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COTTON FIBER AND AIR FLOW EXAMINED VIA A MATHEMATICAL EXAMINATION

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Abstract. When cotton fibers are cleaned, there is a very high chance that they will come into contact with one another in a single particle. When it comes to technical activities, a group of cotton fibers made up of several fibers may interact with a machine's working parts more frequently than a single cotton filament. It should be noted that the continuous media theory must be applied in order to describe the movement of cotton fiber during cleaning, pipe movement, removal from the saw teeth of a spinning gin machine with the aid of an air stream, and removal from the machine after the air has been removed.

Introduction. Here, the air-fiber mixture creates a single, continuous medium whose motion is dictated by the law of interaction between the fiber and air particles. Air particles and cotton fiber, the two constituents of such a medium, have different velocities. Consequently, at every location in the medium, a force proportional to the difference in the component velocities is generated. Such settings are typically regarded as multi-velocity (in our example, two-velocity) environments, and specific theories are adopted to investigate the environment's condition and motion laws. Such settings are typically regarded as multi-velocity (in our example, two-velocity) environments, and specific theories are adopted to investigate the environment's condition and motion laws. One of the most significant theories in the theory of multi-component environments, which was initially put forth by academician H.A. Rakhmatulin [1], is that the pressure is the same for every component of the environment. If one of the components of the environment is a moving elastic medium and the other is a viscous fluid, the pressure of the fluid component is determined, and Hooke's law is used to determine if the component is a deformable solid. The Bio-Frenkel model is the name given to this type of two-component ecosystem.

Thus, if the shear deformation in the deformable component is not taken into account, and the average hydrodynamic pressure in it is taken to be equal to the air pressure, then it is possible to obtain a two-component medium model proposed by Academician H.A. Rakhmatulin. In the literature, such media are called heterogeneous mixtures, and their motion is studied on the basis of the theory of multi-velocity media. For such media, the concept of initial (true) densities is given. For a mixture of air and cotton fiber, we denote these quantities by $\rho_1^{(0)}$ and $\rho_2^{(0)}$. Let us assume that the mixture in a container with a volume of V . In it, V_1 part of the first component (air) V_2 is occupied by the second component (cotton fiber pieces), and their densities are ρ_1 and ρ_2, respectively.

Results and Discussions. According to the law of conservation of mass, we can write the equations

$$\rho_1^{(0)}V_1 = \rho_1 V\ ,\ \rho_2^{(0)}V_2 = \rho_2^{(0)}(V - V_1) = \rho_2 V \qquad (1)$$

This ratio V_1 / V is usually called the porosity of the medium, we denote this ratio by, according to formula (2.3)

$$m = \frac{V_1}{V} = \frac{\rho_1}{\rho_1^{(0)}}\ ,\ 1 - m = \frac{V - V_1}{V} = \frac{V_2}{V} = \frac{\rho_2}{\rho_2^{(0)}} \quad (2)$$

Thus, m part of the medium is occupied by air, and $1 - m$ part by cotton particles. Equations (2.4) can be written as

$$\rho_1 = m\rho_1^{(0)}\ ,\ \rho_2 = (1 - m)\rho_2^{(0)} \quad (3)$$

From these expressions, the following equality follows:

$$\frac{\rho_1}{\rho_1^{(0)}} + \frac{\rho_2}{\rho_2^{(0)}} = 1 \quad (4)$$

Thus, it is sufficient to know to determine the components of the medium.

We consider the one-dimensional motion of a two-component medium in a stationary state. According to the model of K.A. Rakhmatulin, the equations of motion of the flow can be written as follows [2]:

$$\rho_1 u_1 \frac{\partial u_1}{\partial x} = -\frac{\rho_1}{\rho_1^{(0)}}\frac{\partial p}{\partial x} + k(u_2 - u_1) \, (5)$$

$$\rho_2 u_2 \frac{\partial u_2}{\partial x} = -\frac{\rho_2}{\rho_2^{(0)}}\frac{\partial p}{\partial x} + k(u_1 - u_2)\, , (6)$$

Where $u_1(x)$ and $u_2(x)$ are the velocities of the components, $p(x)$ - the pressure that is the same for both components, k - the coefficient of interaction between air and cotton fiber. Using equations (3), equations (5) and (6) can be written as follows:

$$m\rho_1^{(0)} u_1 \frac{\partial u_1}{\partial x} = -m \frac{\partial p}{\partial x} + k(u_2 - u_1) \quad (7)$$

$$(1-m)\rho_2^{(0)} u_2 \frac{\partial u_2}{\partial x} = -(1-m) \frac{\partial p}{\partial x} + k(u_1 - u_2), \quad (8)$$

According to equations (2.8), the density of the components of the medium is expressed by the porosity of the medium. If each component is considered an ideal incompressible medium, then, according to the law of conservation of matter, the following equations are valid for each component:

$$\rho_1 u_1 = \rho_{10} u_{10}, \ \rho_2 u_2 = \rho_{20} u_{20} \quad (9)$$

or using equation (2.10):

$$m\rho_1^{(0)} u_1 = m_0 \rho_1^{(0)} u_{10}, \ (1-m)\rho_2^{(0))} u_2 = (1-m_0)\rho_2^{(0)} u_{20},$$

Where , m_0 -is the given porosity at some point of the medium, u_{10} , u_{20} is the given velocities of the components from this point.

