Determination of flight time of particle after reflection from lid of mixing chamber of mixer

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Abstract. An improved design of the continuous mixer cover is proposed. The mixer cover has reflectors mounted on the work surface and made as plates. The reflectors are positioned at an acute angle to the working surface of the mixer lid. The top of the reflector is facing in the direction opposite to the direction of movement of the feed particles. The aim of the study is the theoretical study of the trajectory of the feed particles to determine the axial velocity of the feed mixture in the free space of the mixing chamber of the continuous mixer. The trajectory of the feed particles in the mixing chamber of the mixer has been studied. The equations for determining the flight time of the particle after reflection from the lid of the mixing chamber of the mixer are obtained.

1 Introduction

Currently, two feeding technologies have become widespread: separate feeding of each of the components of the diet and feeding with feed mixtures [1]. In recent years, feeding with feed mixtures has become increasingly widespread. From a zootechnical point of view, it is important not only to introduce the components provided by the diet into the composition of the feed mixture in the required ratio, but it is also necessary that all of them are evenly distributed throughout the entire volume of the mixture [2-8]. The uniformity of the mixture ensures the same nutritional value of the feed in all parts of its volume. The final operation of preparing feed mixtures is mixing components in special devices – mixers [9].

Of great importance for improving the efficiency of the preparation of feed mixtures is the choice of the mixing method and the device for its implementation [10].

2 Methods

Based on the analysis of the influence of the mixing chamber shape on the technological process [1-5], it can be assumed that the presence of free space between the lid and the mixer's working body ensures chaotic movement of feed particles after the feed mass hits the

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lid, which improves mixing conditions. It is advisable to provide the mixing chamber with a lid of such a shape that would ensure the dismemberment of the thrown feed mass and direct the movement of the reflected particle along with the rotation of the screw.

The proposed design of the continuous mixer lid is equipped with reflectors that change the trajectory of the feed particle in the mixer mixing chamber (Fig.1). Here, the directions of the trajectory of the feed particles largely depend on the angle of inclination of the working surface of the lid relative to the horizontal (angle α) and the angle of inclination of the reflecting plane of the reflector relative to the working surface of the mixer lid (angle ρ).

The presence in the proposed mixer design of a multi-entry screw with turns alternately interrupted by the size of one step and free space in the upper part of the mixer body contributes to the tossing of feed particles and, accordingly, lengthening the trajectory of its movement. This takes a certain amount of time, which affects the value of V_n.

The axial velocity V_n can be determined by the formula:

$$V_n = \frac{S}{T}, \quad (1)$$

where T is the total time of passage of the feed particle along the length of one step of the turn, *C*.

The value of T, according to Fig. 1 is equal to

$$T = T_1 + T_2 + T_3 + T_4, \quad (2)$$

where T_1 is the time of movement of particles along the winding of the screw (path EA), c; T_2 is the time of flight of particles when they are tossed (path AB, VC), c; T_3 is the time of movement of particles with the screw after their reflection (path *K C*), c; T_4 is the delay time of particles due to the presence of displacement between adjacent screw windings, *C*.

