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EXPERIMENTAL STUDY OF THE PERFORMANCE OF A CENTRIFUGAL DOSING-MIXER WITH OVERPRESSURE IN THE DOSING ZONE

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In modern technological processes for processing bulk materials, multicomponent batchers and mixers play a significant role, providing accurate dosing and uniform mixing of components in a continuous mode. One of the most promising designs is centrifugal batchers, which are widely used in the food, chemical, pharmaceutical, and construction industries due to their compactness, reliability, and high performance. However, in order to ensure a stable and controlled supply of components, it is necessary to study in depth the relationship between the design and technological parameters of the dispenser.

The study of the effect of the metering disk rotation speed, the angle of its conical surface and overpressure allows us to establish the patterns of particle movement, optimize the metering mode and ensure the stable quality of the finished mixture. The use of a three-factor experiment makes it possible to quantify the influence of these factors and build an empirical model of the dosing process, which will be the basis for further optimization of the design and operating modes

The aim of the study is to substantiate the influence of the main factors such as the rotational speed of the dosing disk, the angle of the conical disk's generating surface and the overpressure in the dosing zone on the uniformity of the mixture supply and the performance of a centrifugal dosing mixer.

Thus, the expediency of this study is due to the need to improve the efficiency of the dosing process in centrifugal multicomponent mixers, where the uniformity of component feeding and process stability largely depend on a rational combination of design and technological parameters. One of these little-studied but promising control factors is the overpressure in the dosing zone, which can significantly affect the movement of bulk particles, intensifying their movement along the disk.

In the context of this study, considering overpressure as the third factor in a three-factor experiment (along with rotational speed and cone angle) allows us to obtain a more complete picture of the physical processes occurring in the dosing zone. The analysis of the experimental results made it possible to establish that an increase in pressure within the optimal range contributes to a more uniform distribution of the material over the working surface of the disk, an increase in dosing accuracy, and an improvement in the overall performance of the metering and mixing device.

Key words: *metering mixer, parameters, overpressure, research, dosing, performance, dosing disk, rotation frequency.*

Eq. 3. Fig. 4. Table.2. Ref. 16.

1. Problem formulation

In modern mechanical engineering for the food, chemical, pharmaceutical and construction industries, there is a growing demand for equipment capable of providing continuous, accurate and stable dosing of bulk materials with different physical and mechanical properties. One of the most effective designs is centrifugal feeders, which provide intensive transportation and pre-mixing of particles due to the rotation of a conical disk [1]. Their use is especially relevant when processing light, dusty or hygroscopic components, for which classic gravity or screw dosing systems are not effective enough [2].

Recent studies indicate the prospects of using excess pressure in the dosing zone, which allows reducing dust formation, increasing dosing accuracy and improving the stability of material supply [3]. However, the issue of a comprehensive analysis of the influence of this factor together with the main geometric and kinematic parameters of the design remains open. This especially concerns the interaction of the disk rotation frequency, the angle of the generating conical surface and excess pressure, which together determine the nature of the movement of an elementary particle on the working surface of the device.

Studying these patterns is important from the point of view of optimizing the design of the dispenser, ensuring uniform supply of components and increasing the overall efficiency of the process. Conducting a three-factor experiment with a variation of the specified parameters allows not only to identify the dominant factors, but also to build empirical mathematical models that accurately reflect the operation of the system in real conditions.

The feasibility of this study is due to the need to increase the reliability and accuracy of dosing in continuous systems, especially under conditions where stable mixture supply critically affects the quality of the final product. The results of the study can be used to develop new generations of dosing devices, taking into account adaptive control of technological parameters, including pressure in the dosing zone.

2. Analysis of recent research and publications

The problem of accurate and stable dosing of bulk materials remains relevant in the conditions of modern development of technological processes. The literature is widely presented with works devoted to optimization of the designs of dosing devices, in particular screw, vibration and centrifugal systems [4, 5]. Centrifugal dosing devices, due to their structural simplicity, reliability and ability to work with a wide range of bulk substances, are increasingly used. The main attention of researchers is focused on studying the influence of kinematic and geometric parameters - the frequency of rotation of the dosing device, the shape of the working surface, the angle of inclination of the forming surface, etc. - on the uniformity and productivity of dosing [6].

