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Experimental Study of Parameters of Grain Milling Product Separation in Pneumatic Screw Classifier

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Present study was aimed to improve efficiency of sieve and screen separators by reducing specific load on a sieve (screen) through preliminary separation of the initial mixture of crushed material on air delivery stage in pneumatic screw classifier. Parameters of grain milling product separation in pneumatic screw classifier using planning of multifactorial experiment and processing of statistical data are presented. We have built pneumatic screw classifier prototype and performed its production check basing on these results.

Key words: Grain processing, pneumo-centrifugal sorting, pneumatic screw classifier, grain milling products.

Sorting of a material mixture into several fractions differing in size, density, and aerodynamic properties is one of the most important operations in many industrial branches, where grinding of raw material with subsequent classification of obtained milling products or simply sorting of the original product into several fractions is required. One of the promising ways to intensify mentioned technological processes is to use pneumo-centrifugal devices.

Efficiency of a grain processing facility depends on reliability of technological lines and a number of losses of raw materials at all process flow stages, while product quality becomes top priority. Sorting processes on such facilities are based on screen and sieve separators[11].

Many studies of Russian and foreign scientists are devoted to improvement of their efficiency. Obtained results suggest that efficiency of sieving depends on following factors: specific load on the sieve; homogeneity of granulometric composition, shape and state of processed material surface, methods of cleaning and aligning abilities of sieves[8, 9, 10].

Fractional technology is one of the promising ways to intensify bulk material sorting: fractionation of source material according to aerodynamic properties[13, 14, 15].

In this regard, it is reasonable to divide initial mixture into several fractions similar by particle size and shape and send them to the appropriate systems to enhance sieving efficiency.

This problem may be technically solved by using pneumo-centrifugal separators for fractionation of milling products during their transportation. They are more energy-efficient compared to separators with linear air currents.

Studies aimed to improve efficiency of separation based on the patterns of particle movement in centrifugal force field allowed to elaborate pneumatic screw classifier for separation of grain milling products[7].

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METHODS

Experimental studies were conducted to confirm basic theoretical regulations, as well as to determine the rational parameters of grain grinding products separation in pneumatic screw classifier.

Experimental program included

- Study of aerodynamic and physical-mechanical properties of grain grinding products;
- Design and manufacture of experimental unit to study aerodynamic parameters of the airflow that affect grain milling products separation;
- Study of influence of the factors on separation process in pneumatic screw channel;
- Determination of airflow structure in separation zone;
- Choice of multifactorial experiment plan, establishment of levels and intervals of variation of the studied process parameters;
- Determination of rational technological and geometrical parameters of the grain grinding product separation;
- Production check of the experimental classifier unit.

Experimental unit was built for laboratory studies. The unit consisted of pneumatic screw classifier Figure 1, two cyclone-separators each with own ventilator, bunker with dozer, and material lines.

Research single-factor experiments were conducted to determine the significance and optimal interval of factors for subsequent studies. During these experiments we evaluated parameters influencing grain milling product separation in pneumatic screw classifier[2].

It was found that the best results are obtained in selected intervals of technological and design parameters, Table 1.

Total extraction factor h (%) was selected as optimization criterion; it is determined by formula (1):

$$\eta = 1 - (1 - \eta_1)(1 - \eta_2)(1 - \eta_3) \qquad ...(1)$$

Where h_1, h_2, h_3 are extraction factors of large fraction from the first outlet, medium fraction from the second outlet, fine fraction from the third outlet, respectively

Extraction factor h_1, h_2, h_3 (%) is characterized by the ratio of extracted particles P_i to their quantity in the initial mixture P_0. It is calculated according to the formula:

$$\eta_{1\text{-}3} = (P_i / P_o)\,100. \qquad ...(2)$$

Basing on a priori information, it is assumed that the response function is described by a second-order polynomial:

$$Y = b_0 + \sum_{i=1}^{n} b_{ii} x_i^2 + \sum_{i=1}^{n} b_i x_i + \sum_{i<j}^{n} b_{ij} x_i x_j . \qquad ...(3)$$

We selected composite symmetric three-level design B_4 considering the number of significant factors and recommendations for choosing experiment designs [5]. This design was selected on the basis of recommendations for choosing designs with the best joint characteristics. Design matrix is shown in Table 2.

Pneumatic screw classifier was built and tested on flour-grinding mill MVS-01 with performance of 1000 kg/h.

The screening and factorial experiments justified values of geometrical and technological parameters of pneumo-centrifugal air separation system. Pneumatic screw classifier was designed and built according to the technical task.

Test program of experimental unit was based on IS 101.3-2001. Test program included: examination of unit construction, assessment of working conditions, determination of performance indexes for optimal performance.

Technical characteristics of the unit are based on the results of laboratory tests, designed and manufactured experimental sample of pneumatic screw classifier. Technical characteristics should contain indicators resulting from cyclone type[6].

Adjustment experiments were conducted in order to determine optimal adjustment operation mode. One should focus on extraction purity of required particle fraction while setting the air flow rate. Three experiments in each mode with each grinding system were conducted.

