Experimental studies of pneumatic impulse booster when unloading cement from metal tanks

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Abstract. The paper is devoted to solving the problem of increasing the efficiency of discharging powdered cement from metal tanks using an air-pulsed booster. The results of research on the experimental facility and the method of transition from them to production tanks, which are most common in mortar-concrete installations and inventory warehouses of cement, are presented. The scheme of the experimental stand developed by the authors is given. The authors obtain experimental dependences of the effectiveness of cement collapse on the power in the system of pulsed air supply and the effectiveness of its collapse on the size of the gap. Further, the paper establishes the nature of the outflow and the formation of cement hang at the bottom of the tank. Based on the results of experimental studies using the similarity theory and dimensional analysis, the parameters of the system of cement collapse in real tanks are determined.

1. Introduction
The problem of cargo processing and storage of bulk materials using storage tanks and bins is given considerable attention both in our country and abroad. Studies related to the storage and gravitational flow of bulk materials were conducted with various bulk materials such as coal, ore, crushed stone, grain, fine chemicals, and dustlike materials. This paper is devoted to the study of the process of unloading cement from containers that have a cylindrical-conical shape, using the pneumatic impulse system for the collapse of a frozen material. It should be noted that in the conditions of dispersed construction sites in agro-industrial and road construction, the most widely used roadside cement warehouses with a capacity of 360, 480 and 720 tons, which have mobility [1].

The practice of their operation has shown that the aeration roofing devices provided for by the project are not effective and difficult to operate. The complexity of their operation lies in the fact that, due to the humid air, air tracks often fail and there is a need to perform hazardous work related to lowering workers to the lower part of the tank and working with life threatening from collapse, stuck on the walls of cement. Therefore, there was a need to develop a set of blasting devices, which can be serviced from the outside of the tanks.

At the Voronezh State Technical University, the authors carried out experimental studies of the process of unloading cement from metal containers using a special driver — a deflector [2,3]. The deflector is a kind of "nozzle" through which compressed air is fed in short pulses into the frozen material. Figure 1 shows the scheme of the developed system, which consists of deflectors, high-speed shut-off valves and pipelines.
Figure 1. System of pneumatic impulse collapse of cement hangs: 1-deflector; 2-distribution manifold; 3 - stop valve; 4- air deflector screen; 5- deflector housing; 6- disc valve stem; 7 - spring; 8- adjusting screws.

The collapse of the frozen material is as follows. First, compressed air is supplied to two adjacent inclined rows from one distribution manifold. The result is a collapse of the sector of the frozen material located between the inclined rows of deflectors. After unloading the collapsed material, air is supplied to the next two rows of deflectors, etc. until complete elimination of freeze. After the collapse process is completed, the deflectors are purged. For the effective use of the proposed system of pneumatic destruction, it was necessary to conduct studies of the parameters and modes of its operation, as well as taking into account the influence of technological parameters of storage and unloading of bulk material [4-7].

The study of the process of unloading cement, the formation of hangs and their collapse by means of pneumatic pulses was performed using an experimental test bench, which consists of a bunker and a pneumatic screw elevator. The bunker model is made in the scale of 1: 6 to the geometric dimensions of the tank 120 tons: diameter - 500 mm, height of the cylindrical part - 2000 mm, conical - 265 mm.

The model of the tank and the bunker are communicated by means of a flexible rubber hose, due to which, when the model is loaded with cement, the air, after passing through the same filter, was released into the atmosphere. The pressure of compressed air in the receiver was maintained using a pressure regulator. Cement unloading from the model began no earlier than 40 minutes after it was loaded, since during this time the process of deaccumulating air from cement loaded in a small container ends [8-11].
As a result of experimental studies of the process of unloading cement, the following has been established. When the slide gate is opened, there is a massive outflow from the model, in which almost the entire volume of cement comes into motion. In the upper cylindrical part of the material flow is limited by the walls, in the lower cylindrical part for one fourth of its height - a narrowing of the flow occurs.

After lowering the free surface of the cement in the model at 0.2-0.3 m, the process of transition to the “normal” form of expiration begins. At the same time, there is a slowdown in the movement of the wall layers of cement, and in the central part a new channel of expiration is formed. The upper level of the cement at the model wall is lowered by another 0.1 m, after which full braking of the near-wall layers of material occurs and its “normal” discharge occurs through the central channel, the diameter of which in the upper part is 0.25-0.30 m. This is explained by the fact that as the material level is lowered, the energy of the moving material is insufficient to overcome the forces of resistance to movement along the boundaries of the existing discharge channel.

The material is unloaded up to the moment when, after the next lowering of the cement level, the ultimate stress state does not appear in the remaining part of the material, and the friction and adhesion forces with the wall are capable of holding it. These conditions characterize the process of formation of freeze-in bulk materials in tanks.