Some studies indicate the effectiveness of conical surfaces in organizing dosing in conditions of limited space and high rotation speed [7, 8, 9, 10, 11]. However, even with perfect geometric solutions, many researchers record instability of the feed when changing the properties of the material - humidity, flowability, granulometric composition.

In the works [12, 13], a relationship between the characteristics of the movement of bulk materials along conical surfaces was established, which confirms the importance of studying flow hydrodynamics for optimizing the designs of batchers and mixers.

In the last decade, studies have begun to appear that analyze the possibility of using controlled excess pressure in the dosing zone to compensate for fluctuations in the physical properties of the material. In the works of L. Zhang [14] it was found that controlled pressure can positively affect the speed of particle movement, reduce the tendency to form stagnant zones and improve flow uniformity. Similar conclusions were also obtained in the studies of M. Gupta and V. Sharma, where it is emphasized that the introduction of auxiliary pressure allows to increase the efficiency of feeding in continuous pharmaceutical mixers [15].

Despite this, a systematic analysis of the influence of excess pressure in combination with geometric and kinematic parameters within the framework of a complex multifactorial experiment is practically absent. There is still a lack of generalized models that would allow determining the optimal operating conditions of the dispenser, taking into account not only the design parameters, but also the physical conditions in the dosing zone. This creates a need for in-depth experimental studies aimed at developing empirical relationships between the input and output parameters of the dosing process.

3. The purpose of the article

The purpose of the research is to substantiate the influence of the main factors such as the frequency of rotation of the dosing disk, the angle of the generator of the conical disk, and the excess pressure in the dosing zone on the uniformity of the mixture supply and the performance of the centrifugal dosing mixer.

4. Results and discussion

The study was conducted to establish the patterns of influence of the design and technological parameters of the centrifugal batcher on the productivity and uniformity of dosing of loose components in the presence of excess pressure in the feed zone.

Dosing is carried out due to the centrifugal force created by the rotation of the paired discs of the dispenser and the excess pressure in the dosing zone. The main parameters that affect the dosing performance are the frequency of rotation of the disc, the angle of the generator of the dosing disc and the pressure created in the zone of exit of the bulk material from the surface of the disc.

