# ANALYTICAL ASSESSMENT OF THE PNEUMATIC SEPARATION QUALITY IN THE PROCESS OF GRAIN MULTILAYER FEEDING
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# *АНАЛІТИЧНА ОЦІНКА ЯКОСТІ ПНЕВМОСЕПАРАЦІЇ ПРИ БАГАТОРІВНЕВОМУ ВВЕДЕННІ ЗЕРНА*

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## ABSTRACT
*The design of a pneumatic separator with the feeding device for grain multilayer feeding was suggested in this paper. The application of the device enables increasing the uniformity of the airflow field velocity and the quality separation indicators. In order to determine the impact of grain multilayer feeding on the quality of grain cleaning we conducted a quantitative distribution of light grain impurities in the operating separation area. As a result, a statistical model of the probability of light impurities passing through the grain layers in the process of grain multilayer feeding in pneumatic and separating channel was obtained and the influence of specific load on the quality of grain cleaning was analytically determined.*

## РЕЗЮМЕ
*Запропоновано конструкцію пневмосепаратора з живильним пристроєм для багаторівневого введення зернового матеріалу, використання якого дозволяє підвищити рівномірність поля швидкостей повітряного потоку та якісні показники сепарації. З метою визначення впливу багаторівневого введення зернового матеріалу на якість очищення зерна проведено кількісний розподіл легких домішок в робочій зоні сепарації. В результаті отримано статистичну модель ймовірності проходження легких домішок через зернові шари при багаторівневому введенні зернового матеріалу в пневмосепаруючому каналі та аналітично визначено вплив питомого навантаження на якість очищення зерна.*

## INTRODUCTION
Today Ukraine is one of the leading countries in the production of grain and one of the three world exporters of grain crops (*Materynska O.A., 2013*). That requires introducing new production technologies that can provide high performance of grain cleaning and its compliance with the standards of cleanliness and humidity (*Grabar I.G., 2013*).

The required quality of food grain can be achieved only through the effective and timely grain cleaning from impurities which substantially affect the terms of storage and selling conditions. In this case the pneumatic separation is very important. It separates a significant amount of impurities at various stages of grain cleaning (*Vasylkovskyi M.I., 2006*).

Air separation is one of the most common ways of grain cleaning. This process is versatile due to the separation of any material – from the smallest grain (alfalfa, poppy, etc) to the largest (corn, beans) and can partially reduce its moisture content and minimize damage (*Dryncha V.M., 2006*). However, the efficiency of the air flow depends on many factors: the size of specific grain load, aerodynamic properties of the components, airflow velocity, geometrical parameters of the pneumatic separating channel and others. (*Kroulík M., 2016, LukaszukJ., 2008*).

But, despite the widespread application and versatility of pneumatic separation, the efficiency of the air flow is significantly reduced due to uneven grain location in the operating separation area. The increase of grain specific feeding causes the increase of aerodynamic resistance in the area of grain input and output, which in its turn increases the uneven airflow velocity in the cross section of the pneumatic separating channel (*KovrikovI.T., 2003, Burkov A.I., 2000*).

The increase of evenness of the air flow velocity field can be achieved by using the feeding devices of the pneumatic separating channels (*Saitov A.V., 2015*). This improves interaction of the grain components and the air flow, thereby increasing the quality of separation, which improves the efficiency of the air flow and the quality of grain cleaning (*Panasiewicz M., 2008, Leshchenko S.M., 2008*).

