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Application of the Laws of Dynamics of Dispersed Systems to Model Classification Processes of Mixtures of Components with Different Physical Properties

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In the era of limiting the use of primary raw materials in production technologies, it is becoming necessary to reuse secondary raw materials (closed-loop economy). These raw materials very often consist of a large number of various physically and chemically homogeneous substances, but their reuse requires a prior purification process to remove undesirable components (raw material enrichment). A pneumatic classification process can be employed for this purpose. The paper presents the possibility of modeling complex classification processes. For this purpose, the basic laws of dynamics of dispersed systems were used. Mathematical programming methods were applied to identify the presented model. The identification of the model was carried out using the results of experimental studies on the separation of a mixture of different components in a two-stage classification system. The presented experimental results and the computational model can be used to formulate and solve optimization problems of fractionation of dispersion materials and to increase the efficiency of the process in classification systems.

topics: classification, Maxwell–Boltzmann law, modelling, flow dynamic classifier

1. Introduction

The shrinking resources of primary natural resources, as well as the change in the structure of energy production, force us to reorganize, among others, the technology of manufacturing new products. Technologies that fit into the circular economy model are being implemented.

A different perception of used goods became one of the ideas of a new look at the economy. Goods that were no longer needed began to be seen in the context of the potential recovery of energy necessary in the process of their prior production, as well as the reuse of waste materials in the manufacturing technologies of new products.

The reuse of specific components of waste raw materials requires the removal of unnecessary elements. In this aspect, processes enabling the separation of raw materials present in waste products are gaining new significance. One such process is the classification process.

The classification process is an extremely complex and it is difficult to formulate an unambiguous, deterministic mathematical description for it. However, becoming familiar with it enables the use of separated, clean components in the manufacturing technologies of new products.

The issue of the mechanical classification of raw materials is important both from scientific and practical points of view.

The subject of the research is the process of aerodynamic classification of granular materials, taking place in a flow dynamic classifier [1–4]. The analyzed case was the process of multi-stage classification of a mixture of heterogeneous components [4, 5].

The aim of the undertaken research is to develop an appropriate mathematical model to describe the classification of a mixture of heterogeneous components. The specific aim of this paper was to conduct experimental research and to determine the process-specific physical quantities, the results of which will be used to identify and verify the developed mathematical model.

2. Research methods

In the classification process, the movement of grains is chaotic, which means that they move in different directions at different speeds. The fundamental dependence determining the number of particles of a given speed or energy is the Maxwell–Boltzmann law [4–6]

$$\frac{\partial f}{\partial t} + \frac{\partial (v_k f)}{\partial z_k} + \frac{\partial (a_k f)}{\partial v_k} = \dot{f}, \tag{1}$$

where $f(\boldsymbol{r}, \boldsymbol{v}, x, \tau)$ — density of grain distribution in relation to Cartesian coordinates $\boldsymbol{r} = (z_1, z_2, z_3)$, speed components $\boldsymbol{v} = (v_1, v_2, v_3)$ and grain size x; $\boldsymbol{a} = (a_1, a_2, a_3)$ is the acceleration of grains. Repeating the index k ($k = 1, 2, 3$) means summing with respect to that index.

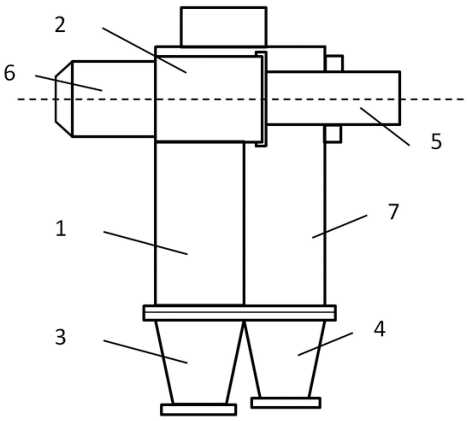

Fig. 1. Diagram of the two-stage flow dynamic classifier: 1 — gravity separation stage; 2 — centrifugal degree of classification; 3 — gravity stage return tank; 4 — centrifugal stage return tank; 5 — centrifugal fine material outlet; 6 — electric motor; 7 — second stage return conduit.

TABLE I

The mass of the components of the mixture in the series of experiments.

test number	p [kPa]	n [1/s]	τ [s]	m_{Si} [g]	m_{Ca} [g]
1	400	30	360	1000	0
2	400	30	360	800	200
3	400	30	360	600	400
4	400	30	360	400	600
5	400	30	360	200	800
6	400	30	360	0	1000

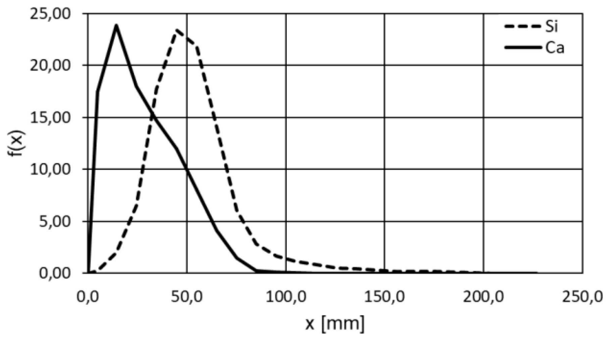

Fig. 2. The particle size distribution of the individual components of the mixture.

