CHAPTER II

LITERATURE REVIEW

The aerosol particles deposition in fibrous air filter is of interest to many researchers because fibrous air filter is used in various industries for dust collection and environmental protection. The highly complex phenomenon of aerosol particle deposition may be classified by four steps: 1) deposition on a clean fiber, 2) deposition on previously depositing particles to form dendrites and promote dendritic growth, 3) further growth resulting in intermeshing of neighboring dendrites and , finally, 4) internal cake formation. The re-entrainment of deposited particles may occur at any of the steps, depending on the relative magnitudes of particle-particle and particle-fiber adhesion forces on the one hand and fluid drag and inertial forces on the other.

Both experimental and theoretical investigations on aerosol filtration have been carried out extensively. Generally, the most of the theoretical studies utilized the single fiber concept and were confined to the initial filtration period, i.e. when a filter is relatively clean. In other words, they did not cover the equally important period when deposition was at an advanced stage. An excellent review of the topic was given by Davies (1973). Other study on the theory of aerosol filtration with fibrous air filters were published by Fuchs (1964) and Kirsch et al. (1978).

2.1 Experimental study

The first systematic experimental study, Billing (1966) studied deposition of electrically neutral polystyrene monosized latex particles on a single glass fiber and took numerous photographs of the dendritic growth process. But a detailed analysis of his data was impeded at the time by the lack of an adequate theoretical model.

Barot (1977) used an apparatus similar to that of Billings to obtain dendritic growth data for monosized latex aerosols with nine different particle diameters ranging from 1.09 to 2.02 μm. His data were also in agreement with simulation studies (Tien et al., 1977).

Bhutra and Payatakes (1979) studied on deposition of monodisperse aerosol particles on a single metal fiber under condition of dominant inertial impaction and interception. They fed a neutralized solid methylene blue aerosol through an aluminium tube of 31 mm. diameter at the center of a stainless steel fiber of 25 μm. diameter. During each run, the deposition process was interrupted at regular intervals and deposits on the same area of the fiber surface were examined; the angular positions of all individual dendrites, and their sizes and configurations were recorded and photographed. Their datas were in accordance with the predictions of deterministic models developed and modified by Payatakes (1977) and Payatakes and Gradon (1980).

Kanaoka et al., (1980) proposed simulation results along with experimental ones from their study on the growth processes of particle dendrites on a dust loaded fiber. Sodium chloride and methylene blue particles were used as test aerosols. They were generated by an ultrasonic nebulizer and a vibrating orifice monodispersed aerosol generator. Their theoretical predictions agreed qualitatively well with experimental results, but the values of the collection efficiency raising factor λ were about half of the predicted ones. The discrepancy between the experiment and the simulation can be explained by considering the following facts: 1) the microstructures of filter are different, one by one, even if the packing densities of the filters are the same, 2) the structure of a real filter is more complicated than that of a filter assumed in the simulation, and 3) re-entrainment of captured particles from fibers in the filter have not occured in the simulation.

2.2 Modelling study

In formulating a theoretical model of the phenomenon, two different approachs can be applied: first is deterministic approach and, second is stochastic approach. The deterministic approach is formulating a mathematical model which there is no uncertainty in the values of the variables and parameters. Other, the stochastic approach is using the variables and parmeters to describe the input-output relationship, that is, not known precisely but governed by certain probabilitic laws. The stochastic approach is, in general, more difficult to work with than the deterministic approach, but in many cases stochastic approachs provide more insight into the characteristics and behavior of a real process. The deterministic approach hasbeen pursued mostly by Payatakes (1976, 1976a, 1076b, 1977, 1980, 1980a) for interception, and/or convective diffusional, and/or inertial impaction, and, corresponding the stochastic approach for the same case have been carried out by Tien et al. (1977); Wang et al. (1977); Kanaoka et al. (1980, 1981, 1983).

2.2.1 Deterministic approach

Radushkevich (1964) was the first to model the growth of particle clusters on collectors. He assumed that a given dendrite can be characterized completely by the number of member particles. This implied that no distinction existed between member particle at different positions in a dendrite, therefore prediction regarding the dendrite configuration was not possible, even though configuration was a factor of primary importance in the determination of the effect of the dendrites on both filtration efficiency and resistance to flow. Furthermore, the facts that a new dendrite is generally of a slimmer structure protruding from the collector surface in to the bulk flow and that the probability of a new particle additions depends on the site of deposition along the dendrite suggest that the configuration of the dendrite should significantly affect its rate of growth.

