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Deposition mechanism and the efficiency of fibrous filters

Sarah J. Dunnett¹, Charles F. Clement²

¹Department of Aeronautical and Automotive Engineering, Loughborough University, Loughborough, Leics. LE11 3TU, U.K.
²15 Witan Way, Wantage, Oxon, OX12 9EU, U.K.

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INTRODUCTION

Fibrous filters generally consist of many threadlike fibres oriented more or less normal to the fluid flow which passes through them. Particles carried by the fluid flow may impact upon the fibres and become removed from the flow. The collected particles accumulate forming complex structures which influence the fluid flow and further deposition. Understanding the process of particle deposition and its effects upon further deposition are crucial in understanding the performances of fibrous filters. We have been developing a numerical model of fibrous filtration aimed at investigating deposition due to various mechanisms and the effect filter properties and particle characteristics have upon it (Dunnett and Clement 2006, 2009). We have shown that deposit porosity does not influence further deposition for small particles where diffusion is dominant, but that deposition by interception can be strongly enhanced at high porosity. In this paper we examine which deposition mechanism is expected to dominate for a given particle size and flow velocity, and calculate the deposition efficiency as the deposit builds up.

NUMERICAL MODEL

In our first work, Dunnett and Clement (2006), a numerical model has been developed which determines the flow field, and particle motion, around a single fibre by solving the diffusion equation for the particle concentration, n:

\[
U_r \frac{\partial n}{\partial r} + U_\theta \frac{\partial n}{\partial \theta} = \frac{2}{Pe} \left( \frac{\partial^2 n}{\partial r^2} + \frac{1}{r} \frac{\partial n}{\partial r} \right)
\]

where \( U_r \) and \( U_\theta \) are the components of flow velocity in the r and \( \theta \) directions respectively and Pe is the Peclet number given by \( Pe = Ud/D \). \( U \) is the mean flow velocity, \( d \) the fibre diameter and \( D \) is the coefficient of diffusion of the particles.

Boundary conditions on this equation account for the effects of particle interception with the surface. This deposit mechanism becomes more important as the size of the particle increases and dominates when \( s = \kappa/\delta > 1 \). This parameter was introduced by Stechkina and Fuchs (1966) where \( \kappa \) is the ratio of the particle to fibre diameters and \( \delta = (4k/Pe)^{1/3} \), where \( k \) is the hydrodynamic factor, is the non-dimensional thickness of the diffusion layer. The change of deposition mode at \( s = 1 \) is responsible for the change in analytic behaviour of the diffusion equation reported in Figure 3 of Dunnett and Clement (2006). Here, we show in Figure 1, how \( s = 1 \) arises in terms of the particle radius, \( R \), and the flow velocity for two fibre sizes. The importance of impaction as a deposition mechanism only occurs at much larger values of \( R \).

![Flow Velocities and R for s = 1](image)

In calculations with a deposit having a high porosity (Dunnett and Clement 2009), flow lines pass through the deposit, and deposition is dominated by direct capture of particles rather than by diffusion. We will report the results of calculations of the total deposition rate as the deposit builds up. When the principal mechanism is diffusion, a relatively slow increase occurs. In the interception region, a sufficiently large deposit must first be formed by diffusion and interception before there is significant flow through the deposit. After this has happened, there is a large increase in the deposition rate. Such increases will only occur if the porosity, \( \phi \), which is the fraction of the porous media that is occupied by void space, reaches values of over 0.8.

REFERENCES