Concerning the impact of a Submerged Body on Particle Movement in a Fluidized Bed in Terms of Body-Bed Heat Transfer

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Abstract: - According to results of tracking a magnetolabeled particle in the monodisperse fluidized bed of silica-alumina catalyst, in which a gas-tight cylinder simulating a heat transfer surface was submerged vertically and in axial alignment with the apparatus, there has been confirmed the formation of a special zone near the body with the width up to 20 mm and local vertical circulation of particles. The zone is formed with a rise in gas velocity and a gradual deterioration of particle exchange with the core of the bed so that the time of the particle residence in the zone is increased up to 0.36-0.5 s, whereas in the core of the bed it is 0.25-0.4 s. The lower the initial height of the bed is, the lower the gas velocity at which a near-surface zone is formed. Formation of the near-surface zone can have a direct impact on the heat transfer rate and this fact should be taken into account when constructing models of external heat transfer in a fluidized bed.

Key-Words: - monodisperse fluidized bed, magnetolabeled particle, magnetometer, particle displacement, particle velocity, probability, external heat transfer.

1 Introduction

Currently, there is a widespread use of fluidization technology for burning low grade solid fuels. The high rate of heat transfer between the fluidized bed and heat exchangers submerged in the bed provides an intense heat removal from the bed and maintaining the temperature in the bed excluding the melting of fuel ash. Further improvement of the design of burning installations and other types of fluidized bed reactors directly depends on the development of heat transfer models allowing not only to obtain adequate heat transfer coefficient values but also indicate the direction of heat transfer enhancement between the fluidized bed and heat exchanger submerged therein.

2 Problem Formulation

Known high indexes of heat transfer rate between the fluidized bed and the body submerged therein are attributed to intense movement of solid particles. On the other hand, a number of external heat transfer models are known in which the heat transfer from the surface submerged in the fluidized bed is completely determined by the thermal resistance of a gas film formed at the surface [1-4].

Obviously, it is not entirely true because studies show that at the surface of the body submerged in the bed in addition to the gas film a special zone is formed which is filled with fluidized medium having the increased porosity and local circulation of particles therein [5, 6]. The rise of gas bubbles at the heat transfer surface induces here the light phase injection from the core of the bed [6], which leads to an increase in gas velocity at the heat transfer surface and decrease in gas velocity in the core of the bed [7]. Obviously, the rate of body-bed heat transfer will directly affect the rate of particle exchange between the above-mentioned near-surface zone and the core of the bed.

The latter assumption is confirmed by the results of the study of heat transfer [9] between a heater (cylinder 42 mm in diameter) vertically submerged in the bed and a bed of corundum (equivalent particle diameter is 1.1 mm) and silica-alumina catalyst (equivalent particle diameter is 2.74 mm). In this regard the bed heat transfer was studied both with an open heater and with the same heater but placed in a tube coaxial with the heater. The ratio between the diameter of the heater and diameter of the coaxial tube was varied within the range of 0.34 - 0.76. Some results of heat transfer measurements performed in this study are shown in Figure 1.

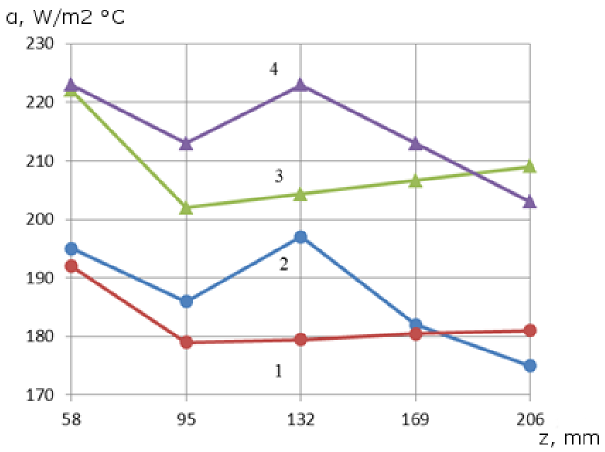

Figure 1. α_r versus the height of the body in the presence (curves 1 and 2) and in the absence (curves 3 and 4) of the screen tube.

1, 3 - alumina silicate, 2, 4 - electrocorundum.

Conspicuous is the fact that the tube coaxial with the heater reduces the heat tramsfer rate slightly: for the bed of electrocorundum - by 1-8%, for the bed of silica-alumina catalyst - by 1-25%. If the apparatus diameter exceeded the diameter of the vertical cylindrical heater more than twice, the screen in a form of the tube coaxial with the heater did not affect the heat transfer rate at all. In other words, the mechanical barrier to the particle migration to and from the submerged body has virtually no effect on the heat transfer rate. Consequently, we can assume that the near-surface zone formed in the vicinity of the submerged body has an injecting impact on the particles when they move radially and does not allow them to move away considerably from the submerged body thereby acting as a major barrier to intensive exchange of particles with the core of the bed. The proof of this assumption is the goal of the present work.

