

ASSESSMENT INDICES FOR THE EFFICIENCY OF THE SEPARATION PROCESS ON A SIEVE WITH CONICAL SEPARATION SURFACE

INDICI DE APRECIERE A EFICIENȚEI PROCESULUI DE SEPARARE PE O SITĂ CU SUPRAFAȚA DE SEPARARE CONICĂ

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ABSTRACT

The objective of this paper is to present the efficiency of the separation process on a sieve with a conical separation surface, with a vertical shaft and having vibrational motion. Separation intensity curves of rape seeds through circular sieve apertures were drawn by regression analysis of the quantities of material separated at different distances from the central axis of the sieve, using the Gaussian distribution law. The coefficients of the regression equation and the correlation coefficient of the distribution function with experimental data show a high degree of correlation between them. The movement of the material on the sieve and the separation process, in general, was assessed by the position of the distribution curve maximum, depending on the material flow rate.

REZUMAT

Obiectivul acestei lucrări este acela de a prezenta eficiența procesului de separare pe o sită cu suprafața de separare conică cu ax verticală având mișcare vibratorie. Curbele intensității de separare a semințelor de rapiță prin ochiurile circulare ale sitei au fost trasate prin analiza de regresie a cantităților de material separat la diferite distanțe de axa centrală a sitei, utilizând legea de distribuție Gauss. Coeficienții ecuației de regresie și coeficientul de corelație a funcției de distribuție cu datele experimentale arată un grad ridicat de corelație între acestea. Mișcarea materialului pe sită și procesul de separare, în general, a fost apreciat prin poziția maximului curbei de distribuție, în funcție de debitul de alimentare cu material.

INTRODUCTION

Nationally, the concerns of designers and builders to make machines and plants for seed cleaning and sorting are very high, due to the need to increase the quality used for both sowing and consumption, (Casandroi, 1993; German R.F. and Lee J.H.A., 1969; Stoica D., 2011, Constantin et al, 2019).

The particles of raw materials contain different impurities that cannot be admitted into the products (grist, semolina, flour, etc.), because they negatively influence both the separation process and the quality of the finished products, (Casandroi, 1993; Stoica D., 2011; Tucu D., 1994, Dal-Pastro et al., 2016).

The processing capacity is influenced by the size of the useful surface of the perforated sheet with which the upper sieve frame is equipped and the characteristics of the seed mixture (moisture, content of impurities etc.).

Removing the hazardous impurities from the mass of stored seeds and reducing or preventing damage caused by impurities on the quality of agricultural crop seeds lead to an increase in the storage period and a reduction in storage losses. In the paper of (Zhou XianQing et al., 2009), the influence of impurities on microbial activity and storage quality was analyzed, at a temperature of 30°C and relative humidity 80-90%, under simulated storage conditions. The results showed that the remaining impurities in the wheat seeds had a negative effect on their storage quality. Microbial activity was faster, and the storage quality of the wheat suffered. That's why the impurities must be separated, as much as possible, before storing wheat, to reduce the negative effects on wheat quality during storage.

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On the sieves of the machines intended for cleaning and sorting the seeds of agricultural crops, the seeds are separated due to the sifting state generated by the oscillation movement of the sieves and, eventually, of a stream of air running through the material layer on the sieve, bottom up. Material separation is a complex process influenced by many factors, as: the physical properties of the components subject to separation, the geometry of the separation surface, the kinematic and functional parameters of the sieve (Jun-xia Yan, 2010; Pruteanu et. al, 2018; Constantin G.A., 2014; Constantin G.A. et al, 2014).

The shape and geometrical characteristics of the sieve are chosen according to the particle size of the material to be separated. Feeding mode and thickness of the material layer on the sieve must be provided by a uniform supply flow; at a flow too high there is the danger to find, in the refusal of the sieve, undersized particles which did not meet the necessary conditions for separation (to get in touch with the sieve and to have the time required to train through the apertures). Also, the length of the particle path on the sieve is a factor that directly influences the quality of separation. The inclination angle of the sieves and the shape of the material particles subjected to the sifting are also the factors that indicate (show) the efficiency of the sifting process, (Voicu Gh., 2011; Casandroi, 1993).

