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A. Leudanski[1], D. Chirkun[1], V. Golubev[2], D. Sarsenbekuly[2], D. Zhumadullayev[2]

[1]Belorussian State Technological University, Minsk, Belarus;
[2]M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan.
E-mail: daulet_ospl@mail.ru

EXPERIMENTAL RESEARCH OF A MULTISTAGE GRAVITATIONAL CLASSIFIER

Abstract. The classification of polydisperse materials is widely used in many industries. Of the wide range of classification equipment, the most promising are multistage gravitational classifiers. The classification process in multistage gravitational classifiers is quite complicated and requires the necessary experimental research to ensure the given efficiency. To receive reliable information allowing to obtain the most effective recommendations for their structure and use, a set of experimental research was carried out. The research results showed that multistage classifiers of small sizes provide a consistently high quality of separation, however their performance, for an apparatus with a cross section of 80x80 mm no more than 100 kg/h, is insignificant, as a result of which they cannot be used for most production processes. Classifiers with higher performance must have significant sizes. It is advisable to use multistage shelf classifiers with boundary separation sizes of 0.5-2 mm. With a boundary size of less than 0.5 mm, a steady decrease in the separation efficiency is observed, and with a boundary size of the order of 0.05-0.1 mm, the classification efficiency decreases sharply. With an increase in the boundary separation grain of more than 2 mm, a decrease in the classification efficiency is also observed (figure 1). The experiments to determine the separation efficiency in the modernized and conventional structures of classifiers in the separation of quartz sand with particle sizes of 0-2 mm relative to the boundary separation size of $\delta_{гр}$ = 1 mm showed the following. The mutual arrangement of the efficiency curves shows that an increase in the separation efficiency for the modernized classifier is up to 10% when the optimum, providing the highest quality separation, air velocity per section of the apparatus is achieved. Similar results were obtained for other materials (sylvinite, meal, gypsum) for various boundary separation sizes (from 0.5 to 2 mm). In general, the separation efficiency in the modernized structure of the shelf classifier for various materials was 5-10% higher than in a conventional one. The experimental research of the modernized classifier structure showed that the proposed structural additions, ceteris paribus, contribute to a more uniform distribution of material over the working volume of the apparatus, which, of course, leads to an increase in the quality of separation.

Key words: experimental research, gravitational classifier, multistage, separation efficiency, boundary sizes, section, holes.

Introduction. The grinding and fractionation processes are widely used in many industries. Currently, there are major trends in the development of milling equipment combining grinding and fractionation [1-11]. It should be noted in advance that many researchers [12-18] were involved in the development and research of multistage gravitational classifiers, monographs were written on this subject, and several dissertations were performed. The available data describe in detail the effect of technological and structural factors on the separation process. Thus, it was established that multistage classifiers work quite efficiently with boundary separation sizes from 0.2 to 2-3 mm, while the concentration of the solid phase should not exceed 2-2.5 kg/m^3 of the carrier medium (air). There are empirical dependencies for calculating the air consumption for classification depending on the size of the apparatus and the boundary separation grain. The number of overflow shelves is usually taken 6-10, while the shelves are located at an angle of 45° to the horizon, overlap the classifier section to its middle and the height step between the shelves is taken equal to the width of the apparatus section. Compliance with these recommendations allows achieving separation efficiency in laboratory models up to 90% [12-17]. At the same time, as already noted above, in industrial tests, the separation efficiency of multistage classifiers is significantly decreased, which shows a significant influence on the separation process of the scale factor during the transition from laboratory to industrial plants. In well-known and previously noted works, this factor is practically not paid attention to, only some of them [12, 13] indicate that with an increase in the size of the classifier, its efficiency decreases, however there is no quantitative assessment of this phenomenon.

Research methods. When determining the hydrodynamic parameters and the distribution of dispersed particles of classification substances, standard methods of physicochemical research were used.

The experimental research of a gas-centrifugal classifier was carried out with the aim of:

a) testing the obtained mathematical model of the motion of a single particle in a swirling gas medium;

b) determination of excess pressure on the inner wall of the perforated element;

c) determining the boundary size of the particles passing through the perforation holes.

To study the scale factor influence on the separation of polydisperse materials in a gravitational multistage classifier, several geometrically similar apparatuses with cross-section sizes of 80x80 mm, 140x140 mm, 200x200 mm, 300x300 mm were designed and manufactured. The results of these experimental research on quartz sand with a particle size of 0-5 mm are presented in figure 1.