3 Methods and equipment

We have studied the movement of the silica-alumina catalyst particles (particle diameter is 2.5-3.0 mm, critical velocity of fluidization W_{cr}=0.86 m/s) in a fluidized bed created in the apparatus with inner diameter D = 172 mm. The apparatus was installed on the air distribution grill. The cylinder d = 40 mm in diameter was submerged into the apparatus along the longitudinal axis so that the distance from the lower rounded end of the cylinder to the air distribution grill was 10 mm. Selection of the relation between the apparatus diameter and the cylinder diameter was determined on the basis of conditions for ensuring the high quality of fluidization [9].

A magnetolabeled particle obtained by sintering the ferromagnetic powder and polypropylene was introduced into the bed to investigate the movement of particles. After the magnetization of the particle in a constant magnetic field the magnetic moment was 0.39 A/m. The diameter and weight of this particle were the same as those of other particles of the bed.

Magnetosensitive equipment continuously measuring the particle coordinates was installed outside the apparatus and consisted of three three-component magnetometers, each of which measured corresponding components of the particle magnetic field. The magnetometers were provided with magnetosensitive sensor units, which were two-leg differential ferroprobes. Each measuring channel had the following characteristics: measurement range – ±500 γ; (γ = 10–4 Oe); sensitivity – 0.02 V/γ; nonlinearity – 5%; supply voltage – 10 V. The output signals of the magnetometers were recorded on a computer by means of which they were converted into components of the particle displacement vector.

The experiments were carried out at the height of the fixed bed equal to H_0=0.25D, H_0=0.5D, and H_0=1.0D and air velocities taken relative to the cross-sectional area of the empty apparatus equal to 1.5W_{cr}, 2.5W_{cr}, and 3.5W_{cr}.

Vertical and radial displacements of the particle Z(t) and R(t) (measuring relative to the center of the apparatus) were considered as random processes, stationary in a narrow sense. To judge the behavior of particles in the bed on the behavior of one particle the time of this particle observation should be twice as long as the effective correlation time numerically equal to the area under the curve of the normalized correlation function of a random process R(t) or Z(t). In preliminary experiments it was found that this area is maximum for a random process R(t) in case of H_0=1.0D and W=1.5W_{cr}. It was found that the estimated length of implementation (time of observation) in each experiment should be at least 78 s; actual length of implementation was not less than 100 s. The error in determining the coordinates of the labeled particle was ±10%. In case of the defined time of observation the point and method of the labeled particle insertion into the bed make no difference.

The components of the labeled particle velocity vector were determined by numerical differentiation at a sampling interval of 0.2 s. When estimating the probability distribution density histograms of the particle residence in different zones of the bed the whole volume of the bed was divided into cells. The cell dimensions ΔR and ΔZ were assumed equal to

10 mm. When estimating the probability distribution histograms of vertical VZ and radial VR components of the particle velocity vector relative to the axis V_Z and V_R the cell dimensions were $\Delta V_Z=\Delta V_R=0.04$ m/s. The probability of the particle residence in one cell or another or probability of imparting one or another velocity to the particle was determined as the ratio of number of test parameter value "hits" in the cell to the total number of experimental values obtained in this experiment.

3 Results and discussion

The analysis of the particle path along the height and radius of the apparatus shows that with a rise in gas velocity the nature of the particle displacement changes along the cross-section and the height of the bed. Figures 2a and 2b illustrate the projections of the particle path section onto the horizontal and vertical planes at the velocity $W=1.5W_{cr}$ and initial height of the bed $H_0=0.5D$. From Fig. 2a we can see that the particles move freely over the entire cross-section of the bed. In this mode the particles are most likely to be in the center of the ring limited by radii 20 mm <R <60 mm. With regard to the particle displacement in the vertical plane, it is most likely to be near and above the boundary of the fixed bed (Fig. 2b). Rise in the gas velocity up to $3.5W_{cr}$ at the same initial height of the bed increases the probability of the particle residence in the zone of 20 mm <R <40 mm (near-surface zone) and dramatically reduces the probability of the particle residence in the area of R> 50 mm (Fig. 3a). In Figures 3a and 3b we can clearly see the path sections when the particle movement temporarily localizes in the near-surface zone up to 20 mm thick where the particle carries out the up-and-down movement and then moves to the core of the bed. We can talk about the formation of local spouting hearth in the near-surface zone because when H0=0.5D and W=3.5Wcr the most probable value $V_R\approx0$ mm/s (Fig. 4). In forming this zone the velocity of particle displacement to and from the cylinder is equal to $V_R=\pm$ 40-80 mm/s (Fig. 3), wherein the probability of imparting negative and positive velocity to the particle is approximately equal. In other words, during the formation of the near-surface zone there is a circulation of particles in a horizontal plane and during the final formation of the near-surface zone this circulation disappears and particles move from the near-surface zone and back randomly.