The geometric dimensions of the particles and their distribution, as well as the ratio between the average particle size and the characteristic size of the sieve apertures influences the separation process, so: for values of average particle size d smaller than $0.7 \cdot a$ (a – diameter of sieve apertures or small side of elongated holes), the particles pass easily through the aperture, and for values d greater than $1.5 \cdot a$, the particles pass quickly along the sieve and it does not prevent the passage of small particles through the apertures. For particle size d , between $0.7 \cdot a$ – $1.5 \cdot a$, these tend to clog the apertures in the sieve, in this case it is necessary that the sieves have apertures with size a bigger by 10–15%, for proper separation (Casandroi, 1993; Voicu Gh and Casandroi T, 1995).

The temperature of the products should be as close to or below the ambient temperature, because this influences the separation capacity inversely, in this sense the products are cooled to separate (Casandroi, 1993; Voicu Gh and Casandroi T, 1995). Electric conductivity and static electricity negatively affect the sifting capacity of the sieves (Casandroi, 1993; Voicu Gh and Casandroi T, 1995). The speed of movement and the character of the material movement on the sieve directly influence the process of material separation, these being given by the kinematic regime of the sieve separation block. In the case of fixed sieves, particle displacement occurs due to the slope of the sieve and only small impurities can be separated, without proper separation by the width or thickness of the particles (Casandroi, 1993; Voicu Gh and Casandroi T, 1995).

The description of seed separation on sieve with oscillation motion and the vibrational movement of sieves was made by different authors in two different ways (Bracacescu et al., 2014; Casandroi et al., 2009; Constantin, 2014; Jun-xia et al., 2010; Kharchenko et al., 2019; Simonyan & Yiljep, 2008; Szymański T., Wodziński P., 2003).

Some approach the stochastic description of the separation process, through mathematical models that result from the correlation with the results obtained in the experiments of some functions or laws of distribution existing in mathematical statistics (Voicu Gh. et. al, 2006). Stochastic models can describe both the intensity of material separation along the length of the sieve, as well as the cumulative separation of the material at various distances from the feed end of the sieve along its length (Voicu Gh. et. al, 2006).

The second way of describing the process of separation on the sieve, is the deterministic model, that takes into account the main parameters, which characterizes the process of separation, mathematical model that is determined by applying the theory of dimensional analysis, based on the results of experimental research to determine the values of the dimensionality criteria and the coefficients of the mathematical model.

The paper presents the influence of the material feed flow on the material movement and the separation process for a sieve with outer vertical conical work surface, with horizontal oscillating motion, for a preset oscillation frequency and four values of the amplitude of the sieve oscillation.

MATERIALS AND METHODS

The experimental stand, presented in detail in the paper (Stoica D. et. al, 2012; Stoica D., 2011), has a conical sieve suspended with the separation surface of perforated sheet with holes ϕ 4.2 mm, having a horizontal inclination of 8° , driven in oscillating motion by a mechanism with an eccentric arranged tangentially at the distance d (variable), from the centre of the sieve. The sieve is suspended at the top and bottom by means of three metal cables with a diameter 1.5 mm arranged circularly at 120° .

The experiments were performed with rape seeds having dimensions between $\phi 1.25\text{--}2.5$ mm (at over 95% percentage) and moisture content of 8.05%. In the mixture of seeds subjected to separation were introduced straw particles with dimensions between 3-4 mm at approx. 3% percentage.

The eccentric drive system allowed the three-stage oscillation frequency to be changed (500, 520 and 790 min^{-1}) and the amplitude of the four-stage oscillations. The diameter at the base of the cone was $\phi 430$ mm, and the specific number of circular apertures on the separation surface was 2.25 apertures/cm² (the active surface of the sieve was approx. 31%), diameter of the funnel hole for feeding the sieve was $\phi 25$ mm. The simplified scheme of the experimental installation is shown in Figure 1.

