A Theoretical Study of the Drift Processes of Cotton Particles Under the Influence of Air

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Abstract: This article examines a mathematical model of the movement of cotton flakes in an air flow. A differential equation describing the movements of cotton has been compiled. The differential equations take into account the mass of cotton fluff, as well as the resistance forces of the air flow. Taking into account the corresponding initial conditions, analytical solutions to the problem are obtained. In the Maple-16 program, graphs of changes in speed and pressure were obtained, representing the process of pushing a cotton fly on an inclined plane under the influence of an air flow. The graphs show that increasing the angle of inclination leads to an increase in particle speed. The law of change of these speeds grows nonlinearly in the interval 0<t<3s, and then follows an asymptotic linear law. Increasing the air flow speed and the angle of descent to the plane reduces the cotton fly rate by an average of 35%. Thus, the movement of cotton particles accelerates with an increase in the angle of inclination of the plane, and an increase in the angle of descent of the air flow leads, on the contrary, to a decrease

1 INTRODUCTION

It is known can take additional measures to activate cotton ginning. One of these measures is the use of air flow. That is, under the influence of air flow, it is possible to change the position of the cotton piece on the tooth of the saw cylinder and its movement. In addition, under the influence of the air flow, there is also the possibility of removing the seed separated from the fiber in the drying zone for a short period of time. For this purpose, it is important to determine the system of forces affecting the objects of the air stream. The properties of air flow, their forces of interaction with bodies have been comprehensively studied in the science of hydrodynamics (Saadi, 1976; Sajin, Gudim, Reutsky, 1988; Targ, 1972; Karimov, Baxritdinov, Azambayev, 2020; Muradov, Mardonov, Karimov, 2014). Under the influence of the flow, an aerodynamic force is created on the body depending on the flow speed. If the speed of the flow is not high, usually the value of this force is proportional to the air and object speeds. It is known that the speed of cotton particles under the influence of air flow is around 10-17 m/s. In order to activate the drying, it is important to study the laws of movement of cotton particles.

2 MATERIALS AND METHODS

Let's assume that the body under the influence of the air flow moves along the BC curve with the trajectory equation y=f(x) in the two-dimensional X0Y system (Fig. 1). We denote $\vec{V}_0 = \{V_{0x}, .V_{0y}\}$ the velocity vector of the stream, $\vec{V} = \{V_x, .V_y\}$ by the particle velocity vector. If we determine the angle α_0 3 of the

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vector $\vec{V}_0$ axis with OX the external one, then using the figure 1

$$V_{0x} = \left|\vec{V}_0\right|\cos\alpha_0 \,, \qquad (1)$$
$$V_{0y} = -\left|\vec{V}_0\right|\sin\alpha_0$$

we form equalities. According to the law of aerodynamics, the air resistance force vector is $\vec{F}(V_{0x}-V_x, V_{0y}-V_y)$ directed along the particle's relative velocity vector $\vec{V}_0 - \vec{V}$. If this is the modulus of the force

$\left|\vec{F}(V_{0x}-F_x, V_{0y}-V_y)\right|$, relative velocity modulus

$$\left|\vec{V}_0 - \vec{V}\right| = \sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2}$$

is defined as , then the force due to air flow can be written by the following vector.

$$\vec{F}(V_{0x}-V_x, V_{0y}-V_y) =$$
$$\left|\vec{F}(V_{0x}-F_x, V_{0y}-V_y)\right|\left[\frac{V_{0x}-V_v}{\left|\vec{V}_0-\vec{V}\right|}\vec{i} + \frac{V_{0y}-V_y}{\left|\vec{V}_0-\vec{V}\right|}\vec{j}\right]$$

where ($\vec{i}$, $\vec{j}$) *OX* and *OY* axes are unit vectors directed along. Thus, the projections of the force under the influence of the air flow on the *OX* and *OY* axes are expressed by the following formulas.

$$F_x = \left|\vec{F}(V_{0x}-F_x, V_{0y}-V_y)\right|\frac{V_{0x}-V_v}{\left|\vec{V}_0-\vec{V}\right|}, \qquad (2)$$

$$F_y = \left|\vec{F}(V_{0x}-F_x, V_{0y}-V_y)\right|\frac{V_{0y}-V_y}{\left|\vec{V}_0-\vec{V}\right|}$$

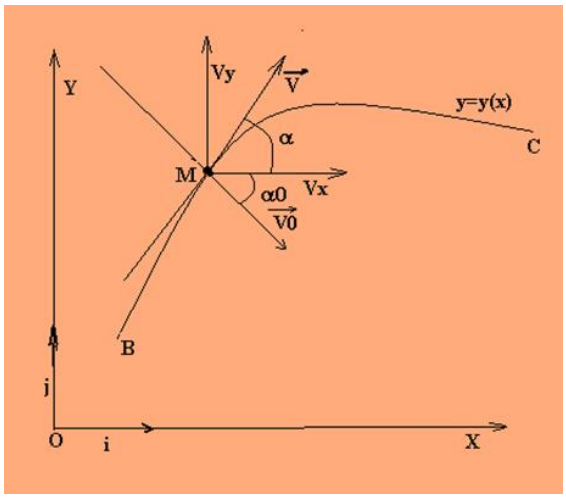


Figure 1: Under the influence of the air flow of the cotton piece movement scheme.

