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Mechanics of the Movement of Grain on a Helical Surface in the Induction Dryer

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Abstract: The study describes the theory of motion of grain on the helical surface which is the main working body of the high-frequency induction grain drying machine. Derived received the equation for of forming a helical surface of helicoids with a variable steepness, depending on the initial velocity V_0 of the falling grain, moisture W in each moment of movement along the curve f(ρ, α) where ρ and α vary depending on the coefficient of dynamic friction as a function of its grain moisture. Researchers used Excel to calculate the value of the function in Excel for a range of input values and here this clearly demonstrates how changing the angle of inclination of the forming helix and its polar radius depending on humidity at the moment when moving on the helical oids surface inside the emitter of microwave drying. On the basis of these provisions, it was made and carried out an experiment on the use of frequency variation for grain drying. The aim of the experiment was to obtain curves of drying grain at varying independent factors. The independent factors taken initial grain moisture content (W, %), the permittivity of the grain, the oscillator frequency (ω, Hz), loss factor. Problems of increasing the efficiency of thermal technology of grain drying is based on the expansion of integrated technological research, the establishment of kinetics of grain drying process, the development of methods for calculating the drying process of grain.

Key words: Drying grain, high-frequency induction drying, the fixed helical surface, friction coefficient, grain moisture, grain speed

INTRODUCTION

Kazakhstan is one of the most important producers of hard wheat. Nowadays the grain yield in Kazakhstan is 20 million tons and in the best years yields were collected up to 34 million tons. The main part of this grain is exported to the different countries of the world. Considering that the major grain-producing regions are located in the rainy northern part of the country, harvesting encounters a problem of high such as increased grain moisture, reaching up to 20%. At harvest in late of August or at the beginning of September moisture in the of straw exceeds the humidity of the grain by for 10-20% while rice harvesting grain moisture and the difference stems happens even triple (Fig. 1).

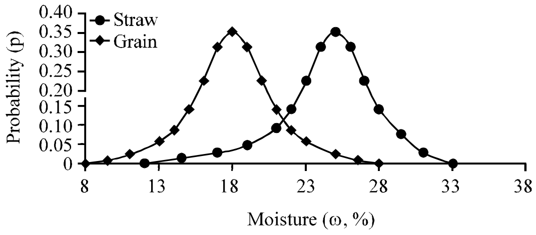

Fig. 1: Probability of moisture in grain and straw

MATERIALS AND METHODS

In this regard, the grain is harvested in Northern Kazakhstan or rice in the South regions must be dried for preservation. We propose a high-frequency induction drying that has advantages over the traditional methods (Barroso and de Paula, 2010). The main differences is that the energy is not used for heating the material of grain it is focused on the internal moisture in the grain which is caused by this is possible because of the different permittivity of the two media water and materials of the grai. Because of this the coefficient of efficiency of the proposed at drying method is greater than traditional drying chambers and in addition there is no thermal injury of the grain. Technological scheme of this dryer is shown in Fig. 2. It contains a high-frequency generator and actuating coil that goes around a cylinder which made from dielectric material.

In this cylinder, there is a fixed helix surface on which grain fallsis filling from the top by gravitational forces. Here there is one feature. The helical surface should have a variable steepness, decreasing from top to bottom. This is due to the fact that as the grain is drying thepneess coefficient of dynamic friction between helical surface and grain is decreasesing. Generally, the coefficient of dynamic friction between the helical surface and grain

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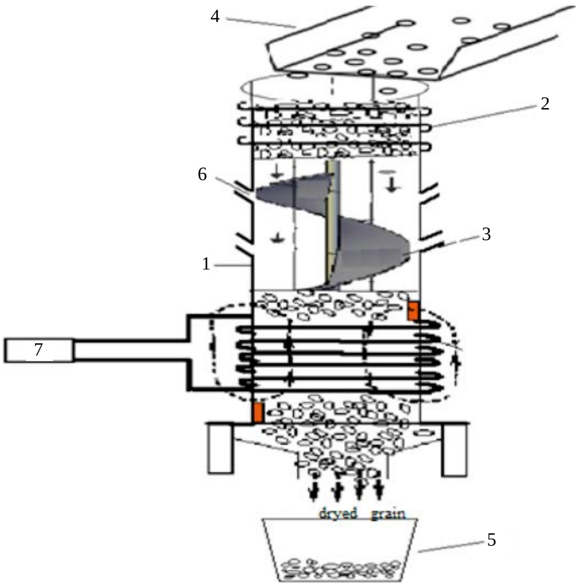