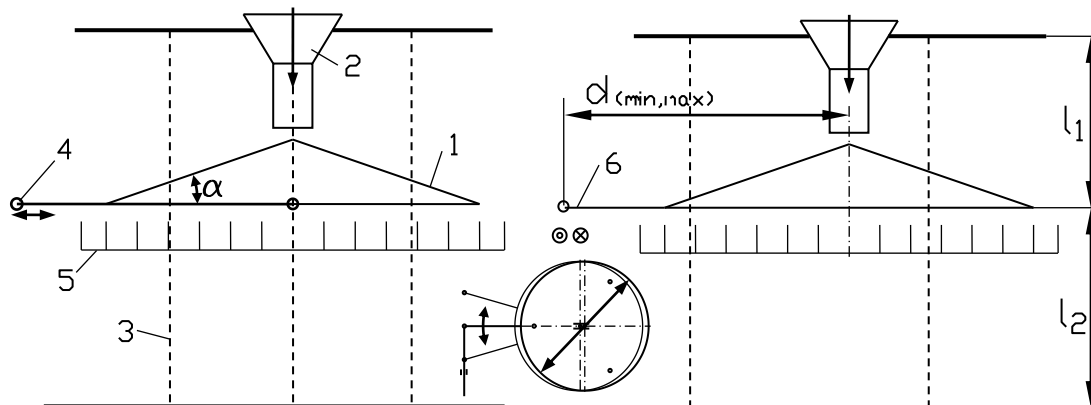


Fig. 1 - Scheme of the suspended conical sieve used for experiments (views to 90°)

1) conical sieve with apertures $\phi 4.2$ mm; 2) height adjustable feed funnel; 3) elastic cables made of steel wire; 4) drive mechanism with oscillating slide; 5) collection box with concentric compartments; 6) lever linking to the connecting rod of the drive mechanism

The amplitude of the sieve oscillation was measured horizontally at the connection point of the sieve with the arm 6, for maximum opening of the drive mechanism connecting rod.

To express the influence of the feed flow on the separation process on the conical sieve, the seeds separated by the apertures of the sieve were collected in a box with several concentric collecting compartments. The mass of seeds collected in each compartment was compared to the initial mass of the sample (that was of 0.500 kg), the results being presented as a percentage compared to this. The feed rate was calculated by reporting the seed mass of the sample at the drain time of the funnel material, which could be adjusted by the distance between the outlet and the sieve.

It is worth mentioning that, during experimental determinations, it was found that the seed impurities in the seed mass were completely separated beyond the bottom edge of the sieve, in all the tests carried out, so that the separation process is presented by the distribution of the separated material along the radius of the sieve cone base.

The experimental results are presented in Table 1.

They were drawn, comparatively (on the same graph), distribution curves of seed separation frequency on the mesh generatrix for three feed rate values used in experiments, under the conditions in which the other parameters of the working regime (amplitude of oscillations A and frequency of oscillation F) were kept constant. Based on the experimental data, the separation curves were plotted by nonlinear regression analysis, using the Gaussian law, expressed by equation 1:

$$p_x(\%) = A_o \cdot \exp\left(-\frac{(x - x_c)^2}{2 \cdot w^2}\right) \quad (1)$$

where: $p_x(\%)$ represents the percentage weight of the separated material over a length interval (radius) of sieve.

According to mathematical statistics, in relation (1) „ A_o ” represents the maximum percentage of material collected in the boxes below the sieve, „ x_c ” represents the radius of the sieve corresponding to the maximum percentage of separated seeds (or the average of the Gaussian distribution function), and „ w ” represents the dispersion to the maximum position. These coefficients depend on the parameters of the sieve working regime and are determined from the regression analysis, together with the correlation coefficient R^2 .

RESULTS AND DISCUSSIONS

The data presented centrally in Table 1 were processed and synthetically ordered according to the values of the feed flow and after the amplitude of the oscillation at one of the three oscillation frequencies used in the experiments ($F = 520 \text{ min}^{-1}$).

