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Issue Article

Mukhiddin Khudjaev
Tashkent State Transport University
Professor, Tashkent, Uzbekistan
mukhiddinkhudjaev@gmail.com

Anvar Rizaev
Institute of Mechanics and Seismic Stability of Structures named after M.T.Urazbaev
Uzbekistan Academy of Sciences,
Professor, Tashkent, Uzbekistan

Davronbek Qoldoshev
Institute of Mechanics and Seismic Stability of Structures named after M.T.Urazbaev
Uzbekistan Academy of Sciences
Head of department, Tashkent, Uzbekistan

Nargiza Djuraeva
Institute of Mechanics and Seismic Stability of Structures named after M.T.Urazbaev
Uzbekistan Academy of Sciences

Shoxrux Ganjaev
Institute of Mechanics and Seismic Stability of Structures named after M.T.Urazbaev
Uzbekistan Academy of Sciences

DETERMINING THE VELOCITY OF EXIT OF THE MEDIUM FROM A COTTON HARVESTER PNEUMATIC CONVEYING SYSTEM

Abstract*: The pneumatic conveying system of a cotton harvester is studied. The law of conservation of mass is applied to a continuous medium moving through a pipeline. An analytical expression is derived for the velocity of the medium exiting the pneumatic conveying chamber of the cotton harvester, based on the known inlet velocities of the media entering from the loading slot and the air jet opening.*

Key words*: pneumatic conveying system, law of conservation of mass, air jet, medium velocities.*
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Introduction

Analyzing the flow parameters of a medium within the pneumatic conveying chamber of a cotton harvester presents an interesting practical challenge. This analysis allows us to determine the optimal parameters for designing an efficient pneumatic conveying system.

The theoretical framework for studying the motion of fibrous materials in a pipeline is introduced, taking into account the variations in velocity and pressure within the air mixture [1]. The flow of an aerosol mixture containing fibrous material through a horizontal, circular cylindrical pipe is examined. The mathematical modeling of material flow through pipelines and the description of the governing equations consider the physical and mechanical properties of fibrous media, including compressibility, deformability, geometric shape variability during flow, and high porosity. To generalize the system of equations governing motion and continuity for a compressible aerosol mixture, a new equation is proposed that relates the flow pressure to the true density of the medium. The solutions to these equations yield a law that describes how both velocity and pressure change within the aerosol mixture.

Reference [2] analyzes analytical studies of aero-elastic oscillations of cotton-air masses in cotton-harvester pipelines, developing a mechanical-mathematical model of these oscillations in straight pipelines of a pneumatic system, along with a calculation algorithm. Unlike previous work, this study considers the transport process as a function of changes in the longitudinal and transverse displacements of the center of gravity of a cotton batch, caused by airflow pressure pulsations.

In reference [3], studies were conducted to determine the aerodynamic drag for one type of material used in suction pipelines. Reference [4] includes an analysis of the pneumatic transport system of a cotton harvester. This paper calculates the aerodynamic drag in the suction pipelines of a picking machine for different pipeline materials and provides recommendations for enhancing the performance of cotton harvesters. These recommendations aim to identify materials that minimize drag values and energy consumption. When upgrading cotton harvesters for improved performance, it is suggested to construct the suction pipeline using these optimal materials.

The flow of an air-cotton mixture through a pipeline with variable cross-section is examined as a multi-velocity non-homogeneous medium [5]. Equations for cotton porosity, air pressure, and component velocities are derived. This multi-velocity model of the cotton-air mixture as a non-homogeneous medium in pneumatic pipelines provides a more accurate description of the air and material flow during pneumatic conveying, making it suitable for pneumatic conveying calculations and design.

Reference [6] examines the pneumatic conveying system of a cotton harvester. This paper proposes upgrading the system to improve its performance. A refinement of the piping system is proposed for the cotton harvester's design, corresponding to a final velocity of less than 6 m/s in the harvester's receiving chamber.

In this article, using the law of conservation of mass, an analytical expression is obtained for the velocity of the medium exiting the cotton harvester's pneumatic conveying chamber.

Material

Consider the piping of a cotton harvester's pneumatic conveying system. It is known that the cotton harvester's pneumatic conveying system transports raw cotton, which enters the chamber through the loading slot and then through the chamber into the hopper. From section 2, the cotton collected by the harvester and ejected through the loading slot enters the chamber at a velocity of v_2 and a specific flow rate Q_2 (Fig. 1). A high-velocity air stream is supplied from section 3 (the velocity and flow rate of the medium in this section are v_3 and Q_3, respectively), directing the cotton toward the hopper through section 1 (the velocity and flow rate of the medium in this section are v_1 and Q_1). It is required to determine the velocity of the medium exiting the chamber at section 1.