Material was fed into pneumatic screw classifier through designed receiver with adjustable flow splitter to regulate material load on the classifier.

The experiment began in steady-state mode. Material flow was blocked by the flap, and all outputs were directed to containers; after each repeated experiment material flow was stopped on signal by closing the flap, and time of sampling was placed. Extracts were weighted and sampled for analysis. All output samples had labels.

Unit performance was determined according to the air flow rate per hour.

Analysis of samples taken during unit test consisted of

- Collection of sample weights for determination of quality of the source material and extracts from the unit;
- Determination of fractional composition of source material and extracts.

Obtained results were processed using mathematical statistics, dependency graphs were plotted, the the total extraction factor h (%) with assessment of unit competence in the process flow design.

In order to calculate economic efficiency, we drew milling balance before and after the introduction Table 4 and 5. This document fully reflects all features of technological process in this facility.

Milling balance is a tabular record of distribution of all products on technological systems, as well as extracts of products from all systems. Milling balance reflects not only technological process according to its design, but also process management, therefore it provides a complete analysis of the process flow in the facility.

Calculation of milling balance requires setting the load on I break system as 100%, i.e. grain mass changes in the preparatory division of a mill are not taken into account due to removing of impurities and moisturization of grain. Therefore, the amount of obtained flour and bran, as well as semolina (if present), should be 100%. Mass of all products is expressed in percentage to I break system.

These balances are recorded as tables: for each system separately or for total milling – as so-called cross tables.

Pneumatic screw classifier is a part of the experimental unit. The main body contains pneumatic crew channel with radial flow into axial pipe windows.

Pneumatic screw classifier has following technical characteristics:

Performance, kg/h...100
Mass concentration, kg/kg............................≤ 0.64
Air input rate, m/s. ....≤12
Pneumatic screw channel diameter, m 0.3
Channel cross-section dimensions m × m..x 0.075 0.075

Pneumatic screw classifier was mounted directly behind the grinding mill of the first break system in production line. Air flow rate in outlet pipes was regulated by TRIAC transducers and grinded grain load – by a splitter set into the drift from grinding mill on the plansifter.

RESULTS

Determination of aerodynamic properties of grain milling showed that particle suspension velocity ranges from 0.5 to 5.5 m/s, estimated equivalent diameter ranges from 122 to 1040 µm, respectively.

Research data on the influence of mean rate ratio in the axial and tangential pipes indicate that extraction factor maxima in pipe samplers are obtained under the ratio of the rate in pneumatic duct to the rate in axial pipe V_{pd}/V_{ax} H" 0.8.

Study of influence of the conical part of the unit on grain milling product separation in pneumatic screw classifier allowed to determine rational angle of conical part disclosure as 60 degrees.

It was also found that grain milling products divided according to suspension velocities after I break system have different internal friction coefficients.

Experiments with design matrix were followed by data processing and building of mathematical model. Quadratic model coefficients were determined according to formulas[5].

Processing of experimental results were conducted using recommendations[1, 3, 4].

In accordance with the hypothesis adopted in this study, we attempted to create a comprehensive study of the pneumatic screw classifier that would ensure the grain milling product separation into three fractions with different suspension velocities. Table 2 presents the results of experimental research.

We obtained regression equation in form of (x 1, x 2, x 3, x 4) based on experimental results and their statistical We obtained regression equation η (x_1, x_2, x_3, x_4) based on experimental results and their statistical processing using standard programs.. Mathematical model describing the efficiency of separation process:

$$\eta = 90{,}556 + 1{,}201x_1^2 + 3{,}511x_2^2 + -2{,}237x_3^2 - 1{,}77x_4^2 - 0{,}483x_1 - 0{,}721x_2 - 0{,}028x_3 - 1{,}575x_4 - 0{,}941x_1x_2 - 0{,}29x_1x_3 + 1{,}087x_1x_4 - 0{,}455x_2x_3 - 0{,}445x_2x_4 + 0{,}827x_3x_4 \quad ...(4)$$

Experimental results were processed by statistical methods.

Check of the model adequacy was carried out using Fisher criterion.

Regression equation in decoded form:

$$\eta = 83{,}46 + 0{,}075\alpha^2 + 0{,}8777U_1^2 - 0{,}5592U_2^2 - 0{,}1106q^2 - 2{,}5283\alpha - 14{,}0358U_1 + 6{,}2868U_2 + 5{,}2614q - 0{,}1177\alpha U_1 - 0{,}036\alpha U_2 + 0{,}0679\alpha q - 0{,}1182U_1U_2 - 0{,}056U_1q + 0{,}1032U_2q \quad ...(5)$$

Equation (4) was cited to canonical form for the analysis and systematisation:

$$Y = 91{,}94 + 1{,}3158X_1^2 + 3{,}44331X_2^2 - 2{,}50204X_3^2 - 1{,}55228X_4^2 . \quad ...(6)$$