Table 1

Variation of the amount of material collected under the sieve (%), for the oscillation frequency $F = 520 \text{ min}^{-1}$ and four amplitudes of the sieve oscillation, at three feed rates

Den No.	$F = 520 \text{ min}^{-1}$. $M_p = 0.500 \text{ kg}$		The sieve interval from which seeds are collected (m)								
	Amplitude of the oscillations	Feed rate	Separated seeds	0	0.04	0.07	0.10	0.13	0.16	0.205	Over sieve
1	$A_1 = 3.58 \text{ mm}$	$Q_1 = 0.02 \text{ kg/s}$	g	0	113	120	140	125	2	0	0
			%	0	22.6	24	28	25	0.4	0	0
$Q_2 = 0.033 \text{ kg/s}$		g	0	104	131	108	99	56	2	0	
		%	0	20.8	26.2	21.6	19.8	11.2	0.40	0	
3		$Q_3 = 0.042 \text{ kg/s}$	g	0	104	131	108	99	56	2	0
			%	0	20.8	26.2	21.6	19.8	11.2	0.40	0
4	$A_2 = 3.74 \text{ mm}$	$Q_1 = 0.02 \text{ kg/s}$	g	0	201	215	84	0	0	0	0
			%	0	40.2	43	16.8	0	0	0	0
$Q_2 = 0.033 \text{ kg/s}$		g	0	104	131	108	99	56	2	0	
		%	0	20.8	26.2	21.6	19.8	11.2	0.40	0	
6		$Q_3 = 0.042 \text{ kg/s}$	g	0	114	141	90	70	39	21	25
			%	0	22.8	28.2	18	14	7.80	4.20	5
7	$A_3 = 3.91 \text{ mm}$	$Q_1 = 0.02 \text{ kg/s}$	g	0	195	210	94	1	0	0	0
			%	0	39	42	18.8	0.2	0	0	0
$Q_2 = 0.033 \text{ kg/s}$		g	0	127	138	107	56	53	19	0	
		%	0	25.4	27.6	21.4	11.2	10.6	3.8	0	
9		$Q_3 = 0.042 \text{ kg/s}$	g	0	115	150	88	65	36	20	26
			%	0	23	30	17.6	13	7.2	4	5.2
10	$A_4 = 4.10 \text{ mm}$	$Q_1 = 0.02 \text{ kg/s}$	g	0	187	208	102	3	0	0	0
			%	0	28	36.6	19	12	4	0.4	0
$Q_2 = 0.033 \text{ kg/s}$		g	0	140	183	95	60	20	2	0	
		%	0	28	36.6	19	12	4	0.40	0	
12		$Q_3 = 0.042 \text{ kg/s}$	g	0	134	176	81	48	26	12	23
			%	0	26.8	35.2	16.2	9.60	5.20	2.40	4.60

Based on the percentages of the material collected under the sieve at different distances from the vertical axis of oscillation, the graphs presented in fig. 2 were drawn, for the four amplitudes.

Each of the four graphs shows three distribution curves of the material on the collection radius of the sieve, representing the variation of separated seeds percentage according to the preset feed rate and used for experiments.

These separation curves were plotted by regression analysis of the experimental data with the Gaussian distribution function (relation 2), allure of these curves being about the same, but with more or less significant differences, depending on the parameters of the working regime used in experiments, respectively with the feeding flow.

The values of the coefficients of the regression equation (equation 2, A_0 , x_c , w), as well as the values of the correlation coefficients χ^2 and R^2 for the four amplitudes of the oscillation at each of the three feed rates are presented in table 2.

Analyzing the data in tables 1 and 2 and the graphs in fig. 2, it is found that the position of the maximum separation curves for the three feed rates, $Q_1 = 0.020 \text{ kg/s}$, $Q_2 = 0.033 \text{ kg/s}$, $Q_3 = 0.042 \text{ kg/s}$, changes at each of the four amplitudes of the oscillation.