Using expressions (3) and (9), we find the relationship between

$$u_1(x), u_2(x) \ .$$

$$\bar{u}_2 = \frac{\beta \bar{u}_1}{\bar{u}_1 - \lambda} \quad (10)$$

Here $\bar{u}_i = u_i / u_{10}$, $\beta = (1-\lambda) u_{20} / u_{10}$, $\lambda = \rho_{10} / \rho_1^{(0)}$

By removing the pressure from equations (6), we find the relationship between the derivatives $\frac{du_1}{dx}, \frac{du_2}{dx}$:

$$\bar{u}_1 \frac{d\bar{u}_1}{dx} - \gamma \bar{u}_2 \frac{d\bar{u}_2}{dx} = \bar{k}(\bar{u}_2 - \bar{u}_1) \quad (11)$$

Here, using the relations $\gamma = \rho_2^{(0)} / \rho_1^{(0)}$, $\bar{k} = k / \rho_1^{(0)} u_{10}$ we find the derivative (11)

The initial conditions necessary to solve equation (12 are usually determined depending on the formulation of the problem. Suppose that the medium moves in a pipe with a constant S_0 cross-sectional area. Then, for each component (air and cotton fiber), the following amount of mass flow passes through $x = 0$ the cross-sectional area in a unit time interval:

$$Q_1 = \rho_{10} u_{10} S_0,\ Q_2 = \rho_{20} u_{20} S_0 \quad (12)$$

Usually Q_1 and Q_2 in technology, air and cotton fiber consumptions are called, respectively. From these equations, we find the velocities u_{10} and u_{20}:

$$u_{10} = \frac{Q_1}{\rho_{10} S_0}, u_{20} = \frac{Q_2}{\rho_{20} S_0} \quad (13)$$

Using the determined velocities, the porosity values in the initial and arbitrary sections are found using the following formulas:

$$m_0 = \rho_{10} / \rho_1^{(0)} \text{ or } m_0 = 1 - \rho_{20} / \rho_2^{(0)}$$

$$m = \frac{\rho_{10} u_{10}}{\rho_1^{(0)} u_1} \text{ or } m = 1 - \frac{\rho_{20} u_{20}}{\rho_2^{(0)} u_2}$$

To find the pressure in the environment, we take this equation:

$$\rho_{10} u_{10} \frac{du_1}{dx} + \rho_{20} u_{20} \frac{du_2}{dx} = -\frac{dp}{dx}$$

Integrating the equation with the initial conditions $u_1(0) = u_{10}$, $u_2(0) = u_{20}$, $p(0) = p_0$ we find the dynamic pressure $\Delta p = p - p_0$:

$$\Delta p = \rho_{10} u_{10} (u_{10} - u_1) + \rho_{20} u_{20} (u_{20} - u_2)$$

We consider the following special cases.

1. The velocity of the cotton fiber is zero. The air flow passes through the stationary cotton mass. In the above formulas, we assume that $u_2 = 0$. In this case, the second expression of (10) is exactly fulfilled. From the first of them, we determine the density of the raw material and the porosity of the medium from the arbitrary value of the variable air (3):

$$\rho_1=\rho_{10}u_{10}/u_1,\ \rho_2=\rho_2^{(0)}(1-\frac{\rho_{10}u_{10}}{\rho_1^{(0)}u_1}),\ m=\frac{\rho_{10}u_{10}}{\rho_1^{(0)}u_1}$$

To find the unknown air velocity and pressure in these expressions, we accept in equations (11) and (12) as $u_2=0$, $\rho_1=\rho_{10}u_{10}/u_1$:

$$\rho_{10}u_{10}\frac{du_1}{dx}=-\frac{\rho_{10}}{\rho_1^{(0)}}\frac{u_{10}}{u_1}\frac{dp}{dx}-ku_1$$

$$0=-(1-\frac{\rho_{10}u_{10}}{\rho_1^{(0)}u_1})\frac{dp}{dx}+ku_1$$

From this system, we determine $\frac{du_1}{dx}$ and $\frac{dp}{dx}$.

$$\frac{du_1}{dx}=-\frac{k}{\rho_{10}}\frac{u_1}{(u_1-a_1u_{10})},\ \frac{dp}{dx}=-\rho_{10}u_{10}\frac{du_1}{dx}$$