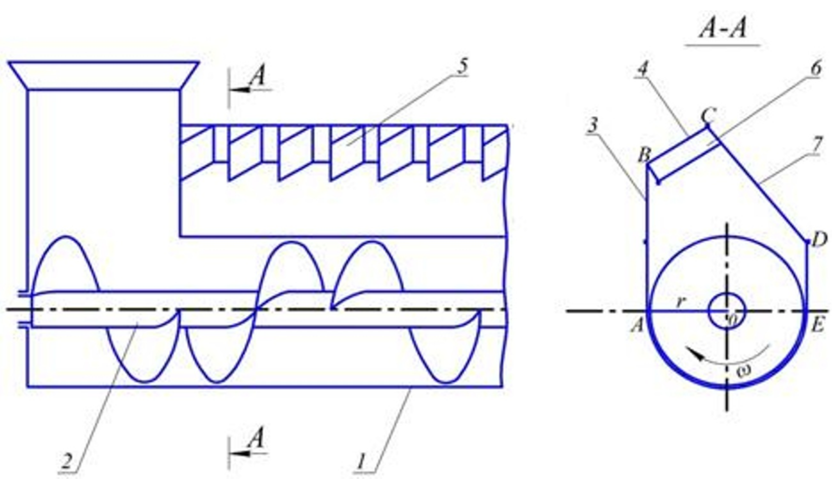

Fig. 1. Mixer with reflectors on the working surface of the lid: 1 is housing; 2 is screw; 3 is the vertical wall of the lid, 4 is the working surface of the lid, 5 is reflecting plane of the reflector, 6 is the vertical wall of the reflector, 7 is cover

To determine the flight time T_2 of a particle thrown from point *A*, we assume that when the particle approaches point *A*, the friction between the particle and the screw turns disappears, as well as the friction between the particle and the casing. At this time, the longitudinal velocity of the particle V_n decreases sharply; therefore, it could be assumed that the particle is thrown perpendicular to the radius of the screw, i.e., during flight, it does not make a longitudinal movement.

Neglecting the air resistance, we assume that the particle is absolutely elastic; that is, the recovery coefficient K_p, when the particle hits the lid, is equal to one (K_p=I). Then along the flight path of the particle shown in Fig.2. it is possible to determine the flight time T_2

$$T_2 = t_{21} + t_{22} \qquad (3)$$

where t_{21} is the flight time of the particle when tossed, with; t_{22} is the flight time of the particle after reflection, s.

In our previous studies [1-4], it was found that when the working surface of the proposed mixer lid is at an angle α to the horizontal plane, the thrown particles are reflected from the working surface of the lid (the side of the sun) and are directed to the right side, that is, along with the rotation of the screw. In this case, the reflected particles transfer their kinetic energy to the screw, thereby reducing the energy consumption for mixing [3, 4]. In this case, the particles reflected from the lid do not move in the longitudinal direction. As a result, it does not affect the performance of the mixer. To solve this problem, in the well-known mixer design, the working surface of the mixer lid is equipped with reflectors made in the form of plates installed sequentially above the screw, each of which is located at an acute angle to the working surface of the mixer lid. The top of the reflector is facing in the direction opposite to the direction of feed movement. The feed particles thrown by the screw turn are reflected from the reflector and fly with the trajectories of transverse and longitudinal movement in the direction of unloading the finished feed mixture. The longitudinal movement of the particle increases the axial speed of the feed mixer, which affects the productivity of the mixer.

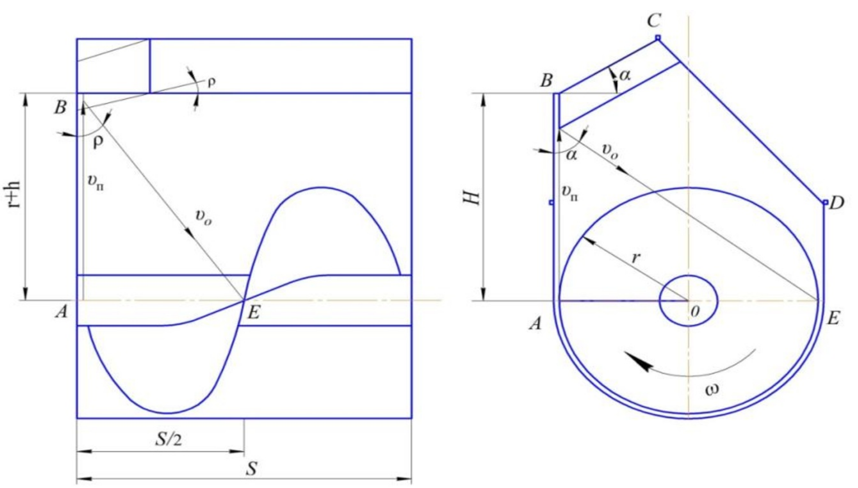

Fig. 2. Schemes of particle motion with trajectories of longitudinal and transverse displacement

