Western European Journal of Modern Experiments and Scientific Methods
Volume 2, Issue 6, June, 2024
https://westerneuropeanstudies.com/index.php/1
ISSN (E): 2942-1896 Open Access| Peer Reviewed

MOVEMENT OF A SINGLE PARTICLE UNDER THE INFLUENCE OF GAS FLOW IN THE CHANNEL

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Abstract

This study investigates the dynamics of a single particle subjected to gas flow within a confined channel. Using both experimental observations and numerical simulations, we explore the interplay between particle characteristics, gas flow velocity, and channel dimensions. The particle's trajectory, velocity, and orientation are analyzed under varying flow conditions to identify key parameters influencing its movement. Results reveal that the particle's behavior is significantly affected by factors such as drag force, lift force, and particle-wall interactions. The findings enhance our understanding of particulate matter transport in gaseous environments, which is crucial for applications in industrial processes, environmental engineering, and aerosol technology.

Keywords: Particle dynamics, gas flow, confined channel, drag force, lift force, particle trajectory, particle-wall interaction, numerical simulation, experimental observation, particulate matter transport.

Introduction

During flow classification, polydisperse particles move in a perforated channel due to the influence of a gas or liquid flow. Due to the slight excess pressure in the channel, the solid phase partially passes through the perforation holes, and along with it, small particles of the solid phase will be removed from the channel. Large particles, under the influence of the gas flow, continue to move in the channel without clogging the perforation holes. Let us consider the influence of gas velocity in the channel and perforation holes, as well as the size of the holes themselves, on the boundary grain of the classification. According to this scheme, a single spherical particle, under the influence of a gas flow, moves along the perforated bottom of the channel. The perforated bottom is made of triangular profiles installed at a distance b from each other. The gas velocity in the flow core W∞, near the perforated wall, the gas velocity profile is described by the dependence. Under the influence of a small excess pressure P, part of the gas is removed through the perforation slits at a speed Wist, the specific value of which can be determined using dependencies [1,2,3,4]. According to this scheme, a particle in a gas flow participates in two movements: along the perforated surface due to the influence of a gas flow moving at a speed of W∞, and perpendicular to the perforated surface with a speed of Vo. The velocity Vo is determined by the speed of gas outflow through the perforation slits and the

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resulting forces of gravity and Archimedes. Thus, a particle moving in a perforated channel, having passed a certain distance, will approach the perforated bottom [5,6,7,8,9,10].

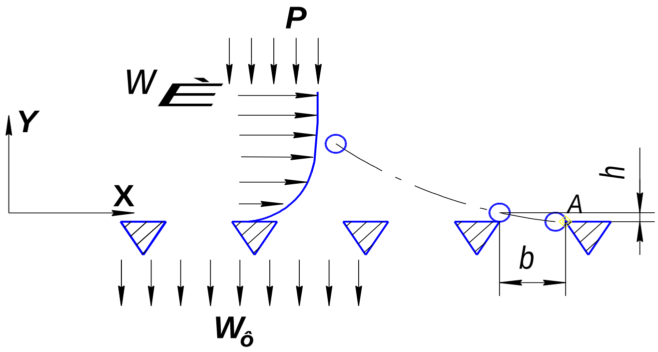

Fig.1. Scheme of particle motion in a gas flow with outflow through a perforated bottom