Research results. The obtained experimental data are presented in figure 1, 3.

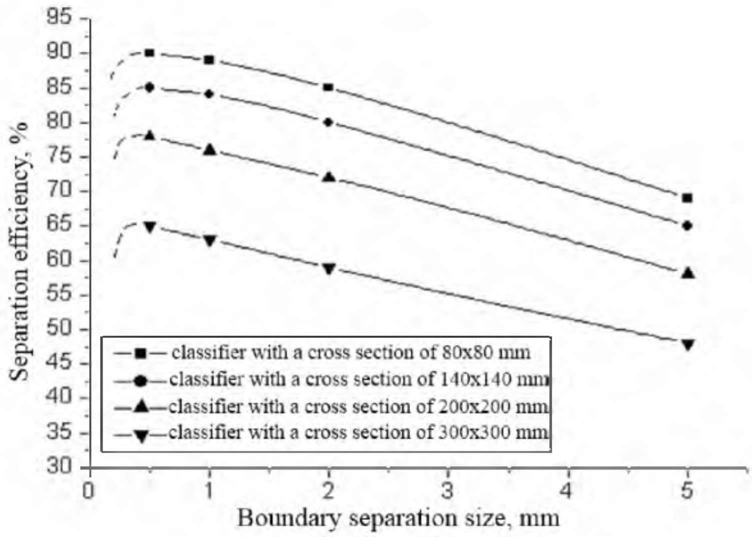


Figure 1 – Separation efficiency depending on the cross-sectional size of the classifier

Visual observations of the separation process carried out during the experiments showed the following. When a coarse fraction was unloaded from the classifier, the material from the last inclined shelf did not flow uniformly over the entire width of the shelf, however it was largely concentrated at its edges, i.e. at the side walls of the apparatus. And the larger the cross-sectional sizes of the classifier, the more this phenomenon manifested itself. This indicates that the material in the classifier's working volume is distributed unevenly, and as it moves down it may be pushed aside by the air flow to the apparatus walls. In addition, the pulsating nature of the descent of the material flow from the last shelf was observed. The material was unloaded into the tank not by a uniform flow, but by pulsating, with sharp discharge fluctuations. Naturally, with these phenomena, part of the starting material does not have time to contact with the air, but simply falls down, as a result of which the large product is contaminated with fines and the separation efficiency decreases.

Thus, it can be seen from the series of experiments that multistage classifiers of small sizes provide a consistently high separation quality, however their performance, for an apparatus with a cross section of 80x80 mm no more than 100 kg/h, is insignificant, as a result of which they cannot be used for most production processes. Classifiers with higher performance must have significant sizes, and, therefore, as the above research has shown, the separation efficiency will be low, which again complicates their implementation in production.

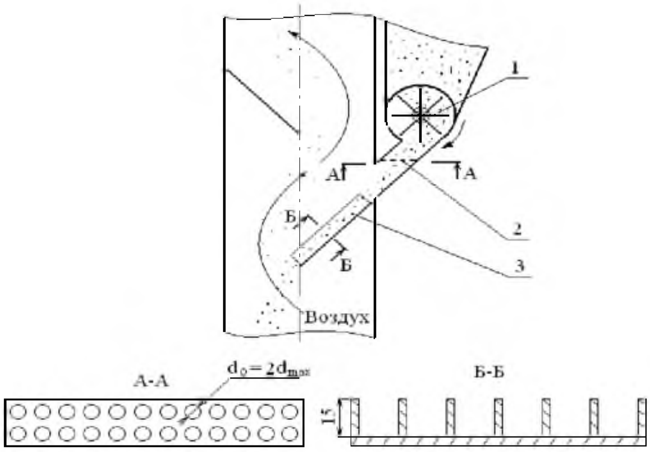
To solve this problem, in order to more evenly distribute the material over the cross section of the apparatus, which should increase the quality of separation, some structural additions were made to the existing classifier structure (figure 2).

