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The separation of light impurities of safflower seeds in the cyclone of the grain cleaning machine

K D Astanakulov[1*], M R Karimov[2], I Khudaev[1], D A Israilova[1], and F B Muradimova[1]

[1]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, 39 Kori Niyazov, 100000 Tashkent, Uzbekistan
[2]Termez branch of Tashkent State Technical University, 24 Manguzar, Termez, Uzbekistan

[*]Email: komiljon.astanaqulov@gmail.com

Abstract: At present, the grain cleaning machines used for cleaning safflower seeds are not effective in cleaning safflower seeds due to the high energy consumption, metal and material content. For this reason, in Uzbekistan an energy and resource-saver grain cleaning machine has been developed which meets the needs of the farms in the cleaning of safflower seeds. When cleaning safflower seeds, the unfamiliar compounds in its content, including 2-3% light impurities should be separated. The quality of safflower seeds cleaning from light impurities depends on the number of fan rotations, the slope and height of the suction pipe and the quenching of the separated light impurities depend on the cyclone parameters. According to the theoretical and experimental studies, light compounds falling into a cyclone with a diameter of less than 20 m/km rise with air and fall with large ones. In addition, the rotation frequency of the fan in the grain cleaning machine is 2200 rpm (air flow rate 5.1 m/s), the height of the suction pipe is 70-130 mm and the slope is in the range of 20-40 degrees and the separation of light impurities of safflower seeds were achieved at around 85 percent.

1. Introduction

Safflower is one of the oldest types of oil seed crops; it belongs to the family Astradace Asteraceae, Carthamus L. - family and still has 19 species. The origin of the safflower is mainly Asian countries, in particular China, Israel, Egypt, Syria, Iran, Pakistan, Afghanistan, Central Asia and the Caucasus. Safflower is also widely grown worldwide as it is native to arid environments where it can grow even in difficult soils [1, 2]. The average yield of safflower is 10-12 c/ha on arable lands and 19-22 c/ha on irrigated lands [3, 4].

In Uzbekistan safflower is usually grown in rainfed lands. Because of much erosion in rainfed areas, where safflower is grown, it is recommended to tillage with anti-erosion technology and technical means before sowing [5-9].

According to the World Food Organization (FOA), 284,000 hectares of lands where safflowers are currently cultivated in the world and 1,417,000 tons are harvested annually.The total amount of impurities in the seeds of safflower harvested in combines is 8-13%, and light mixtures are 2-3% [10, 11]. In order to process the safflower, unfamiliar compounds in its composition should not exceed 2%. Currently, the OVS-25, Petkus-vibrant K-521, Petkus-Gigant K-531 and other grain cleaning machines are not used effectively for cleaning the seeds of safflower due to their high energy consumption, metal and material content.

Therefore, there is a need in Uzbekistan to develop an energy-efficient grain cleaning machine that will meet the needs of farms in the cleaning of safflower seeds. A number of studies have been conducted on the purification of the grains. There are a number of ways to clean the grain from unfamiliar compounds. Namely, grain is cleaned with sieves, purified from airflow stream by light impurities, stalks, weed seeds, small troops, trimmings, weeds, black moth and other diseases by water or fluid [12-21]. Also, rotary and optic cleaning devices were developed too for grain cleaning [22-24]. More fan air flow is used to separate light impurities in the grains or seeds.

Assessing the adequacy of mathematical models of light impurity fractionation in sedimentary chambers of grain cleaning machines, ttheoretical background of calculation of the parameters of the device for grain cleaning from ergot sclerotia, research of a diametrical fan with suction channel are highlighted in the studies of following researchers [25, 26]. Researchers [27, 28] studied analysis of airflow velocity field characteristics of an oat cleaner based on particle image velocimetry technology and others processes.

In reports [29, 30] analyzed the air velocity in the grain separation tunnel where in the non-material components were separated to have a full understanding of the separation wind flow. The air velocities of both sides of the main separation fan were faster than the air velocity at the center.The air velocity distribution pattern (AVDP) of the first cross-flow auger showed a high correlation with that of the inlet part at a 5 % significance level.

Based on the above mentioned research, a grain cleaning machine was developed to clean the safflower seeds from unfamiliar compounds where the separation of light impurities through using an air stream was studied.

All in all, Uzbekistan has developed an energy-efficient grain cleaning machine that meets the needs of farms for the purification of safflower seeds from unfamiliar compounds. The light compounds in the seed impurities are separated using a fan air flow in the machine and large compounds are separated in the sieves. The separation of light impurities using a fan air flow was first studied based on the technological working process of the machine.

