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SYSTEMS OF PNEUMATIC TRANSPORTATION OF CEMENT AND OTHER FINE MATERIALS WITH THE MINIMUM ENERGY CONSUMPTION

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ABSTRACT

Transportation of fine construction materials during the manufacturing of concrete mixes is carried out by systems of pneumatic transportation. The expense and pressure of air in the systems are overstated during their design to avoid the blockage of pipelines. As a result, the energy consumption of the equipment increases. At the same time, the equipment wear is accelerated and the systems are operated on the unstable modes. Therefore, the operational reliability of such equipment decreases and the process of cleaning of the exhaust air becomes complicated. The solution of the problem of ecologically safety transportation of fine construction materials with the minimum energy consumption is given in the article. The authors developed a new type of energy saving systems of pneumatic transportation. It allows reducing overstated reserves of the air expense and pressure during the design of the systems.

Keywords: pneumatic transportation, fine materials. dust removal equipment, pape line.

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1. INTRODUCTION

Pneumatic transportation systems can be simple (with one pipeline) and branched (with two and more pipelines) depending on quantity of pipelines [1].

The branched pneumatic transportation systems have a number design features and dynamic properties. We can identify three types them, which are shown in fig. 1.

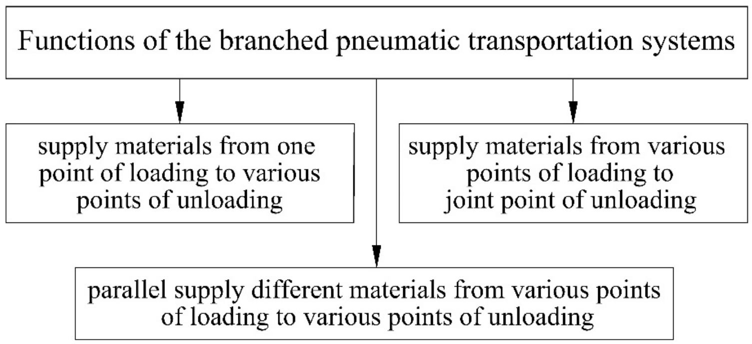

Fig.1. Types of the branched pneumatic transportation systems

The branched pneumatic transportation systems can have up to 20-30 and even more loading and unloading points. The loadings of pipeline can be equal and various. The main feature of the branched pneumatic transportation systems is influence of the loading change in one of pipelines on the reliability of other pipelines. It means that such systems is technologically connected [2].

The aims of the research work are the following:

- identify key parameters of such systems;
- consider the main aerodynamic characteristics of the pneumatic transportation stream;
- identify problems of maintenance of optimum working speed of transportation;
- make the analysis of goal functions of management and select effective managing influences;
- make the mathematical analysis of dynamics of the pneumatic transportation process.

2. KEY PARAMETERS OF THE PNEUMATIC TRANSPORTATION SYSTEMS

Transportation of firm particles (disperse phase) at the systems happens under the influence of the aerodynamic forces, which occur in the result of interaction between particles of the transported material and an air stream. Particles of a disperse phase are reason of the turbulent disturbance, which occurs in the volume of an air stream. They make external impact on pattern of their movement [3].

Therefore, it is necessary to take into account the presence of pulsation speeds in the air stream if we consider mechanism of the firm particles movement. The disperse medium has a property "memory of tension". It means that any dynamic influence on granular medium does not take place without trace. The granular medium remembers by saturation limit of information, expressed through the tension. The saturation limit of information is determined by physical-mechanical properties of the fine material (fig. 2).

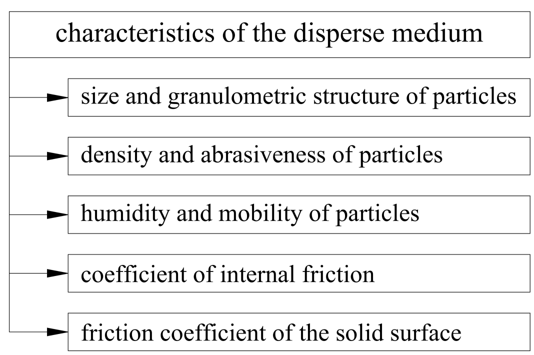

Fig.2. Characteristics of the disperse medium, which influence on energy consumption

The transported fine materials seldom have a spherical form and they are usually poly-disperse. The average size of particles is an integral characteristic, taking into account distribution of the particle size.

It is necessary to measure the granulometric structure of the transported material for determination of this characteristic. We can also assume that the distribution of the particle size is deterministic and describe it in the form of some function with constant coefficients.