The essence of these structural additions is as follows. After the rotary feeder, the perforated sheet (item 2, figure 2) with the hole of d_o size 2 times larger than the maximum particle size in the material to be separated was installed in the feeding tube of the classifier, which follows from the condition to prevent clogging of the holes. Such a structural feature will allow to smooth out the pulsating nature of the movement of the starting material supplied from the feeder. In addition, in order to more evenly distribute the material already in the classifier's working volume and prevent the material accumulation at the apparatus walls, the inclined shelves located below the feeder were made with longitudinal slides (item 3, figure 2). These slides prevent the material from moving in the cross direction of the inclined shelves.

To study the efficiency of structural changes introduced into the classifier apparatus, a series of experiments was carried out to determine the separation efficiency of the polydisperse material into fractions in the modernized structure, the results of which were compared with the separation efficiency in the conventional classifier structure. Classifiers with cross-sectional sizes of 200x200 mm were used as model classifiers, providing a feed capacity of 300 kg/h.

Figure 3 shows the results of experiments to determine the separation efficiency in the modernized and conventional structures of classifiers in the separation of quartz sand with particle sizes of 0-2 mm relative to the boundary separation size of $\delta_{гр} = 1$ mm.

The mutual arrangement of the efficiency curves (figure 3) shows that an increase in the separation efficiency for the modernized classifier is up to 10% when the optimum, providing the highest quality separation, air velocity per section of the apparatus is achieved. Similar results were obtained for other materials (sylvinite, meal, gypsum) for various boundary separation sizes (from 0.5 to 2 mm). In general, the separation efficiency in the modernized structure of the shelf classifier for various materials was 5-10% higher than in the conventional one.



1 – feeder; 2 – perforated sheet; 3 – slides of the inclined shelves

Figure 2 – Structural additions made to the classifier apparatus

Thus, these facts confirm the opinion of many researchers that the separation quality in gravitational classifiers largely depends on the uniform distribution of the starting material over the entire working volume of the apparatus. Naturally, the larger the classifier, the more difficult it is to ensure uniform flow of the medium and material, which, as shown by the above experimental data (figure 3), to a decrease in the separation efficiency. Therefore, at high performance it is more expedient not to increase the size of the classifier, but to partition several relatively small apparatuses into spacer blocks. This will allow to achieve the required performance by setting the required number of sections, and the separation efficiency will be as high as for single classifiers of small sizes.

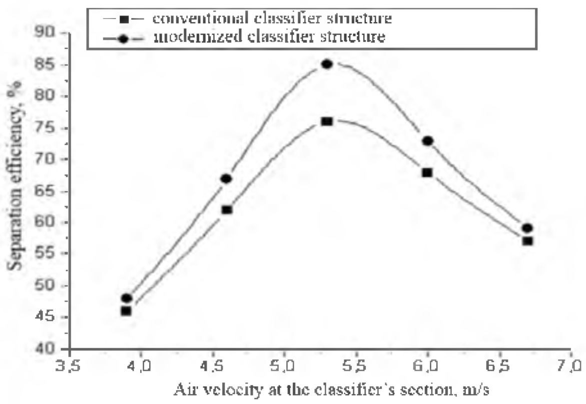


Figure 3 – Separation efficiency of classifiers

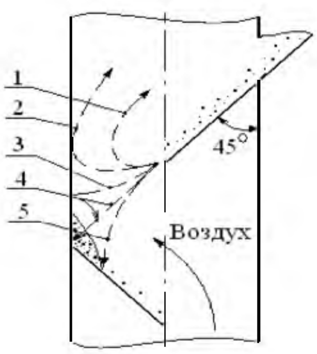
At the same time, visual observations of the separation process in the modernized classifier structure showed that although it was possible to achieve a more uniform distribution of the material across the width of the apparatus, however, there was still a pulsating character of the large fraction descent from the last shelf, as in the case with the conventional classifier structure. The material from the feeder was supplied in a uniform flow, due to the installation of the perforated sheet behind the feeder (item 2, figure 2), and already at the exit from the classifier the material consumption was uneven, pulsating.

To study the causes of this phenomenon, windows were made in the side walls of the apparatus. During the experimental installation operation, these windows were hermetically sealed with organic glass plates, which allowed to visually observe the material movement during the classification process.

The observation of the classification process allowed to establish the following mechanism for the distribution of the material to be separated in the working volume of the classifier, shown in figure 4. Quartz sand with a particle size of 0-2 mm was used as a model material, the separation was carried out relative to the boundary size of $\delta_{гр} = 1$ mm.