2. Method

Firstly, the separation of light impurities of safflower seeds in the proposed grain cleaning machine was theoretically studied. And the experimental studies were conducted to verify the results of theoretical studies and to clarify the parameters and operating modes of the car fan and suction line.

An experimental sample of the machine was made to conduct experimental studies (See Figure 1).

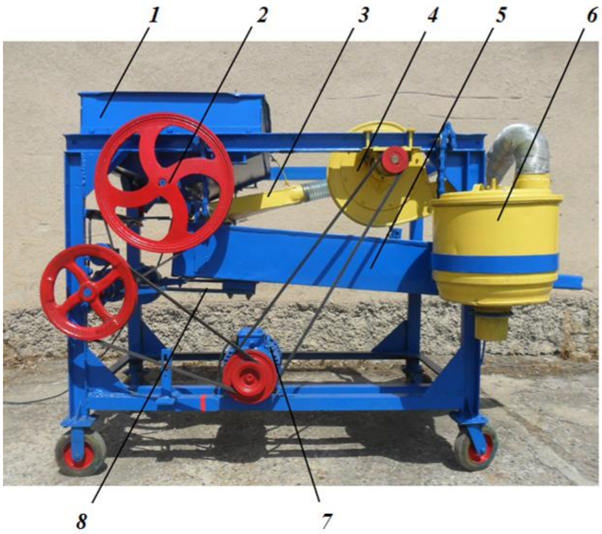


Figure 1. Experimental sample of grain cleaning machine: 1 - bunker; 2 - supply bar; 3 - suction pipe; 4 - fan; 5 - sieve; 6 - vacuum cleaner; 7 - electric motor; 8 - vibrator.

For the experiments SAUS (State all-union standard) 20915-2011 “Agricultural machinery: On the basis of "Methods of determination of conditional tests" the moisture and size-mass classifications of unfamiliar compounds in the seed impurities were determined. In the experiments, the effect of the number of fan rotations, the slope and height of the suction pipe on the completeness of the separation of light impurities and the loss of seeds were determined as well. In conducting research SAUS (State all-union standard) 33735-2016 "Agricultural machinery. Grain cleaning machines. Test Methods and State Standard 12096-76. “Safflower for post-harvesting. Technical requirements” standard guidelines were used.

3. Results and Discussions

Dust, fine leaves and other light impurities are removed from the bunker by the air flow generated by the fan from the safflower seeds coming into the suction pipe through the supply shaft.

In this case, $V_{kr.l.i} < V_a < V_{s.s.}$ depending on the condition, we determine the number of fan rotations using the following expression:

$$n_f = \frac{15\alpha_a V_{kr.l.i} B_p h_p}{\pi^2 k_f R_f^2 B_b}, \tag{1}$$

Here, α_a – is the coefficient providing sufficient air velocity, $V_{kr.l.i}$ – flight (critical) velocity of light impurities, m / s; B_p – is the width of the pipe, m; h_p – is the height of the pipe, m; k_f – is the coefficient taking into account the decrease in air velocity; R_f – fan radius, m; B_b – width of the fan blade, m.

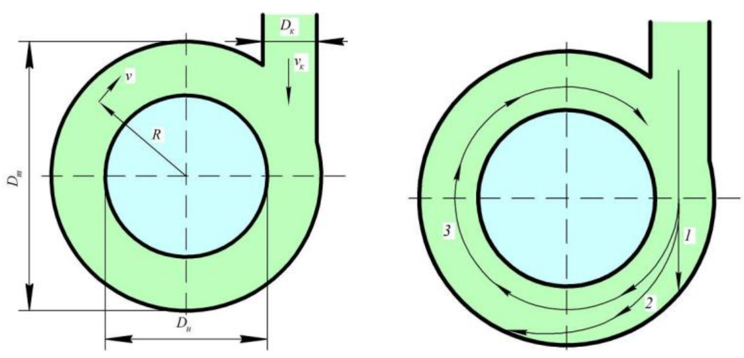
For this expression α_a =1.1-1.7, $V_{kr.l.i}$=5 m/s, B_p=0.7 m, h_p=0.08 m, k_f=0.15-0.2, R_f=0.15 when setting the values of 15 m, B_n=0.05 m, and it follows the number of fan rotations should be $n_в$=2200 min^{-1}

The air flow generated by the fan is directed to the cyclone along with the air flow, absorbing dust and light compounds from the seed impurities. The polluted air flow enters the cylindrical part of the cyclone body at high speed and makes a downward linear motion. Under the influence of centrifugal forces created by the rotational motion of the current, particles of dust and light compounds move towards the cyclone walls. Particles that reach the walls of the cyclone fall under the conical part of the cyclone under the influence of secondary current and gravity and are expelled through the lower outlet pipe when extinguished. The stream of purified air flows out through the upper outlet pipe.