Poly-dispersion of cement is caused by the technology of its grinding. This technology means that readymade cement should have a high specific surface and meet a certain particle size distribution for the curing process improvement.

The density of fine material depends on a way and storage period. Properties of fine materials largely depends on porosity ε, characterizing a gas share of the stream. We can see specific phase transformation in the certain range of values ε. For example, if ε<0.5-0.6 fine materials can show properties of a solid body, if ε>0.6 they get properties of pseudo-liquid. This feature is used for improvement of flowability of the compacted or packed material by using compulsory supply of gas in the material (aeration loosening).

The particle compaction characterizes the property of fine materials to lose mobility of particles at long storage or at the vibration impact. The particle compaction rises with the humidity increase and the increase of the layer height. The humidity changes elastic properties of particles and influences on the losses of pressure during pneumatic transportation. The particle abrasiveness is connected with their using-up ability, which is shown at direct contact of particles with a firm surface. Cement, mineral powder, ashes and sand have the considerable using-up ability.

The value of the natural slope corner depends on humidity of material and its condition (rest, movement), that is on the value of coefficients of internal and external friction. The value of slowdown of the particle speed after mechanical shock with the internal surface of the pipeline is determined by coefficient of restitution. Its value depends on elastic properties of the transported material and condition of the pipeline internal surface.

3. MAIN AERODYNAMIC CHARACTERISTICS OF THE PNEUMATIC TRANSPORTATION STREAM

The main aerodynamic characteristics of the pneumatic transportation stream are shown in fig. 3.

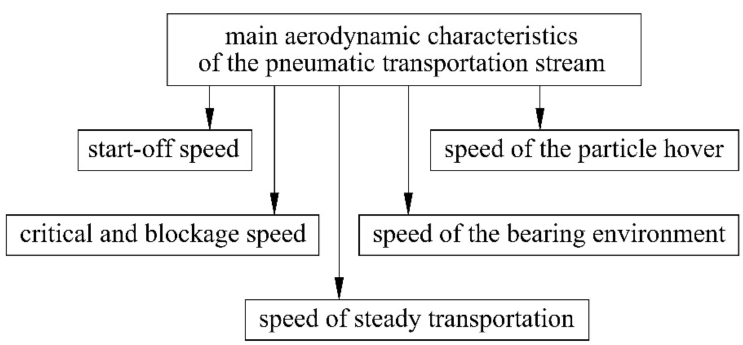

Fig.3. Aerodynamic characteristics of the pneumatic transportation stream

The value of speed of the particle hover depends on conditions of a flow of the particle, which are determined by the sizes of cross section of the stream and particle, as well as influence of the next particles. The research results show that the speed of the particle hover in cramped conditions is less than free conditions. It is necessary to take into account geometrical and aerodynamic coefficients of a form when we determine the speed of the particle hover.

Speed of start-off is the minimum speed of air, at which the single particle, lying at the bottom of the horizontal pipeline (the slope angle of pipeline to the horizon is less than 60°), starts moving on the pipeline. Critical speed is speed, under which loss of the particles from the airstream on the bottom of the horizontal pipeline takes place. The critical speed is start-off speed for its physical essence. It is necessary to avoid precipitation of particles on the pipeline bottom when we arrange the pneumatic transportation. Speed of steady transportation is the minimum air speed, providing steady movement of particles in suspension. The transportation mode in thin phase (with low mass account concentration) is characterized by the high speeds of the bearing environment, which considerably exceed the speed of the particle hover, and the large air expenses. Losses of pressure in the pipeline are small; distribution of particles for pipeline section is almost uniform.

The value of local speeds of bearing environment exceed the value of speed of removal of the solid component particles under large concentration of particles in the stream. It characterizes pneumatic transportation in dense phase. As a result, differential pressure in the pipeline increases. This transportation mode is favorable for reduction of specific transportation costs, because the value of the average speed of bearing environment at this mode is less than at transportation in thin phase.

4. PROBLEMS OF MAINTENANCE OF OPTIMUM WORKING SPEED OF TRANSPORTATION

Reliable and economical work of the pneumatic transportation system depends on right choice of working speed of transportation. It is important, because high speed causes the increase of energy consumption, quality loss of particles and short life of equipment, on the contrary, slow speed, which is slower than critical speed, causes the pipeline blockage.

