TANGENTIAL FRICTION ON THE WALL OF A CONTAINER WITH A SPHERICAL CHARGE AND FLUID MOTION THROUGH THE CHARGE

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Viscous tangential stress on the interior wall of a container with a spherical charge, that develops in filtration of an incompressible fluid through the charge is investigated. Based on an analysis of an experimental dependence of the dimensionless stress on the Reynolds number, two critical Reynolds numbers are determined: the first number corresponds to the beginning of an abrupt drop in the stress, and the second number, to its reaching a regime that is self-similar in velocity. Comparison with the theory permits interpretation of the effects of pseudoturbulence and turbulence, respectively.

Processes that occur in granular media are complex; therefore, many essential details of hydrodynamics and transfer remain little studied. The hydrodynamic features of processes in the wall zone directly adjacent to the heat-exchange surface have practically not been investigated [1].

We study the properties of the viscous tangential stress on the interior wall of a container with a spherical charge that develops with fluid motion through the charge. Elements similar to the studied ones in geometry and occurring hydrodynamic processes are widely used in a variety of apparatuses of modern technology: filters, heat exchangers, and catalytic chemical reactors. The mechanism of the effect of by-passing of a part of the flow through the wall zones in those devices [1] is, as is expected, associated with friction properties on the interior walls. The obscure causes of the high level of by-passing make it important to study friction properties.

An experimental study of tangential stress involves great methodological difficulties, by virtue of which the number of works on this problem is small.

In [2], stress was determined by an electrodiffusion method as a function of the rate of filtering through the charge in the range of the Reynolds numbers of from 0 to 170 (the Reynolds number is constructed from the sphere diameter and the filtering rate of the fluid). The fluid is an electrolyte, \( \rho = 1000 \text{ kg/m}^3, \mu = 0.001 \text{ kg/m}.\text{sec} \). The container is a tube with diameter \( D = 13.8 \text{ mm} \); the spheres are of two sizes: \( d = 1.07 \) and \( 3.2 \text{ mm} \). We used sensors of the dimensions, much larger and smaller than the diameter of the sphere, that yielded readings, coincident within 5%, with good reproducibility in multiple repackings of the charge.

In [3], the friction was found from the slope of the velocity profile near the wall in a cell of cubic packing of spheres using a laser Doppler anemometer in the range \( \text{Re} = 800-2900 \). Measurements are performed at several points along and transverse to (at the maximum cross-section) the longitudinal axis of symmetry of the cell. An immersion liquid \( - \rho = 1300 \text{ kg/m}^3, \mu = 0.0013 \text{ kg/m}.\text{sec} \) – was used. The packing is nine spheres of \( d = 18.3 \text{ mm} \) in a row.

We represent the data on the tangential stress on the container wall \( \tau_s \) as a function of the rate of liquid filtering through the charge \( U_m \) [2] in dimensionless form: \( \tau_s(0) = \tau_s d/\mu U_m \) versus \( \text{Re} = \rho U_m d/\mu \) (the solid lines in Fig. 1). Unlike the dimensional stress, which grows monotonically with the flow rate, the dimensionless stress is characterized by a more complex dependence on the number \( \text{Re} \). On the experimental curves, we can distinguish three characteristic regions: 1-2, 2-3, and 3-4. The first region 1-2 is distinguished by an increase in the stress as a function of \( \text{Re} \), the second region 2-3 corresponds to an abrupt drop in the observed dimensionless stress on the wall with a gradual decrease in the rate of the drop. The beginning of the drop corresponds to point 2 and is a
salient point. The third region 3-4 is distinguished by the self-similarity of stress in the Reynolds number (it begins from point 3). Point 3 cannot be distinguished on the curve as clearly as 2, since the curve degenerates asymptotically into a horizontal straight line. We determine the position of point 3 in Fig. 1 by the condition of its 5% deviation from asymptote.

We determine two critical Reynolds numbers: the first number corresponds to the beginning of the abrupt drop in the frictional stress, and the second one, to the beginning of self-similarity. The plots show that flow in the charge of larger spheres is characterized by larger first and second critical Re numbers.

The data of [3] cannot be processed in terms of the filtering rate without averaging the tangential stress over the entire solid wall adjacent to the cell of the packing. The magnitudes of the stresses turn out to be dependent on the position of the measurement point with respect to the cell. The maximum stress is recorded on the wall in the diffuser cross-section on the axis of symmetry of the cell, and the minimum stress (it is negative), in the sphere afterpart, in the region of return flows. Data on the dimensionless stress as a function of Re were obtained by processing the results of [3] and are given in Table 1. Points 1-4 are located along the cell's axis of symmetry, respectively, in the minimum, diffuser, maximum, and confuser cross-sections of the cell, and points 5-7, on the axis that is perpendicular to the axis of symmetry of the cell in the maximum cross-section with lateral shifts from the axis of symmetry of 3.6 and 9 mm. From the data of Table 1, we can establish that, despite the two- to threefold change in the number Re, the dimensionless stress is approximately the same at the characteristic points; consequently, the average stress will be the same, too. This qualitative result enables us to conclude that there exists at large Re numbers self-similarity of the tangential stress with respect to Re in cubic packings of spheres, too.

When an electrodiffusion stress meter was used [2], averaging was apparently performed by the device itself.

We move on to a theoretical analysis of the properties of tangential stress on the wall of a container with a spherical charge and an incompressible viscous fluid moving through it.

An essential factor retarding a theoretical study of the problem is the absence of a universally adopted and reliably substantiated closed equation of filtration that enables us to allow for the condition of adhesion on a solid wall. We know the Brinkman equation [4]:

$$\frac{dP}{dx} = -\frac{\mu}{kU} + \mu \frac{d^2U}{dy^2}.$$  (1)