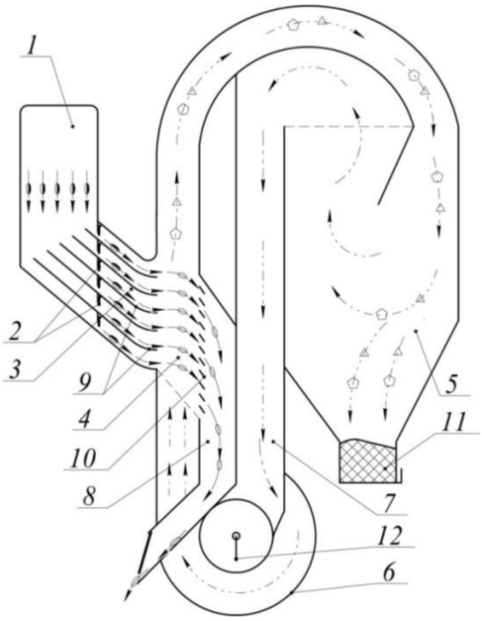
Despite a large number of works on theoretical research of the pneumatic separation quality (*Hamuev V.G., 2016, Leshchenko S.M., 2012*), the problem of quality indicators analytic assessment is very important and requires a detailed analysis of the process especially in the conditions of grain contact interaction in the operating separation area.

So, the research is to study the impact of grain interaction on pneumatic separation quality indicators while applying feeding devices. That will improve the air flow efficiency and reduce the power consumption for grain cleaning.

## MATERIAL AND METHOD

The analysis of feeding devices operation led to the conclusion that the main disadvantage of active feeders used in the pneumatic grain cleaning machines is the additional energy, thereby increasing the power consumption and complexity of the pneumatic separating channel design. Therefore, among all types of feeders the gravity feeders are widely used due to their simplicity of design and reliability. These feeders are used in grain cleaning machines and some feeders became the result of scientific research (*Baldanov V.B., 2015, LevdanskyiE.Yu., 2012, Doshi J.S., 2013*).

On the basis of the research analysis of pneumatic separation and of feeding devices designs, the Department of Agricultural Engineering of the Central Ukrainian National Technical University designed and manufactured a prototype of a new pneumatic separator with the feeding device for grain multilayer feeding (*Patent of Ukraine №8058A, 2005*) (Fig. 1). The design of the pneumatic separator ensures even distribution of grain material in the operating separation area and significantly reduces air flow resistance in the input and output zones and makes velocity field uniform (*Nesterenko O.V., 2015*).




a

b

**Fig. 1 – Experimental air separator**

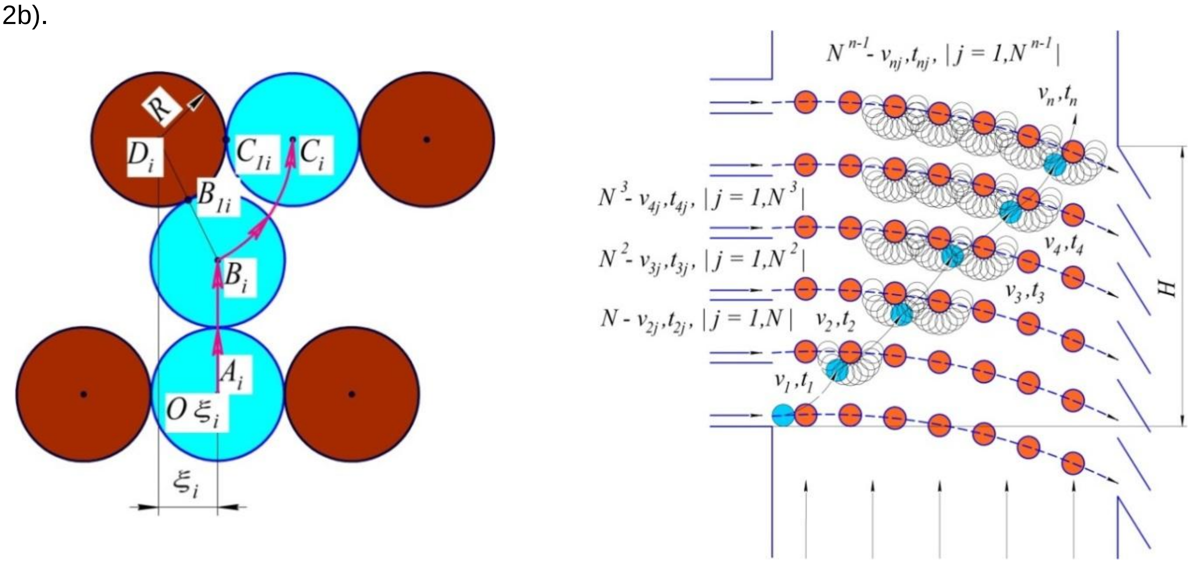
*a – functional scheme of pneumatic separator; b – multilayer feeding device*

