Calculation of deposition on fibrous filters due to impaction – critical trajectories

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Introduction

Fibrous filters are routinely used to remove particles from the air. The filters consist of numerous fibres arranged in such a way that they are mostly perpendicular to the air flow through it. The packing fraction of such filters is generally small enabling the modelling of filter performance to be undertaken using single fibre theory. When the filters are in use particles collect on the fibres and are removed from the air. The deposit collected on the fibres affects the air flow through the filter and hence the subsequent deposit of particles. To date we have a fairly good understanding of the performance of fibrous filters at the start of their lives when no deposit is collected. However the feedback effects of the deposit upon the filter performance are less well understood. The aim of the present work is to consider this feedback effects for particles of the size for which impaction is the main mechanism of deposition. In particular an efficient mathematical technique has been developed to determine the particle trajectories that separate the impacting and non-impacting particles.

Numerical model and procedure

A numerical model has been developed previously, Dunnett and Clement (2012), which investigates the performance of fibrous filters in the early stages of particle loading. In the model the Boundary Element Method is used to determine the flow field around a single fibre containing deposit. The neighbouring fibres are taken into account in the model by the application of the boundary conditions. The deposit collected on the fibre is assumed to form a smooth porous layer and the flow through the porous layer is assumed to be modelled by Darcy's law. The model has been used to consider the deposition of particles due to diffusion and interception. In this work we are extending the work to consider particles for which impaction is the main mechanism of deposition. This is the case for Stokes numbers, St ≥1 where $\mathrm{St} = \dfrac{d_p^2 \rho_p U_0 C}{18 \mu d_f}$ d_p, d_f are the particle and fibre diameters, ρ_p the particle density, C the Cunningham correction factor, μ the air viscosity and U_0 the flow velocity away from the fibre.

For impaction, critical trajectories exist which define the region from which particles will deposit on the fibre. These trajectories are tangential to the fibre surface at impact, see Figure 1. Away from the fibre particles are initially moving with the flow in the x direction with velocity $u = U_0$ and the problem of finding the critical trajectory reduces to that of finding the distance from the axis, y_0, for a trajectory to reach the appropriate tangential boundary condition on the fibre surface. This reduces to solving the differential equations for a trajectory which satisfy a particular boundary condition.

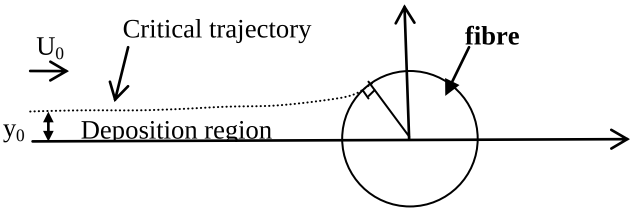

Figure 1. Critical trajectory

It has been found that the critical trajectories can be found in an efficient manner adopting an iterative procedure of solving the differential equations based on a modification of Newton's method. This results in a reduction in the numerical simulations needed to determine the region of deposition on the fibre surface and the filter efficiency. The procedure can be adopted for clean fibres and also for fibres that contain a porous layer of deposit.

As the deposit collects on the fibre it forms a surface on the face of the fibre facing the flow which grows with time. The critical trajectories define the outer edge of that surface.

In the work presented here we will investigate the deposition surface formed on the fibres for various situations of concern in filtration. The results will be compared with available experimental data.

References

Dunnett, S.J. and Clement, C.F. (2012) J. Aerosol Sci. 53, 85-99