

Research Article

Determination of the Axial Velocity of the Material Being Sorted in a Rotating Perforated Drum

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Abstract

This article provides a comprehensive investigation into the motion of bulk materials inside a perforated rotating drum separator, paying particular attention to the correlation between the kinematic characteristics of particles, the structural and geometric parameters of the drum, and the combined effects of gravitational and centrifugal forces. The study develops a theoretical model that captures the dynamics of axial velocity and the residence (exit) time of bulk materials as they move under the simultaneous influence of rotational motion, centrifugal action, and the inclination of the drum relative to the horizontal plane. To establish the governing relationships, Newton's second law of motion is employed together with energy-based analytical formulations, which makes it possible to derive mathematical expressions describing both the axial displacement of the particles and the time required for their discharge from the drum. These analytical equations are subsequently solved numerically using Microsoft Excel across a wide range of operating conditions, including variations in rotational speed, inclination angle, drum diameter, and length. The numerical results reveal that the axial velocity of the bulk material reaches a stable value after a relatively short transient phase, indicating a quasi-steady state of motion within the drum. In addition, it is shown that the discharge or exit time of the material grows almost linearly with increases in drum length and other key operating parameters, which confirms the strong dependence of throughput capacity on design variables. The outcomes of the research clearly demonstrate that angular velocity of the drum and its inclination angle play a decisive role in governing the efficiency of the screening process. These parameters not only affect the residence time of particles but also determine the quality of separation and the overall performance of the equipment. The developed model and the obtained findings thus provide a reliable theoretical and numerical foundation for the scientific optimization of perforated drum separator design, enabling engineers to enhance process efficiency, reduce energy consumption, and improve the uniformity of material separation in industrial applications.

Keywords

Perforated Drum, Movement, Velocity, Bulk Material, Time, Screening, Elastic Blade, Angle

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1. Introduction

The main purpose of studying the screening process of bulk materials is to determine the relationship between the kinematic and structural parameters of screening machines and the physical and mechanical properties of the material being screened. In the search for effective methods of screening bulk materials, special attention is given to the use of centrifugal separators. This is because, during the screening process, the bulk material is subjected to inertial forces greater than the force of gravity. When the bulk material is under the influence of centrifugal force, the screening process becomes more intensive. As a result, the particles of the bulk material remain in constant contact with the screening surface, increasing the probability of passing through the perforations and enhancing the movement velocity of the material, which ultimately improves the efficiency of the separator [1, 2].

N. V. Gladkov concluded that "... the completeness of screening on a flat grate depends on the number of successive displacements of each particle during its time on the grate" [3].

The optimal screening mode can be achieved based on the following conditions:

- 1) the bulk material must move along the grate in such a way that it mixes across the grate surface while allowing smaller fractions to pass through the openings in time;
- 2) the force acting on each particle of the bulk material should be approximately vertical, i.e., normal to the grate surface;
- 3) the bulk material should be evenly distributed across the grate.

A number of researchers have conducted studies on the motion of bulk materials inside rotating perforated drums. Among them are scientists from the University of Birmingham in the United Kingdom — Y. L. Ding, R. Forster, J. P. K. Seville, and D. J. Parker — whose work can be cited as an example [4]. In their study, a mathematical model describing the motion of bulk material in a rotating drum was developed based on the Eulerian approach [5].

2. Experimental Procedures

In our research, we examine the movement of the bulk material being screened along the axis of rotation of the drum. As is known, the perforated drum is positioned at an angle relative to the horizontal plane and performs rotational motion around its own axis. According to the calculation scheme in *Figure 1a*, we consider the motion in the two-dimensional coordinate system XOY.

Let the perforated drum rotate around its own axis with an angular velocity of ω . In that case, the angular velocity of the bulk material being screened inside the drum, moving together with the drum, can be expressed as follows [1]:

$$\omega' = k\omega \quad (1)$$

where k is the coefficient that accounts for the slippage of the bulk material relative to the drum.

If the influence of elastic blades inside the perforated drum is taken into account, the bulk material will also have an additional angular velocity denoted by ω_0 . Thus, the angular velocity of the bulk material being screened together with the drum can be rewritten as follows:

$$\omega' = k\omega + \omega_0 \quad (2)$$

Let us denote the axial velocity of the bulk material inside the drum as v_x . According to Newton's second law, the equation of motion can be written as follows:

$$m \frac{dv_x}{dt} = F_h + F_q \quad (3)$$

where m is the mass of the bulk material, in kg; F_h is the driving force moving the bulk material along the length of the drum, in N; and F_q is the resistance force opposing the motion, in N [6].