When $H_0=0.25D$ even at W≤2.5Wcr there is a sharp increase in the probability of the particle residence near the cylinder in the zone of 10-20 mm wide. In this case the most probable value $V_R\approx0$ mm/s. When $H_0=1.0D$ and gas velocities $W>2.5W_{cr}$ the formation of the near-surface zone is also observed (at a distance of 10-20 mm from the cylinder generating line). However, the probability of the particle residence in the area of R> 50 mm at $H_0=1.0D$ and $W=3.5W_{cr}$ is higher than at the same gas velocity but at the height of the bed $H_0=0.5D$. In other words, in the high bed the high velocity gas flow moving close to the submerged body has a less ejecting impact on the movement of particles than in the low bed.

During the formation of the near-surface zone the particle residence time in this zone is 0.35-0.4 s, which is approximately equal to the particle residence time in the core of the bed (0.3-0.38 s). When the formation of the near-surface zone ends, the particle residence time in the zone is increased to 0.36-0.5 s whereas in the core of the bed it is 0.25-0.4 s. The resulting time values of the particle exposure at the heat transfer surface are comparable with the experimental data obtained in the work [10].

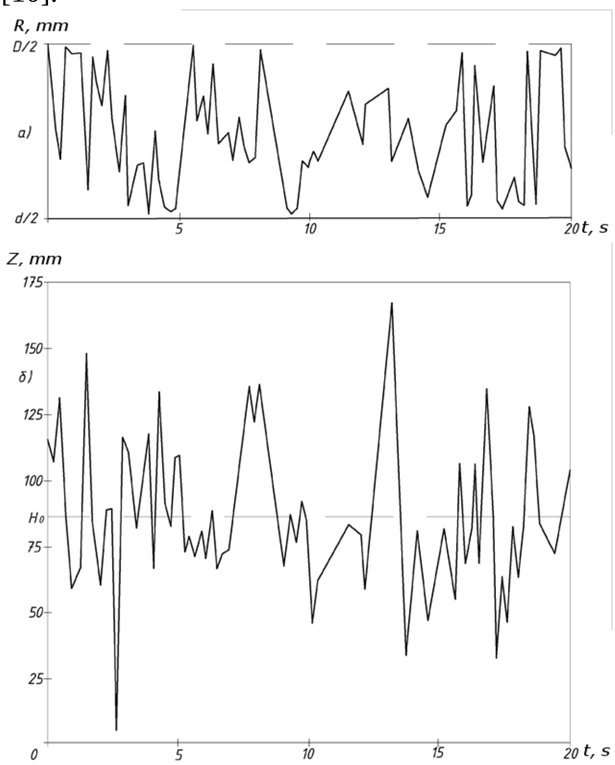

Figure 2. Projections of the particle trajectories in: a) horizontal, and b) a vertical planes at a velocity $W=1.5W_{cr}$. and the initial bed height $H_0=0.5D$.

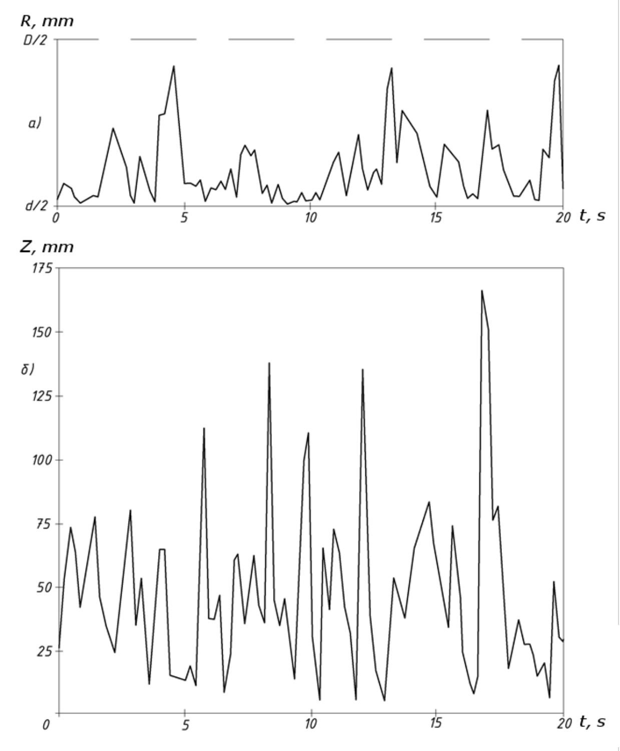

Figure 3. Particle path projections onto:
a) horizontal and b) vertical planes at the velocity $W=3.5W_{cr}$ and initial height of the bed $H_0=0.5D$.