As can be seen from equation (6), regression coefficients of canonical equation have different signs, therefore, minimax-type response surface [1] with coordinates of the figure center $x_1 = 0.4017$; $x_2 = 0.1262$; $x_3 = 0.1124$; $x_4 = -0.364$ (factors are, respectively: pitch angle, ° = 13.6068°; air flow rate in axial pipe U_1 = 10, 2524 m/s, air flow rate in

Table 1. levels of experimental factors

Factors	Reference designations	Code	Levels of factors -1	0	1	Variation interval
Pitch angle, °	α	X_1	8	12	16	4
Air flow rate in axial tube, U_1, m/s	U_1	X_2	8	10	12	2
Airflow rate in the medium fraction outlet, U_2, m/s	U_2	X_3	5	7	9	2
Material load on the classifier, q, kg/s	q	X_4	0.026	0.030	0.034	0.004

Table 2. Experimental research results

Number of experiment	X_1	X_2	X_3	X_4	Y_1	Y_2	Y_3		$S^2(Y_u)$
1	2	3	4	5	6	7	8	9	10
1	-1	-1	-1	-1	94.99	93.61	94.08	94.23	0.49
2	-1	-1	-1	1	88.21	89.53	88.68	88.81	0.45
3	-1	-1	1	-1	92.91	93.84	94.23	93.66	0.46
4	-1	-1	1	1	89.83	92.32	91.24	91.13	1.56
5	-1	1	-1	-1	97.54	96.03	96.48	96.68	0.6
6	-1	1	-1	1	88.83	90.25	86.37	88.48	3.85
7	-1	1	1	-1	94.28	94.92	95.82	95.01	0.6
8	-1	1	1	1	89.47	90.15	90.61	90.08	0.33
9	1	-1	-1	-1	93.29	92.40	91.85	92.51	0.53
10	1	-1	-1	1	91.37	92.52	91.97	91.95	0.33
11	1	-1	1	-1	91.87	93.30	94.02	93.06	1.20
12	1	-1	1	1	93.56	91.81	92.55	92.64	0.77
13	1	1	-1	-1	93.44	93.02	92.21	92.89	0.39
14	1	1	-1	1	88.48	88.12	87.52	88.04	0.24
15	1	1	1	-1	87.83	87.43	86.90	87.39	0.22
16	1	1	1	1	89.30	88.80	90.07	89.39	0.41
17	1	0	0	0	91.09	92.65	94.96	92.90	3.79
18	-1	0	0	0	91.09	92.65	94.96	92.90	0.43
19	0	1	0	0	92.00	91.31	90.69	91.33	4.26
20	0	-1	0	0	92.86	91.01	95.13	93.00	3.24
21	0	0	1	0	93.93	97.49	96.17	95.86	0.38
22	0	0	-1	0	89.72	88.50	88.98	89.07	0.59
23	0	0	0	1	89.10	88.20	87.57	88.29	0.6
24	0	0	0	-1	88.30	87.56	86.75	87.54	0.86
								$\Sigma S^2(Y_u)$	26.58

Table 3. Results of production check of pneumatic screw classifier

Load on the classifier, q, kg/h	Extraction factor (η, %) by fractions				
	Tailing fraction	Coarse grits	Medium grits	Fine grits	Dunst + flour
100	86.78	18.95	22.87	25.15	32.48
	86.27	19.48	26.64	24.44	32.62
	85.29	18.08	24.08	23.05	30.79
Mean value	86.11	18.83	24.53	24.21	31.96
85	84.07	18.78	22.25	22.23	33.84
	86.24	19.55	20.78	20.16	32.05
	88.13	18.82	20.94	21.06	33.27
Mean value	86.15	19.05	21.32	21.15	33.05
70	83.10	6.14	9.18	8.31	27.27
	84.41	6.92	9.42	10.29	26.05
	89.69	8.07	10.29	10.03	17.51
Mean value	85.73	7.04	9.63	9.54	23.61

SP - sieve purifier r.s. - reduction system

pneumatic duct pipe U_2 = 6.7752 m/s, material load on the classifier, q = 0.0285 kg/s).

Cross-section of X_1 and X_2 were obtained through substitution of x_3=0 and x_4=0 in equation (4):

$$\eta = 90{,}556 + 1{,}201x_1^2 + 3{,}511x_2^2 - 0{,}483x_1 - 0{,}721x_2 - 0{,}941x_1x_2 \quad ...(7)$$

We differentiated equation (7) for each variable, equated the derivatives to zero and got a system of linear equations consisting of two equations.

Solution of linear system of equations is new response surface center coordinates: x_1 = 0.2547; x_2 = 0.1368.

After substitution of found values x_1 and x_2 in equation (7) we obtained the value of the total extraction factor in the surface center Y_S = 91.69.