Fig. 2 shows that with a change in the angle of inclination of the reflecting plane of the reflector relative to the working surface of the mixer lid, it is possible to change the direction of the trajectory of the reflected particles from the reflecting plane of the cover reflector. By changing the trajectory of the reflected particles, it is possible to change the meeting point of the particles with the screw in the opposite direction, the ejection zone, and the longitudinal movement in the direction of unloading the finished feed mixture.

3 Results and discussion

In [3], the case is considered when the particles move in the O*xz* plane; that is, the movement occurs only along the cross-section. The proposed design of the continuous mixer lid is equipped with reflectors that change the trajectories of feed particles in the mixing chamber of the mixer (Fig.3). In this case, the direction of the trajectory of feed particles depends largely on the angle of inclination of the reflecting plane of the reflector relative to the working surface of the mixer lid.

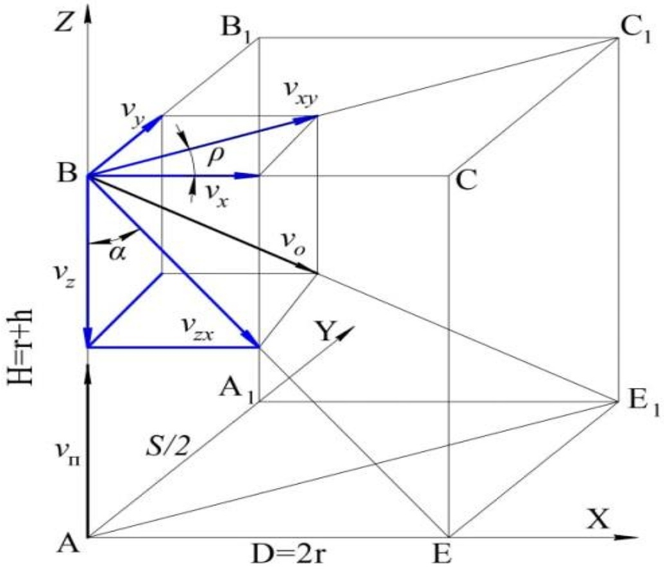

Fig. 3. Diagram of the trajectory of a particle in the o*xyz* space

Let's consider the most general case when the reflected particles from the lid move in the Oxyz space. Let's make up the equation of motion of a particle with an initial velocity numerically equal to υ_p, that is, $|\overline{v_п}| = |\overline{v_z}|$, directed along a vector that forms an angle α with the O*z* axis, in turn, another component of the vector v_{xy} in the plane Ohu v_x forms an angle p with the Oh axis (Fig.3.), provided that the particle is absolutely elastic, that is, $K_p = 1$.

Thus, the velocity v_o is decomposed into three components: v_x, v_y and v_z, which are directed along the corresponding x, y, and z axes and have the following numerical values:$v_x = v_o sin\alpha \cdot cos\rho$, $v_y = v_o sin\alpha \cdot sin\rho$ and $v_z = -v_o cos\alpha$. Since the velocity of the particle$v_0$at point *B* has components $v_{xy} = v_{z1} \cdot sin\rho$and $v_{z2} = -v_{z1} \cdot cos\rho$.The component$v_{xy}$can be considered as the sum of $\overline{v_x}$ and $\overline{v_y}$,, which are determined by the following expressions $v_x = v_{xy} \cdot cos\rho$and$v_y = v_{xy} \cdot sin\rho$.The initial conditions for such a choice at point *B* look like this.