When the classifier is working, the starting material, falling down from the inclined shelf, experiences the effect of an ascending air flow. Small particles, with a size smaller than the boundary, are picked up by the air flow and carried upward (items 1, 2, figure 4). Large particles, with a size larger than the boundary, overcome the resistance of the air flow and fall down (items 3-5, figure 4). Boundary-sized particles with the same probability can be carried up into a small product, and fall down into a large one, depending on the influence of many unaccounted or random factors (items 2, 3, figure 4).

Therefore, as can be seen from figure 4, there is a kind of "bombing" by large particles of the shelf attachment area to the classifier wall. Moreover, the velocity vector of large particles is often directed almost perpendicular to the surface of the next shelf (item 4). As a result of this, as the visual observations have shown, a large fraction accumulates here, which was further confirmed by analysis of samples from the material residues in the corners between the shelves and the classifier case taken when the experimental setup was stopped. Upon reaching a certain amount of the material, this accumulation abruptly breaks down, which explains the pulsating nature of the movement of a large fraction at the classifier exit.



(1 – 5) – various size particle movement trajectories

Figure 4 – Various size particle movement in the working volume of the classifier

It would seem that the inclination angle of the shelves is large enough (45°) so that the material slides down, in fact the friction coefficient of various materials on steel is lower than unity for most materials (from the condition that the body is at rest on an inclined surface, it follows that the friction coefficient should be equal to the tangent of the inclination angle of the surface). However, it should be appreciated that the fact that particles falling into the angle between the shelf and the classifier wall are pressed to some extent by the ascending air flow and, in addition, are pressed to the shelf by the following layers of material. All this complicates the movement of the material down, therefore, its accumulation occurs despite the structural conditions of unhindered sliding down the inclined shelf.

The processing of the experimental data for the group of materials studied allowed to obtain a dependence for determining the air velocity over the classifier cross section, which provides the most high quality separation

$$W = 0{,}53 \cdot v_{вит} \cdot \rho_{ч}^{0{,}06} \quad (1)$$

where $v_{вит}$ – particle staying velocity, m/s; $\rho_{ч}$ – density of the material to be separated, kg/m^3.

The dependence (1) is in good agreement with the methods for calculating the air velocity proposed by other researchers [2, 6], which are based on the choice of gas velocity W in the apparatus within

$$W_{кр1} < W < W_{кр2}, \quad (2)$$

where $W_{кр1}$ – velocity of the required fraction pneumatic transport start, m/s; $W_{кр2}$ – velocity, the excess of which leads to a sharp increase in the intensity of the removal of a large fraction into a small product, m/s.

Conclusions. The obtained experimental data (figure 1) allow to draw some conclusions:

1. It is advisable to use the multistage shelf classifiers with the boundary separation sizes of 0.5-2 mm. With the boundary size of less than 0.5 mm, a steady decrease in the separation efficiency is observed, and with the boundary size of the order of 0.05-0.1 mm, the classification efficiency decreases sharply. With the increase in the boundary separation grain of more than 2 mm, the decrease in the classification efficiency is also observed. The reason for this is that in order to rise sufficiently large particles into a small product, significant air velocities in the classifier are required (in order to rise into a small product particles of quartz sand with a size of 2 mm and a density of 2000 kg/m^3, the air velocity per section of the apparatus is 7.8 m/s). At high air velocities, the hydrodynamics of the flow of medium and material are disturbed, random turbulent pulsations and turbulences occur, which negatively affect the separation performance. In addition, large particles moving down into a large product can entrain smaller particles, which also reduces the separation efficiency.

2. With the increase in the size of the classifier's cross section, ceteris paribus, the separation efficiency decreases. If a laboratory classifier with the cross section size of 80x80 mm provides the separation efficiency of up to 90-92%, then for an industrial sample with the cross section size of 300x300 mm, it does not exceed 65%. The reasons for this, according to many researchers [12, 13, 20, 21, 22], is that in multistage classifiers (as, indeed, in any other gravitational apparatuses) with significant geometric sizes it is very difficult to uniformly distribute the material over the entire volume of the apparatus and also organize a stable air flow velocity field, avoiding various random pulsations, vortices, circulations, and other similar phenomena that occur during the movement of gases or liquids.

Thus, the experimental research of the modernized classifier structure showed that the proposed structural additions (figure 2), ceteris paribus, contribute to a more uniform distribution of the material over the working volume of the apparatus, which, of course, leads to the increase in the quality of separation.