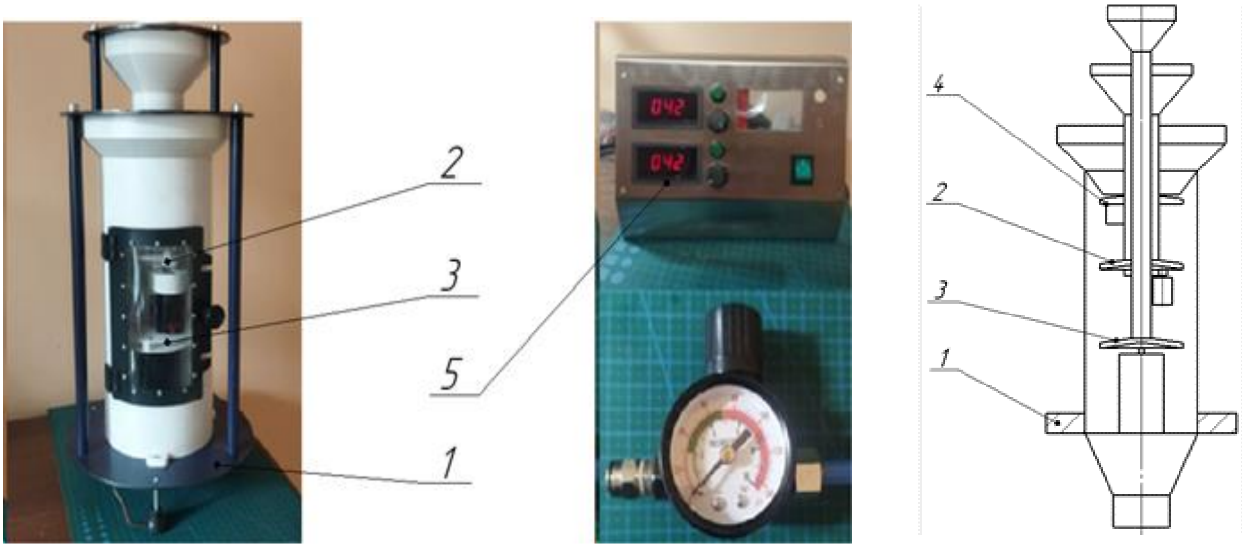

Fig. 1. General view of laboratory equipment:
1 – base; 2 – dispenser of the main component; 3, 4 – dispensers of the introduced components; 5 – control unit

The response criteria in our study were dispenser performance *Q* (kg/min), the following factors were selected: the speed of rotation of the dosing disc *n* (rpm) – x_1, angle of the generating cone α (degrees) – x_2 and excess pressure in the dosing zone *P* (kPa) – x_3. The rotation speed values were set at 400, 900, and 1400 rpm, the generator angle was set at 5°, 10°, and 15°, and the excess pressure was adjusted at 0, 50, and 100 kPa.

Table 1

Intervals and levels of variation of factors

Factor	Marking	Dimension	Factor levels			Variation interval ε
			upper	null	lower	
			Code values			
			+1	0	-1	
Angular frequency of rotation of the disk, *ω*.	x_1	min^{-1}	1400	900	400	500
The angle of the metering disc generator, *α*.	x_2	degree	15	10	5	5
Excessive pressure, *P*.	x_3	kPa	100	50	0	50

Taking into account the real operating modes of a multicomponent centrifugal dispenser, we used a second-order polynomial, which allows us to effectively systematize experimental data and investigate the response surface for extremum. To conduct a planned three-factor experiment that investigates the dependence of the dispenser's productivity on the frequency of rotation of the dosing disk, the angle of the generating surface, and the magnitude of the excess pressure in the dosing zone.

The columns of the planning matrix contain the coded values of the independent factors, and the corresponding response column contains the results of the performance measurements obtained during the experiment. The values of the factors in their natural form are given in Table 2. The excess pressure was created by a controlled pneumatic system and monitored by a manometer. The experiments were carried out in a stationary mode, with a constant supply of bulk material and recording the results in three repetitions to ensure the reliability of the data.

Table 2

Matrix of a planned three-factor experiment

№ experiment	Factor levels			Productivity of the batcher-mixer			
	x_1	x_2	x_3	y_1	y_2	y_3	y
1	1	1	0	2,698	2,818	2,684	2,639
2	-1	-1	0	1,155	1,145	1,099	1,127
3	1	-1	0	2,921	3,082	2,791	2,995
4	-1	1	0	2,471	2,769	2,785	2,639
5	0	1	1	3,396	3,321	3,125	3,297
6	0	-1	-1	2,201	2,047	2,158	2,107
7	0	1	-1	3,159	2,911	3,09	3,037
8	0	-1	1	2,543	2,297	2,562	2,472
9	1	0	1	3,712	3,359	3,203	3,465
10	-1	0	-1	1,868	1,864	2,091	1,951
11	1	0	-1	3,272	3,361	3,637	3,417
12	-1	0	1	1,893	1,914	1,809	1,851
13	0	0	0	2,936	2,794	2,814	2,902
14	1	1	1	4,407	4,493	4,675	4,368
15	-1	-1	-1	1,381	1,403	1,463	1,378
16	-1	1	1	2,524	2,864	2,821	2,743
17	-1	-1	1	1,73	1,826	1,966	1,875
18	-1	1	-1	2,181	2,07	2,098	2,244
19	1	-1	-1	2,705	3,086	3	2,901
20	1	-1	1	2,481	2,676	2,538	2,565
21	1	1	-1	4,425	4,086	4,515	4,290
22	0	0	-1	2,66	2,548	2,752	2,605
23	0	0	1	2,307	2,314	2,523	2,432
24	0	1	0	4,104	4,242	4,187	3,962
25	0	-1	0	2,461	2,6	2,455	2,570
26	1	0	0	3,63	3,509	3,5	3,732
27	-1	0	0	2,276	2,132	2,207	2,217