Assume that air resistance is proportional to relative velocity, then the relation of the force vector to relative velocity is as follows.

$$\vec{F}(V_{0x}-V_x, V_{0y}-V_y) = C_0(\vec{V}_0 - \vec{V}\,)$$

here C_0 - is the coefficient determined by experience.

The modulus of this force This formula is

$$\left|\vec{F}(V_{0x}-F_x, V_{0y}-V_y)\right| = C_0$$
$$\sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2}$$

expressed by and its projections on the coordinate axes are as follows.

$$F_x = C_0\sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2}$$
$$\frac{V_{0x}-V_v}{\left|\vec{V}_0-\vec{V}\right|} = C_0(V_{0x}-V_x) \qquad (3)$$
$$F_y = C_0\sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2}$$
$$\frac{V_{0y}-V_y}{\left|\vec{V}_0-\vec{V}\right|} = C_0(V_{0y}-V_y) \qquad (4)$$

Formulas (3) and (4) can be used in practice when the air flow is at a small speed.

Let us assume that the strength of the air flow is proportional to the square of the relative speed, i.e

$$\vec{F}(V_{0x}-V_x, V_{0y}-V_y) = C_1(\vec{V}_0 - \vec{V}\,)^2$$

Here C_1 - is the coefficient found by experience.

We find the modulus of a vector and its square property.

$$\vec{F}(V_{0x}-V_x, V_{0y}-V_y) = C_1[(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2]$$

Formula (2) takes the form in this case

$$F_x = \quad (5)$$

$$C_1[(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2]\frac{V_{0x}-V_v}{\sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)}} =$$

$$= C_1(V_{0x}-V_x)\sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2}$$

$$F_y = \quad (6)$$

$$C_1[(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2]\frac{V_{0y}-V_y}{\sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)}} =$$

$$= C_1(V_{0y}-V_y)\sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2}$$

Formulas (5) and (6) are appropriate for high-speed flows

Let's consider the issue below. Let's assume that a piece of cotton is in equilibrium at a moment on an inclined plane making an angle of β with the horizon $t = 0$ and is affected by $t > 0$ air currents. Let's study the law of character of the particle (Fig. 2). *OX* - we direct the axis along the inclined plane, and the *OY* axis perpendicular to it. Let the air flow vector form an angle γ with the inclined plane ($0 \le \gamma \le \pi/2$).We take the strength of the air flow as proportional to the relative speed. For the resulting coordinate axes $V_{0x} = V_0 \cos\gamma$, $V_{0y} = V_0 \sin\gamma$, $V_y = 0$

Then the projections of the air current forces on the *OX* and *OY* axes will be as follows.

$$F_x = C_0 \quad (7)$$

$$\sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2}$$

$$\frac{V_{0x}-V_v}{\left|\vec{V}_0 - \vec{V}\right|} = C_0(V_0\cos\gamma - V_x)$$

$$F_y = C_0 \quad (8)$$

$$\sqrt{(V_{0x}-V_x)^2 + (V_{0y}-V_y)^2}$$

$$\frac{V_{0y}-V_y}{\left|\vec{V}_0 - \vec{V}\right|} = C_0 V_0 \sin\gamma$$

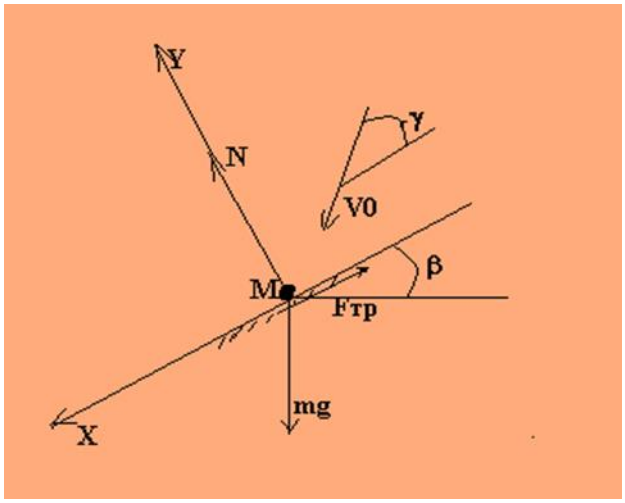


Figure 2: Scheme of the movement of a piece of cotton on an inclined plane under the influence of air flow.