Canonical transformation of equation (7) was conducted; it is expressed by the following equation:

$$Y = 91{,}69 + 1{,}10831X_1^2 + 3{,}60304X_2^2 . \quad ...(8)$$

Response surface is a paraboloid (Figure 2). Both factors B_{11} and B_{22} have the same signs. Centers of ellipses represent minima, as factors are positive and ellipses are extended along the axis x_1:

$$tg\,2\alpha = \frac{b_{ij}}{b_{ii} - b_{jj}} = \frac{-0{,}941}{1{,}201 - 3{,}511} = 0{,}40751 \quad ...(9)$$

In this case factor value x_1 of the adopted factor variation interval moves a 0.2547 variation step away from the plan center and makes 13° in-kind; factor value x_2 moves a 0.1368 step or 10.3 m/s, while Ys = 91.69% and angle of coordinate axis rotation from the initial state is á = 11°.

Analysis of the response surface Figure 2 indicates that the rate changes in axial pipe to the right and to the left from the response surface center leads to a higher extraction factor (92.8–96.4%, which makes 3.7%) than change of pitch angle (95.29–96.40% – 1.1%). Therefore, the rate in axial pipe (X_2) has a greater impact on the total extraction factor than the pitch angle (X_1).

Study of influence of X_1 and X_3 on optimization criterion was conducted in a similar way. Regression equation (10) and response surface (Figure 3) were obtained, center of factor variation intervals was shifted, in coded form: x_1 = 0.1988; x_3 = 0.0191; Y_S = 91.75, axis rotation angle á = -2.41°, regression coefficients B_{11} = 1.20665; B_{33} = -2.24292:

$$Y = 91{,}75 + 1{,}20665X_1^2 - 2{,}24292X_3^2 . \quad ....(10)$$

In this case, coefficients B_{11} and B_{33} have different signs. Hyperbola are stretched along the B_{11} axis with a lower absolute value of coefficient in canonical equation. In this case, the response value increases from the center of figure along this axis and decreases along the B_{33} factor axis. Center of the response surface is called saddle or minimax, the response surface – hyperbolic paraboloid.

Analysis of the response surface Figure 3 indicates that the rate changes in axial pipe to the right and to the left from the response surface center leads to a lower extraction factor (90.7–93%, which makes 2.5%) than change of pitch angle (90.7–89.5% – 1.3%). Therefore, the rate in pneumatic screw channel pipe (X_3) has a greater impact on the total extraction factor than the pitch angle (X_1).

Study of influence of X_1 and X_4 on optimization criterion was conducted in a similar way. Regression equation (11) and response surface (Figure 4) were obtained, center of factor variation

Table 4. Basic quantitative milling balance

Systems	Products received		Products obtained		
	Name	Quantity,% to I br.s.	Name	Quantity,% to I br.s.	Product direction
I br.s.	Grain	100	1st tailing	67	II br.s.
			2nd tailing	26	SP
			1st pass	7	Top grade flour.
	Total	100		100	
II br.s.	1st tailing of I br.s.	67	1st tailing	29	III br.s.
			2nd tailing	29	SP
			1st pass	9	Top grade flour.
	Total	67		67	
SP	2nd tailing of I br.s.	26	1st tailing	3.5	III br.s.
	2nd tailing of II br.s.	29	2nd tailing	2.4	III br.s.
			3rd tailing	30	1 r.s.
			Pass	16.9	1 r.s.
			tailings	2.2	
	Total	55		55	
III br.s.	1st tailing of II br.s.	29	1st tailing	8.9	Bran
	1st tailing of SP	3.5	2nd tailing	6	Bran
	2nd tailing of SP	2.4	1st pass	7	First grade flour
			2nd pass	13	2 r.s.
	Total	34.9		34.9	
1 r.s.	3rd tailing of SP	30	1st tailing	16	2 r.s.
	Pass of SP	16.9	2nd tailing	6.9	2 r.s.
			1st pass	24	Top grade flour.
	Total	46.9		46.9	
2 r.s.	2nd pass of III br.s.	13	1st tailing	8.9	3 r.s.
	1st tailing of 1 r.s.	16	2nd tailing	3	3 r.s.
	2nd tailing of 1 r.s.	6.9	3rd tailing	4	3 r.s.
			1st pass	20	First grade flour
	Total	35.9		35.9	
3 r.s.	1st tailing of 2 r.s.	8.9	1st tailing	6	Bran
	2nd tailing of 2 r.s.	3	2nd tailing	2.9	Bran
	3rd tailing of 2 r.s.	4	3rd tailing	2	Bran
				5	First grade flour
	Total	15.9		15.9	-

