Modeling the sunflower seeds separation process in air-sieve grain-cleaning machines

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Abstract. In modern seed-cleaning machines, pneumatic systems have been widely used in recent years. To minimize costs in pneumatic systems of seed-cleaning machines, while increasing performance and improving the functional efficiency, it is necessary to improve their constructive and technological parameters. Improving pneumatic system parameters requires the development of a methodology for modeling the processes of airflow motion for their qualitative characteristics. To improve the efficiency of the vertical pneumatic channel of air-sieve grain-cleaning machines, it has been proposed to modernize it, which will improve the quality of separation of sunflower seed heap in it. The device and technological process of operation of a modernized air-sieve grain-cleaning machine of the MVU-1500 type in sorting a heap of sunflower seeds are presented. The movement of the components of a sunflower seed heap in a vertical pneumatic channel of an air-sieve grain-cleaning machine of the MVU-1500 type is examined and the proportionality coefficients of the airflow for the components of a sunflower seed heap are determined. The obtained values of the theoretical proportionality coefficients of the airflow for the components of a sunflower seed heap vary widely depending on the composition (organic impurity – 0,015≤k≤0,061; seeds of the leading crop – 0,120≤k≤0,162; broken seeds – 0,096≤k≤0,115 and hulled seeds – 0,134≤k≤0,153). Mathematical modeling of the technological process of the improved air-sieve grain-cleaning machine of the MVU-1500 type makes it possible to increase the efficiency of the vertical pneumatic channel by 15-20% without deteriorating the quality of the material itself, as a result of which the specific energy consumption of the process will decrease.

1. Introduction
One of the difficult and important tasks of post-harvest processing is the cleaning of seeds from impurities and sorting. In this regard, it is advisable to create new methods that are more efficient and to improve existing grain and seed cleaning machines [1].

In modern grain and seed cleaning machines, pneumatic systems have been widely used in recent years. To minimize costs in pneumatic systems of grain and seed cleaning machines, and to increase the performance and improve operation quality, it is necessary to improve their design and technological parameters. Improving the parameters of pneumatic systems requires the development of a methodology for modeling air-flow processes for their quality characteristics [2, 3].

Pneumatic systems are used as part of complex grain and seed cleaning machines at all stages of seed cleaning, as well as separate machines – the pneumatic separators [4].

The universal grain-cleaner is equipped with a pneumatic suction system, as it emits less dust into the environment and is better suited for use in closed areas. The pneumatic system of this machine has...
two pneumatic separation channels to ensure high separation efficiency of the grain heap during secondary cleaning [5-9].

To increase the efficiency of the vertical pneumatic channel of the air-sieve grain cleaning machine, its modernization was proposed, which will improve the quality of separation of the heap of sunflower seeds.

2. Materials

According to the Patent of the Russian Federation (RU 2681493), of MVU-1500 type (Figure 1 a), an air-sieve grain-cleaning machine contains an upper sieve boot 1, a lower sieve boot 2, a common settling chamber connected to a fan (not shown), a pneumatic channel 3 for preliminary aspiration. It also has a pneumatic channel 4 for final aspiration, a feed roller 5, a valve 6, an auger 7 for removing heavy impurities, an auger 8 for removing light impurities, a flap 9 for fine adjustment of the pneumatic pre-aspiration channel. There is also a flap 10 for fine adjustment of the pneumatic channel for final aspiration, a flap 11 for air supply coarse adjustment, an exhaust pipe 12, chutes 13. At the end of the lower sieve boot, under the opening of the vertical pneumatic channel for the final aspiration, there are splitters 14 (Figure 1 b), the inner surface of which has a coating with a low friction coefficient, for example, of fluoroplastic, in an amount of at least three, located at an angle 40-45° in the horizontal plane. Installed at least three splitters so that the width of the pneumatic channel for final aspiration was approximately 1500 mm and, based on design considerations and metal consumption, we obtain the length of the splitter of 500 mm. Splitters 14 (Figure 1 c) are made in the form of combs, the teeth 15 of which have the shape of a truncated cone, the upper base of which is 1/3 of the lower one. Based on design considerations, with a splitter length of 500 mm, we obtain four teeth, each of which is 125 mm. Moreover, the angle in the upper base of the cone is 20-30°, and the lower base of the cone has holes for its attachment to the lower sieve boot 2.

![Figure 1](image-url). The air-sieve grain-cleaning machine of MVU-1500 type according to the Patent (RU 2681493): a - the machine general view; b - the splitter location; c - the splitter general view

Splitter teeth 14 on the sides have oppositely directed welts 16, the height of which is 1/4 of the width of the pneumatic channel 4 for the final aspiration, and the upper base of the splitter cone 14 has
a width equal to 5-6 times the width of the seed. The width of the upper base of the splitter cone is 5-6 sizes of the seed width, because with an average seed width of 7 mm, we get the size of this base – 42 mm, that is, about 5 to 6 sunflower seeds can be placed in the upper base of the cone.

3. **Movement of the components of the heap of sunflower seeds in the vertical pneumatic channel of the air-sieve grain-cleaning machine of MVU-1500 type.**

When the components of the heap of sunflower seeds descend from the lower sieve boot into the vertical pneumatic channel (Figure 1 b), the following forces act:

- $F_A$ – the Archimedean force, kN;
- $F_{ar}$ – the air-flow resistance force, kN;
- $F_{sg}, F_{rg}$ – the seeds and the refuse gravity force, respectively, kN.