Fig. 2: Technological scheme of the grain dryer

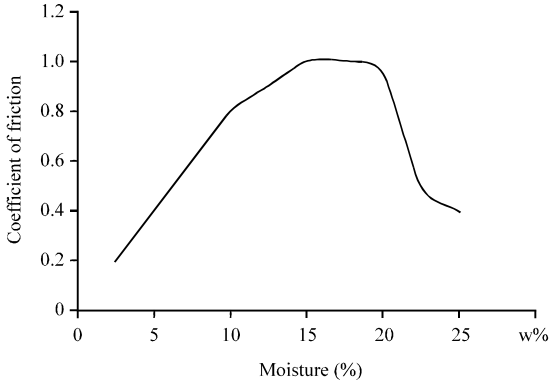

Fig. 3: Dependence of the coefficient of dynamic friction of grain from moisture

initially increases with increasing moisture because there is an effect of adhesion but then at a certain moisture, coefficient of friction begins to decline because moisture forms a lubricating layer between the grain and the surface asits shown in Fig. 3. With further increases in humidity in such mixed environment, the grain and moisture goes to quasi-liquid state and the coefficient of friction drops sharply (Fig. 3).

RESULTS

We can see from Fig. 3 that the area of realin the range of grain moisture from 5-25% this dependence is linear and has the following form:

$$\text{Kтр} = 0.010W+0.33 \tag{1}$$

where, W moisture in %. The initial speed of the grain upon in contact with the helical surface is determineds by the following equation of free fall:

$$V_0 = \sqrt{2gh_0} \tag{2}$$

where, h_0 is the distance from the exit of the hopper to the horizontal plane of the section of the helical surface (Fig. 2). In Eq. 2, the air resistance is neglected, since the velocity of grain is small.

Grain the on the helical surface should not move immediately down on that surface as angle of friction KPt_0g is greater than the angle of elevation Li_0 of the helical surface (Cheng *et al*., 2007). Only after some heating of the moisture in the grain and the partial some lowering of humidity will the friction coefficient will start decreasing and the grain will slide moves down but then it will stop when it reaches a change in the steepness of the surface and because in this part KPt_0 lies $<Li_1$ etc. This should continue until the grain reaches the intended aimed moisture content.

In the process of drying grains, moisture in the grain heats up and evaporates that lead to decreasing of as the moisture of the grain decreases at exact moment and proportionally to it the coefficient of friction decreases proportionally as well. When the coefficient of friction reaches a value less than the angle of inclination of the helix surface, grain starts to slidemove down again and the process repeats (Han, 2010).

The velocity of movement of grain in the vertical plane should not be too slow, because of possible overheating of the grain (water in the grain could be boiled). On the other hand, it should not be high following author Mohamed Hemisatal recommends drying time of no >2 min (120 sec) because longer times may result in otherwise reduced germination of the grain. Thus, time of an exposition of magnetic electric field for grain is reduced and it will leave insufficiently dried.

Under such circumstances spatial movement of grain when there is a centrifugal force moves grain into the periphery of a casing can be neglected. Accordingly, the coriolis acceleration is neglected. The problem is reduced to finding of the forming helical surface projected on the plane X-Y plane (Fig. 4).

We are set by a boundary condition of constantcy of speed of the grains movingement on the surface (Metaxas and Meredith, 1983):

$$V = V_0 = \text{const} \tag{3}$$

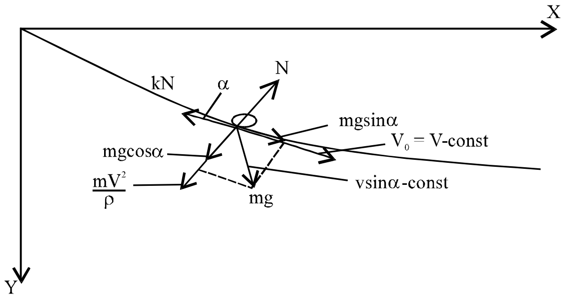

Fig. 4: The forces acting on the grain that moving on the helical surface

In addition, it is required to define a form of curve satisfying these conditions. Equation assumes the form:

$$m\frac{dV}{dt} = mg\sin\alpha\text{-}kN = 0 \qquad (4)$$

Substituting the Eq. 3 in Eq. 4 we have:

$$mg\sin\alpha\text{-}kmg\ \cos\alpha + km\frac{V_0^2}{\rho} = 0 \qquad (5)$$

Considering that:

$$\sin\alpha = \frac{dy}{ds};\ \cos\alpha\frac{dx}{ds};\ \rho = \frac{ds}{d\alpha};\ d\alpha = \frac{y''dx}{1+y'^2}$$