The material accumulations falling down from the inclined shelves violate the classifier's hydrodynamics, limit the contact of particles with the air flow, as a result of which the quality of separation in industrial installations is reduced in comparison with laboratory models, where the above phenomenon manifests itself to a lesser extent.

In order to improve the quality of separation, theoretical research of particle movement in the working volume of the classifier were carried out, aimed at studying the mechanism of accumulation of material particles on the inclined shelf and eliminating the causes of this phenomenon.

А. Левданский[1], Д. Чиркун[1], В. Голубев[2], Д. Сарсенбекулы[2], Д. Жумадуллаев[2]

[1] Беларусь мемлекеттік технологиялық университеті, Минск, Беларусь;
[2] М. Әуезов атындағы Оңтүстік Қазақстан мемлекеттік университеті, Шымкент, Қазақстан

КӨП КАСКАДТЫ ГРАВИТАЦИЯЛЫҚ КЛАССИФИКАТОРДЫ ЭКСПЕРИМЕНТАЛДЫҚ ЗЕРТТЕУ

Аннотация. Полидисперсті материалдардың жіктелуі өнеркәсіптің көптеген салаларында кеңінен қолданылады. Классификациялық жабдықтың үлкен шеңберінен көп каскадты гравитациялық классификаторлар неғұрлым перспективалы болып табылады. Көп каскадты гравитациялық классификаторлардағы жіктеу процесі өте күрделі болып табылады және берілген тиімділікті қамтамасыз ету үшін қажетті Тәжірибелік зерттеулер жүргізуді талап етеді. Оларды құрастыру және пайдалану бойынша неғұрлым тиімді ұсыныстар алуға мүмкіндік беретін шынайы ақпарат алу мақсатында эксперименттік зерттеулер кешеиі өткізілді. Зерттеу нәтижелері шағын өлшемді көпкаскадты жіктегіштер бөлінудің тұрақты жоғары сапасын қамтамасыз ететінін көрсетті, алайда олардың өнімділігі 80х80 мм қимасы аппарат үшін 100 кг/сағ артық емес, болмашы, осының салдарынан көптеген өндірістік үдерістер үшін оларды пайдалануға болмайды. Өнімділігі анағұрлым жоғары жіктегіштердің едәуір мөлшерлері болуы тиіс. Көпкаскадты сөрелік жіктегіштерді бөлудің шекаралық өлшемі 0,5–2 мм болған кезде пайдалану орынды. шекара мөлшері 0,5 мм-ден кем болған кезде бөлу тиімділігінің бұлжытпай төмендеуі байқалады, ал шекті мөлшері 0,05–0,1 мм болған кезде жіктеу тиімділігі күрт төмендейді. Бөлінудің шекаралық астығы 2 мм-ден артық ұлғайған кезде жіктеу тиімділігінің төмендеуі байқалады (1-сурет). $\delta_{гр}$ = 1 мм бөлудің шекаралық өлшеміне қатысты 0–2 мм бөлшектері бар кварц құмын бөлу кезінде классификаторлардың жаңғыртылған және кәдімгі конструкцияларындағы бөлу тиімділігін анықтау бойынша эксперименттер мынаны көрсетті. Тиімділік қисығының өзара орналасуы жаңғыртылған жіктеуіштер үшін бөлу тиімділігінің өсімі оңтайлы, неғұрлым сапалы бөлуді қамтамасыз ететін аппараттың қимасына ауа жылдамдығына жеткен кезде 10 %-ға дейін құрайтынын көрсетеді. Ұқсас нәтижелер басқа материалдар үшін алынды (сильвинит, ірі тартылған ұн, гипс) әр түрлі шектік бөлу мөлшері кезінде (0,5-тен 2 мм-ге дейін). Тұтастай алғанда, әр түрлі материалдар үшін сөрелік жіктегіштің жаңғыртылған конструкциясына бөлу тиімділігі әдеттегі материалдарға қарағанда 5-10 % – ға жоғары болды. Жіктеуіштің жаңғыртылған конструкциясының эксперименттік зерттеулері ұсынылған конструктивтік толықтырулар өзге де тең жағдайларда аппараттың жұмыс көлемі бойынша материалды біркелкі бөлуге ықпал ететінін көрсетті, бұл, әрине, бөліну сапасының артуына алып келеді.

