Improvement of the design of the aeration device of the pneumatic chamber pump

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Abstract. The production of building materials is a complex technological process involving the processing of raw materials with various physical and mechanical properties, as well as using a variety of degrees of complexity of technological equipment and auxiliary mechanisms. High-pressure pneumatic transport has found application in construction, refractory, chemical and other industries. It is widely used for transportation of fine-grained bulk materials such as cement, alumina, soda, apatite, ash, clay, synthetic products, mineral fertilizers. The process of pneumatic transportation occurs due to the action of compressed air on the material being moved. However, at the same time, as a rule, there are through channels in the material layer, which leads to an increased consumption of compressed air, part of the unloaded material remains at the bottom of the pump chamber, which reduces productivity. Due to the fact that some fluidizing devices can form through channels in the material layer and given the large volumes of material being transported, it is necessary to solve issues to improve the efficiency of pneumatic chamber pumps and reduce the consumption of compressed air required for transporting bulk materials. This can be achieved by organizing effective fluidization of the material, that is, uniform mixing of the transported material with air.

1. Introduction

Pseudo-fluidizing is a transition state between a stationary layer of bulk material and the entrainment of the material by the compressed air flow, which occurs in a certain range of air flow rates through the material layer, which depends on the design of aerating devices. It should be noted here that an increase in the concentration of the cement-air mixture leads to an increase in the performance of the pneumatic chamber pump.

Pneumatic transportation has a number of advantages over traditional means of transporting bulk materials: high lifting height and transportation distance (up to 3000 m), the use of areas unsuitable for other transportation methods, the complete absence of residues and losses of the transported product in pipelines, the exclusion of violations of technological and hygienic conditions of the air environment in industrial premises due to the lack of dusting, ease of installation, the possibility of full automation of management, compactness. However, pneumatic transportation consumes a large volume of compressed air. Therefore, for some materials, the air consumption reaches 250 m³ per ton [1-4].

Depending on the location of the chamber, pneumatic chamber pumps are available with vertical, horizontal or inclined chambers. However, vertical pneumatic chamber pumps are widely used due to better material flow conditions and, consequently, more uniform discharge [5-7].
2. Materials and methods

A pneumatic chamber pump with upper material discharge and aeration device is a metal tank, the upper part of which is made in the form of a hemisphere, and the lower part is made in the form of a hemispherical bottom. The loading spout is closed with a conical valve.

Pump operation is periodic. They open the loading spout, and the chamber is filled with the transported material to a certain level. Then the fuelling port is hermetically closed with a valve and a tap is opened to supply compressed air to the space between the porous partition and the bottom of the chamber. Air penetrates through the porous partition into the chamber, brings the material to the fluidized state, and the chamber is discharged through the discharge pipe. After emptying the chamber, the air supply stops and the operation cycle repeats.

To solve the problem of reducing the consumption of compressed air for cement transportation, a new design of the aeration device of the pneumatic chamber pump was developed.

The proposed design of a multi-nozzle aeration device has a number of features that increase its efficiency in comparison with other used multi-nozzle systems. First of all, the number of aero elements that are evenly spaced across the entire cross-section of the chamber and have certain bending and turning angles has been significantly increased. As a result of a closer arrangement of the nozzles, the volume of stagnant zones located between them decreases and the uniformity of cement distribution increases.

The pneumatic chamber pump contains a chamber with a loading valve located in the upper part for supplying the material to be transported and a spout for releasing compressed air. At the bottom of the pump chamber, a multi-nozzle aeration device is placed, which is a pipe made in concentric circles, in the lower part of which are welded nozzles directed towards the bottom, the output ends of which have a bending angle of 50-70° relative to their vertical axis, and relative to the radius drawn through the nozzle axis from the center of the aeration device, have a rotation angle of 20-25°.

The discharge pipe located in the center of the pump chamber is a vertical pipe equipped with a confuser in the lower part. In the center of the bottom of the pump chamber there is a central nozzle, which is necessary to increase the speed of the cement-air mixture in the discharge pipe. A pipe is welded inside the upper part of the chamber to supply compressed air above the layer of loaded material.

The nozzles of the aeration device are oriented in such a way that the outgoing jets have velocity components directed downwards and tangentially to the air rings. This allows creating a vortex field in the lower part of the pump chamber that narrows to the entrance to the discharge pipe, preventing the formation of through channels in the material layer. As a result of air jets flowing out of the nozzles, the cement is intensively mixed with air and the cement layer is agitated. A number of authors claim in their works that the best pseudo-fluidizing properties have aeration devices that have flat aeration elements using porous partitions. Their main advantage is that they create a uniform pseudo-fluidized layer. As porous partitions of aeration devices, technical felt, fiberglass, and polystyrene are used, but they have a big drawback – clogging of pores as a result of humidification. Ceramic partitions are also used, which have good anti-corrosion properties and can withstand high temperatures, but quickly fail when the temperature changes. Metal partitions do not have the above disadvantages, but they are prone to corrosion. In general, gas distribution grilles tend to clog the pores and nozzles, which can lead to complete sticking of the holes, and, consequently, a decrease in the live section of the partition, which leads to a deterioration of the pseudo-fluidization of the material.

If the flow of the conveying agent (compressed air) passes through the material layer at different speeds, the state of the pseudo-fluidized bed is different depending on the speed of this flow. In order to achieve efficient pseudo-fluidization with an optimal flow rate of compressed air, it is necessary to maintain a constant airflow rate, which depends on the pseudo-fluidization rate of the material.