According to the data in Table 2, the results of calculations, using the generally accepted methodology [16], formed a regression equation that models the productivity of the batcher-mixer in natural factors at an excess pressure of P=0 kPa, which will take the form:

$$y = 1,6412 + 0,001004 \cdot \omega + 0,1026 \cdot \alpha - 0,000000528 \cdot \omega^2 \quad (1)$$

where y –productivity of the batcher-mixer, kg/min; ω – angular speed of rotation of the dosing disk, min^{-1}; α – angle of the generator of the metering disk, degrees.

A graphical representation of the dependence is shown in Fig. 2.

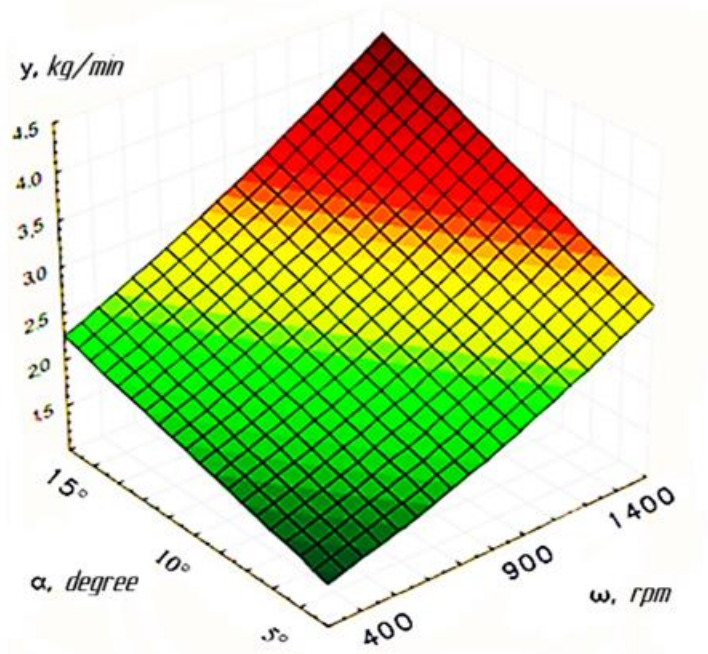

Fig. 2. Dependence of the productivity of the batcher-mixer at excess pressure P=0 kPa

The response surface demonstrates a clearly pronounced influence of both factors on the productivity. With increasing the angle of the generating disk α and the angular frequency of rotation ω, a monotonic increase in productivity is observed. The lowest values are observed at the minimum values of both factors, while the highest values are at the maximum. The surface has a moderate curvature, which indicates a nonlinear, but quite predictable nature of the change in productivity.

The regression equation that models the productivity of the batcher-mixer in natural factors at an excess pressure of P = 50 kPa will take the form:

$$y = 2,5877 + 0,001536 \cdot \omega + 0,1092 \cdot \alpha - 0,000000571 \cdot \omega^2 \qquad (2)$$

A graphical representation of the dependence is shown in Fig. 3.