*1 – batcher; 2 – batch gates; 3 – multilayer feeding device; 4 – pneumatic separating channel; 5 – settling chamber; 6 – fan; 7 – air channel;8 – airproof outlet channel;9 – indirect gravity curves;10 – louver type unit; 11 – impurity receiving collector; 12 – adjusting air velocity shutter*

The main specific feature of the new pneumatic separator is the application of a gravitational multilayer feeding device. As a result, there is a separation of the inlet grain flow into several single-layer air streams that are delivered to different height operating areas of the pneumatic separating channel (*Nesterenko O.V., 2012*). In this case, the output of the cleaned grain out of the separation area is carried out through the louver bar and the airproof outlet channel.

Accordingly, while using the design of the pneumatic separator it is necessary to determine the quality characteristics of grain cleaning as ascending trajectories of light impurities from the lower layers will intersect with the descending trajectories of grain fractions. Therefore, to determine the effect of the multilayer inlet of grain material on the quality of separation we studied the quantitative distribution of light impurities in the operating separation area.

In the case of grain multilayer feeding into the pneumatic separating channel, there will be a contact action among some light impurities and taking into account that the trajectory of the impurity will be changed after the contact with the grain we may observe the least positive situation for impurities of the lowest layer (Fig. 2b).




**a** b

**Fig. 2 – The scheme of passing impurity with grain multilayer feeding:**
*a – through the grain layer; b – from the lower grain layer*.

The contact action of the impurity in the multilayer grain flow is multistaged. In this case, the motion of the centre of impurity mass $O_{\xi i}$ consists of three successive stages (Fig. 2 A):

- contactless motion of impurities between the layers –section $A_i\,B_i$;

- contact of impurities with grain at the point $B_{1i}$;

- the motion of impurities in grain and the point of contact traces the trajectory $B_{1i}\,C_{1i}$ and the mass centre of a separate particle of impurities will be $B_i\,C_i$.

Since the motion trajectory and the time of impurities motion between grain layers depends on the initial horizontal displacement $\xi_i$ of the impurity and grain mass centre, which is a random variable and can have any value in the range [0; 2R], then for quantitative distribution of light impurities we need to distinguish their kinematic characteristics at the output from every subsequent layer, which depends on the contact point of impurities with grains from another upper layer.

In this case, the section $\xi_i \in [0;2R]$, $/i=1,N/$ is divided into $N$ similar equal intervals $(\xi_{i,\,j-1};\ \xi_{i,\,j})$, $/j=1,N/$ with the length 2R/N (Fig. 2b).

Then, the impurities from the first layer after passing:

- the second layer will be distributed into $N$ equal by quantity groups. Each group will have its own kinematic characteristics – $V_{2,j}\cdot t_{2,j}$,$/j=1,N/$. At the same time, some of the groups may have similar kinematic characteristics;

- the third layer will be divided into $N^2$ groups – $V_{3,j}\cdot t_{3,j}$,$/j=1,N^2/$;

- the fourth layer will be divided into $N^3$ groups – $V_{4,j}\cdot t_{4,j}$,$/j=1,N^3/$; …;

- the $n$ layer will be divided into $N^{n-1}$ groups– $V_{4,j}\cdot t_{4,j}$,$/j=1,N^{n-1}/$.

Since the duration of impurities motion for some groups is longer during the time of grain passing the depth of the pneumatic separating channel, then the number of groups for grain layers can be significantly lower. The probability to select such impurities is considerably reduced as since reaching the louver unit they can get into the airproof channel for receiving clean grains and they will not be processed in the following layers.