Payatakes and Tien (1976) proposed a preliminary model of the formation of chain-like agglomerates on fiber during filtration of aerosols in fibrous media. Their work was intended for the description of filtration performace, both filtration efficiency and pressure drop, over the entire loading period. The model was limited by two assumptions; first, the dendrite layer adjacent to the collector could contain only one particles at most; second, the particles colliding with the upper half of a dendrite particle became members of the immediately higher layer. They found that the dendrite configurations predicted theoretically were in agreement with those observed experimentally by comparison with photographs of dendrites on a single fiber (Billing 1966).

Payatakes (1977) extended previous work, which considered only contribution of particle deposition from the tangentical flow component by pure interception. He developed a revised and generalized version of the model. The major revisions were made: allowance was made for collisions with a particle in a give dendrite layer that led to retension in the same layer; radial as well as angular contribution to depositions were considered; and the dendrite layer adjacent to the collector was allowed to contain more than one particle. These revisions led to a substantially more realistic theoretical model. The behavior of this model was demonstrated in the simple case of deposition by pure interception. The present treatment of deposition by pure interception is more rigorous than and superseded that adopted in previous work.

Payatakes and Gradon (1980) extended the model to include the case of deposition by inertial impaction and interception mechanism. Also the shadow effect was incorporated in the analysis. Furthermore, the model canbe readily extended to deal with the case of deposition by convective Brownian diffusion. They showed the calulated profiles of the expected dendrite configuration as a function of age and angular position and the transient behavior of a fibrous filter of different thickness. These observations were in agreement with experimental data.

Payatakes and Gradon (1980a) extended the model to include the case of submicron particles. The main transport of the model is convective Brownian diffusion. They presented solutions for the cases of nonslip flow around the fiber; and nonslip, slip and free molecular flow around particles. They found that dendrites form over the entire fiber surface. Moreover, the profiles of the expected dendrite configuration depend strongly on the angular position. In addition, a larger interception parameter values lead to more pronounced dendrite depostion.

Tanthapanichakoon et al. (1993) has developed a simple population balance model for predicting dendritic growth of aerosol particles and the accompanying increase in the collection efficeincy on a single fiber via convective diffusional deposition by using only a fast personal computer without requiring much computational time. The simulation results of the new simplified model agrees fairly well with those obtained previously by Monte-Carlo simulation of the stochastic model. Although a new simplified model has required the optimal values of two parameters, e_N and e'_N.

2.2.2 Stochastic approach

Tien et al. (1977) were the first to use stochastic approach to represent the random location of incoming particles in their simulation. They proposed model for the formation and growth of dendrites on a two dimensional collector in an aerosol stream. Their simulations were carried out on a crossection of the collector by taking into account the randomness of individual particles together with the corresponding trajectories determined from the equation of motion. The formation and growth of particle dendrites were simulated and found to resemble those obtained from experiments.

Wang et al. (1977) proposed two concepts; first, characteristic of particle in suspension in terms of their interaction with a collector surface, namely, the shadow effect created by deposited particles, and secondly, random behavior of approaching particles. The random distribution of approaching particles in their upstream positions were stochastic in nature, but the particle motion is deterministic. They have simulated the dendritic growth process on a sphere and a two dimensional cylinder. They found that their simulation resulted in insufficient depiction of true phenomenon.

Kanaoka et al. (1980, 1980a) have also simulated the growing process of particles dendrites on dust load fiber via Monte-Carlo simulation of stochastic model for inertial interception collection mechanism. Moreover, they found that the shapes of dendrites thus obtained from simulation agreed fairly well with experimental investigations and the ratio of the collection efficiency of dust-loaded single fiber to that of a clean fiber was expressed as a linear function of the mass of deposited particles in a unit filter volume. In addition, the values of a collection efficiency raising factor λ were in qualitative agreement with previous experimental study.

Kanaoka et al. (1983) proposed a three-dimensional stochastic model to the case of aerosol particle depostion by convective Brownian diffusion. This model was utilized to simulated collection and agglomeration process of particles on a cylindrical fiber. They dicussed the effect of Peclet number, interception parameter and the accumulated mass of particles on fiber; the distribution of captured particles on a fiber; and the evolution of the collection efficiency of a dust-loaded fiber through the simulation. They found that the ratio of the collection efficiency of dust-loaded single fiber is expressed as a linear function of the mass of particles depositing in a unit filter volume. In addition, the coefficient in the linear function, collection efficiency raising factor, depended on Peclet number and interception parameter.

Montree et al. (1991) proposed also a three-dimensional method for the stochastic simulation of dendritc growth of polydispersed for the case of convective Brownian diffusion. They found this study were almost the same as those obtained for monodispersed aerosols and range of standard deviation of polydispersity of aerosols particles does not affect the average performances of the dust-loaded fiber.