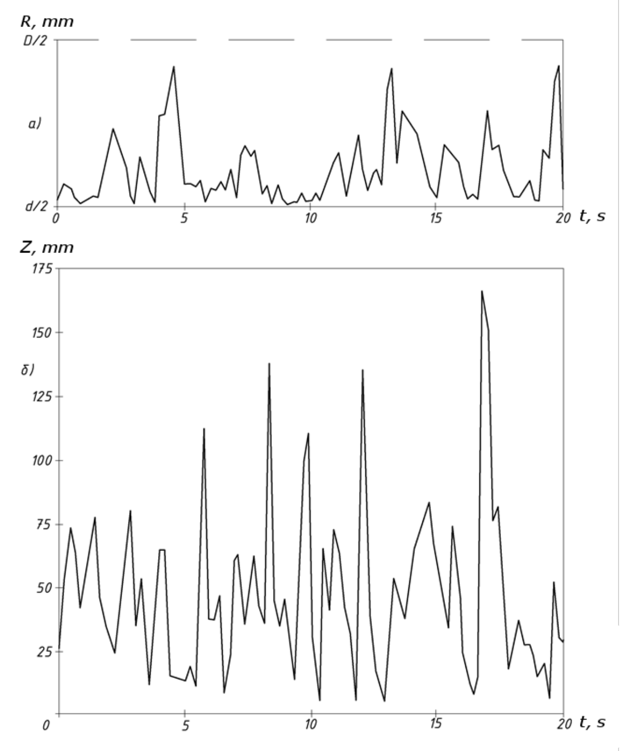

Figure 4. Assessment of the probability distribution density of V_R values in the layer with the cylinder at H_0 = 1.0D: a) W=1.5Wcr; b) $W=2.5W_{cr}$; c) $W=3.5W_{cr}$.

Increasing the time of the particle residence in the near-surface zone while reducing the time of their residence in the core of the bed and eliminating the expressed circulation of particles in the radial direction during the final formation of the near-surface zone should lead to a decrease in the rate of body-bed heat transfer. Therefore, the formation of the near-surface zone should be in the same range of gas velocities for this class of particles in which the external heat transfer rate reaches its maximum and then begins to decrease. This assumption is confirmed by experimental data on the external heat transfer in the bed of the silica-alumina catalyst particles with an average particle diameter of 2.75 mm (Fig. 5).

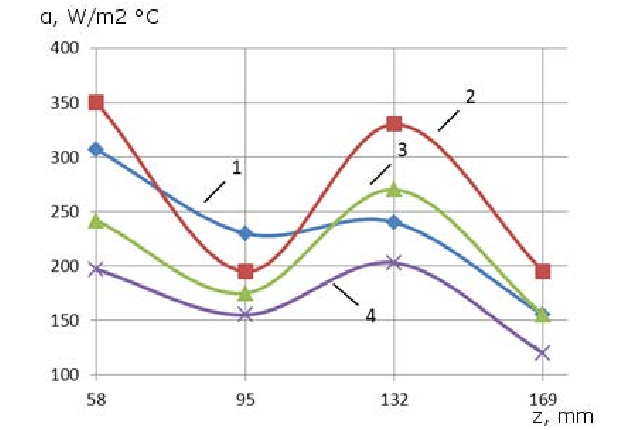

Figure 5. Variation of a coefficient of heat transfer from the bed of silica-alumina catalyst particles (average diameter 2.5 mm) to the vertical cylindrical heater 42 mm in diameter versus the fluidization number N: 1 – N = 1.5, 2 – N = 2.5, 3 – N = 3.5, 4 – N = 4.5. Reproduced from data of the work [8].

4 Conclusion

We can consider the matter to be proved that the formation of the near-surface zone can cause the extreme dependence of the external heat transfer rate and body-bed temperature gradient on the gas velocity since the low time of the particle residence in the core of the bed leads to underutilization of the thermal capacity of the particle getting into the core of the bed from the near-surface zone. Earlier in the construction of various heat transfer models this fact was not taken into account.

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