$$\text{By} \quad t_{20} = 0; X_{20} = 0; Y_{20} = 0; Z_{20} = H \tag{4}$$

$$v_{x20} = v_{z1} \cdot sin\alpha \cdot cos\rho$$
$$v_{y20} = v_{z1} \cdot sin\alpha \cdot sin\rho \tag{5}$$
$$v_{z20} = -v_{z1} \cdot cos\alpha$$

Let's make up the differential equations of motion of a particle at an arbitrary point V of the Oxyz space, which moves only under the action of gravity $G = mg$, which is directed vertically downward.

$$m\frac{dv_{x2}}{dt_{22}} = 0 \quad (6)$$
$$m\frac{dv_{yz}}{dt_{22}} = 0 \quad (7)$$
$$m\frac{dv_{z2}}{dt_{22}} = -mg \quad (8)$$

Or considering that

$$v_{x2} = \frac{dx_2}{dt_2}, \quad v_{y2} = \frac{dy_2}{dt_2}, \quad v_{z2} = \frac{dz_2}{dt_2}, \quad (9)$$

We get

$$m\frac{d^2x}{dt^2} = 0 \quad (10)$$

$$m\frac{d^2y}{dt^2} = 0 \quad (11)$$

$$m\frac{d^2z}{dt^2} = -mg \quad (12)$$

Multiplying equations (6), (7), and (8) dt_{22}, previously dividing them by $m \neq 0$, we obtain

$$v_{x2} = C_1^1 \quad (13)$$

$$v_{y2} = C_2^1 \quad (14)$$

$$v_{z2} = -gt_{22} + C_3^1 \quad (15)$$

To determine the integration constants C_1^1, C_2^1 and C_3^1 and $t_{22} = 0$, we use the initial conditions (1) and (2), according to which for $t_{22} = 0$,

$$v_{x20} = v_{z1} \cdot sin\alpha \cdot cos\rho$$
$$v_{y20} = v_{z1} \cdot sin\alpha \cdot sin\rho$$
$$v_{z20} = -v_{z1} \cdot cos\alpha$$

Substituting these initial conditions (13), (14), and (15), we get

$$C_1^1 = v_{x2} = v_{z1} \cdot sin\alpha \cdot cos\rho \quad (16)$$

$$C_2^1 = v_{y2} = v_{z1} \cdot sin\alpha \cdot sin\rho \quad (17)$$

$$C_2^1 = v_{z2} = -v_{z1} \cdot cos\alpha \quad (18)$$

So we have

$$v_{x2} = v_{z1} \cdot sin\alpha \cdot cos\rho$$
$$v_{y2} = v_{z1} \cdot sin\alpha \cdot sin\rho$$

$$v_{z2} = -gt_{22} - v_{z1} \cdot cos\alpha \quad (19)$$

Given (6), we have

$$\frac{dx_2}{dt_{22}} = v_{z1} \cdot sin\alpha \cdot cos\rho \quad (20)$$

$$\frac{dy_2}{dt_{22}} = v_{z1} \cdot sin\alpha \cdot sin\rho \quad (21)$$

$$\frac{dz_2}{dt_{22}} = -gt_{22} - v_{z1} \cdot cos\alpha \quad 22)$$

Multiplying equations (20), (21), and (22) dt_{22} and integrating, we have

$$X_2 = v_{z1} \cdot sin\alpha \cdot cos\rho \cdot t_{22} + C_4 \quad (23)$$

$$Y_2 = v_{z1} \cdot sin\alpha \cdot sin\rho \cdot t_{22} + C_5 \quad (24)$$

$$Z_2 = -\frac{gt_{22}^2}{2} - v_{z1} \cdot cos\alpha \cdot t_{22} + C_6 \quad (25)$$