Integrating these equations $u_1(0)=u_{10}$, $p(0)=p_0$ under the conditions, we find

$$u_{10}-u_1-au_{10}\ln\frac{u_1}{u_{10}}=-\frac{kx}{\rho_{10}}\ (14)$$

$$p=p_0+\rho_{10}u_{10}(u_{10}-u_1),\ a_1=\rho_{10}/\rho_1^{(0)}$$

2. A weight of cotton fiber moves in a shaft with a zero air flow velocity. The flow rate of the raw material in the initial section $x=0$ of the shaft is equal to Q_2. We find the laws of distribution of the air, raw material densities and raw material velocities over the height of the shaft. We denote the cross-sectional area of the shaft by S_0 In equations (5) and (6),

we can say

$$u_1=0,\ \rho_2=\rho_{20}u_{20}/u_2,\ u_{20}=Q_2/S_0\rho_{20},\ \rho_1=\rho_{10}(1-\frac{\rho_{20}u_{20}}{\rho_2^{(0)}u_2})$$

and take its weight into account. Then equations (5) and (6) take the following form.

$$0=-(1-\frac{\rho_{20}u_{20}}{\rho_2^{(0)}u_2})\frac{dp}{dx}+ku_2\ \rho_{20}u_{20}\frac{du_2}{dx}=-\frac{\rho_{20}}{\rho_2^{(0)}}\frac{u_{20}}{u_2}\frac{dp}{dx}-ku_2+\frac{g\rho_{20}u_{20}}{u_2}$$

From this system, we determine the derivative $\frac{du_2}{dx}$:

$$\frac{du_2}{dx} = \frac{k}{\rho_{20}} \frac{(u_2 - a_2 u_{20})b - u_2^2}{u_2(u_2 - a_2 u_{20})}$$

Here $a_2 = \rho_{20} / \rho_2^{(0)}$, $b = g\rho_{20} / k$, is expressed by this integral:

$$\int_{u_{20}}^{u_2} \frac{u(u - a_2 u_{20})du}{(u - a_2 u_{20})b - u^2} = \frac{kx}{\rho_{20}} \ (15)$$

3. The mass of cotton fiber moves under the influence of constant air pressure. In this case, we obtain the law $p = p_0 + \Delta px / L$ of variation of the pressure in a limited interval $0 < x < L$ of x, where $\Delta p = p_L - p_0$, p_0 and p_L $x = 0$ are the pressures at the sections. Substituting p the expression of into equations (5) and (6) and using equations (7) and (10), we construct a system for finding $u_1(x)$ and $u_2(x)$.

$$\rho_{10} u_{10} \frac{du_1}{\partial x} = -\frac{\rho_{10} u_{10}}{\rho_1^{(0)} u_1} \frac{\Delta p}{L} + k(u_2 - u_1) \ (16)$$

$$\rho_{20} u_{20} \frac{du_2}{dx} = -\frac{\rho_{20} u_{20}}{\rho_2^{(0)} u_2} \frac{\Delta p}{L} + k(u_1 - u_2) , (17)$$

We add these equations one by one, integrate the result, and find the relationship between $u_1(x)$ and $u_2(x)$

$$\rho_{10} u_{10} (u_1 - u_{10}) + \rho_{20} (u_2 - u_{20}) = -\Delta p / L$$

Expressing u_2 and u_1 from this equation throughout

$$u_2 = -u_1 \frac{\rho_{10} u_{10}}{\rho_{20} u_{20}} + \frac{\Delta p + \rho_{20} u_{20}^2 + \rho_{10} u_{10}^2}{\rho_{20} u_{20}}$$

we put it in equation (16).

$$\frac{du_1}{dx} = -\frac{c_2 u_1^2 + c_1 u_1 + c_0}{u_1}$$

Here $c_0 = \dfrac{a_1 \Delta p}{\rho_{10} L}$, $c_2 = \dfrac{k}{\rho_{10} u_{10}} (1 + \rho_{10} u_{10} / \rho_{20} u_{20})$, $c_1 = -\dfrac{k}{\rho_{10} u_{10}} \dfrac{\Delta p + \rho_{20} u_{20}^2 + \rho_{10} u_{10}^2}{\rho_{20} u_{20}}$

Integrating the last expression, we get:

$$x = \sqrt{4c_0c_2 - c_1^2}\, ln \frac{c_2u_{10}^2 + c_1u_{10} + c_0}{c_2u_1^2 + c_1u_1 + c_0} + 2c_1 \left[arctan \frac{2c_2u_1 + c_1}{\sqrt{4c_0c_2 - c_1^2}} - arctan \frac{2c_2u_{10} + c_1}{\sqrt{4c_0c_2 - c_1^2}} \right], \qquad (18)$$

This equation expresses the law of displacement of the fiber bundle as it moves along the pipe until it enters the fiber cleaner.

Conclusions. The distance between the cotton gin machine and the fiber cleaner can be determined by analyzing the equation closely, and we can see that air parameters, such as density, pressure, and speed, as well as the density and aerodynamic resistance coefficients of cotton fiber, as well as the width and height of the conveyor system, all play a role in the distance cotton travels between the gin machine and fiber cleaner. There are three variables that can be controlled directly: air pressure, speed, and material transfer—that is, the height of the pipe—and it is only by adjusting these variables that it is possible to ensure which zone of cotton fiber goes into the fiber cleaner system.

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