Mass of all obtained products expressed as a percentage to I br.s.:

top grade flour	40%;
first grade flour	32%;
bran	25.8%.
feed	2.2%
Total	100%

intervals was shifted, in coded form $x_1 = 0.3536$, $x_4 = -0.3369$ $Y_S = 91.98$, axis rotation angle $\alpha = 10.05°$, regression coefficients $B_{11} = 1.2968$; $B_{44} = -1.866$;

$$Y = 91{,}98 + 1{,}2968X_1^2 - 1{,}866X_4^2. \quad ...(11)$$

Analysis of the response surface Figure

Table 5. Designed quantitative milling balance

Systems	Products received: Name	Products received: Quantity,% to I br.s.	Products obtained: Name	Products obtained: Quantity,% to I br.s.	Product direction
II br.s.	Grain	100	large fraction	74	1st break plansifter
			medium fraction	23	2nd break plansifter
			fine fraction	3	1 r.s. plansifier
	Total	100		100	
I br.s.	large fraction on the 1st break plansifter	74	1st tailing	48	II br.s.
			2nd tailing	18	SP
			1st pass	8	top grade flour
	Total	74		74	
II br.s.	1st tailing of I br.s.	48	1st tailing	18	III br.s.
	medium fraction on the 2nd break plansifter	23	2nd tailing	43	SP
			1st passage	10	Top grade flour.
	Total	71		71	
SP	2nd tailing of I br.s.	18	1st tailing	3.8	III br.s.
	2nd tailing of II br.s.	43	2nd tailing	2.9	III br.s.
			3rd tailing	33.2	1 r.s.
			Pass	18.9	1 r.s.
			Tailings	2.2	
	Total	61		61	
III br.s.	1st tailing of II br.s.	18	1st tailing	3.7	Bran
	1st tailing of SP	3.8	2nd tailing	2.5	Bran
	2nd tailing of SP	2.9	1st pass	6	First grade flour
			2nd pass	12.5	2 r.s.
	Total	24.7		24.7	
	3rd tailing of SP	33.2	1st tailing	20	2 r.s.
	Pass of SP	18.9	2nd tailing	8.6	2 r.s.
	fine fraction on 1 r.s. plansifter	3	1st passage	26.5	Top grade flour.
	Total	55.1		55.1	
2 r.s.	2nd passage of the III br.s.	12.5	1st tailing	6.9	3 r.s.
	1st tailing of 1 r.s.	20	2nd tailing	3.5	3 r.s.
	2nd tailing of 1 r.s.	8.6	3rd tailing	5.2	3 r.s.
			1st pass	25.5	First grade flour
	Total	41.1		41.1	
3 r.s.	1st tailing of 2 r.s.	6.9	1st tailing	6.2	Bran
	2nd tailing of 2 r.s.	3.5	2nd tailing	3.4	Bran
	3rd tailing of 2 r.s.	5.2	3rd tailing	2	Bran
			1st pass	4	First grade flour
	Total	15.6		15.6	-

Mass of all obtained products expressed as a percentage to I br.s.:

top grade flour	44.5%;
first grade flour	35.5%;
bran	17.8%.
feed	2.2%
Total	100%

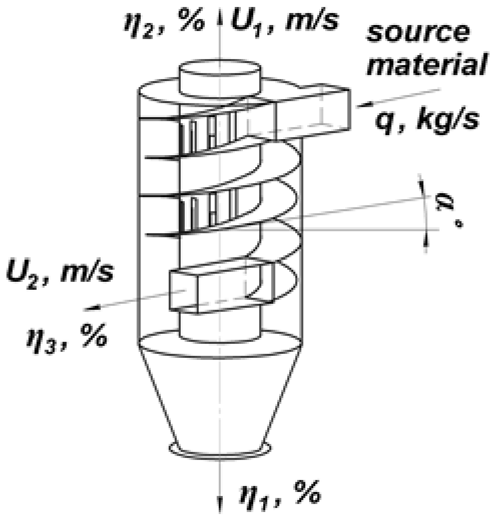

Fig. 1. Factors influencing the grain milling product separation in pneumatic screw channel

4 indicates that the material load changes to the right and to the left from the response surface center leads to a lower extraction factor (93.3–91.4%, which makes 2%) than change of a pitch angle (90.1–91.4% – 1.4%). Therefore, the material load on the classifier (X_4) has a greater impact on the total extraction factor than the pitch angle (X_1).

Study of influence of X_2 and X_3 on optimization criterion was conducted in a similar way. Regression equation (12) and response surface (Figure 5) were obtained, center of factor variation intervals was shifted, in coded form: x_2 = 0.1016, x_3 = -0.0166 Y_S = 91.76, axis rotation angle á = -2.25°. Regression coefficients B_{22} = 3.5197; B_{33} = 2.2459-:

$$Y = 91,76 + 3,5197X_2^{\ 2} - 2,2459X_3^{\ 2} \quad .....(12)$$

Analysis of the response surface Figure 5 indicates that the rate changes in axial pipe to the