Түйін сөздер: эксперименталды зерттеулер, гравитациялық классификатор, көпкаскадты, бөлу тиімділігі, шекаралық өлшемдер, қима, тесіктер.

А. Левданский[1], Д. Чиркун[1], В. Голубев[2], Д. Сарсенбекулы[2], Д. Жумадуллаев[2]

[1]Белорусский государственный технологический университет, Минск, Беларусь;
[2]Южно-Казахстанский государственный университет им. М. Ауэзова, Шымкент, Казахстан

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ МНОГОКАСКАДНОГО ГРАВИТАЦИОННОГО КЛАССИФИКАТОРА

Аннотация. Классификация полидисперсных материалов широко используется во многих отраслях промышленности. Из большого круга классификационного оборудования к наиболее перспективным относятся многокаскадные гравитационные классификаторы. Процесс классификации в многокаскадных гравитационных классификаторах является достаточно сложным и требует проведения необходимых экспериментальных исследований, чтобы обеспечить заданную эффективность. С целью получения достоверной информации, позволяющей получить наиболее эффективные рекомендации по их конструированию и использованию был проведен комплекс экспериментальных исследований. Результаты исследований показали, что многокаскадные классификаторы небольших размеров обеспечивают стабильно высокое качество разделения, однако их производительность для аппарата сечением 80×80 мм не более 100 кг/ч незначительна, вследствие чего для большинства производственных процессов они не могут быть использованы. Классификаторы с более высокой производительностью должны иметь значительные размеры. Многокаскадные полочные классификаторы целесообразно использовать при граничных размерах разделения 0,5 – 2 мм. При граничном размере менее 0,5 мм наблюдается неуклонное снижение эффективности разделения, а при граничном размере порядка 0,05 – 0,1 мм эффективность классификации резко падает. При увеличении граничного зерна разделения более 2 мм также наблюдается (рисунок 1) снижение эффективности классификации. Эксперименты по определению эффективности разделения в модернизированной и обычной конструкциях классификаторов при разделении кварцевого песка с размерами частиц 0 – 2 мм относительно граничного размера разделения $\delta_{гр}$ = 1 мм показали следующее. Взаимное расположение кривых эффективности показывает, что прирост эффективности разделения для модернизированного классификатора составляет до 10 % при достижении оптимальной, обеспечивающей наиболее качественное разделение, скорости воздуха на сечение аппарата. Аналогичные результаты были получены для других материалов (сильвинит, мука грубого помола, гипс) при различных граничных размерах разделения (от 0,5 до 2 мм). В целом, эффективность разделения в модернизированной конструкции полочного классификатора для различных материалов была на 5 – 10 % выше, чем в обычной. Экспериментальные исследования модернизированной конструкции классификатора показали, что предложенные конструктивные дополнения при прочих равных условиях способствуют более равномерному распределению материала по рабочему объему аппарата, что, естественно, приводит к повышению качества разделения.

Ключевые слова: экспериментальные исследования, гравитационный классификатор, многокаскадный, эффективность разделения, граничные размеры, сечение, отверстия.

Information about authors:

Leudanski Aliaksandr Eduardovich, Doctor of Technical Sciences, Associate Professor of the Department "Processes and Apparatuses of Chemical Production", Belorussian State Technological University, e-mail: alex levdansky@mail.ru, https://orcid.org/0000-0003-2684-7771;

Chirkun Dmitrii Ivanovich, Candidate of Technical Sciencesteacher of the Department "Processes and Apparatuses of Chemical Production", Belorussian State Technological University, e-mail: alex levdansky@mail.ru, https://orcid.org/0000-0003-0195-2575;

Golubev Vladmir Grigorevich - Doctor of Technical Sciences, Professor of the Department of Oil and gas business, M.Auezov South Kazakhstan State University, e-mail: golubev 50@mail.ru, https://orcid.org/0000-0001-7370-3872;

Sarsenbekuly Didar - PhD, senior teacher of the Department of Technological Machines and Equipment, M.Auezov South Kazakhstan State University, e-mail: sarsen_d-001@mail.ru, https://orcid.org/0000-0003-0595-4375;

Zhumadullayev Daulet Koshkarovich - PhD, senior teacher of the Department of Technological Machines and Equipment, M.Auezov South Kazakhstan State University, e-mail: daulet_ospl@mail.ru, https://orcid.org/0000-0002-6552-2817

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