That Eq. 5 will change a look:

$$y(y''\text{-}k) + kV_0^2\frac{y''}{1+y'^2} = 0 \qquad (6)$$

Thus, we have a will receive the differential equation of the second order to define of the forming helical surface on which drying grain would move with a constant speed:

$$y''\text{-}\frac{g}{kV_0^2}(y'\text{-}k)\ (1+y'^2) = 0 \qquad (7)$$

For the solution of this equation we will enter substitution:

$$y^1 = q \qquad (8)$$

And the Eq. 7 takes the form:

$$\frac{dq}{dx} = \frac{g}{kV_0^2}(q\text{-}k)(1+q^2) \qquad (9)$$

Or:

$$dx = \frac{kV_0^2\,dq}{g(q\text{-}k)(1+q^2)} \qquad (10)$$

Integrating, we have:

$$\int dx = h_0\int\frac{dq}{(1+q^2)(bq\text{-}1)} \qquad (11)$$

where, $\alpha = h_0 = V_0^2/g$ is distance from the hopper to the neck of grain dryer:

$$b = \frac{1}{k} \qquad (12)$$

For the integration of Eq. 11, we decompose the fraction into two elements:

$$\frac{1}{(1+q^2)(bq\text{-}1)} = \frac{Aq+B}{1+q^2} + \frac{C}{bq\text{-}1} \qquad (13)$$

Simplifying, we have:

$$Abq^2\text{-}Aq + Bbq + C + Cq^2 = 1$$

Equating the coefficients of equal exponenta yields come to the expression:

$$A = \frac{-b}{1+b^2};\ B = -\frac{1}{1+b^2};\ C = \frac{b^2}{1+b^2}$$

Having substituted in the Eq. 11, we get will receive:

$$x = a\frac{-b}{1+b^2}\int\frac{qdq}{1+q^2} - \frac{a}{1+b^2}\int\frac{dq}{1+q^2} + \frac{ab^2}{1+b^2}\int\frac{dq}{bq\text{-}1} + C_1 \qquad (14)$$

where, C_1 is constant determined from the boundary conditions (Eq. 3). Integrating Eq. 14 by parts:

$$x = \frac{ab}{1+b^2}\ln\frac{bq\text{-}1}{\sqrt{1+q^2}} - \frac{a}{1+b^2}\text{arctg}\ q + C_1 \qquad (15)$$

The constant C_1 is determined from the basic conditions at $x = 0$; $q_0 = y^1 = V_0$. From here:

$$C_1 = \frac{a}{1+b^2}\text{arctg}\ q_0 - \frac{ab}{1+b^2}\ln\frac{bq_0\text{-}1}{\sqrt{1+q_0^2}}$$

Equation 15 is transformed into:

$$x = \frac{ab}{1+b^2}\ln\left[\frac{(bq\text{-}1)\sqrt{1+V_0^2}}{(bV_0\text{-}1)\sqrt{1+q^2}}\right] + \frac{a}{1+b^2}(\text{arctg } V_0 \text{-arctg } q) \tag{16}$$

To determine the second cartesian coordinate y, consider the expression: dy/dx = q, substituting the value of x from Eq. 16. We obtain:

$$dy = \frac{aqdq}{(1+q^2)(bq\text{-}1)} \tag{17}$$

Expanding the fraction to the elements, we have:

$$dy = \frac{a}{1+b^2}\left(\text{-}\frac{q}{1+q^2} + \frac{b}{1+q^2} + \frac{b}{bq\text{-}1}\right)dq$$

By integrating, we obtain:

$$y = \frac{a}{1+b^2}\left(\ln\frac{bq\text{-}1}{1+q^2} + b\,\text{arctg } q\right) + C_2 \tag{18}$$

Constant C_2 is determined from the boundary conditions. For $q = q_0 = V_0uy = 0$:

$$C_2 = \text{-}\frac{a}{1+b^2}\left(\ln\frac{bV_0\text{-}1}{\sqrt{1+V_0}} + b\text{arctg } V_0\right)$$