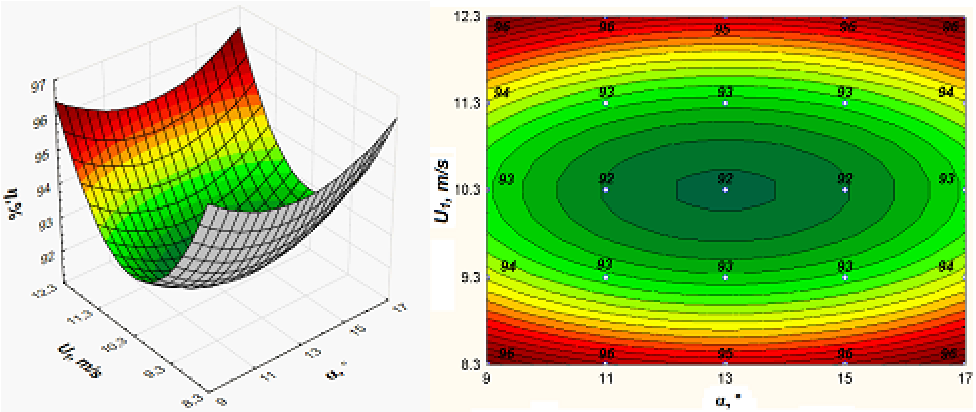

Fig. 2. Influence of factors X_1X_2 (a) response surface (b) two-dimensional section

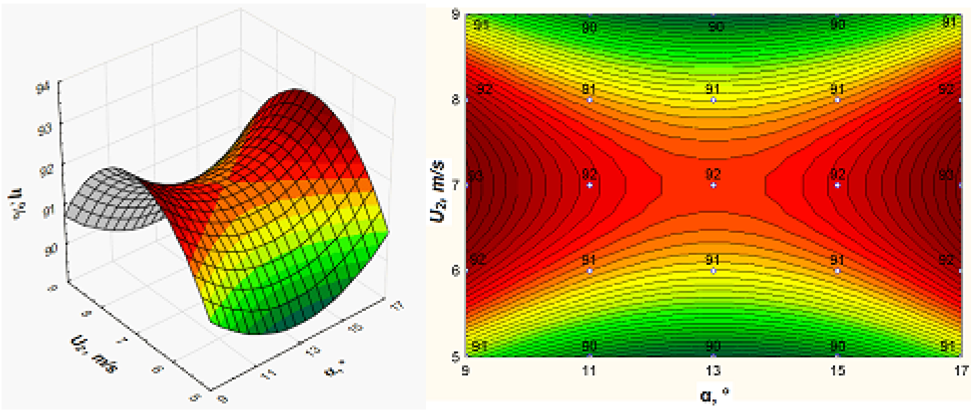

Fig. 3. Influence of factors X_1X_3 (a) response surface; (b) two-dimensional section

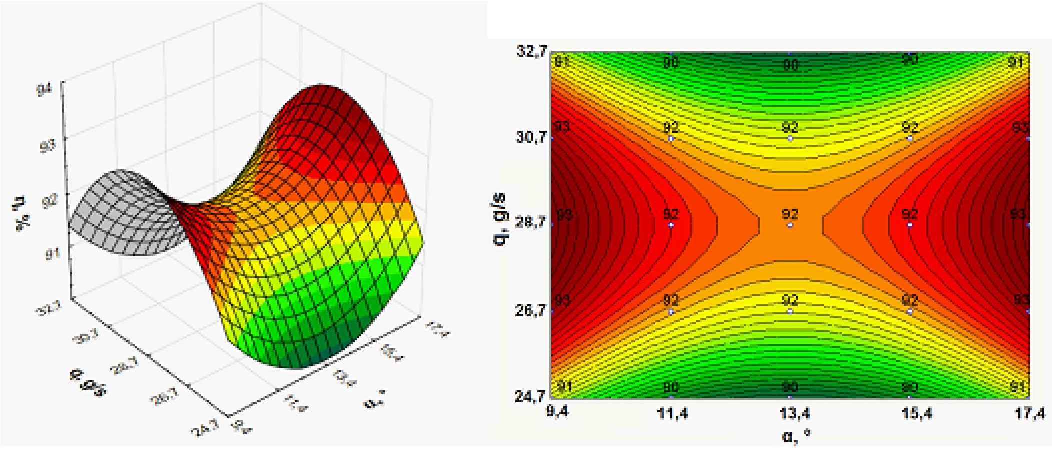

Fig. 4. Influence of factors X_1X_4 (a) response surface (b) two-dimensional section

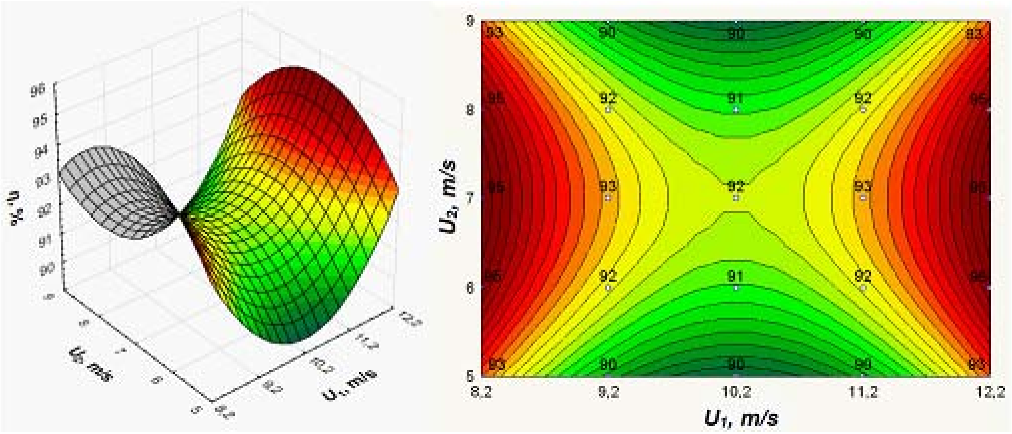

Fig. 5. Influence of factors X_2X_3 (a) response surface; (b) two-dimensional section