Thus, if the point of the separation curve's maximum position is at 0.078 m from the center of sieve oscillation vertical axis for oscillation amplitude $A_1 = 3.58 \text{ mm}$ and flow Q_1 , for higher material flows (Q_2 , Q_3), this point approaches even more the vertical axis of the sieve, values that are influenced, we suppose, also by sieve apertures dimension.

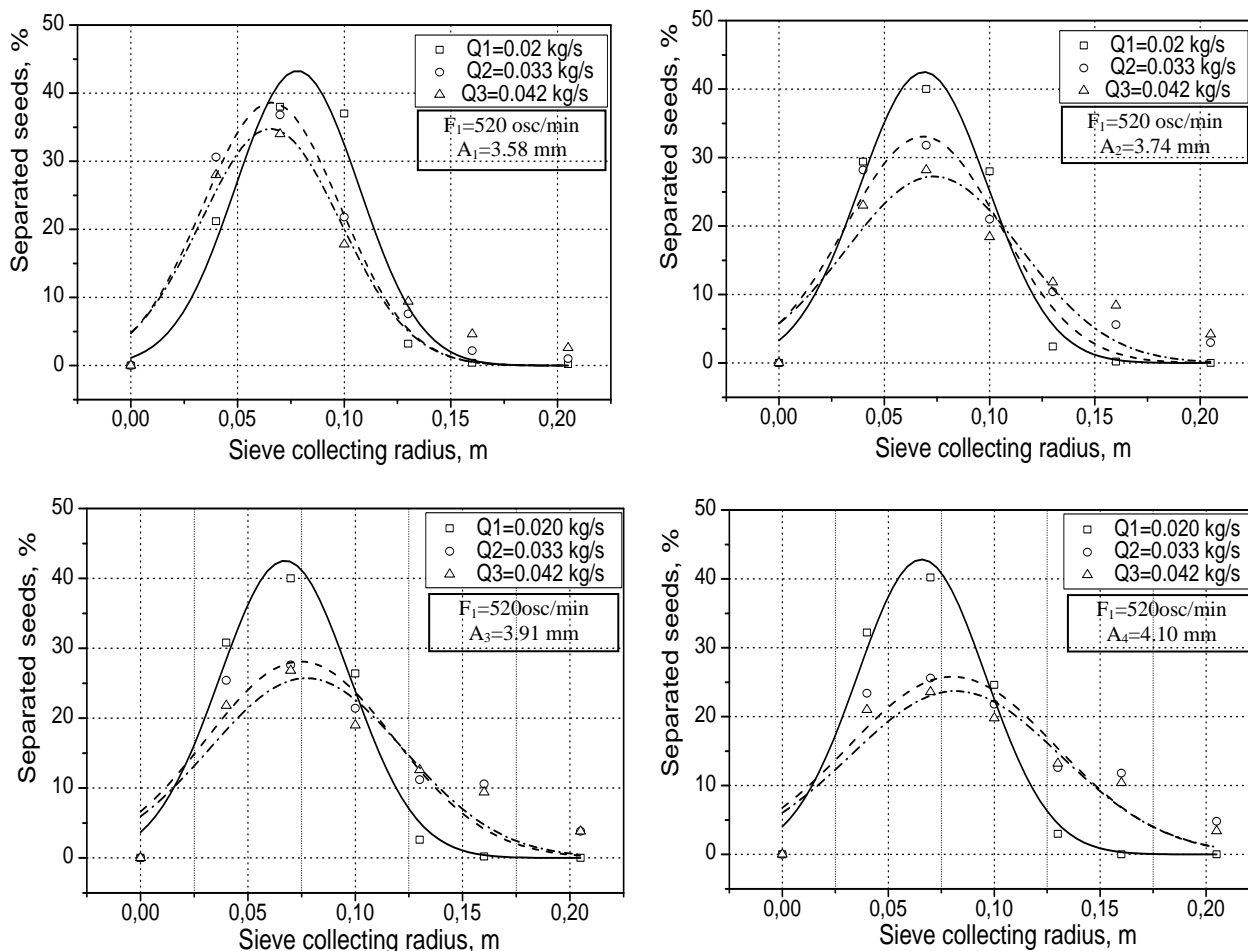


Fig. 2 - The influence of the feed flow on the seed separation process on the conical sieve generatrix, at the oscillation frequency $F = 520 \text{ min}^{-1}$ and four amplitudes of the oscillation