And Eq. 18 takes the form:

$$y = \frac{a}{1+b^2}\left[\ln\left(\frac{(bq\text{-}1)\sqrt{1+V_0^2}}{(bV_0\text{-}1)\sqrt{1+q^2}} + b(\text{arctg } q\text{-arctg } V_0)\right)\right] \tag{19}$$

For forming the screw line, it is more convenient to consider it in polar coordinates:

$$\rho = \sqrt{y^2+x^2} = \frac{\sqrt{\left[\frac{a}{1+b^2}\ln\left[\begin{matrix}\frac{(bq\text{-}1)\sqrt{1+V_0^2}}{(bV_0\text{-}1)\sqrt{1+q^2}} + \\ \frac{a}{a+b^2}\{\text{arctg } V_0 \text{-arctg } q\}\end{matrix}\right]\right]^2}}{+\left[\frac{a}{a+b^2}\left\{\begin{matrix}\ln\left(\frac{(bq\text{-}1)\sqrt{1+V_0^2}}{\sqrt{1+q^2}\,(bV_0\text{-}1)}\right\} + \\ b(\text{arctgq-arctg } V_0)\end{matrix}\right.\right]^2} \tag{20}$$

DISCUSSION

Considering our condition that:

$$y^1 = q = \text{tg}\alpha > k\text{тр} = 0.01W+0.33 \tag{21}$$

And that:

$$b = \frac{1}{0.01W+0.33} \text{ and } a = h_0 = \frac{V_0^2}{g} \tag{22}$$

We finally obtain the dependence of defining the shape forming a helical surface, depending on the moisture content of grain and the distance from the hopper to the mouth of the dryer:

$$\rho = \sqrt{\begin{matrix}\left\{\frac{ab}{1+b^2}\ln\left[\frac{(bq\text{-}1)\sqrt{1+V_0^2}}{(bV_0\text{-}1)\sqrt{1+q^2}}\right] + \frac{a}{1+b^2}[\text{arctg } V_0 \text{-arctg } q]\right\}^2 + \\ \left\{\frac{a}{1+b^2}\left[\ln\left[\frac{(bq\text{-}1)\sqrt{1+V_0^2}}{\sqrt{1+q^2}\,(bV_0\text{-}1)}\right] + b(\text{arctg } q\text{-arctg } V_0)\right]^2\right\}\end{matrix}} \tag{23}$$

After simplification we come to the final function describing required shape forming in polar coordinates:

$$\rho = \frac{V_0^2}{g}\sqrt{\begin{matrix}\left(\frac{1}{1+\left(\frac{1}{0.01W+0.33}\right)^2}\right) \\ \left[\ln\left(\frac{\text{tga}/0.01W+0.33\text{-}1\sqrt{1+V_0^2}}{\sqrt{1+\text{tga}}\left(V_0/0.01W+0.33\right)}\right)^2\right] + (\text{arctg } V_0\text{-a})^2\end{matrix}} \tag{24}$$

For engineering interpretation of Eq. 24, researchers used Excel to calculate the value of the function in Excel for a range of input values and here this clearly demonstrates how changing the angle of inclination of the forming helix and its polar radius depending on humidity at the moment when moving on the helical oids surface inside the emitter of microwave drying. In essence, we see that this screw has technologically feasible parameters in both the on angle of the helical surface and the screw line and on polar radius.

Evaluation: Thus, we derived received the equation for of forming a helical surface of helicoids with a variable steepness depending on the initial velocity V_0 of the falling grain, moisture W in each moment of movement along the curve f(ρ, α) where ρ and α vary depending on the coefficient of dynamic friction as a function of its grain moisture (Fig. 5).

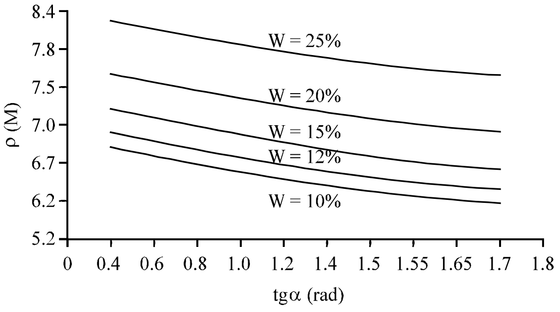

Fig. 5: Main parameters of helical surface

CONCLUSION

Thus, this study describes the was first justified self-regulating movement of grain in a helical surface with variable steepness in at he microwave drying facilities and how the variable steepness of the helical surface can be designed to fit the relevant conditions of initial grain velocity falling on the surface, initial moisture content of the grain and desired final moisture content of the dried grain.

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