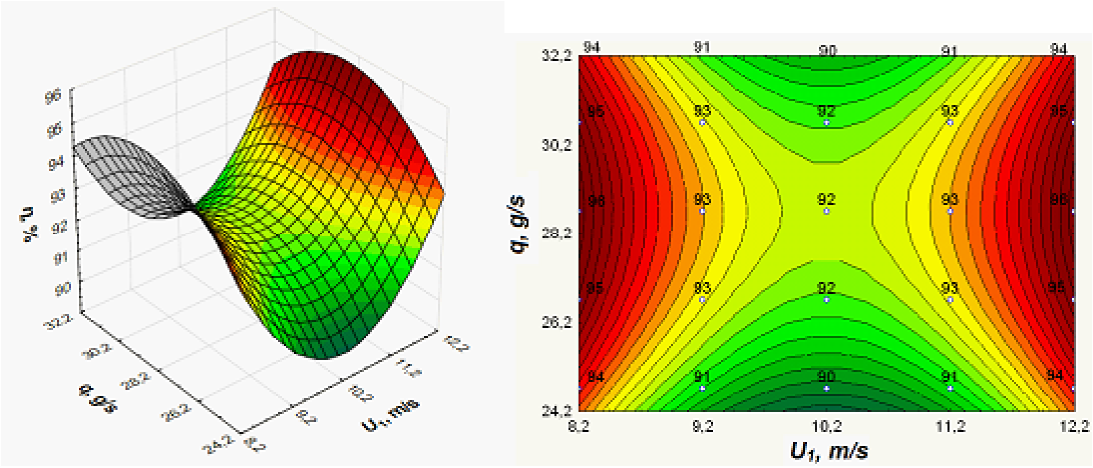

Fig. 6. Influence of factors X_2X_4 (a) response surface (b) two-dimensional section.

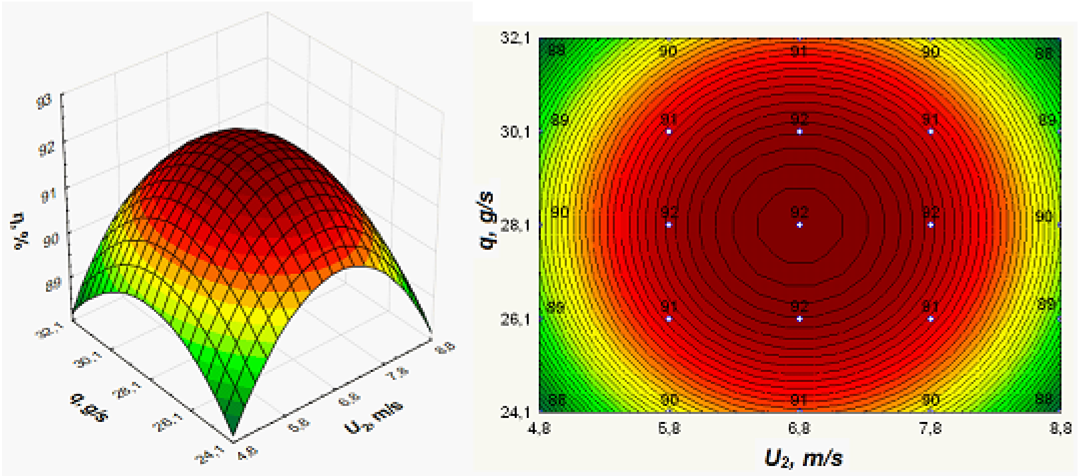

Fig.7. Influence of factors X_3X_4 (a) response surface (b) two-dimensional section

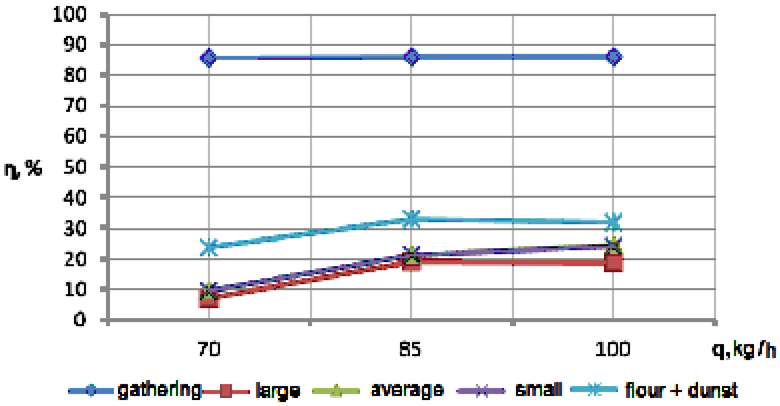

Fig. 8. Dependency of extraction factor η (%) from load (q), kg/h

right and to the left from the response surface center leads to a higher extraction factor (89.5–93%, which makes 3.7%) than change of rate in pneumatic duct pipe (90.7–89.5% – 1.3%). Therefore, the rate in axial pipe (X_2) has a greater impact on the total extraction factor than the rate in pneumatic duct pipe (X_3).

