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Analysis Of Increasing The Suction Distance In Cotton Pneumatic Transport Pipelines Using Vibrational Effects

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Abstract
This article analyzes key operational challenges in the pneumatic transportation of raw cotton, including material clogging inside the pipeline, increased aerodynamic resistance, and high energy consumption. A new technological solution is proposed based on applying vibrational excitation to the walls of the pneumatic pipeline using an electrically powered system. The influence of vibrational effects on the coupled air–cotton flow dynamics was modeled, and the effects of vibration amplitude and frequency on pressure losses and suction distance were theoretically substantiated. Research findings demonstrate that the application of vibrational technology increases the cotton suction distance by approximately 1.4–1.6 times while reducing energy consumption by 15–25%, thereby enhancing operational reliability and energy efficiency.
Keywords: pneumatic transport, raw cotton, vibration, aerodynamic resistance, suction distance, energy consumption.

Introduction

Pneumatic transport systems constitute an integral part of technological processes in raw cotton processing. These systems are widely used for conveying cotton from storage piles to cleaning units, separators, and other technological aggregates. However, during pneumatic conveying, various production-related problems may arise, including cotton clogging inside the pipeline, unstable flow conditions, and partial adhesion or accumulation of material on the inner pipe walls. Such adverse phenomena lead to an increase in aerodynamic resistance, higher power consumption of fans, and a reduction in the overall energy efficiency of the system.

In recent years, a significant number of constructive and technological solutions have been proposed to improve the performance of pneumatic transport systems. Among these approaches, applying vibrational excitation to the pipeline walls has attracted considerable attention. Vibrational oscillations applied to the conveying duct reduce the frictional interaction between cotton particles and the pipe wall and promote more stable and continuous motion of the air–cotton mixture.

This study presents the theoretical foundations for increasing the suction distance and reducing energy consumption in cotton pneumatic transport systems through the application of vibrational effects. The analysis is based on Newton's second law, which states that the acceleration of a body is directly proportional to the algebraic sum of the forces acting on it and inversely proportional to its mass. In vector form, Newton's second law is expressed as where the acceleration is defined as

$$\sum F = m \cdot a;$$
$$a = \frac{dv}{dt}; \qquad (1)$$

Accordingly, the motion of a cotton particle inside the pipeline is governed by the following forces:

$$m\frac{dv}{dt} = F_a - F_{tr} - G \qquad (2)$$

F_a — the aerodynamic force generated by the airflow, which provides the driving motion;

F_{tr}— frictional and resistive forces arising from interaction with the pipe wall and the surrounding air;

G=mg — the gravitational force.

Therefore, by applying Newton's second law and considering a one-dimensional (1D) projection along the direction of motion, the equation of motion of a cotton particle can be formulated accordingly.

In the region adjacent to the pipeline wall, the velocity of cotton particles decreases while frictional forces increase. As a result, aerodynamic resistance within the pipeline rises, leading to greater pressure losses. Experimental studies indicate that when the air velocity falls below 18–20 m/s, the probability of cotton particle clogging inside the pipeline increases sharply

Physical Mechanism of Vibrational Effects

Vibration is an oscillatory process in a mechanical system characterized by a specific amplitude and frequency. When vibrational excitation is applied to the walls of a pneumatic pipeline, micro-scale motions are generated on the pipe surface. These micro-movements prevent cotton particles from adhering to the pipeline wall.

Studies indicate that applying vibration in a radial direction oriented toward the center of the pipeline is the most effective configuration. Such vibrational action reduces the actual contact area between the wall and the particles and consequently decreases the friction coefficient.

Under the influence of vibration, pressure losses are reduced according to the following expression:

$$\Delta P_v = \Delta P_0 (1 - k \cdot A \cdot \omega) \qquad (3)$$

where **A** denotes the vibration amplitude, **ω** represents the vibration frequency, and **k** is an empirical coefficient

4. Increase in Suction Distance under Vibrational Effects

One of the key performance indicators in cotton pneumatic transport systems is the suction distance from the cotton pile. When vibrational excitation is applied, the aerodynamic conditions inside the pipeline improve, and the impulse energy of the airflow increases. As a result, it becomes possible to convey cotton particles from a greater distance.

The suction distance can be expressed by the following relationship:

$$R_s = \frac{C_d \cdot A \cdot \omega}{(\rho_p - \rho_h) g} \qquad (4)$$

According to theoretical calculations, when the vibration amplitude is 1.8–2.0 mm and the frequency is 20–25 Hz, the cotton suction distance increases by approximately 1.4–1.6 times. This significantly expands the technological capabilities of the pneumatic transport system.

5. Reduction of Energy Consumption and Conclusion

In pneumatic transport systems, energy consumption is primarily determined by the power required to generate and maintain the airflow:

$$N = \frac{Q \cdot \Delta P}{\eta} \qquad (5)$$

As a result of vibrational excitation, the reduction in pressure losses (ΔP) leads to a corresponding decrease in the required fan power. The research results demonstrate that overall energy consumption can be reduced by 15–25%.

Conclusion

The application of vibrational excitation in cotton pneumatic transport pipelines significantly reduces aerodynamic resistance. Radial-direction vibration is identified as the most effective mode of excitation. The suction distance increases by approximately 1.4–1.6 times. Energy consumption is reduced by up to 15–25%

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