Blockage speed is a speed of the bearing environment, at which the pipeline blockage occurs. The blockage is an outcome of the unstable transportation mode, which occurs in the result of different reasons: from the load change to problems of maintenance. The load increase under the constant air speed causes the uneven distribution of particles for section and length in the horizontal pipeline. The drop of particles on the pipeline bottom takes place under the influence of gravity force, stability of the stream is broken, the blockage occurs. The blockage starts under less air speeds in vertical pipeline, because there is less stream separation due to the opposite orientation of gravity and aerodynamic force. The air speed, which is close to the blockage speed, is boundary condition of the pneumatic transportation existence in thin phase.

The research works analysis of the blockage appearance shows that we cannot identify a general pattern of sustainable transportation without depending on the following parameters: characteristics of transported material; direction of transportation; number of the pipeline rotates; level of branching of the pneumatic transportation system. Branches cause falling of the stream speed and, as a result, earlier blockage appearance. It is difficult to measure precisely the air speed, which causes the blockage, because the transportation mode is unstable in this area, the significant fluctuations of pressure and speed take place [4, 5].

The branched pneumatic system of transportation of fine materials is technologically connected system with high performance. Any change of the materials volume in pipeline causes redistribution of air consumption between the all pipelines. In this case, there is at least one pipeline in the system, in which the air consumption reduces as compared with original value. The transportation of material stops and the blockage starts when the air speed reduces to the value, which is below minimum. Thus, it is necessary to keep the air speed in the all pipelines for providing the normal process of the pneumatic transportation.

Non-stationary nature of influence on the system causes discrepancy of the quality parameters to required limitation. Therefore, the automated control system has to adapt for changing of maintenance conditions by changing control parameters. It is necessary to create the information environment for development of an effective automated control system for pneumatic transportation. It allows realizing suitable management, excluding the influence of load fluctuations on the speed of transportation of solid particles.

The analysis of tool and information support of the process of pneumatic transportation shows that reliable information about it can be received by using the jet pneumatic method. It provides universality in measurement of parameters and the high reliability in the conditions of a dust content due to existence of the weighed particles.

5. ANALYSIS OF GOAL FUNCTIONS OF MANAGEMENT

This stage is the most important in development of the management algorithms of the pneumatic transportation process. Various scientists consider as goal functions of management the following [6, 7]:

- reduce of specific energy consumption for transportation;
- uniform distribution of material for the pipeline section;
- alignment of a high-speed field;
- minimization of the transport equipment wear;
- increase of transportation way;
- increase of the transportation reliability under low aero mix movement speeds;
- providing capacity of pipelines;
- maintaining the quality of the transported material;
- reduction of capital and operating costs during construction and operation of the pneumatic transportation systems.

The above-mentioned functions are closely connected with each other. The realization of these functions, connected with aerodynamic parameters, requires the increase of energy consumption and costs of pneumatic transportation.

The operating experience of the pneumatic transportation systems in various industries shows that the main cost components of the transportation are energy and depreciation components, reaching 50% and 30% respectively. Thus, they depend on transportation parameters [8].

We can consider thoroughly these parameters. The major factor, limiting service life of the pneumatic transportation equipment, is intensive wear of the elements in the result of influence of abrasive particles of the transported material. Branches are one of the most vulnerable sites from the point of view of wear. The service life of a steel knee is hundred times less than the rectilinear steel pipeline in the equipment of delivery action at cement transportation. Abrasive wear of pipelines and their elements occurs owing to the scratching and shock influence of particles. It depends on the speed of movement of a two-phase stream (it is proportional to the 3rd degree of speed), density of the stream, sizes of particles, the turbulence intensity of the stream, wear resistance of the pipeline material.

The damages of the pipeline, occurring in the result of wear, can distort considerably aerodynamic parameters due to suction of external air or partial emission of the stream outside. The increase the air consumption in the result of suction causes the growth of hydraulic resistance of the pipelines and dust collectors, which can put the equipment out of action. Reduction of the air consumption causes slowdown of the speed in the pipelines. It can cause the particles drop from the stream and the pipeline blockage. It is necessary to have information about density of the transported aero mix for maintenance of pipelines in working conditions. The signal of critical change of the stream density allows carrying out timely diagnostics of the pipeline damage and responding appropriately. Engineers try to solve the problem of wear reduction of the pipelines by using methods of aerodynamic regulation and application of perspective coverings of an internal surface of steel pipelines. Aerodynamic regulation for the purpose of wear reduction is made by arranging steady transportation of abrasive material. In this case, the possibility of the particles drop from the stream is practically excluded and we can avoid undesirable increase of the air consumption. In other words, the wear reduction requires maintenance of the optimum working parameters of the stream.