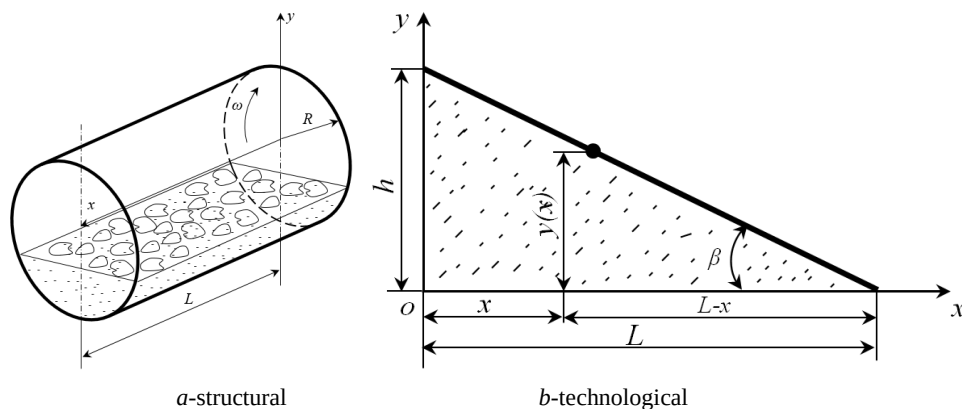


Figure 1. Calculation scheme.

The forces acting on the bulk material being screened are expressed as follows:

$$F_h = -\text{grad}U \quad (4)$$

$$F_q = m\omega'v \quad (5)$$

where U is the potential energy of the material being screened at an arbitrary point “ x ” along the length L of the perforated drum, in J [7].

According to the calculation scheme in *Figure 1b*, the potential energy at an arbitrary point “ x ” is given by the following expression:

$$U(x) = mgy(x) \quad (6)$$

where g is the acceleration due to gravity, in m/s^2 and $y(x)$ is the function representing the height of the screened material at an arbitrary point “ x ”, in m.

According to *Figure 1b*, the function representing the height of the screened material at an arbitrary point “ x ” is expressed as follows:

$$y(x) = \frac{h(L-x)}{L} \quad (7)$$

where h and L are parameters characterizing the bulk material, in m.

If we take into account that $\text{tg}(\beta) = \frac{h}{L}$ is given, and consider equation (7), then expression (6) takes the following form:

$$U(x) = mg(L-x)\text{tg}(\beta) \quad (8)$$

Taking expression (8) into account, we rewrite expression (4) as follows:

$$F_h = mgtg(\beta)\vec{i} \quad (9)$$

where $\vec{i}$ is the unit vector along the Ox -axis.

Taking expressions (5) and (9) into account, we reformulate expression (3) and obtain the following [8]:

$$m \frac{dv_x}{dt} = -m\omega'v_x + mgtg(\beta) \quad (10)$$

By dividing both sides of expression (10) by m , we obtain the following:

$$\frac{dv_x}{dt} = -\omega'v_x + gtg(\beta) \quad (11)$$

We seek the solution to equation (11) in the following form:

$$v_x = c(t)e^{-\omega't} \quad (12)$$

Here, the unknown function $s(t)$ must satisfy the following differential equation, namely:

$$c'(t) = gtg(\beta)e^{\omega't} \quad (13)$$

The solution of equation (13) will have the following form:

$$c(t) = \frac{g}{\omega'} \text{tg}(\beta) e^{\omega't} + C_0 \quad (14)$$

Substituting expression (14) into expression (12), we obtain the following:

$$v_x = \frac{g}{\omega'} \text{tg}(\beta) + C_0 e^{-\omega't} \quad (15)$$

To determine the integration constant in expression (14), we introduce the following initial conditions:

$$t = 0; v_x = 0 \quad (16)$$

Taking expression (15) into account, we determine the following from expression (14):

$$C_0 = -\frac{g}{\omega'} \text{tg}(\beta) \quad (17)$$

Taking the above expression (17) into account, we rewrite expression (15) as follows:

$$v_x = \frac{g}{\omega'} \text{tg}(\beta)(1 - e^{-\omega't}) \quad (18)$$

If the perforated drum is inclined at an angle α relative to the horizontal plane, then the velocity of the bulk material being screened along the axis of the drum can be expressed as follows [9]:

$$v_x = \frac{g}{\omega'} \text{tg}(\beta) \cos(\alpha)(1 - e^{-\omega't}) \quad (19)$$

If we take expression (2) into account, then expression (19) takes the following form:

$$v_x = \frac{g}{(k\omega + \omega_0)} \text{tg}(\beta) \cos(\alpha)(1 - e^{-(k\omega + \omega_0)t}) \quad (20)$$