Forces acting on a particle: The projection of the force of gravity on an inclined plane - $F_g = mg\sin\beta$, friction force - $F_{mp} = fN$, force of air flow - F_x .

The expression of normal force is *N* written as shown in Figure 2.

$$N = mg\cos\beta + F_y$$

So

$$F_{mp} = f(mg\cos\beta + F_y) = f(mg\cos\beta + C_0 V_0 \sin\gamma)$$

Taking the mass of the particle as *m*, we construct the equation of its motion along an inclined plane (Targ, 1972)

$$m\dot{V}_x = F_x + mg\sin\beta - F_{mp}$$

If we put in this equation F_x and F_{mp} the expression of forces

$$m\dot{V}_x = C_0(V_0\cos\gamma - V_x) + mg(\sin\beta - f\cos\beta) - fC_0V_0\sin\gamma \quad (9)$$

3 RESULTS

Solving this equation with the condition that $V_x = 0$ $t = 0$, we determine the velocity of the particle $V_x = V_x(t)$. Then, let the displacement of the particle on the inclined plane be $u = u(t)$, and solve equation $\frac{du}{dt} = V_x(t)$ with condition ,and

calculate the law of motion of the particle. In order for a particle to start moving on an inclined plane $t=0$, the acceleration must be $V_x(0)>0$. Then, from equation (3), we get the following inequality

$$V_x(0)=C_0V_0\cos\gamma+mg\sin\beta-f(mg\cos\beta+C_0V_0\sin\gamma)>0 \quad (10)$$

From this inequality we get the air flow velocity condition

$$V_0>V_*=\frac{mg(f\cos\beta-\sin\beta)}{C_0(\cos\gamma-f\sin\gamma)}$$

The conditional solution of equation (9) $V_x(0)=0$ is as follows

$$V_x=\frac{\lambda}{\mu}[1-\exp(-\mu t)] \quad (11)$$

Here

$$\lambda=\mu(\cos\gamma-f\sin\gamma)+g(\sin\beta-f\cos\beta),$$

$$\mu=C_9/m$$

Integrating equation (11) with condition $u(0)=0$, we get the equation of motion of a particle on an inclined plane

$$u=\frac{\lambda}{\mu^2}[\mu t-1+\exp(-\mu t)]$$

In particular, we get $V_*=\dfrac{mgf}{C_0(\cos\gamma-f\sin\gamma)}$

formulas for $\beta=0$ point. Velocity V_* is said to be the velocity of the air moving the particle, and for this velocity to be positive, $\cos\gamma>f\sin\gamma$ must be fulfilled.

We reduce the equation (3) to the following form

$$\dot{V}_x+\mu V_v=A_0 \quad (12)$$

Here $\mu=\dfrac{C_0}{m}$,

$$A_0=\frac{C_0V_0(\cos\gamma-f\sin\gamma)+mg(\sin\beta-f\cos\beta)}{m}$$

(12) we obtain solutions for velocity and displacement with conditions $V_x=0$, $u(0)=0$,

$$V_x=\frac{A_0}{\mu}[1-\exp(-\mu t)],$$

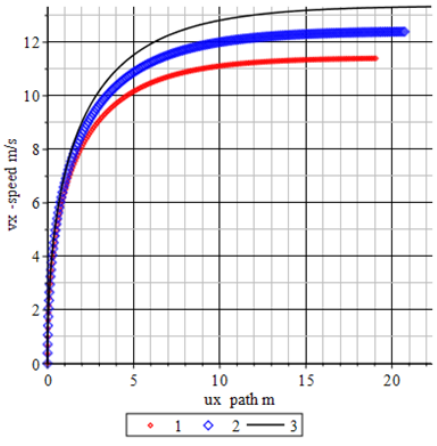
$$u=\frac{A_0}{\mu^2}[\mu t-1+\exp(-\mu t)]$$

4 DISCUSSION AND CONCLUSION

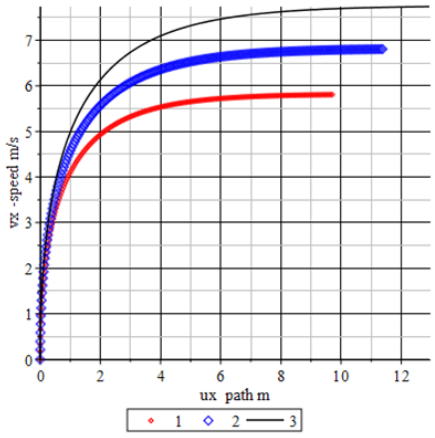
Graphs of speed and pressure changes representing the pushing process of a piece of cotton on the same plane under the influence of air flow were obtained in the Maple-16 program. These graphs are presented in Figures 3-4.

