it generates radioactive wastes in that it cannot be reused. In the U.S., the number of HEPA filters, which are located in the HVAC system of nuclear power plants, generated as wastes is annually 31,055, and tremendous economic/social costs are incurred to deal with them [1].

Thus, it is needed to develop the metal fiber filter that can be reused and has performance equal to the HEPA level to replace the glass fiber HEPA filter. This study, to draw the optimal design factors of the metal fiber filter for removing radioactive aerosol, analyzed the design condition by reflecting the actual temperature and pressure condition that can be generated in the nuclear HVAC system to the particle collection mechanism by single fiber.

2. Methods and Results

2.1 Characteristics of Radioactive Aerosol

Radionuclides exist independently in the form of free ion, or stick to aerosol particles floating in the air by absorption or adhesion. As a result of summarizing the size and concentration of radioactive aerosol through a literature analysis, it turned out that diameters of particles can be divided to that of fine aerosol and that of coarse aerosol, which are in the range of 0.18 ~ 8 μm and 8 ~ 110 μm on average, respectively [2, 3, 4, 5].

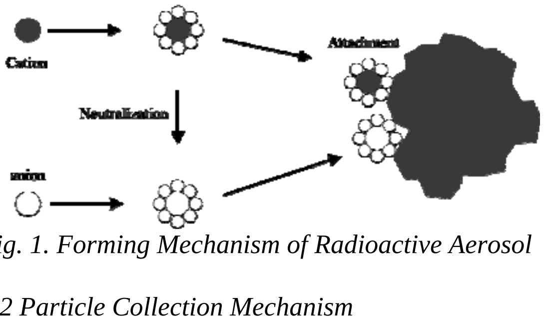

Fig. 1. Forming Mechanism of Radioactive Aerosol

2.2 Particle Collection Mechanism

The five basic mechanisms of particle collection by single fiber are interception, inertial impaction, diffusion, gravitational settling, and electrostatic attraction, totally five. Generally, the total collection efficiency (η_{total}) of a filter can be shown as the formula (1) below by collection efficiency (η_s) by material property of the fiber and single fiber. In the formula, ε represents a porosity, L filter a thickness (mm), D_f a filter fiber diameter (μm), and β a heterogeneous constant.

$$\eta_{total} = 1 - \exp\left(-\frac{4(1-\varepsilon)\cdot L \cdot \eta_S}{\pi \cdot D_f \cdot \beta}\right) \quad (1)$$

In the typical filter particle collection mechanism, the general material property of air in the condition of normal temperature and pressure was applied to calculate the efficiency, but this study drew a modeling condition closer to the actual results by considering viscosity and the mean free path of gas in the state of actual temperature (20 °C) and pressure (1 bar) within the nuclear plant facility.

2.3 Results of Particle Collection Efficiency Modeling for Each Design Factor

As a result of calculating the collection efficiency of each radioactive aerosol particle diameter according to changes of design factors that influence the particle collection efficiency, changes of the particle collection efficiency according to a fiber diameter, filter thickness, and solidity were analyzed as Fig. 2.

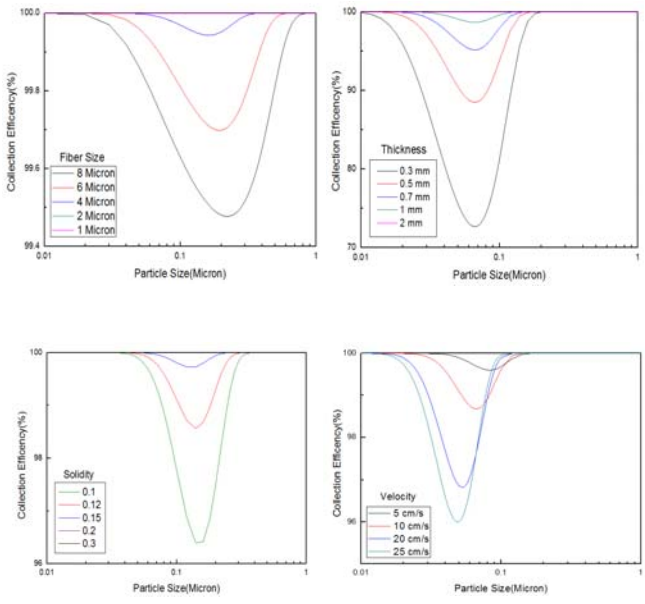

Fig. 2. Results of Particle Collection Efficiency Modeling for Each Design Factor

As a result of calculating the particle collection efficiency in the optimal condition by considering the results of particle collection efficiency modeling for each design factor, the particle collection efficiency turned out as shown in Fig. 3.

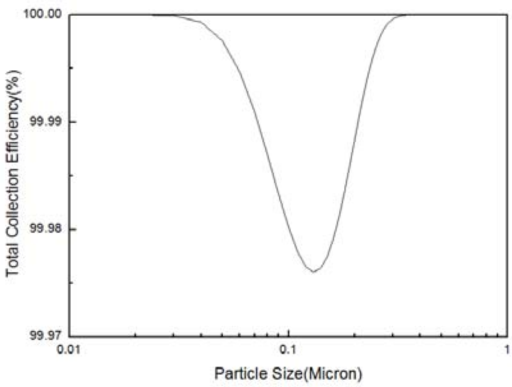

Fig. 3. Results of Particle Collection Efficiency Modeling for Optimal Design Factor

2.4 Results of Pressure Drop Modeling for Each Design Factor

As a result of predicting the pressure drop according to changes of design factors of the filter, it was calculated that the pressure drop is directly proportional to increase of the thickness. In addition, it was analyzed that, as shown in Fig. 4, as a diameter of the fiber gets smaller and a porosity gets bigger, the pressure drop increases.

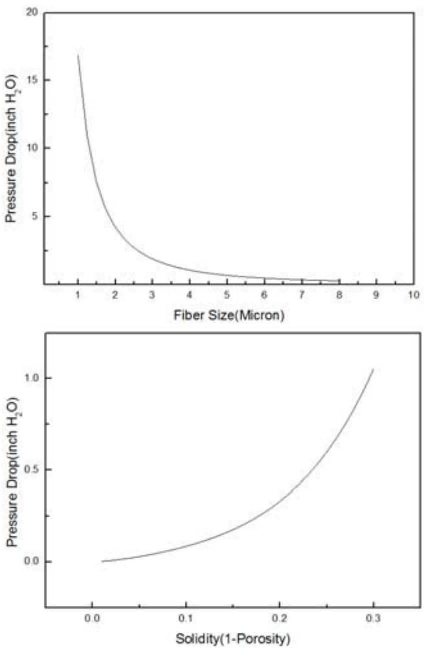

Fig. 4. Results of Pressure Drop Modeling for Each Design Factor

3. Conclusions

As a result of performing modeling for the radioactive aerosol particle collection efficiency and the pressure drop of the filter made up with single metal fiber. It was analyzed that when a diameter of the metal fiber is less than 4 μm, thickness more than 1 mm, solidity more than 0.2, and face velocity less than 5 cm, it shows more than 99.97% particle collection efficiency, which is equal to the HEPA level. Because generally as the particle collection efficiency gets higher, the pressure drop gets bigger, it is judged that the filter design factors should be optimized to satisfy the design condition for the HVAC system. It is also judged that, in the future, an additional verification should be conducted through a comparison of the test results of the filter particle collection efficiency and the pressure drop in the condition of actual temperature and pressure, and the modeling results of this study.

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