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ANALYSIS OF THE INFLUENCE OF AERODYNAMIC QUALITIES OF THE COMPONENTS OF MIXTURES ON SEPARATION IN POWER-SAVING VORTEX VEHICLES

Об'єктом дослідження є газодинамічні вихрові процеси у гетерогенних полідисперсних потоках. Одним з найбільш проблемних питань є визначення аеродинамічних характеристик компонент гетерогенного полідисперсного середовища, які необхідні для створення математичної моделі процесу сепарування. В ході дослідження використовувалися методи математичного моделювання на підставі теорії подібності. Розроблено методику оцінки аеродинамічних параметрів компонент суміші, на підставі якої складено ряд аеродинамічної подібності. Отримано коефіцієнти піднімальної сили, аеродинамічного опору, бічної сили, повздовжнього, поперечного та обертального моментів складових зернової суміші. Це необхідно для теоретичних досліджень газодинамічних процесів у вихрових сепараторах при нестаціонарній тривимірній течії з перемінними густиною потоку, концентрацією та витратою складових сепарованої суміші та несомої фракції. Отримано вібраційний критерій Рейнольдса, на підставі якого визначаються траєкторії й енергія вихрового руху окремих компонент та ступінь поділу гетерогенних сумішей. Це дозволило удосконалити математичну модель процесу розподілу гетерогенних полідисперсних сумішей у запропонованих енергозберігаючих вихрових сепараторах. Отримані результати дали підставу для удосконалення загальної теорії гетерогенних вихрових потоків уведенням критерію зовнішнього збурення, який враховує опір вихрового силового поля та амплітудно-частотний енергетичний рівень. Завдяки цьому забезпечується можливість оцінки впливу будь-якого аргументу на шукану функцію. Результати досліджень дозволили автоматизувати аналіз характеристик процесу й порівняння їх по параметрах з експериментальними даними. А також оцінити відповідність динамічних, кінематичних і газодинамічних функцій, розрахованих по заданих геометричних параметрах вихрових апаратів з функціями, отриманими за усередненими значеннями. Ці дані дозволили відпрацювати діапазон варіацій параметрів геометричного оформлення вихрових апаратів по зонах, параметрах на вході, виході та ступенях сепарації, мінімізувати кількість виготовлених лабораторних і напівпромислових вихрових апаратів і уніфікувати ряд вузлів. У порівнянні з аналогічними відомими сепараторами запропоновані вихрові апарати забезпечують зменшення затрат на підготовку сировини у зерноперероблювальній галузі у десятки разів внаслідок усунення рухливих робочих деталей, вузлів і сит.

Ключові слова: *аеродинамічні параметри, вихровий сепаратор, гетерогенна суміш, швидкість перерозподілу, коефіцієнт опору.*

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1. Introduction

The development of the theory of optimization of heat and mass transfer of heterogeneous vortex flows for separation of the components of the mixture is relevant, as it allows to solve an important economic problem of energy saving and environmental improvement. Let's offer a solution to this problem by introducing vortex devices into the technological processes, which by their design can reduce energy consumption and operate in a closed cycle [1, 2]. Comprehensive studies of the separation of heterogeneous mixtures show that the main characteristics of vortex separators, such as efficiency and clarity, do not always meet the requirements of technological processes [3, 4]. This is primarily due to the fact that the separated mixtures consist of components that vary widely in particle size distribution, density, aerodynamic parameters, critical speeds, concentration, etc. [5, 6]. In the literature on a number of experimental studies of the aerodynamics of aggregates or individual elements, the aerodynamic and gas-dynamic processes of flow around, stalling, jumping of seals and rarefaction for objects of various shapes and sizes are well and fully developed [7, 8]. But the issue of developing a flow around small objects is associated with certain difficulties, in particular, with modeling [9, 10]. The transition from an enlarged model to its original size leads to unreasonable increases in errors for two reasons. Firstly, an increase in the model leads to a distortion of the picture of flow separation and a change in the direction of an increase in the boundary layer, which may not be possible on a small scale, since in two-phase flows the magnitude of the slip coefficient lies within wide limits. And, secondly,