If

$$v_0 = \frac{g}{(k\omega + \omega_0)} \operatorname{tg}(\beta) \cos(\alpha), \quad (21)$$

taking this into account, the exit time of the unscreened bulk material from the drum can be expressed as follows [10, 11]:

$$t(L) = \frac{(k\omega + \omega_0)L}{gtg(\beta)\cos(\alpha)}. \quad (22)$$

To determine the variation laws of the axial velocity and exit times of the bulk material being screened in the perforated drum, we carry out the numerical solution of equations (20) and (22) in Microsoft Office Excel using the following parameter values: $e=2,7$; $k=0,8$; $g=9,81 \text{ m/s}^2$, $\beta=30^\circ$; $\alpha=(5^\circ \div 25^\circ)$, $\omega=(2 \div 3) \text{ s}^{-1}$; $L=(3 \div 11) \text{ m}$ [12, 13].

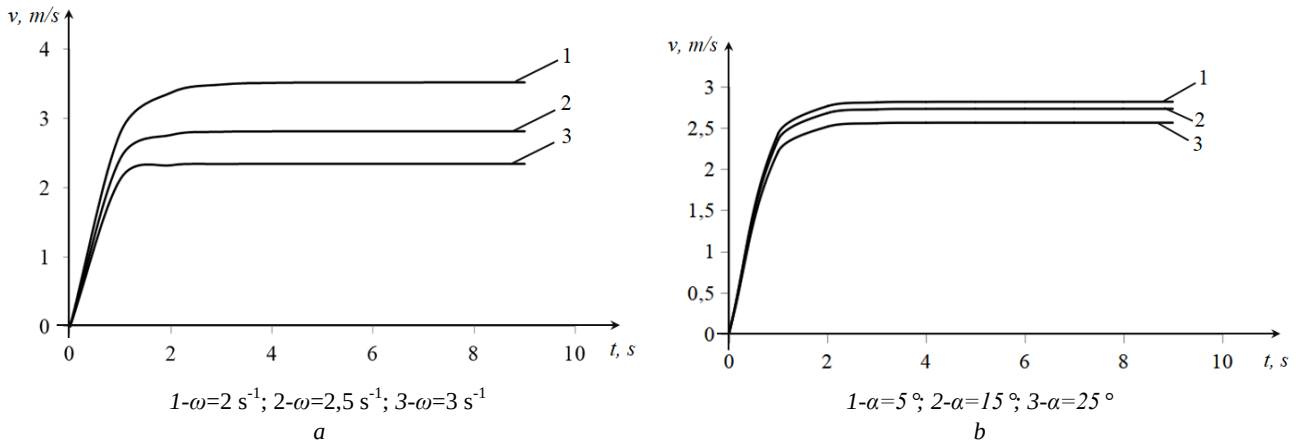


Figure 2. Graph of the variation of the bulk material's axial velocity with respect to time.

Based on the numerical solution of expression (20), the graphs are presented in Figure 2. The curves in these graphs show that the axial velocity of the bulk material stabilizes after approximately 2 seconds and then increases slightly over short intervals, reaching a steady value after 7 seconds. For

example, when the drum's angular velocity is $\omega = 2 \text{ s}^{-1}$, the velocity increases from 0 m/s to 3,27 m/s within the first 2 seconds, then from 3,27 m/s to 3,41 m/s between 2 and 7 seconds, and finally stabilizes at 3,41 m/s after 7 seconds (Figure 2a).

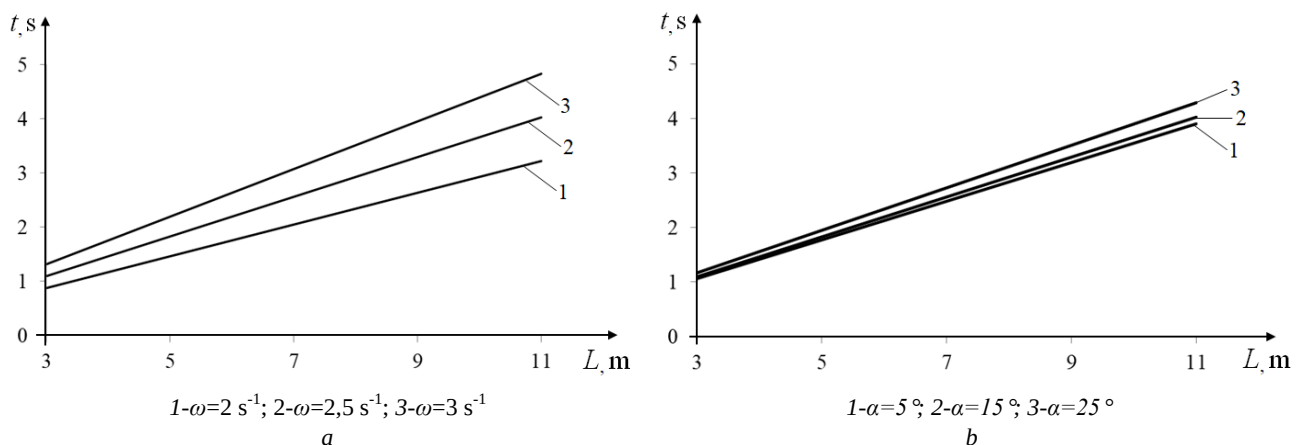


Figure 3. Graph of the variation of the bulk material's falling (exit) time with respect to the drum length.