Substituting into these equations the initial conditions (1), according to which for $t_{20} = 0, x_{20} = 0, \ \ y_{22} = 0, \ \ \ z_{22} = H$

$$C_4 = x_{20} = 0$$
$$C_5 = y_{20} = 0$$
$$C_6 = z_{20} = H$$

Given these data (23), (24), and (25), we find the law of motion (trajectory) of the particle

$$X_2 = v_{z1} \cdot sin\alpha \cdot cos\rho \cdot t_{22} \quad (26)$$

$$Y_2 = v_{z1} \cdot sin\alpha \cdot sin\rho \cdot t_{22} \quad (27)$$

$$Z_2 = -\frac{gt_{22}^2}{2} - v_{z1} \cdot cos\alpha \cdot t_{22} + H \quad (28)$$

heret_{22} - is the flight time of the feed mixture particle from point *B* arbitrary to point *M*.
To find$t_{22}$the flight time of the feed mixture particle from point *B* to point E_1, we use in formulas (26), (27), and (28) the coordinates of the last point *E*, which has coordinates

X_{2E}=2*r*, Y_{2E}=*S*/2, Z_{2E}=0

$$2\text{r} = v_{z1} \cdot sin\alpha \cdot cos\rho \cdot t_{22} \quad (29)$$

$$\text{S}/2 = v_{z1} \cdot sin\alpha \cdot sin\rho \cdot t_{22} \quad (30)$$

$$0 = -\frac{gt_{22}^2}{2} - v_{z1} \cdot cos\alpha \cdot t_{22} + H \quad (31)$$

Thus, we have obtained 3 equations for determiningt_{22}, αandρ
From the formulas (29) and (30), we find t_{22} which is equal to

$$t_{22} = \frac{2r}{v_z \cdot cos\rho \cdot sin\alpha}, t_{22} = \frac{S}{2v_z sin\alpha \cdot sin\rho} \quad (32)$$

Equating the right parts, we get

$$tg\rho = \frac{S}{4r} \quad (33)$$

The validity of this formula can be shown in Fig.3

$$tg\rho = \frac{CC_1}{BC_1} = \frac{S/2}{2r} = \frac{S}{4r} \quad (34)$$

In addition, from Fig.3 it can be shown that

$$cos\alpha = \frac{BA}{BE_1} = \frac{BA}{\sqrt{AE_1^2+AB_1^2}} = \frac{BA}{\sqrt{AE^2+EE_1^2+AB^2}} = \frac{H}{\sqrt{4r^2+\frac{S^2}{4}+H^2}} = \frac{2H}{\sqrt{16r^2+S^2+4H^2}} \quad (35)$$

Solving the quadratic equation (32), we find t_{22}

$$t_{22} = \frac{v_{z1}cos\alpha \pm \sqrt{v_{z1}^2 cos^2\alpha + 2gH}}{-g} \quad (36)$$

Substituting cosα values from (35) to (36), we get

$$t_{22} = \frac{v_{z1} \cdot 2H}{-g \cdot \sqrt{16r^2+S^2+4H^2}} \mp \frac{1}{g}\sqrt{v_{z1}^2 \cdot \frac{4H^2}{(16r^2+S^2+4H^2)} + 2gH} = -\frac{2v_{z1} \cdot H}{\sqrt{16r^2+S^2+4H^2}} \mp \frac{1}{g}\sqrt{\frac{4v_{z1}^2 \cdot H^2}{(16r^2+S^2+4H^2)} + 2gH} \quad (37)$$

Of the two values of t_{22} with the signs "+" and "-", we are satisfied with a positive value for the
definition t_{22}

$$t_{22} = -\frac{2v_{z1} \cdot H}{g\sqrt{16r^2+S^2+4H^2}} + \frac{1}{g}\sqrt{\frac{4v_{z1}^2 \cdot H^2}{(16r^2+S^2+4H^2)} + 2gH} \quad (38)$$

4 Conclusions

As a result of theoretical studies, an equation of the particle's trajectory reflected from the reflecting plane of the cover reflector is obtained, affecting the mixing quality, the required power, and the performance of the continuous mixer when mixing feed.

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