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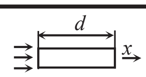
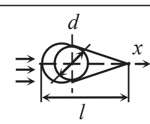
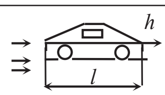
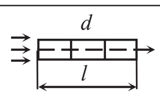
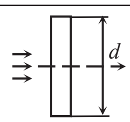
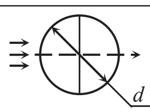
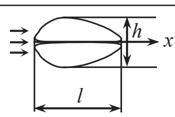
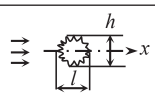
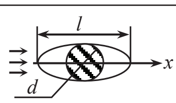
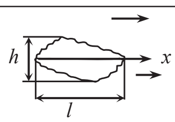
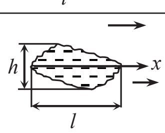
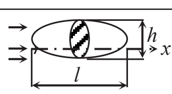
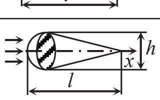
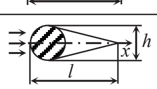
there is an error in the measurement of flow parameters. In addition, the movement of particles in a two-phase flow is movement in the accompanying flows, and not of the individual components, as is considered in a wind tunnel. Thus, the development of methods for assessing aerodynamic parameters is an urgent task. *The object of research* is gas-dynamic vortex processes in heterogeneous polydisperse flows. *The aim of research* is to improve the general theory of separation of heterogeneous polydisperse flows.

2. Methods of research

Research on the determination of aerodynamic drag for a two-phase medium was carried out on the basis of the theory of vortex gas-dynamic separation of a heterogeneous polydisperse flow. Using the theory of similarity and mathematical modeling methods, the aerodynamic series of bodies was constructed from the obtained data [10] (Table 1).

Table 1

Aerodynamic similarity factors

No.	Characteristic form	Body name	l/d l/h	c_v	f_i	Re
1		plate	$l=\infty$ $h\to 0$	≈0	≈0	$2.0\cdot 10^3$
2		body that wraps around well	2.5	0.04 0.05 0.09	d	$2.0\cdot 10^3$
3		car	3.12–4.0	0.24–x 0.37–y 0.45–z	2.24 m^2 2.17 m^2 1.77 m^2	$2.7\cdot 10^3$
4		squares connected	1.5–3.5	0.90	14.0–24.0	$4.6\cdot 10^3$
5		plate	–	1.20	d	$3.7\cdot 10^3$
6		drop (sphere)	1	0.048	$\pi d^2/4$	$4.35\cdot 10^3$
7		wheat	2.6–2.4	0.0478 0.051 0.92	4.7–6.25	$4.35\cdot 10^3$
8		cockle	1.75–1.46	0.08	4.4–13.2	$3.4\cdot 10^3$
9		locust bean	2.5–4.7	0.04 1.0	2.0–15.6	$6.6\cdot 10^3$
10		wild oats	6.1–6.6	0.2	2.3–9.0	$6.0\cdot 10^3$
11		buckwheat	1.25–1.38	0.93	2.56–9.3	$11.0\cdot 10^3$
12		wild radish	1.7–1.62	0.05	3.4–29.0	$1.4\cdot 10^3$
13		Tatar buckwheat	1.8–1.6	0.05	4.8–12.9	$1.4\cdot 10^3$
14		field bindweed	2.2–1.53	0.05	1.54–9.52	$1.5\cdot 10^3$

The solution to the above problem was carried out theoretically and experimentally by blowing models of the components of the grain mixture made in scale 43:1. For comparison, let's used a car, plate, etc. in scale 1:43, as standard models for a small wind tunnel with constant pressure and flow air. Based on the results of the experiments, the criteria of Strouhal, Froude, Euler, Reynolds, Archimedes and Barsukov were determined [10].

The external perturbation on discrete components (deviation of streamlines) was estimated with the derived Barsukov's criterion:

$$Bs = \frac{Eu\cdot \mathrm{Re}}{Ar}\cdot A = \frac{Eu\cdot \mathrm{Re}}{Ar}\cdot\frac{\rho_0 \upsilon_n^2}{\rho\upsilon_0^2-\rho\upsilon^2},$$

where

$$A = \frac{\rho_0 \upsilon_n^2}{\rho\upsilon_0^2-\rho\upsilon^2}$$

– relative dynamic pressure head;

$$\frac{Eu\cdot \mathrm{Re}}{Ar}$$

– «energy» potential of the force field.

3. Research results and discussion

The accuracy of theoretical studies depended on how close to the actual values the aerodynamic drag coefficients of the flow components are determined for the models. With the free spatial positions of the component models during blowing, the obtained coefficients of lift, aerodynamic drag, lateral force, longitudinal, transverse and rotational moments. The flow pattern (streamlines) for grain and impurity models was determined using a uniformly distributed smoke comb with an elementary jet diameter of 2 mm, with a constant Reynolds number. Based on the data obtained, the values of the coefficients were determined depending on the characteristic positions with respect to flows and grain sizes of wheat and impurities, as for standard automobile models, plates, etc. (Table 1).