However, there is a slight increase in the dispersion of the material on the sieve, represented by the coefficient values w from table 2, for the flow Q_1 .

If the amplitude of the oscillation increases to $A_2 = 3.74 \text{ mm}$ or $A_3 = 3.91 \text{ mm}$ and then to $A_4 = 4.10 \text{ mm}$ for higher feed rates, respectively $Q_2 = 0.033 \text{ kg/s}$ or $Q_3 = 0.042 \text{ kg/s}$, it is found that the dispersion of the material on the sieve also increases.

Table 2

The coefficients of the regression equation (eq. 2) A_0 , x_c , w and the correlation coefficients χ^2 and R^2 with experimental data, for three material feed rates at the oscillation frequency $F = 520 \text{ min}^{-1}$ and four amplitudes of the sieve oscillation

Sample No	Working regime	Gaussian type function	A	x_c	w	χ^2	R^2
1	$A_1 = 3.58 \text{ mm}$	$Q_1 = 0.02 \text{ kg/s}$	49.979	0.063	0.029	14.104	0.973
2		$Q_2 = 0.033 \text{ kg/s}$	40.581	0.067	0.033	28.420	0.937
3		$Q_3 = 0.042 \text{ kg/s}$	35.972	0.071	0.036	11.543	0.916
4	$A_2 = 3.74 \text{ mm}$	$Q_1 = 0.02 \text{ kg/s}$	49.746	0.056	0.0263	11.892	0.980
5		$Q_2 = 0.033 \text{ kg/s}$	38.010	0.067	0.034	14.614	0.960
6		$Q_3 = 0.042 \text{ kg/s}$	33.278	0.068	0.034	16.587	0.931
7	$A_3 = 3.91 \text{ mm}$	$Q_1 = 0.02 \text{ kg/s}$	49.370	0.059	0.026	7.483	0.987
8		$Q_2 = 0.033 \text{ kg/s}$	37.400	0.066	0.033	15.012	0.954
9		$Q_3 = 0.042 \text{ kg/s}$	34.065	0.067	0.033	18.308	0.926
10	$A_4 = 4.10 \text{ mm}$	$Q_1 = 0.02 \text{ kg/s}$	49.143	0.061	0.026	4.899	0.991
11		$Q_2 = 0.033 \text{ kg/s}$	37.613	0.065	0.032	19.482	0.938
12		$Q_3 = 0.042 \text{ kg/s}$	35.283	0.065	0.031	21.235	0.919

If at feed rates Q_1 and Q_2 , for the amplitude of oscillation $A_2 = 3.74$ mm, the position of the separation curve maximum does not change significantly, at the feed rate $Q_3 = 0.042$ kg/s, the maximum of the separation curve moves towards the edge of the sieve, at $x_c = 0.074$ m instead of 0.069 m, as in the case of the feed rate Q_1 .

In the same conditions by increasing the dispersion of the material on the surface of the sieve, the percentage of material separated at the maximum point of the separation curve decreases with the increase of the feed rate (see fig. 2,b).