To quantify the outflow of the medium from the pneumatic conveying system chamber, we use the law of conservation of mass for a moving continuous medium and determine the velocity of the medium exiting the chamber at section 1.

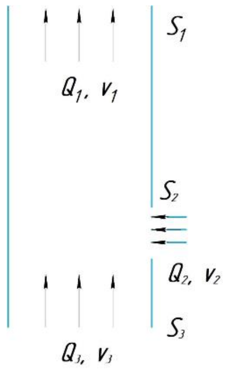

Fig.1.

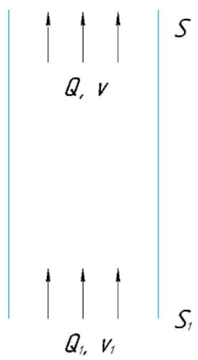

Fig.2.

It is known that the continuity equation expresses the law of conservation of mass, written for a moving continuous medium [7]. According to this law, mass m of the medium entering the chamber and subsequently the hopper remains constant throughout its entire motion, and for this constant, we have:

$$\frac{dm}{dt}=0. \quad (1)$$

Substituting the expression for the mass of the medium as the product of the density and volume of this medium, $m=\rho V$, we obtain

$$\frac{dm}{dt}=\rho\frac{dV}{dt}+V\frac{d\rho}{dt}=0, \quad (2)$$

where V – is the elementary volume of the moving continuous medium, ρ - is the density of the continuous medium, $\frac{dV}{dt}$ - is the rate of relative cubic expansion of fluid equal to $\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}+\frac{\partial u}{\partial z}$.

Considering this and passing to the limit $V\to 0$, from (2), we obtain:

$$\frac{\partial\rho}{\partial t}+\rho(\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}+\frac{\partial u}{\partial z})=0.$$

Substituting the expression for density ρ, which is a function of coordinates and time:

$$\frac{d\rho}{dt}=\frac{\partial\rho}{\partial t}+u\frac{\partial\rho}{\partial x}+v\frac{\partial\rho}{\partial y}+w\frac{\partial\rho}{\partial z},$$

we obtain the differential continuity equation for the unsteady three-dimensional flow of a continuous medium:

$$\frac{d\rho}{dt}+\frac{\partial(\rho u)}{\partial t}+\frac{(\partial\rho v)}{\partial x}+\frac{\partial(\rho w)}{\partial y}=0.$$

Assuming the flow to be stationary, for an incompressible continuous medium, we obtain:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0. \quad (3)$$

The resulting equation is called the differential continuity equation for steady-state motion of an incompressible continuous medium.

We define the continuity equation for a continuous medium outflowing from a channel with inlet cross-section S_1, velocity v_1, flow rate Q_1, and outlet cross-section S, velocity V, and flow rate Q. That is, we first consider the section where the medium exits the chamber and is directed into the hopper (Fig. 2). For this, we use equality $Q_1=Q$. Hence, $S_1v_1=Sv$. The equality obtained

$$\frac{v_1}{v}=\frac{S}{S_1} \quad (4)$$

is the continuity equation for a continuous medium flowing from a channel with inlet cross-section S_1, velocity v_1, flow rate Q_1, and outlet cross-section S, velocity V, and flow rate Q.

Now consider a chamber where part of the medium enters the chamber through a loading slot with cross-section S_2, velocity v_2, flow rate Q_2, and part of the medium enters from a section with cross-section S_3, velocity v_3 and flow rate Q_3. For the flow rates by cross-sections, we obtain:

$$Q_1=S_1v_1,\ Q_2=S_2v_2,\ Q_3=S_3v_3. \quad (5)$$

According to the above law of conservation of mass, for the flow rates we obtain:

$$Q_1=Q_2+Q_3. \quad (6)$$

Substituting (5) into (6), we obtain the continuity equation for the incoming flow into the chamber and the continuous medium exiting it:

$$S_1v_1=S_3v_3+S_2v_2 \quad (7)$$

and from this, we determine the velocity of the medium at the exit, i.e., in section 1:

$$v_1=\frac{S_3v_3+S_2v_2}{S_1}. \quad (8)$$

Thus, we have determined the velocity of the medium exiting the pneumatic conveying chamber of a cotton harvester.

Conclusion

An analytical expression for the velocity of the medium exiting the pneumatic conveying chamber of a cotton harvester was derived, using the known inlet velocities of the incoming media from the loading slot and the air jet opening, to quantitatively assess the outflow of the medium from the pneumatic conveying chamber.

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