In the graphs in Fig. 3a, b, under the influence of the air flow, the speed of the cotton ball is $v=v(x)$ $\gamma=\frac{\pi}{6};\frac{\pi}{4}$ and the angles between the plane and the horizontal: $1-\beta=\frac{\pi}{6};2-\beta=\frac{\pi}{4};3-\beta=\frac{\pi}{3};$ the law of change is presented.

Increasing the angle of inclination by (β) leads to an increase in the speed of the particle. The law of change of these velocities is non-linearly growing in the interval $0<t<3s$, and then follows the asymptotic linear law starting from $t\geq 3s$. Increasing the air flow speed and the angle of descent to the plane reduces the speed of pushing the cotton pad by 35% on average. So, the movement of cotton particles accelerates with an increase in the angle of inclination of the plane, and an increase in the angle of descent of the air flow leads to a decrease on the contrary.

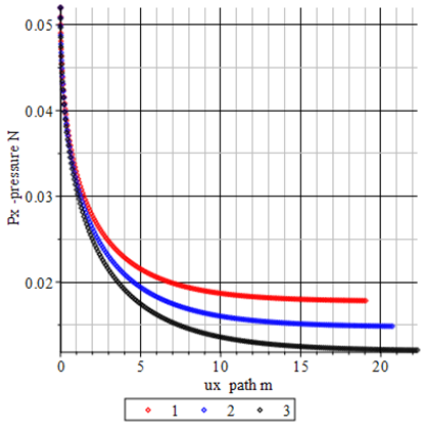


a)

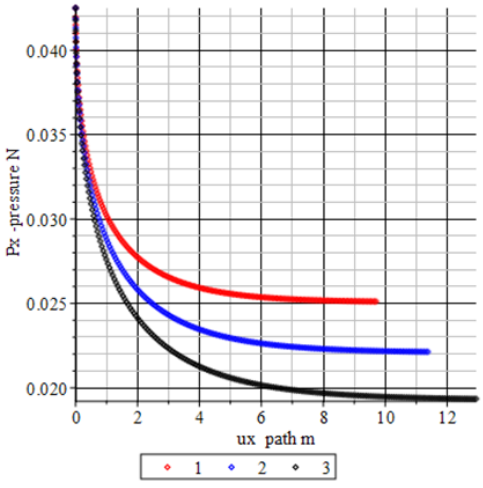


b)

Figure 3: The law of change of the speed of a piece of cotton on an inclined plane depending on the path. Here: m=0.001kg; a)γ=π/6,b)γ=π/4; c_0=0.003; 1-β=π/6;2-β=π/4;3-β=π/3.



a)



b)

Figure 4: The law of change of the speed of a piece of cotton on an inclined plane depending on the path. Here: m=0.001kg; a)γ=π/6,b)γ=π/4; c_0=0.003; 1-β=π/6;2-β=π/4;3-β=π/3.

In the graphs in Fig. 4a,b, the pressure force of the air flow on a piece of cotton: F=*F(x)* $\gamma = \frac{\pi}{6}; \frac{\pi}{4}$ and the angles between the inclined plane and the horizontal:

$1 - \beta = \frac{\pi}{6}; 2 - \beta = \frac{\pi}{4}; 3 - \beta = \frac{\pi}{3};$ the law of change is presented. Increasing the angle of inclination (β) leads to a decrease in the pressure force of the air acting on the particle. This is because the law of change of $0 < t < 3s$ is non-linearly decreasing in the interval and then $t \geq 3s$ follows the asymptotic linear law starting from . Airflow pressure, C v_0 -velocity increases as the angle of incidence increases.

5 CONCLUSIONS

A mathematical model of the movement of a piece of cotton on an inclined plane under the influence of air flow was created.

1. The solutions of the differential equation of motion based on the mathematical model were determined analytically based on the obtained initial conditions.
2. The graphs of a piece of cotton along the plane, the laws of motion and speed, and different angles of inclination were obtained.
3. It was shown in the analysis of the graphs that the movement of cotton balls accelerates with the increase of the angle of inclination of the plane, and the increase of the angle of descent of the air flow leads to a decrease.
4. Increasing the slope angle (β) leads to a decrease in the pressure force of the air acting on the particle. The law of change of this state is non-linearly decreasing in the range $0 < t < 3s$, and then follows the asymptotic linear law starting from $\geq 3s$.

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