From the point of physics of the process, the most informative parameter of management is the true density of aero mix, that is density of gas components of the disperse environment, which allows judging about consumption of the transported material and concentration of firm phase. We can see integral feature of this parameter, because change of loading or speed of the bearing environment immediately affects the aero mix density. It allows considerably reducing the influence of transport delay of the system. Regulation of the material consumption in the system, based on information about density of aero mix and speed of the bearing environment can provide higher precision of regulation in the set mode. It allows applying an optimum type of the managing influence by means of change of the speed of the bearing environment and, as a result, receiving wider range of regulation.

6. RESULTS AND DISCUSSION

Mathematical models of branched and unbranched pneumatic transportation systems, taking into account micro and macro structure of the stream, were made for various technological modes and types of equipment. They were used to research the pneumatic transportation process as the object of optimization and automatic control [9, 10].

Energy expenses were determined by function of the speed of the bearing environment v and density of aero mix ρ_a (1).

$$N = N(v, \rho_a) \tag{1}$$

From energy point of view, the most favorable is keeping working transportation speed close to critical value. However, the unregulated pneumatic transportation system is technologically connected system. It means that reduction of the stream speed below the critical value can be in the loaded pipeline. Therefore, providing of sustainable transportation requires the increase of the working speed. The automatic control is required in such conditions. Its aim is to shift the working speed closer to boundary of sustainable work under the same values of load.

Realization of such regulation is possible in two ways. The first is to increase speed of the bearing environment in the loaded pipeline proportionally to the load growth. Such algorithm of regulation allows carrying out the best compensation of loading in the loaded pipeline. However, the slowdown of speed in the other pipelines occurs due to technological connectivity of the system in the process of regulation in the dynamic mode. In this case, if speed of the bearing environment reaches critical value and even less, emergency mode will occur. It is necessary to involve additional energy resources to avoid this situation. However, it increases energy expenses in the system.

In this connection, another regulation conception is conception of planned ahead energy loss. The point of this conception is the use of partial compensation of load in the loaded pipeline. The reduction of the bearing environment speed occurs if we increase the load. Meanwhile, it does not repeat the low of speed changing at passive mode of the stream stabilization in the technologically connected system. Such regulation leads to some planned ahead energy loss in the loaded pipeline.

In this case, the aim of research is to determine optimal necessary level of concessions, which we have to do in the loaded pipeline to provide sustainable transportation mode in the all pipelines without additional energy consumption. In this way, the algorithm of functioning of the regulation system is reduction of energy consumption for recover of the technologically safe mode of transportation in the loaded pipeline for one regulation cycle.

The analysis of the branched pneumatic transportation systems as the object of management shows that the influence of input and disturbing factors, which can be distinguished by level of the availability to measurement, is typical feature for such systems. The most dangerous disturbing factors are random fluctuations of consumption of the transported material with prevalence of low fluctuations with an amplitude up to 30% and the determined fluctuations with an amplitude up to 100% [11, 12].

The air distribution for separate pipelines in the unregulated pneumatic transportation system takes place in accordance with their hydraulic resistance. Change of loading in one of pipelines influences on operating mode of other pipelines. In this case, transfer from one condition to another is carried out in a split second. High level of hindrances, small lag effect and the hidden nature of the process complicate an assessment of the process conditions and its characteristics. Nonstationary feature of the process characteristics does not allow using usual laws of management. The above-mentioned factors make us adapt the algorithms of management to the current characteristics of the process.

7. CONCLUSION

The research results testify to minimum values of energy costs are on border of physical realization of the pneumatic transportation process. The variation value of the bearing environment speed in the unregulated pneumatic transportation systems is determined by the load value. In this case, the maximum shift of working speed from the optimum point to the increase occurs, that corresponds to the maximum energy consumption.

The aim of development of the automatic regulation system is to shift the working point closer to the border of resistance under the same values of the load. For realization of the developed algorithm of optimization of energy consumption for the loaded pipeline were made the following steps:

- criterion of optimization of energy consumption for the loaded pipeline was determined.
- mathematical model of work of the loaded pipeline, taking into account mass of the transported material was made;
- adaptive system of regulation of the transportation mode in the loaded pipeline was synthesized;

- method of optimization of design and operating parameters of the system was developed.

Concept of adaptive automated management of the technological modes of the branched pneumatic transportation systems was made based on the analysis of the process of pneumatic transportation of cement and other fine construction materials.

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