The airflow will have a helical trajectory within the cyclone. This is the distance from the center of the current to the central vertical axis of the cyclone *(See Figure 2, a*) using the following equation:

$$\pi \cdot \left(\frac{D_m{}^2}{4} - R^2 \right) \cdot h_c = \pi \cdot \left(R^2 - \frac{D_u{}^2}{4} \right) \cdot h_c, \tag{2}$$

In this case, D_m, D_u – the outer and inner parts of the cyclone cylindrical part, respectively diameters, m; h_c – internal height of the cyclone, m.



a) b)

Figure 2. Movement of air flow (a) and dust particle (b) in a cyclone

From (2) we find R from the expression

$$R = \sqrt{\frac{D_m^{\ 2} + D_u^{\ 2}}{8}}, \tag{3}$$

The most inconvenient location of the particles in the stream is near the inner walls of the channel inside the cyclone. As they have to completely cover the distance from the inner walls to the outer walls of the channel, where the flow takes place.

This distance is equal to $\frac{D_m}{2} - \frac{D_u}{2}$.

Particles of dust and light impurities in the most inconvenient position move along a curved trajectory (Figure 2, b, trajectories 2 and 3). It can be seen that the lower the mass of a particle, the closer its trajectory is to the circle (trajectory 3), i.e., the harder it is to separate from the flow.

The velocity and displacement of a particle in the radial direction v_R and T over time Δ (See Figure 3) is found by the following general formulas:

$$T = \frac{\pi R_з}{v_T}; \qquad v_R = \frac{v_T^{\ 2}}{18 R_з} \rho \frac{d^2}{\mu}; \qquad \Delta = \frac{\pi \rho}{18 \mu} v_T d^2 ,$$

In this case, v_R – is the radial component of the particle velocity, m/s; v_T tangential component of particle velocity, m/s; T – time of half-cycle of the stream along the channel, s; R_c – radius of curvature of the particle trajectory, m; ρ - particle density $\rho = 2000 \kappa g / m^3$; μ - dynamic accumulation of air $\mu = 22{,}2 \cdot 10^{-6} H \cdot s / m^2$; d – particle diameter, m; Δ – the particle in the radial direction T of time displacement, m.

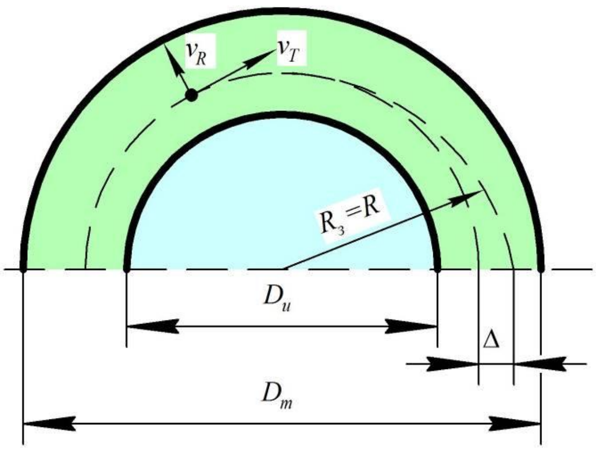


Figure 3. The movement of a particle toward the walls of a cyclone during a circular motion within an air flow

We assume that the tangential component of the particle velocity is equal to the velocity of the air flow along the channel inside the cyclone $v_T = v$, and the radius of curvature of the particle trajectory is equal to the average radius of the cyclone $R_c = R$

The helical ribs inside the cyclone determine the number of rotations of the air flow *n* in the duct. Here, $n = 2$ is equal to the amount of polluted air to be cleaned $Q = \frac{\pi}{4} D_k^{\ 2} v_k$.

This amount of air circulates *n* times inside the cyclone, therefore $Q = \left(\frac{D_m}{2} - \frac{D_u}{2} \right) \cdot \frac{h_c}{n} \cdot v$.

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If we consider n = 2,

This amount of air circulates n times inside the cyclone, therefore

$$v = \frac{\pi \cdot D_k^{\ 2} v_k}{(D_m - D_u) \cdot h_c}. \tag{4}$$

When air circulates twice in a cyclone, the radial displacement of the particle in the air is determined as follows:

$$4\Delta = \frac{2\pi\rho}{9\mu} v_T d^2 \tag{5}$$

According to the graph constructed by expression (5) (See Figure 4), it was found that the light impurities entering the cyclone rise smaller than 20 m/km in diameter with purified air while the larger ones fall down.

