Efficiency of inertial capture of aerosol particles by porous fiber in cylinder array

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The problem of motion of aerosol particles in the air flow through periodic arrays of porous cylinders is numerically solved. The efficiency of inertial capture of particles is studied by varying the parameters of porous cylinders and the dispersed phase.

Problem of the motion of dispersed flow in porous structures is of practical importance due to their applications in air purification devices. The possibility of using porous bodies as elements of porous structures was discussed in Kirsh (2007).

A two-dimensional flow of an incompressible gas with suspended aerosol particles in the flow through an array of porous cylinders with radius r_c is considered. In the assumption that the particle concentration is small, the influence of the dispersed phase on the air flow is neglected. The air motion around the cylinder and in the porous area is described by the equations (Bhattacharyya et.al., 2006):

$$\nabla\bar{u} = 0 \tag{1}$$

$$\varepsilon^{-2}\rho\bar{u}\nabla\bar{u} = -\nabla p + \frac{\mu}{\varepsilon}\Delta\bar{u} - b\frac{\mu}{k}\bar{u} \tag{2}$$

where $\bar{u}$ is the gas velocity, μ and ρ are the dynamic viscosity and air density, p is the pressure, ε is the porosity, k is the permeability of the porous medium. The parameter b equals to zero outside the cylinder and to one inside the cylinder. The gas velocity $\bar{u}$ averaged over the volume of pore space is related to the flow rate, $\bar{u}_f$, by $\bar{u} = \varepsilon\bar{u}_f$.

On the left boundary of the periodic computational domain the free-stream velocity U_0 is given. On the right outer boundary the zero pressure is given. Centerline of the computational domain both outside and inside the porous cylinder corresponds to symmetry conditions. Equations of the carrier phase motion (1-2) are solved by the finite volume method using a CFD code, FLUENT. The flow field was also described analytically using the Kuwabara cell model for porous cylinder (Stechkina, 1979, Kirsh, 2007). The equations of motion of suspended particles are numerically integrated in the obtained velocity field. The particulate flow is characterized by the dimensionless parameters: the Reynolds number $\mathrm{Re} = \rho U_\infty 2r_c / \mu$ (U_∞ – velocity of the undisturbed flow), the Darcy number $\mathrm{Da} = k / r_c^2$, the Stokes number $\mathrm{St} = U_\infty / r_c\tau$ (τ – the relaxation time of a particle).

To calculate the capture efficiency E_e the particle trajectories are traced outside the porous cylinder. The value E_e is calculated as the ratio of the number n_d of particles, which reached the surface, to the total number n_t of started particles: $E_e = n_d / n_t$. The dependencies of E_e on the Stokes number at given values of solidity α=1-ε=0.05 and various Darcy numbers, obtained on the base of numerical and analytical fluid flow models, are presented in fig.1. Lines 1,3,5 and 2,4,6 correspond to the numerical and Kuwabara models. Lines 1-2,3-4,5-6 correspond to Da=0,10^{-2}, 10^{-1}. In the absence of the gas flow through the cylinder (solid cylinder) the efficiency of inertial deposition decreases to zero at the finite Stokes number. For the porous cylinder, at sufficiently small values of St the value E_e remains finite. An increase of the Darcy number leads to a noticeable growth of the value E_e, for example, for the cylinder with the Darcy number Da=0.1 the value E_e is equal ~0.17 at St=0.1. The dependencies of E_e(St) at Da=0.1 for α=0,0.01,0.05 are shown in fig.2. The value E_e is larger at small St for larger α.

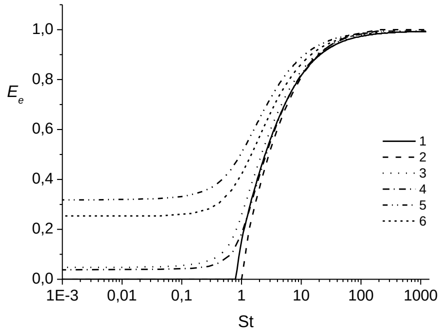

Fig. 1.

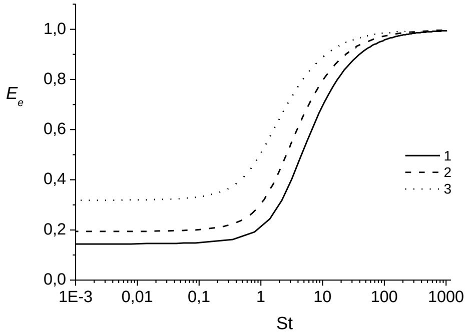

Fig. 2.

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