Let us consider the critical case when a particle with diameter δ has approached the edge of the slit and is in position. With further movement of the particle above the hole, the flow of outflowing liquid will tend to draw the particle into the gap. If the resulting velocity of the center of gravity of the particle at the moment of contact with the opposite wall of the slit is above point A, then a moment will arise that pulls the particle out of the hole, and if it is below point A, then the particle will pass through the slit [11,12,13,14,15]. Therefore, if a particle during its travel time $b-\frac{\delta}{2}$ above the hole will descend into it to a depth $\frac{\delta}{2}$, then it will pass through the gap. Before proceeding directly to calculations of the conditions for the passage of particles through perforation slits, we will make some clarifications and assumptions. First of all, let us clarify the maximum particle size of polydisperse material that is supposed to be fractionated using flow separators. It was previously noted that sieve screens of various designs can be successfully used to classify coarse materials with particle sizes greater than one millimeter. Classification of powders with particle sizes up to0.15 mm can be efficiently carried out in gravitational zig-zag separators or multi-stage shelf separators. Therefore, the main classification task in flow-through separators is the separation of polydisperse materials with a particle size of less than 0.15 mm. The scope of application of this classification is primarily grinding (cement, grain, etc.), as well as the preparation of especially fine powders in various industries. Thus, considering the classification of small particles, we can assume that the speed of their movement in the perforated channel is equal to the speed of the gas in the core of the flow, i.e. $V_\infty = W_\infty$. Let us make the assumption that the movement of gas with particles in the channel along the perforated wall is laminar and the hydraulic resistance to the movement of particles in the channel is described by Stokes' law [16,17,18,19]. Electrostatic, thermophotoristic, difusiophotoristic and other forces of a non-hydrodynamic nature are absent. When particles approach a perforated wall, the lifting force of Zhukovsky, as well as the Magnus force, due to their smallness, do not have much influence

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on them. This conclusion was made on the basis of numerous studies presented in the previous section. In addition, the presence of gas outflow also reduces the influence of these forces on the settling particle.

Travel time of a particle $b-\frac{\delta}{2}$ along the hole:

$$t=\frac{b-\frac{\delta}{2}}{V_{\infty}} \quad (1)$$

In the direction perpendicular to the slits, the particle moved with a speed Vo, and having entered the stream of gas flowing through the slot, with a speed Wist, it began to move with acceleration [20,21,22,23,24]. During time t, the particle will descend into the hole to a height h equal to:

$$h=V_o t+\frac{at^2}{2} \quad (2)$$

According to Newton's law

$$a=\frac{F}{m} \quad (3)$$

The force of action of a gas jet on a spherical particle is determined by the dependence, which for this case will have the form:

$$F_{г-д}=\xi\frac{\pi\delta^2}{4}\frac{\rho_г W^2_{ucm.omн}}{2} \quad (4)$$

The movement of the gas stream in the gap itself under real conditions is turbulent, and, therefore, the value of the drag coefficient ξ is constant and equal to $\xi=0{,}48$ [1,2,3]. Substituting the value of Fg-d from the equation and the value of the particle mass m, we find the acceleration:

$$a=\frac{0{,}33\rho_г W^2_{ucm.\,omн}}{\delta\rho_ч} \quad (5)$$

In the equation, the velocity Vo is determined by the rate of gas outflow through the perforation holes and the gravitational settling of the particle:

$$V_o=W_{ucm}C+\frac{\delta^2(\rho_ч-\rho_г)g}{18\mu} \quad (6)$$

Substituting into the equation instead of Vo its value instead of t its value from the value a we obtain an equation for determining the height to which the particle will fall when moving above the slit of the bottom of the horizontal channel.

$$h=\left[W_{ucm}c+\frac{\delta^2(\rho_ч-\rho_г)g}{18\mu}\right]\frac{b-\frac{\delta}{2}}{V_{\infty}}+\frac{0{,}33\rho_г W^2_{ucm.omн}\left(b-\frac{\delta}{2}\right)^2}{2\delta\rho_ч V^2_{\infty}} \quad (7)$$

Gas flow rate W_{ucm} through the slits is equal to:

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$$W_{ucm} = \frac{1}{\sqrt{1+\xi\left(\frac{W_{\infty}}{W_{ucm}}\right)^{1,2}}}\sqrt{\frac{2\Delta P}{\rho_{г}}} \quad (8)$$

$$W_{ucm.omн} = W_{ucm} - V_{o} = \frac{1}{\sqrt{1+\xi\left(\frac{W_{\infty}}{W_{ucm}}\right)^{1,2}}}\sqrt{\frac{2\Delta P}{\rho_{г}}} - \left(W_{ucm}C + \frac{\delta^{2}\left(\rho_{ч}-\rho_{г}\right)g}{18\mu}\right) \quad (9)$$

Where ΔP − pressure drop on both sides of the slots, in our case will be equal to the pressure in the channel.

The condition for determining the limiting diameter of a particle δ that can pass into the slot b is the value $h = \frac{\delta}{2}$.