According to these circumstances, the height of lifting impurities depends on the contact point with the grain. Setting the scale height of lifting impurities, we make analysis of the process of impurity passing through the grain layer and determine its final elevation point. That is which $n$ grain layer the impurity reaches, and in this case the impurities from all grain layers are added according to the height levels.

The scale of the impurities elevation height is calculated by the formula:

$$\Delta Y = \frac{Y_{\max} - Y_{\min}}{n}, \tag{1}$$

where, $Y_{max}$ is the maximum elevation height (the impurities from the upper layer move easily upward);

$Y_{min}$ is the minimum elevation height (the impurities from the lower layer collide with the grains from all layers in the worst case).

This distribution is made for the grain flow in which the distance between the surfaces of the grains in the direction of the grain flow is equal to their size (2R). For the rarefied grain flow, we introduced the coefficient of rarefaction $f_p = l/2R$, which characterises the density of grain position in the horizontal motion in the pneumatic separating channel.

As a result, the productivity of the pneumatic separating channel (taking into account the rarefaction of the grain flow) is determined by the formula:

$$q_B = 3600\frac{\pi}{6}\left(B \cdot v \cdot n \cdot R \cdot \gamma\right) \cdot \frac{2}{1 + f_p}. \tag{2}$$

Where $B$ is the width of the channel, m;

$v$ – the velocity of feeding the grain into the pneumatic separating channel, m/s;

$n$ – number of layers, pieces;

$R$ – grain radius, m;

$\gamma$ – grain volume weight, kg/m$^3$;

$f_p$ – the coefficient of rarefaction of the grain flow in the pneumatic separating channel.

Modelling of light impurities quantitative distribution with a multilayer feeding of grain material was carried out using the Mathcad software.

## RESULTS

The results of the research helped us obtain the statistical probability model of light impurities passing through grain layers in the grain multilayer feeding into the pneumatic separating channel (Fig. 3).

The analysis of variation characteristics of light impurities distribution (Fig. 3), which were obtained for each layer of grain material input, enables asserting that at six-layer feeding with maximum specific load, the highest percentage of impurities remaining in the cleaned grain appear from the first and second (located lower) feeding layers, 15% and 12.8% respectively. Thus, light impurities appear in the cleaned grain only from the three lowest layers of grain feeding and a full selection of light impurities takes place from IV to VI feeding layers (located the highest). Under such conditions the installation place of the louver unit top depends on the number of layers involved in the feeding device. The louver unit will be located at the height $H$ = 0.05...0.055 m.

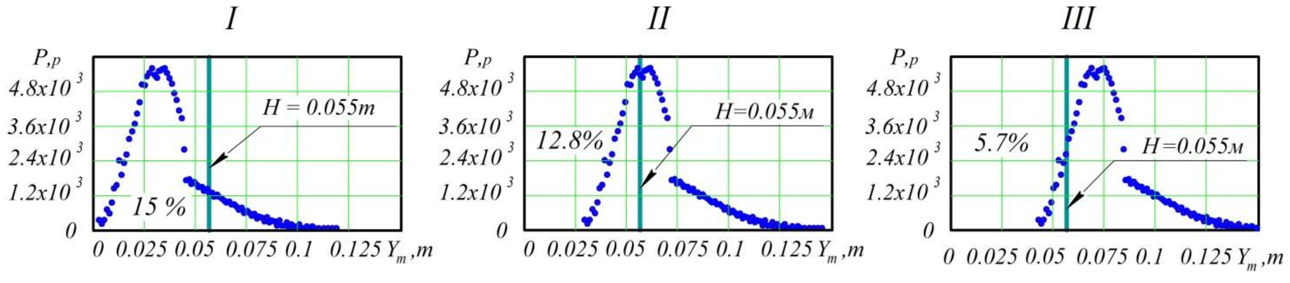



**Fig. 3 – Quantitative characteristics of impurities in the cleaned grain with a multilayer feeding**

*I – III – the ordinal number of grain feeding layer*

Taking into consideration the rarefaction coefficient and the number of layers used in the feeding device and according to distribution results, we obtained analytical dependence of separation completeness of light impurities $\varepsilon$ on the productivity of the pneumatic separating channel $q_B$ with a multilayer feeding of grain material (Fig.4).