From the analysis of the separation curves in fig. 2,c, at the same frequency of oscillation $F = 520 \text{ min}^{-1}$, but at slightly greater amplitude of oscillation, $A_3 = 3.91$ mm, the dispersion of the material over the sieve collection area increases with increasing feed flow, the percentages of separated material at the maximum point decrease insignificantly, but the maximum of the separation curve moves significantly from the vertical axis of the screen to its edge. Thus, if at the feed rate $Q_1 = 0.02$ kg/s, the position of the separation curve maximum is at $x_c = 0.067$ m relative to the axis of sieve oscillation, at the feed rate $Q_2 = 0.033$ kg/s the separation curve maximum moves from 0.074 m, at $x_c = 0.077$ m for the feeding flow $Q_3 = 0.042$ kg/s, from where it can be assumed that the sieve can work at a much larger load of material at this oscillation amplitude for the analyzed oscillation frequency ($F = 520 \text{ min}^{-1}$).

The same phenomenon can be observed from the analysis of the separation curves in fig. 2,d for the amplitude of the oscillation $A_4 = 4.10$ mm.

We find that the position of the separation curve maximum with respect to the collecting radius of the sieve, moves from the axis of oscillation to the edge of the sieve as the feed flow increases from 0.066 m (for $Q_1 = 0.02$ kg/s) at $x_c = 0.082$ m (for $Q_3 = 0.042$ kg/s). It is worth mentioning that, (as well as amplitude A_3) the percentages of separated material at higher feed rates decrease significantly, with the increase of the separated material dispersion on the generatrix of the sieve.

The synthetic representation of those presented above can be seen from the analysis of the curves in fig. 3, which shows the position of the separation curve maximum in relation to the collection radius of the sieve according to the material flow rate.

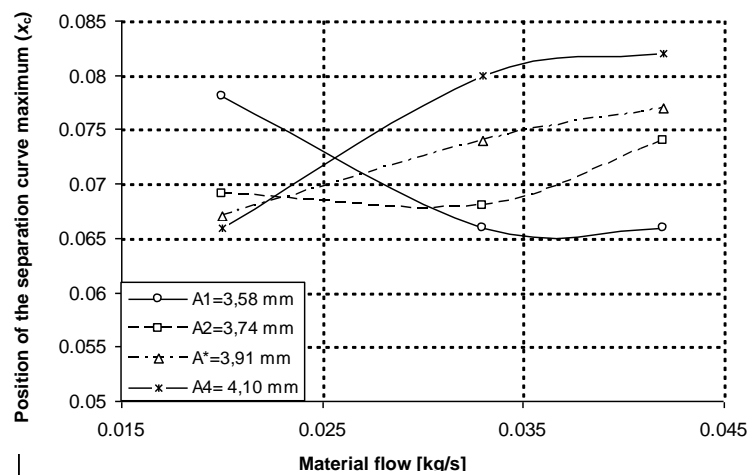


Fig. 3 - at the frequency $F = 520 \text{ min}^{-1}$ and four amplitudes of the sieve oscillation, depending on the material flow rate

CONCLUSIONS

A vertical conical sieve with circular apertures and a horizontal oscillating motion was used to analyze the sifting process and the separation of rape seeds through the apertures, for three different feed rates and four amplitudes of the sieve oscillation.

From the data presented in the paper, it was found that the position of the maximum distribution curve of the separation changes with the change of the feed rate and the amplitude of the sieve oscillation. At low feed rates ($Q_1=0.02$ kg/s), the maximum of the separation curve approaches the axis of oscillation of the sieve as the amplitude of oscillation increases, while for higher feed rates, this point departs from the axis of oscillation when the amplitude of oscillation increases.

Separation curves were plotted by regression analysis of experimental data with Gaussian distribution function, aspect of these curves being about the same, but with more or less significant differences, depending on the parameters of the working regime used in experiments, respectively with the feeding flow.

We can say that at low feed rates ($Q_1 = 0.02$ kg/s, $Q_2 = 0.033$ kg/s) and low oscillation frequencies (like the one I presented earlier, $F = 520$ min⁻¹) under the experimental conditions performed in the present paper, material losses over the outer edge of the sieve are minimal (in table 2 they have zero value for the flows Q_1 and Q_2).

The data presented in the paper can be a reference base for the specialists (designers and users of machines) in the field of seed processing of agricultural crops and, especially, of those in the field of cleaning and conditioning before storage and industrial processing.

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