Using the equation, the boundary size of the slit for the passage of particles of size 0.05; 0.1i0.15 mm when the airflow speed in the channel changes W∞= 5÷15 m/s and excess pressure P=500÷3000 Pa. Particle density variedρ_h=1000÷3000 kg/m3, and the live cross-section of the cracks was c=0.15. The calculation results are presented in the graph. The graph shows that for all real changes in parameters: air speed in the channel, excess pressure, and particle density, the slit width for the passage of a particle of a boundary size is required to be several times larger than the particle size [25-30]. Consequently, clogging of cracks with particles during flow classification is eliminated, and by changing the above parameters, it is possible to easily adjust the size of the boundary grain during the classification process.

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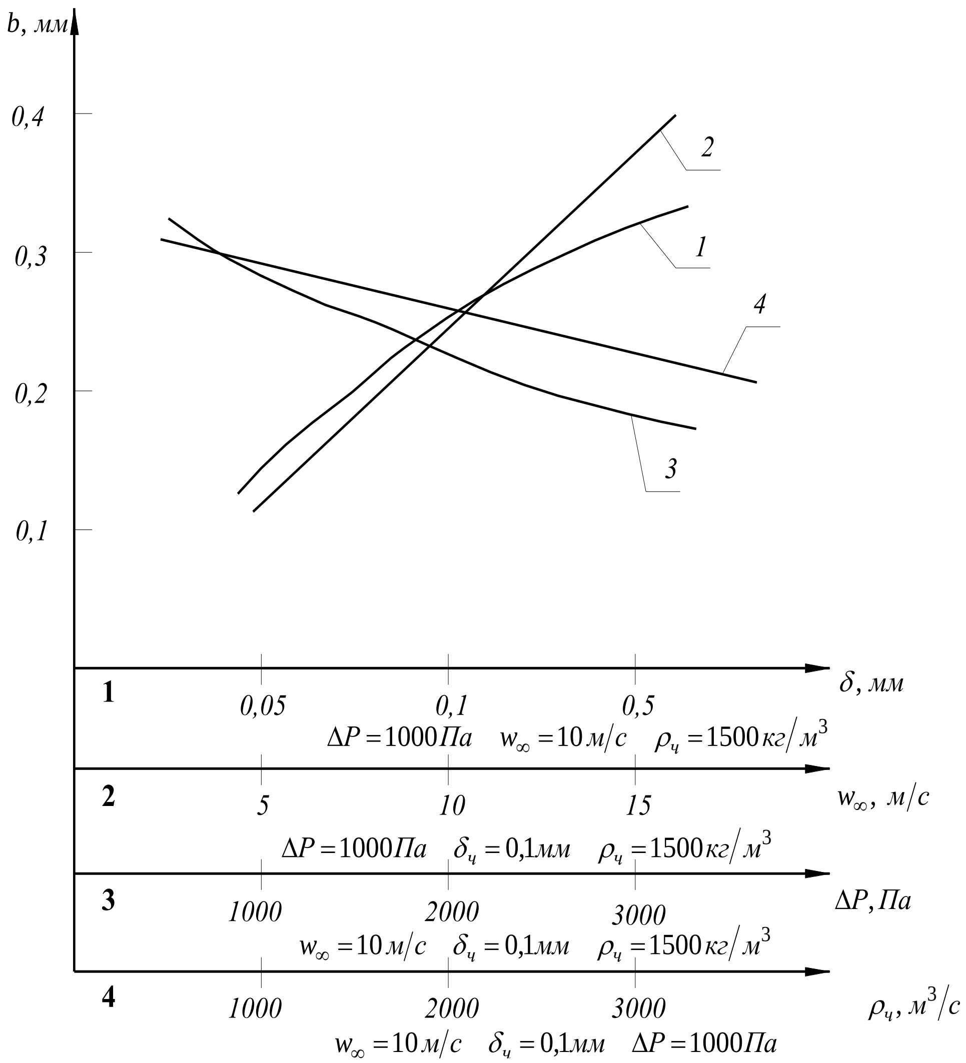

Fig. 2. Dependences of the size of the boundary grain on the parameters of flow classification

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