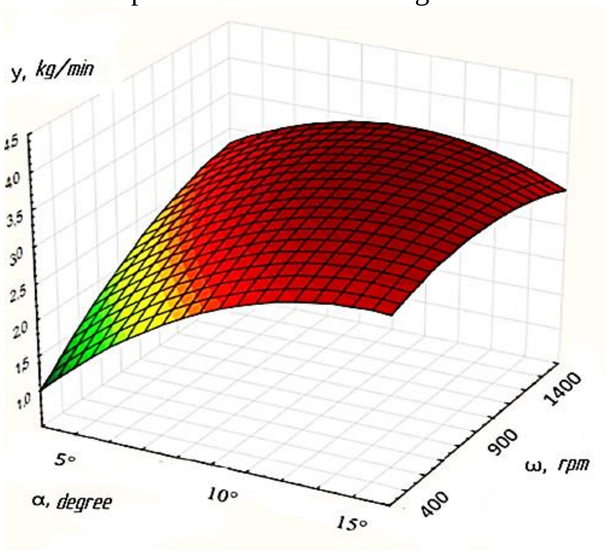

Fig. 3. Dependence of the productivity of the batcher-mixer at an excess pressure of P = 50 kPa

The graph shows the influence of the angle of the generator of the dosing disk α and the angular frequency of rotation ω on the productivity of the dosing mixer y under the condition of a constant excess pressure of 50 kPa. It can be seen that with an increase in both the angle α and the frequency of rotation ω, the productivity increases. Particularly intensive growth is observed in the initial areas, after which the surface acquires a more gentle character. The maximum productivity approaches 3.5 kg/min, which indicates increased mixing efficiency at moderate pressure. The general shape of the surface demonstrates the nonlinear nature of the influence of factors, with the predominant influence of the frequency of rotation on the final result.

The regression equation that models the performance of the batcher-mixer in natural factors at an excess pressure of P = 100 kPa will take the form:

$$y = 3,5341 + 0,002068 \cdot \omega + 0,1158 \cdot \alpha - 0,000000613 \cdot \omega^2 \quad (3)$$

A graphical representation of the dependence is shown in Fig. 4.

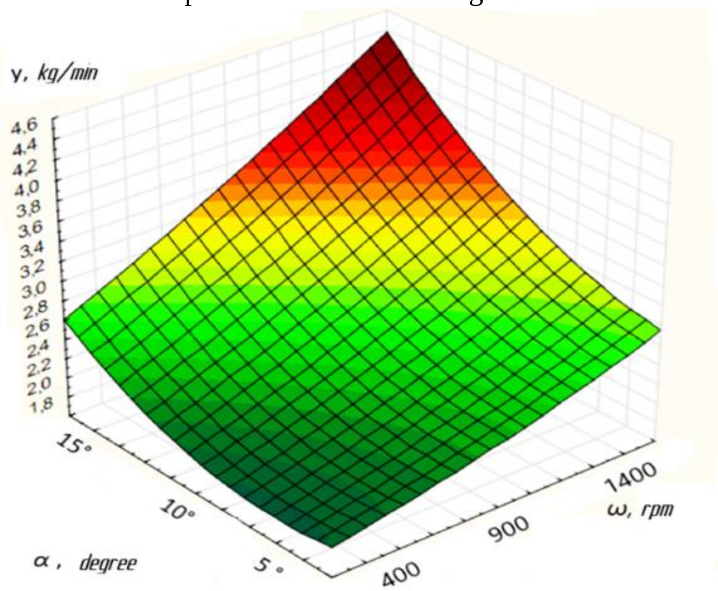

Fig. 4. Dependence of the productivity of the batcher-mixer at excess pressure P = 0 kPa

The graph shows that the productivity of the batcher-mixer significantly depends on both the angular frequency of rotation of the disk and the angle of the generator of the batching disk. With an increase in both factors, a steady increase in productivity is observed. The lowest productivity values (1,8 kg/min) are observed at the minimum values of the parameters (ω = 400 rpm, α = 5°), while the maximum values (4,6 kg/min) are achieved at ω = 1400 rpm and α = 15°. This indicates the influence of both factors on productivity, and also confirms the feasibility of their optimization.

5. Conclusion

As a result of the three-factor experiment, in which the frequency of rotation of the dosing disk, the angle of the generating conical surface and the excess pressure in the dosing zone were considered as factors, a generalized idea of the influence of the studied parameters on the performance of the centrifugal dosing mixer was obtained. The constructed mathematical model in the form of a second-order polynomial allowed us to establish the optimal combinations of factors that ensure maximum equipment performance under given technological conditions.