The reliability of the selected value of the drag coefficient in the constructed series of bodies was confirmed on the basis of the mid-section intersection f_1 and the ratio of characteristic sizes (l/h or l/d) along the x axis. In addition, the flow velocity, the characteristic profiles of the parts of the bodies, their sizes and the completeness of the shape along the x, y, z axes were additionally taken into account. In this case, it was necessary to evaluate the state of the surface of the bodies and their location relative to the x axis.

Some error can only be from the impact of flows, breaks, and the rotation of bodies relative to the axes, as well as impacts. External disturbances of the incident flow, which changes the trajectories of the individual components of the mixture, were determined by the criterion of drag of the vortex force field and disturbing vibrations from the incident flow by the criterion *Bs* (Fig. 1). The obtained results are valid for sulfur compounds, dust, coal; mineral impurities, wheat grains, difficult to separate impurities: sown, locust bean, etc.

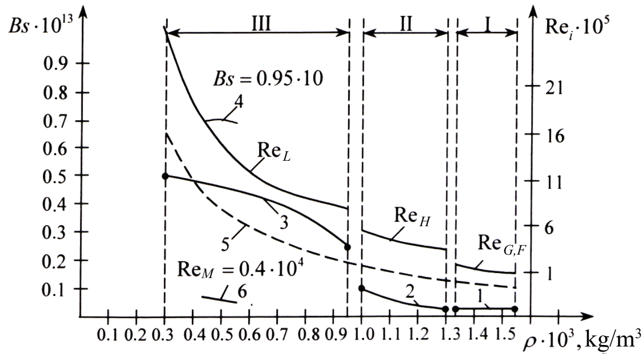


Fig. 1. The nature of the change in the Barsukov's criterion $Bs(\rho)$

In Fig. 1: 1, 2, 3 – heterogeneous mixture components with constant parameters; 4 – flour of the first grade; 5 – calculation according to experimental data for grain entering the elevator (2 % impurity, 12 % moisture); I – pure wheat II – heavy impurities $(\rho\cdot10^3 > 1.0\cdot10^3)$, Re_H – averaged Reynolds vibration criterion for heavy impurities; III – light impurities $(\rho\cdot10^3 < 1.0\cdot10^3)$, Re_L – averaged Reynolds vibration criterion for light impurities; $\mathrm{Re}_{G,F}$ – averaged Reynolds vibration criterion for pure grain and flour of the first grade, respectively.

An analysis of the Barsukov's criterion $Bs(\rho)$ suggests that the value of *Bs* increases with decreasing density of the medium. The rupture of this functional relationship in the density ranges from $(0.95-1)\cdot10^3$ kg/m^3 and $(1.3-1.34)\cdot10^3$ kg/m^3 is completely explained by the difference in the vibration Reynolds number $\mathrm{Re}_{H,L}$ for impurities. This is explained by the fact that impurities differ from pure grain in the shape, size and relative speed of air without taking into account collisions of components (for pure components, curves 1, 2, 3).

4. Conclusions

A technique has been developed for assessing aerodynamic parameters based on the similarity of the natural components that make up the heterogeneous mixture and the models made in size, density and roughness on a scale of 43:1, based on which a series of aerodynamic similarities was first compiled. Based on the calculation of natural origin (the volume of one grain with average linear dimensions $a>b>c$ (6.4>2.8>2.4 mm) $V_n = (0.04\div0.41)\cdot10^{-7}$ m^3, the mass of which $m_n = (0.30\div0.35)\cdot10^{-4}$ kg, the density of one grain (natural) $\rho_n = 0.875\cdot10^3$ kg/m^3 was obtained. For the volume model $V_m = 0.34\cdot10^{-2}$ m^3, the mass density for the manufacture of a model from polyurethane was $\rho_m = 818$ kg/m^3. According to the results of blowing models of components in a small wind tunnel equipped with an aerodynamic three-component balance, the data obtained to determine the drag, longitudinal moment and lifting force.

The general theory of heterogeneous vortex flows has been improved with the help of the proposed criterion of external disturbance – the Barsukov's criterion, which takes into account the drag of the vortex force field and the amplitude-frequency energy level.

Differential relationships have been developed for changing the energy levels of polydisperse heterogeneous flows with a free-flowing one-component flow with specified amplitude-frequency parameters to determine the most

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advantageous gas-dynamic functions and rational geometric dimensions of vortex devices. Equations are introduced into the mathematical model of gas-dynamic separation processes that describe vortex heterogeneous flows, the Reynolds vibration criterion, based on which the trajectories and vortex motion energy of individual components and the degree of separation of heterogeneous mixtures are determined.

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