All these disadvantages can be eliminated by rational selection of the aeration device for a certain type of transported material. In particular, for cement with its physical and mechanical properties, pseudo-fluidization using aeration devices in the form of porous partitions is difficult. The use of nozzle devices with low hydraulic resistance does not always have the necessary effect on the cement,
which, following an increase in efficiency, can lead to an increase in the consumption of compressed air. Therefore, for effective operation of pneumatic chamber pumps with reduced compressed air consumption, it is necessary to use a rational design of aeration devices [6, 8, 9].

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The pneumatic chamber pump contains a chamber with a loading valve located in the upper part for supplying the material to be transported and a branch pipe for releasing compressed air. At the bottom of the pump chamber, a multi-nozzle aeration device is placed, which is a pipe made in concentric circles, in the lower part of which are welded nozzles directed towards the bottom, the output ends of which have a bending angle of 50-70° relative to their vertical axis, and relative to the radius drawn through the nozzle axis from the center of the aeration device, have a rotation angle of 20-25°.

The nozzles of the aeration device are oriented in such a way that the outgoing jets have velocity components directed downwards and tangentially to the air rings. This allows creating a vortex field in the lower part of the pump chamber that narrows to the entrance to the discharge pipe, preventing the formation of through channels in the material layer. As a result of air jets flowing out of the nozzles, the cement is intensively mixed with air and the cement layer is agitated.

3. Results

Thus, due to the specific location of the aeration device nozzles, the pseudo-fluidization of the material is improved and a homogeneous pseudo-fluidized layer is formed at the entrance to the discharge pipe with no empty channels, which reduces the consumption of compressed air and increases the performance of the pneumatic chamber pump.

This is confirmed by the results of simulation modelling of the creation of a pseudo-fluidized layer depending on the shape and location of the nozzles (figure 1) using the software product Solid Works.

Figure 1, a shows that the air stream coming out of the nozzle tends to the discharge pipe in an almost straight trajectory, and only at the entrance to the discharge pipe, due to the meeting of air flows coming out of neighboring nozzles, a pseudo-fluidized layer is created, where an active process of mixing air with cement occurs. However, it is possible to create undesirable pore channels through which air passes without affecting the cement, which is negative in the pseudo-fluidization process. On the other hand, there are so-called dead zones at the bottom of the pump chamber, in which the air jets practically do not have a useful effect on the loaded material, which leads to an increase in the unloading time and compressed air consumption.

![Figure 1. Results of simulation modeling of pseudo-fluidized layer creation depending on the shape and location of the nozzles: a – straight nozzles, b – nozzles with turning and bending angles.](image-url)
Figure 1. b clearly shows the flows that are created by air jets coming out of the nozzles with angles of rotation and bending. As they can see, air flows are more active on the cement in the area of air supply from the nozzles most remote from the discharge pipe, as well as at the bottom of the pump chamber. At the bottom of the chamber, a vortex field is created closer to the center, which has a more effective effect on the material and prevents the formation of through channels, which increases the uniformity of the cement distribution in the pseudo-fluidized layer. Due to the action of the downward and tangential components of the jet velocity, stagnant zones and pore channels are eliminated, which significantly affects the flow of compressed air. At the same time, the created pseudo-fluidization zone (figure 1. b) is larger than when using direct nozzles (figure 1. a), which facilitates the process of involving the cement-air mixture in the discharge pipe, and, consequently, reduces the time of unloading the pump chamber.

Analyzing the results obtained using simulation modeling and based on the fact that the aeration device with nozzles having rotation and bending angles pseudo-fluidizes bulk material more effectively, the main factors affecting the process of pneumatic transportation were determined. The main parameters that characterize this process are the productivity and specific consumption of compressed air. The capacity is directly proportional to the discharge time of the pump chamber, therefore, for convenience, it is necessary to study the dependence of the discharge time [10, 11].

Using the analytical package Maple, three-dimensional figures were constructed showing the dependence of the unloading time on changes in the main factors at fixed time values $\tau_r = 6, 12, 18$ seconds (figure 2). If necessary, they can build these figures for any value of not only time, but also other functions (if there is an appropriate regression equation).

Thus, it is possible to determine the geometric and technological parameters of the pump, that is, at what values of the main factors one or another value of the unloading time, productivity, and air consumption is obtained.

![Graphical structures](image)

**Figure 2.** Graphical structures that display fixed values of unloading time depending on the main factors: 1 - $\tau_r = 6$ sec; 2 - $\tau_r = 12$ sec; 3 - $\tau_r = 18$ sec.

Figure 2 shows surface 1, where any point shows at what values of factors the minimum unloading time $\tau_r = 6$ seconds can be obtained, namely, when the values of the main factors are combined in a
certain range. Geometric parameters are regulated structurally, because this is inherent in the design and manufacture of the laboratory installation, and the excess pressure affects the air flow rate, and, consequently, the energy consumption of the transportation process, it can be assumed that it is advisable to use the values of factors on the surface $I$, choosing the minimum pressure value in the pump chamber. With certain parameters, it is possible to get the maximum performance of the pneumatic chamber pump. In this regard, we can conclude that the second performance is one of the main technical and economic indicators of the pneumatic chamber pump.

4. Discussion
Under certain conditions, for example, when aggregating cement, its bulk density increases, so often when air is supplied from the nozzles, so-called pore or through channels occur, through which air passes through the cement without mixing with it and without creating a fluidized layer in this area.

5. Summary
Thus, the proposed design of the multi-nozzle device has a simple design in comparison with known aeration devices and provides effective aeration of cement in the discharge part of the pump chamber, as well as due to the geometric arrangement of the nozzles, a homogeneous pseudo-fluidized layer is formed in the pump chamber, which reduces the time of its unloading and reduces the consumption of compressed air.

6. References
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