CHAPTER 1

INTRODUCTION

Fibrous filters are at present one of the most effective methods of fine particle purification and has the additional advantage of low energy consumption. For the same degree of purification these filters have minimal resistance as compared with other types of filters. Fibrous material is a system of variously oriented fibers with a prefered orientation across the direction of flow. The porosity of filters is 85-99% and the fiber diameter varies from 10^{2} to 10^{-2} μm. Despite these attractive features the fibrous filters have not yet been applied on an industrial scale. The main reason of its lack of wide industrial application has been the failure in developing effective methods for repetitive cleaning of such filters over long periods of time. Cleaning methods attempted in the past either require excessive energy consumption (for example, cleaning by blowback) or result in structural damage and early disintegration of the filter elements (for example, cleaning by reverse shock wave). Hence, most industrial applications are still confined to cases where high efficiency is demanded and use of disposable filter elements is practical (clean rooms, emergency filtration systems for radioactive aerosols, respiratory mask, etc.)

In recent years, the need for more effective and at the same time less energy-consuming methods for removal of fine particles from industrial effluents has become more imperative. Particulate pollutants of submicron size have been identified as being most hazardous from a public health point of view. In addition, new technological developments such as coal conversion processes (both gasification and liquefaction) need efficient and effective removal of fine particles from both their product and process streams to meet the ecological, as well as engineering requirements. In view of its growing need and importance, filtration in fibrous mats has attracted renewed interest in industry. Proprietary work in material preparation for filter elements and development of ingenious method of cleaning are likely to be achieved in the near future and thus make possible the use of fibrous filters on industrial-scale applications. In order to realize the full potential of these developments, a quantitative understanding of the fibrous filter performance in term of particle deposition over the entire loading period is obviously needed.

The pattern of particle deposition in a fibrous filter is highly complex and intrinsically connected with the efficiency, loading capacity and permeability of the system. Therefore rational design, optimization, operation, troubleshooting and innovation require intimate understanding and reliable analysis of the deposition process and its effect on system variables. Unfortunately, the great majority of the previous theoretical works are concerned with the deposition in a clean fibrous filter, which is close to its initial condition. An excellent review is given by Davies (1973). It has been observed experimentally that aerosol particles deposit not only on the surface of a fiber but also on formerly deposited particles forming chain-like agglomerates or dendrites. This phenomenon leads to substantial increases in collection efficiency and pressure drop. The phenomenon had earlier been observed by a number of investigators, Billings (1966) seemed to be the first to give a systematic approach to it. Like a small tree, each dendrite is rooted at the fiber surface and protrudes into the main flow. As a result, the dendrite itself also acts as a collector and keeps growing as additional particles deposit on it. For simplicity, the dendrites can be considered as additional fine fibers that add substantially to the collection efficiency of the filter as well as to its resistance to flow. A given dendrite will keep growing as long as new particles deposit on it. Given sufficient time the dendrites might grow to an extent that they intermesh with their neigbours forming a porous coat of usually nonuniform thickness around each fiber. If the adhesion forces are sufficiently strong, reentrainment of particle clusters will be negligible and, as the deposition process continues, the particle coatings of neighboring filters might bridge the gap in between, thus creating a secondary porous matrix within the fibrous filter; this matrix can be described as internal cake. If, on the otherhand, the adhesion forces are not strong enough, the drag force exerted on the dendrites, aided by bombardment from newly depositing or merely colliding particles, may cause significant reentrainment of particle clusters. Reentrainment may begin even during the initial period, if the relative magnitude of drag force over adhesion force is high enough. If reentrainment is significant, an internal cake will not occur. Instead continuous reentrainment of particle clusters and subsequent deposition downstream or escapement of particles from the filter will take place. Therefore penetration of large clusters of particles through the filter might occur if the loading level is above some critical value. Obviously, the phenomenon described above is an peculiarly complicated process, possibly defying entirely satisfactory modelling.

In formulating a mathematical model of the phenomenon, two different approaches can be discerned : one is deterministic and the other stochastic. Models for particle dendrite formation or deposition of aerosol on dust loaded fiber during the initial stage have appeared only recently. The deterministic approach has been pursued mostly by Payatakes (1976, 1976a, 1976b, 1977, 1980, 1980a) for interception and/or ineritial impaction and corresponding stochastic studies for the same cases have been carried out by Tien et al. (1977); Wang et al. (1977) and Kanoaka et al. (1980, 1980a). Payatakes et al. (1980a) has extended his model to the domain of submicron particles, where the main transport mechanism is convective Brownian diffusion and Kanoaka et al. (1981) has proposed a stochastic model for the same case.

For the sake of simplicity most investigations (especially theoretical one) on aerosol filtration have been based on the assumption that all particles have the same size; whereas most aerosols (naturally occuring or even those generated by a specially designed generator) are, in reality, more or less polydisperse.

Many natural phenomena are a kind of stochastic processes, i.e. the variables and parameters used to describe the input-output relationship are stochastic, that is, not known precisely but governed by certain probabilistic laws. Thus, knowledge of the state of the variables and parameters at some moment in time will not uniquely determine a subsequent state. Stochastic models are, in general, more difficult to work with than deterministic models (in which there is no uncertainty in the values of the variables and parameters), but in many cases stochastic models provide more insight into the characteristics and behavior of a real process. Aerosol filtration is stochastic in nature, deriving its characteristics directly from the randomness of the approaching particles at the control surface as well as the size of the particles. Furthermore Brownian diffusional effects make the actual trajectory of a submicron particle impossible to be known with absolute certainty.

The present work is, in a sense, a continuation of the work of Kanaoka et al. (1981). It extends their stochastic model for convective diffusional deposition to the case of polydisperse aerosols. In short the present extened model simulates the three-dimensional growth of particle dendrites on a representative fiber of a fibrous air filter; the aerosol particles, however, are not the same size and its size distribution is governed by a log-normal distribution. The applicability of this work is confined to the cases in which the main transport mechanism of all aerosol particles is convective Brownian diffusion

Chapter 2 presents the scope and objectives of this study. A brief review of previous work both on the deterministic and the stochastic analysis of aerosol filtration on a fibrous filter is given in Chapter 3. Chapter 4 introduces the basic theory of aerosol filtration as well as the model for aerosol deposition on a dust loaded fiber by convective Brownian diffusion. The technique of Monte Carlo (or stochastic) simulation and the manner in which stochastic inputs and parameters are digitized in this investigation are explained in Chapter 5. Chapter 6 discusses the statistical method of analysis. Simulation results of dendritic deposition of polydisperse aerosols by convective Brownian diffusion on a dust loaded fiber and the results of statistical analysis are given with discussion are given in Chapter 7. Engineering applications of these results are illustrated in Chapter 8. Finally, Chapter 9 gives a summary of pertinent conclusions and recommends certain future extension of this work.