Study of influence of X_2 and X_4 on optimization criterion was conducted in a similar way. Regression equation (13) and response surface (Figure 6) were obtained, center of factor variation intervals was shifted, in coded form: x_2 = 0.0739, x_4 = -0.4546; Y_S = 92.13, axis rotation angle á = -2.41°. Regression coefficients B_{22} = 3.5202; B_{44} = -1.7791:

$$Y = 92{,}13 + 3{,}5202X_2^2 - 1{,}7791X_4^2. \quad ...(13)$$

Analysis of the response surface Figure 6 indicates that the rate changes in axial pipe to the right and to the left from the response surface center leads to a higher extraction factor (90.4–93.9%, which makes 3.8%) than change of material load (93.9–95.7% – 1.9%). Therefore, the rate in axial pipe (X_2) has a greater impact on the total extraction factor than material load on the classifier (X_3).

Study of influence of X_3 and X_4 on optimization criterion was conducted in a similar way. Regression equation (14) and response surface (Figure 7) were obtained, center of factor variation intervals was shifted, in coded form: x_3= -0.0926, x_4 = -0.4669; Y_S = 92.17, axis rotation angle á = 30.27°. Regression coefficients B_{33} = -2.4781; B_{44} = -1.5285:

$$Y = 92.17 - 2.4781X_3^2 - 1.5285X_4.$$

Response surface Figure 7 is an elliptical paraboloid. Both factors B_{33} and B_{44} have the same signs. Centers of ellipses are maxima, because analysis of the response surface indicates that the rate changes in pneumatic duct pipe to the right and to the left from the response surface center leads to a lower extraction factor (90.7–88.2%, which makes 2.8%) than change of material load on the classifier (89.7–88.2% – 1.7%). Therefore, the rate in pneumatic duct pipe (X_3) has a greater impact on the total extraction factor than material load (X_4).

Factors are negative and ellipses are extended along the x_3 axis.

Canonical transformation of the experimental model obtained by application of symmetric composite plan type B_4 [5] showed that the centers of variation intervals of the studied factors has new coded values: x_1 = 0.4017; x_2 = 0.1262; x_3 = -0.1124; x_4 = -0.364, extraction factor ç = 91.94%

In-kind values of optimization parameters are:

- pitch angle, ° = 13.6°;
- air flow rate in axial pipe, U_1 = 10 m/s;
- air flow rate in pneumatic duct pipe, U_2 = 6.8 m/s;
- material load on the classifier, q = 0.0285 kg/s.

Production tests were conducted on the grinded grain coming from the first grinding mill.

Extraction factor of each fraction type from the corresponding collector depending on the load is presented in Table 3.

Production check of the grain milling product separation into fraction in pneumatic screw channel with radial drainage showed that the load change doesn't result in change of extraction rate of tailing fractions. Extraction factor for the remaining fractions (flour grits and dunsts) decreases along with the load Figure 8.

Balance data are recorded as tables: separately for each system or for hole grinding – in so-called cross table. [12]

Milling balance reproduces technological design in terms of distribution of all products and number of systems in the grinding scheme. Quantitative characteristic of products defines the modes of all systems, i.e. the balance contains complete information about grinding process. Therefore, the milling balance is a document that fully reflects all technological process features in this facility.

Input air flow rate U_{in} = 12 m/s, pitch angle of pneumatic screw channel a° =13°; air flow rate in axial pipe U_1=10.3 m/s; air flow rate in pneumatic duct pipe U_2=6.8 m/s.

CONCLUSION

Following conclusions can be drawn basing on conducted experiments:

1) Air flow rate in axial pipe U_1, m/s, has the biggest impact on extraction factor in the investigated range;
2) Air flow rate in pneumatic duct pipe U_2, m/s, also significantly influences the extraction factor of fractions.
3) Material load on the classifier q, kg/s, has a lesser impact on the extraction factor of fractions.
4) Pitch angle ° has the least impact.

Production tests and operation of the classifier prototype designed and built according to materials of the present study have demonstrated that the device is functional, the total extraction factor of required fractions H" 92%.

Introduction of pneumatic screw classifier allowed to extract 30% of flour and dunsts at the stage of transportation of grinding products after the first break system from grinding mill to plansifter and led to an increase in total flour output by 8% through reduction of losses of flour and dunsts in tailings on break plansifter.

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