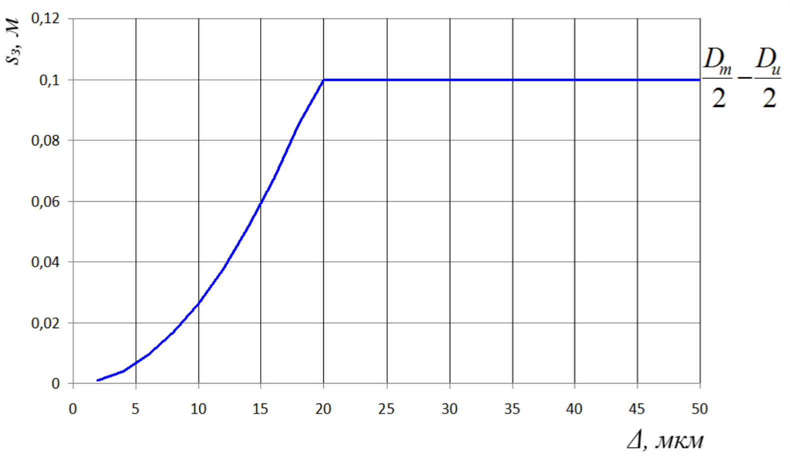

Figure 4. Separation of light impurities in a cyclone

The experimental studies based on theoretical research were conducted as well. The experiments show that the effect of the number of fan rotations (n_f) on the separation of light compounds in the seed ($E_{аж}$) and seed loss ($У_{ноб}$) was studied by varying the number of fan rotations from 1800 min^{-1} to 2400 min^{-1} in 200 мин$^{-1}$ steps.
When the number of rotations of the fan was 1800 min^{-1} and 2000 min^{-1} ,
When the number of rotations of the fan was 1800 min^{-1} and 2000 min^{-1}, the clearance of the seed from light impurities was 76.1–80.8 per cent and the loss was 0.004 and 0.0042 per cent (See Figure 5).

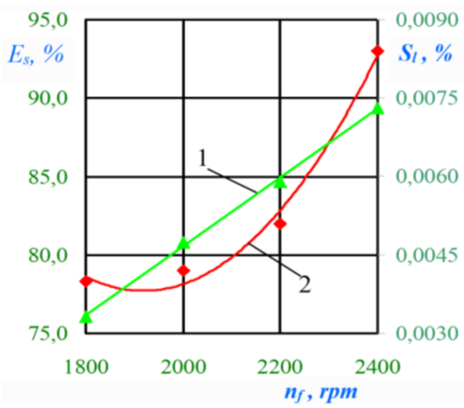

Figure 5. Graphs of change in seed purity and loss depending on the number of rotations of the fan: 1 - separation of light impurities; 2 - seed loss

When the number of rotations of the fan was 2200 min^{-1} and the clearance of light compounds increased rapidly and reached 84.7 per cent and the seed loss was 0.0051 per cent. When the number of rotations of the fan was 2400 min^{-1}, the purification of the seed from light impurities was further accelerated to 89.4 per cent and the loss to 0.0084 per cent.
In this case, when the velocity of the air flow generated by the fan changes from 1800 min^{-1} to 2000 min^{-1}, it is 4.5-4.8 m / s, and when it increases from 2200 min^{-1} to 2400 min^{-1}, it is 5.1-5.4 m. / s ranges.
The change in the separation of light impurities (E_s) and seed loss (S_l) depending on the number of fan rotations in the air cleaning part of the machine can be expressed by the following empirical formulas:

$$E_s = 0{,}0219 n_f + 36.76 \quad (R^2 = 0.9987) \tag{6}$$
$$S_i = 2\cdot10^{-8}\cdot n_f^2 - 7\cdot10^{-5} n_f + 0.0751 \quad (R^2 = 0.9884) \tag{7}$$

According to the results, the rate of separation of light impurities from the seed impurities was high when the number of rotations of the fan was 2200 min^{-1} and the air flow rate was 5.1 m / s.
According to the results of Suction Pipe Height $h_{кув}$ Separation of Light Impurities E_s Seed loss S_l, when the height of the suction pipe varied from 40 mm to 70 mm, the separation of light impurities decreased from 87.8% to 85.3% and seed loss from 0.013% to 0.007% (*See Figure 6*).) When the pipe height was 100 mm and 130 mm, the separation of light joints decreased by 83.2-80.5 percent, and seed loss by 0.005-0.004 percent. h_p=160 mm, the separation of light impurities was 78.4% and the seed loss was 0.003%.