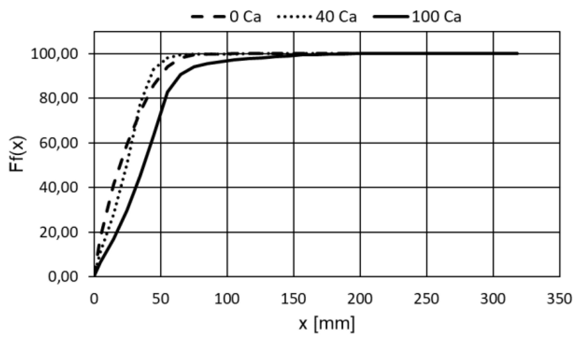

Fig. 3. Cumulative grain composition of the fine product of classification process for different initial compositions.

The general solution of (1) is extremely difficult. To achieve this, the matrix method [4, 5] was used, in which the sought continuous form of the density of matter distribution in the computational space is replaced with a discrete form of selected matrix elements. This allows the multidimensional computational space to be replaced with a one-dimensional chain of elements

$$f = \{f_i\}, \qquad (2)$$

where index i represents the element number of the computational space.

3. Experimental studies

The experimental studies were carried out on a laboratory stand with a two-stage classifier (Fig. 1).

Previously prepared feed, consisting of a mixture of limestone ($CaCO_3$) and quartz sand (SiO_2), was brought into the classification zone along with the carrier air. The limestone content in the mixture ranged from 0 to 100%. In the first phase, the mixture was separated by gravity in the gravity stage of the classifier (no. 1), then the fine product of the process was pneumatically sent to the second centrifugal stage of the classifier (no. 2), and the coarse-grained product left the classification zone by gravity and accumulated in the tank (no. 3).

The coarse-grained product of the second grade of classification flowed through the conduit (no. 7) to the tank (no. 4), and the fine product, together with the air, left the classification zone via the outlet conduit (no. 5). The electric motor (no. 6) was responsible for maintaining constant rotations of the classifier rotor during the experiment.

After each experiment, the products were weighed and sieved. The grain composition of the mixture components was analyzed separately, and the grain composition of the classification products was determined for the mixture of components.

In all the experiments, the rotational speed of the classifier rotor was 30 rpm; the duration of each trial was 360 s; air flow through the classifier — 11.9 m^3/h air pressure — 400 kPa; the feed weight of the mixture remained constant at 1000 g; air temperature in the laboratory — 23°C, relative humidity — 29%; ambient air temperature — 9°C; the atmospheric pressure was 100.9 kPa. The mass of the components of the mixture in the series of experiments is presented in Table I, where the Si index is for quartz sand, Ca is for limestone.

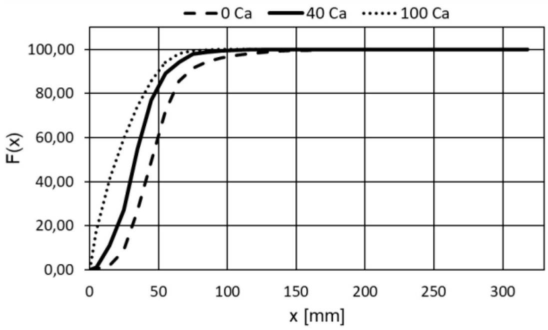

Fig. 4. Cumulative grain composition of the coarse product of the classification process for different initial compositions.

The particle size distribution of the individual components of the mixture and the mixture after the experiments for different initial compositions of the mixture are shown in Figs. 2–4. Grain composition of the components, namely the solid line is for limestone and the dashed line is for quartz sand.

The grain composition of the fine product of the classification process is shown in Fig. 3. The type of line characterizes the case of the mixture classification process with a different proportion of limestone. It can be seen that the curve that characterizes the classification process only of quartz sand is the most different from the others.

In the case of the analysis of the grain composition of a coarse product of the classification, the influence of the initial structure of the mixture of components on the process effect is even more noticeable.

The analysis of the above results shows that the composition of the feed mixture significantly affects the classification effect.

4. Conclusions

As part of the research, experimental results were obtained for the classification of a mixture of heterogeneous components in a laboratory system.

The obtained results will be used to identify and verify the adequacy of the classification process model using a discrete form of the Maxwell–Boltzmann equation.

A mathematical description of the mixture classification process, taking into account the possible requirements for finished products, both in a separate apparatus and in a cascade of classifiers, is an urgent technological task, especially in terms of meeting the challenges of the circular economy. In order to carry out design calculations and improve the process, it is advisable to use simple and adequate models.

An unambiguous and mathematically easy description of the classification process of complex systems, both in terms of the devices used and the materials to be classified, will allow to optimize these systems.This will contribute to significant savings of energy and primary raw materials, which is a significant achievement in the context of the implementation of the circular economy.

Using the laws of physics to describe the phenomena occurring in the economy will help to solve the problems posed by societies in a more friendly perception of the world.

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