The given dependences were obtained at specific load on the layer of the feeding device $q_{bi}$= 250…350 kg/dm·hour at which the single-layer feeding of the grain is carried out.

The analysis of the dependence (Fig. 4) shows that with increasing specific load $q_B$ and, consequently, increasing the number of feeding layers, the completeness of separation $\varepsilon$ decreases. Thus, the number of layers used in the feeding device depends on the purpose of cleaning and its rational meaning is within $n$ = 4...6 pcs.

Reducing the separation quality can be explained by the increasing number of probable contacts of light particles that move from the lower grain layers, respectively, the output velocity decreasing with each passed layer. The time to pass through the depth of the channel also decreases.

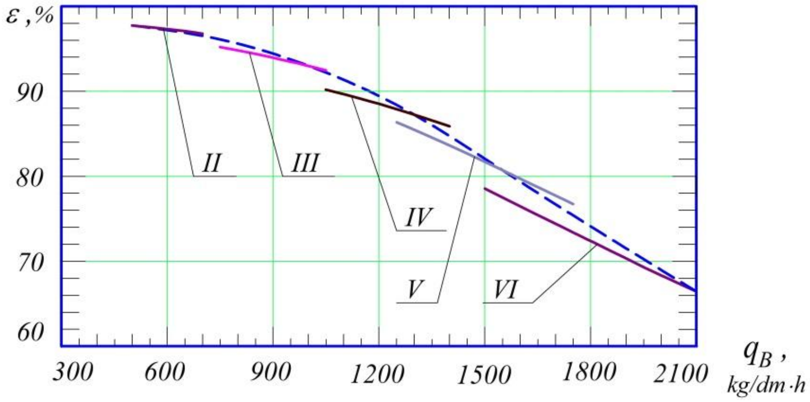



**Fig. 4 – Analytical dependence of the separation completeness of grain material on the specific load value of the pneumatic separating channel, $\varepsilon = f(q_B)$:**
*II – VI is the number of used feeding layers*

With the introduction of two feeding layers, the separation completeness is $\varepsilon$ = 97 ... 98%, with specific load $q_B$ varying from 500...700 kg/dm·hour.

With the introduction of four feeding layers the separation completeness is $\varepsilon$ = 86 ... 91%, with the specific load being able to be set from 1000 to 1400 kg/dm·hour; using six feeding layers, we get $\varepsilon$ = 66 ... 78%, with specific load $q_B$= 1500…2100kg/dm·hour.

The results of experimental studies of the impact of a multilayer feeding on the light impurities separation completeness (*Nesterenko O.V., 2015*) sufficiently prove the analytical studies with correlation values ranging from 7... 9%.

## CONCLUSIONS

As a result of the analytical analysis, the possibility to apply a multilayer feeding in pneumatic systems of grain cleaning machines was grounded. That allows equalizing the velocity field of the airflow in the operating separation area and increasing the separation quality compared to the traditional grain feeding.

The undertaken studies allow reaching the conclusion that reducing the number of used layers from 6 to 2 improves the quality of separation by 22...30%, but the value of the specific load decreases by 1000...1600 kg/dm·hour and the productivity of the pneumatic separator. However, the number of layers used also depends on the purpose of cleaning with the rational value $n$ = 4 ... 6 pcs.

It was determined that the separation probability of light impurities with a multilayer feeding of grain material depends on the time and velocity of their passage through grain layers that vary depending on the contact point of the impurities with grain and the instalment position of the louver unit top. In this case, the increase of the distance between grain particles *2R* in the horizontal direction improves the quality of the material separation, but the separation productivity decreases.

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