Let us write the Newton second law in the form for:

- the organic impurities (fragments of calathiums and stems):
  
  $$ m_{oi} \ddot{a} = F_A + F_{ar} + F_{rg}, $$  

  $$ m_{oi} \frac{d\theta}{dt} = F_A + F_{ar} - F_{rg}. $$  

If

$$ \frac{d\theta}{dt} > 0, $$  

then the expression (2) will be

$$ F_A + F_{ar} \geq F_{rg}; $$  

– of sunflower seeds:

  $$ m_{ss} \ddot{a} = F_A + F_{ar} + F_{sg}, $$  

  $$ m_{ss} \frac{d\theta}{dt} = F_A + F_{ar} - mg. $$  

If

$$ \frac{d\theta}{dt} \leq 0, $$  

then the expression (6) will be

$$ F_A + F_{ar} \leq m_{ss} g. $$  

The resistance force (R) at low air-flow rates (Figure 2) in the pneumatic channel for the final aspiration of the air-sieve grain-cleaning machine of MVU-1500 type is determined by the expression:

$$ R = k \cdot \dot{\theta}, $$
where \( k \) – the proportionality coefficient of the components of heap of sunflower seeds; \( \vartheta \) – the air flow rate, m/s.

**Figure 2.** The dependence of the resistance force on the air flow rate

Sunflower seeds placed in a vertical air stream are subjected to the following forces of resistance (R) and gravity (G).

From the expression (9), the proportionality coefficient at low air flow rates will be:

\[
k = \frac{mg}{\vartheta_{\text{max}}}.
\]

(10)

The resistance force (R) at high air flow rates (Figure 2.2) in the pneumatic channel for the final aspiration of the air-sieve grain-cleaning machine of MVU-1500 type is determined by the expression:

\[
R = k \cdot \vartheta^2.
\]

(11)

From the expression (11) the proportionality coefficient at high air flow rates will be:

\[
k = \frac{mg}{\vartheta_{\text{max}}^2}.
\]

(12)

The force of the air flow in the pneumatic channel for the final aspiration \((F_{\text{ar}})\) and the expression (9) at low rates will be:

\[
F_{\text{ar}} \approx R = k \cdot \vartheta.
\]

(13)

For the organic impurities (fragments of calathiums and stems) of sunflowers seeds the expression (4), according to the expression (13), will be:

\[
F_A + k \cdot \vartheta \geq F_g.
\]

(14)

The Archimedean force for the organic impurities is determined by the expression:

\[
F_A = \rho_{\text{ar}} \cdot g \cdot V,
\]

(15)

Substituting the expression (15) into (14), we perform mathematical transformations and obtain the proportionality coefficient of the air flow in the vertical pneumatic channel at low rates for organic impurities:
\[ k = \frac{m \cdot g - \rho_{ar} \cdot g \cdot V}{\vartheta} \]  

(16)

where \( m \) – the mass of organic impurity (fragments of calathiums and stems), g; \( \vartheta \) – the organic impurity hovering velocity, m/s; \( \rho_a \) – the air density, kg/m\(^3\) (\( \rho_a = 0.093 \) kg/m\(^3\)); \( V \) – the volume of organic impurity, entering a vertical pneumatic channel, m\(^3\).

The volume of organic impurity or sunflower seeds entering a vertical pneumatic channel will be determined by the expression:

\[ V = \frac{4}{3} \pi R_e^3, \]

(17)

where \( R_e \) – the effective radius of organic impurity, sunflower seeds and other components, m.

Let us determine the proportionality coefficient of the air flow for sunflower seeds according to expressions (8) and substitute the expressions (9), (13) and (15) into it, so it will be:

\[ k \cdot \vartheta_s + \rho_{ar} \cdot g \cdot V_s \leq m_{ss} g, \]

(18)

from the expression (18) we find the coefficient \( k \) at low air flow rates in the vertical pneumatic channel:

\[ k \leq \frac{m_{ss} \cdot g - \rho_{ar} \cdot g \cdot V_s}{\vartheta_s}. \]

(19)

Substituting the numerical values into the expression (19), we find the proportionality coefficients of the air flow for the components of the heap of sunflower seeds, the calculation results of which are given in Table 1.

| Name of component in the heap of seeds | Coefficient value          | Reference                                                                 |
|----------------------------------------|-----------------------------|---------------------------------------------------------------------------|
| Organic impurity                       | 0.015 \( \leq k \leq 0.061 \)| GOST 12037-81 “Seeds of farm crops. Methods for determination of purity and seed lot impurity” |
| Main crop seeds                        | 0.120 \( \leq k \leq 0.162 \)|                                                                          |
| Broken seeds                           | 0.096 \( \leq k \leq 0.115 \)|                                                                          |
| Hulled seeds                           | 0.134 \( \leq k \leq 0.153 \)|                                                                          |

4. Conclusion
The obtained values of the theoretical proportionality coefficients of the air flow for the components of the heap of sunflower seeds, as a result of mathematical modeling of the technological process of the operation of the improved air-sieve grain-cleaning machine, allow increasing the efficiency of the vertical pneumatic channel without deteriorating the material quality itself.

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