Based on the numerical solution of expression (22), the graphs are presented in Figure 3. The curves in these graphs show that the exit time of the bulk material from the drum

increases linearly as the drum length increases. In addition, as the angular velocity and inclination angle of the drum increase, the exit time of the bulk material also increases. For example,

when the drum's angular velocity is $\omega = 2 \text{ s}^{-1}$ and the drum length increases from 3 m to 11 m, the material exit time ranges from 0,88 to 3,22 s; when the angular velocity is $\omega = 2,5 \text{ s}^{-1}$, the exit time ranges from 1,1 to 4,03 s for the same length range; and when $\omega = 3 \text{ s}^{-1}$, the exit time ranges from 1,3 to 4,8 s [14, 15].

3. Conclusions

In conclusion, it can be stated that in perforated drums used for screening bulk materials, the velocity and exit time of the material being screened are among the most important parameters. These parameters serve as a basis for determining the performance and for defining the structural and kinematic parameters of the perforated drum.

Abbreviations

m	The Mass of the Bulk Material
F_h	The Driving force Moving the Bulk Material Along the Length of the Drum
F_q	The Resistance Force Opposing the Motion

Author Contributions

Turdaliev Vokhidjon Makhsudovich: Conceptualization, Data curation, Funding acquisition, Resources, Software, Supervision, Validation

Davidbaev Bakhtiyorjan Nizamitdinovich: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Resources, Validation, Visualization, Writing - original draft

Ruzaliev Khojiakbar Shermakhammad Ogli: Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing - review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



Turdaliyev Voxidjon Maxsudovich is a highly respected Doctor of Technical Sciences and a professor, renowned for his extensive contributions to the field of machine details. He has authored numerous articles and books, which are considered fundamental references in the industry. His expertise and profound knowledge have earned him recognition both locally and internationally. Currently, he serves as a department professor at the prestigious Namangan State Technical University, where he imparts his valuable knowledge to the next generation of engineers. Throughout his distinguished career, Professor Turdaliyev has mentored numerous students, many of whom have gone on to achieve great success in their professional fields. His dedication to research, education, and the advancement of machine design has made him a key figure in his field, with a lasting impact on both academia and industry.



Davidbaev Bakhtiyordjan Nizamitdinovich is a distinguished Candidate of Technical Sciences and professor, widely recognized for his significant contributions to the field of machine design. He is the author of numerous scientific articles and books that are regarded as essential references within the discipline. His deep expertise and extensive knowledge have earned him respect both nationally and internationally. At present, he serves as a professor at the prestigious Fergana State Technical University, where he continues to share his invaluable experience with the next generation of engineers. Over the course of his esteemed career, Professor Davidbaev has guided and mentored many students, who have gone on to achieve remarkable success in their professional endeavors. His commitment to research, education, and the continuous advancement of engineering design has established him as a prominent figure whose influence extends across both academia and industry.



Ruzaliev Khojiakbar Shermakhammad Ogli is a PhD candidate and a junior lecturer at the Department of Applied Mechanics. He is currently working on his doctoral research and contributing to the field through teaching and academic involvement. He graduated Fergana Polytechnic Institute in 2019, and his Master of Mechanical Engineering Technology and Equipment from the same institution in 2021. He has participated in multiple international research collaboration projects in recent years.

Research Field

Turdaliyev Voxidjon Maxsudovich: Theory of Machines and Mechanisms, Mechanical Engineering, Elastic Elements in Gear Transmissions, Dynamics and Kinematics of Technological Machines, Vibration Analysis in Gear Systems, Reliability and Efficiency of Machine Components.

Davidbaev Bakhtiyordjan Nizamitdinovich: Theory of Machines and Mechanisms, Machine parts, Cotton separator, Applied Mechanics, Machine Design and Analysis, Dynamic Behavior of Mechanical Systems, Structural Optimization in Mechanical Drives.

Ruzaliev Khojiakbar Shermakhammad Ogli: Theory of Machines and Mechanisms, Machine parts, Mechanical Engineering, Applied Mechanics, Machine Design and Analysis