The results of the analysis of experimental data indicate that the dispersion of the reproducibility of the experiments is within normal limits: the calculated value of the Cochrane criterion G ≤ 0.3 is less than the tabular value. G_{table}= 0,334,which confirms the homogeneity of variances. According to the Student's t-test, it was established that all coefficients of the regression equation are significant and do not exceed the tabulated value of the Student's t-test. t_{table} = 2,12 at a significance level of 0,05. Checking the model for adequacy using the Fisher test showed that F = 3,14 is less than the threshold value F_{table} = 4,10, which confirms the adequacy of the regression model to the experimental data. Therefore, the conducted modeling is statistically justified, and the constructed equations adequately describe the influence of the main factors on the performance of the batcher-mixer.

The use of orthogonal central compositional planning ensured the reliability of the results, and the analysis of variations allowed us to assess the significance of each of the factors. The formed dependencies can be used for further improvement of the designs of such batchers and the development of automated control systems for the batching process of bulk materials. The results obtained are of practical importance for increasing the accuracy of dosing, reducing component losses and ensuring the stability of the composition of mixtures in the food, chemical and pharmaceutical industries.

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ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ПРОДУКТИВНОСТІ ВІДЦЕНТРОВОГО ДОЗАТОРА-ЗМІШУВАЧА ІЗ НАДЛИШКОВИМ ТИСКОМ У ЗОНІ ДОЗУВАННЯ

У сучасних технологічних процесах обробки сипких матеріалів значну роль відіграють багатокомпонентні дозатори-змішувачі, що забезпечують точне дозування та рівномірне змішування компонентів у безперервному режимі. Однією з перспективних конструкцій є відцентрові дозатори, які завдяки своїй компактності, надійності та високій продуктивності знаходять широке застосування в харчовій, хімічній, фармацевтичній та будівельній галузях. Однак для забезпечення *стабільної та контрольованої подачі компонентів необхідне глибоке вивчення взаємозв'язку між конструктивними і технологічними параметрами дозатора..*

Дослідження впливу частоти обертання дозуючого диска, кута твірної його конічної поверхні та надлишкового тиску дозволяє встановити закономірності руху частинок, оптимізувати режим роботи дозатора і забезпечити стабільну якість готової суміші. Застосування трифакторного експерименту дає змогу отримати кількісну оцінку впливу зазначених факторів та побудувати емпіричну модель процесу дозування, що стане основою для подальшої оптимізації конструкції та режимів роботи

Метою досліджень є обґрунтування впливу основних факторів таких як частоти обертання дозуючого диска, кута твірної конічного диска та надлишкового тиску в зоні дозування – на рівномірність подачі суміші та продуктивність відцентрового дозатора-змішувача..

Таким чином, доцільність проведення даного дослідження зумовлена потребою у підвищенні ефективності процесу дозування у відцентрових багатокомпонентних змішувачах, де рівномірність подачі компонентів та стабільність процесу значною мірою залежать від раціонального поєднання конструктивних і технологічних параметрів. Одним із таких малодосліджених, але перспективних керувальних факторів є надлишковий тиск у зоні дозування, який дозволяє суттєво впливати на рух сипких частинок, інтенсифікуючи їх переміщення по диску.

У контексті цього дослідження, розгляд надлишкового тиску як третього фактора у трифакторному експерименті (разом із частотою обертання та кутом твірної конуса) дозволяє отримати повнішу картину фізичних процесів, що відбуваються в зоні дозування. Аналіз експериментальних результатів дав змогу встановити, що збільшення тиску у межах оптимального діапазону сприяє більш рівномірному розподілу матеріалу по робочій поверхні диска, підвищенню точності дозування та покращенню загальної продуктивності дозатора-змішувача.

Ключові слова: *дозатор-змішувач, параметри, надлишковий тиск, дослідження, дозування, продуктивність, дозуючий диск, частота обертання.*

Ф. 3. Рис. 4. Табл. 2. Літ. 16.

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