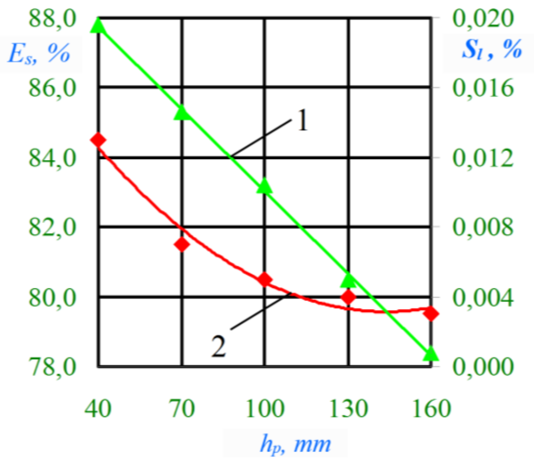

Figure 6. Graphs of the effect of suction pipe balance on light impurities separation and seed loss: 1 - separation of light impurities; 2 - Seed loss

The graph shows that as the suction line height increases, the separation of light impurities and seed loss decreases.
The change of light impurity separation (E_s), seed loss (S_l) in the air cleaning part of the machine depending on the height of the suction pipe can be expressed by the following empirical formulas:

$$E_s = -0{,}0787 h_p + 90.907 \quad (R^2 = 0.9986) \tag{8}$$
$$S_l = 9\cdot10^{-7} h_p^2 - 0.0003 h_p - 0{,}0212 \quad (R^2 = 0.9738) \tag{9}$$

Separation of light impurities in the range of 70-130 mm in height of the suction pipe had good performance while seed loss was low.
The slope of the suction pipe also depends on the separation of light impurities in the composition of the seed impurities coming from the supply jug. The results of the grain cleaning machine suction pipe h_p slope on the effect of light impurities E_s separation and seed S_l loss are shown in Figure 7.
The slope of the suction tube was changed from 10 degrees to 40 degrees by 10 degrees and the effect on the separation of light impurities of the seeds and the loss of seed was studied. When the slope of the pipe is 10 and 20 degrees, the separation of seeds from light impurities is 83.4-82.6 percent, seed loss is 0.012-

0.008 percent, at 30 degrees, respectively, 81.8, 0.005 percent, 40 degrees, the separation of seeds from light impurities is reduced to 80.3 percent and mortality was 0.002 percent.

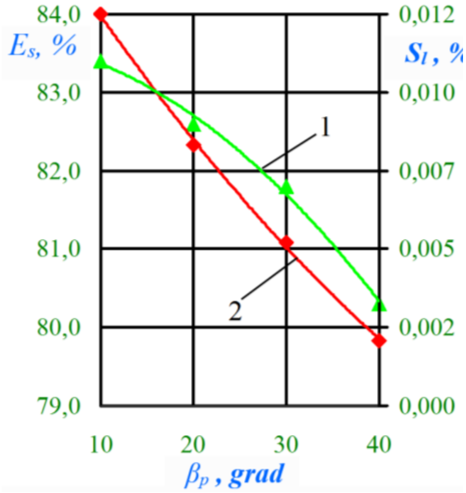

Figure 7. Graphs of the effect of the slope of the suction line on the separation of light impurities and seed loss: 1 - separation of light impurities; 2 - seed loss

The change of light impurity separation (E_s) and seed loss (S_l) in the air cleaning part of the machine depending the slope of the suction pipe β_p can be expressed by the following empirical formulas:

$$E_s = -0.0018\beta_p^2 - 0.0135\beta_p + 83.675 \qquad (R^2 = 0.9953) \qquad (10)$$

$$S_l = 2\cdot10^{-6}\beta_p^2 - 0.0005\beta_p + 0.0163 \qquad (R^2 = 0.9991) \qquad (11)$$

When separating light compounds from the seed impurities coming from the supplier and the results will be as expected when the suction pipe slope is 20-40 degrees.

4. Conclusions

1. The purification of safflower seeds from light impurities depends on the number of fan turns, the slope and height of the suction pipe, and quenching of the separated light impurities depends on the cyclone parameters;
2. It was found that light impurities falling into the cyclone rise smaller than 20 m/km in diameter with air, while large ones fall down;
3. The number of rotations of the fan in the grain cleaning machine is 2200 min^{-1} (air flow rate 5.1 m/s), the height of the suction pipe is 70-130 mm and the slope is in the range of 20-40 degrees and the separation of light impurities of safflower seeds were achieved at around 85 percent.

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