In the cylindrical part of the model, its surface represents a figure close to the surface of the ellipsoid of revolution, in the conical part it approaches the surface of a truncated cone. This form corresponds to the shape of the release figure when the cement has expired, outside of which the movement of the material does not occur.

Fixing the geometric parameters of cement hang-up showed that the distance from the plane of intersection of the surfaces of the ellipsoid of rotation and the truncated cone to the plane of interface of the cylindrical and conical walls is within ± 2-3 cm. to conical. Measuring the dimensions of the radius of the channel in the plane of transition from the surface of the ellipsoid of rotation to the conical surface showed that its value exceeds 1.4-1.6 times the radius of the outlet. For practical calculations, the value of the radius of the cone can be adopted 1.5 of the radius of the outlet. The hinge height \( h \) in the cylindrical part of the model, depending on various conditions, ranged from 0.3 to 0.5 m. The surface of the ellipsoid of revolution touching the cylindrical wall at height \( h \) can be taken to be conical with sufficient accuracy for practice. To establish the value of the angle of inclination of the generatrix of the conical surface to the vertical wall, we compared it with the corresponding angles of inclination of the slip planes.

A survey of production silos with a capacity of 120 tons showed that the hang height of cement in the cylindrical part of the silo is about 1.8 m, and the shape of the hang of cement has a character close to the hang in the model. Since this value of the height of the hang corresponds to the angle of inclination of the conical surface of the material to the vertical wall, equal to \( 45^\circ - \varphi / 2 \), we can assume that the angles of inclination of the sliding surfaces and the surface of the material that is hung in the cylindrical part of the silo are the same.

For experimental studies of the process of collapse of stuck cement using a booster, the experimental setup was equipped with a pneumatic pulse system including deflectors, a receiver with a compressed air pressure regulator, a gate valve with an electromagnetic drive, a distribution manifold with shut-off valves.

When turning on the electromagnetic drive of the shut-off valve, compressed air from the receiver was fed through a distribution manifold to the deflectors installed in a certain sector on the conical bottom of the model installation. Measurement of compressed air flow was carried out with the help of a diaphragm with a hole in its middle part by the pressure drop across this diaphragm.

To assess the effectiveness of the use of the wrapper, the \( ke \) performance criterion was used:

\[
ke = \frac{Qc}{Qf},
\]

where \( Qc \) - mass of the collapsed material, kg; \( Qf \) - mass of the frozen material, kg.
As a result of experimental studies, it was found that the flow characteristics in the system of pulsed compressed air supply and the magnitude of the static air pressure in the deflector change in the process of collapse of suspended cement. Analysis of the measurement of air pressure in the deflector and in the chamber with a flow orifice showed the following: when the shut-off valve with an electromagnetic actuator is turned on, there is a rapid increase in pressure $P_1$ in front of the diaphragm to $P_1'$, which is 0.6-0.7 of its maximum value. Then this pressure increases gradually to its maximum value. The pressure $P_2$ behind the diaphragm at the same time first decreases due to the ejection of air flow, and then increases, but more slowly than the pressure $P_1$. The statistical pressure $P_{st}$ in the deflector increases sharply to a maximum, and then decreases, and when air is exhausted from it, it remains almost constant. Peak pressure $R_{sp}$ in the deflector is the limiting resistance of the frozen material to the impact of a pneumatic impact.

As a result of numerous experiments, it was found that the main parameters affecting the effectiveness of the collapse are the power $N$ of the air flow in the pulsed compressed air supply system and the gap $\delta$ between the air-venting screen and the deflector nozzle.

The dependence of the effectiveness of the collapse of one sector of the suspended cement on the power of the compressed air flow at various values of the gap $\delta$ is shown in Figure 2. With the increase in the power flow in the system of pulsed compressed air supply, the collapse efficiency increases.

The graphs of dependence $ke = f (N)$ with values of $\delta = 2.5; 6; 9$ mm are located lower than at $\delta = 12$ and 17 mm. This is probably caused by the smaller size of the space under the air-baffle screen, which reduces the effectiveness of the impact of the pneumatic impulse on the frozen material.

The dependence of the effectiveness of the collapse on the size of the gap $\delta$ is of an extreme nature with power values above 1.36 kW. Figure 3 show this dependence for different values of the flow power in a pulse feed system.

In order to determine the parameters of the collapse system in real capacities, we used the results of experimental studies based on the application of similarity theory and dimensional analysis. The
theory of similarity, which is widely used nowadays in the simulation of various devices, for solving specific problems, taking into account the basic criteria of similarity [12-14]. Experimental verification of the approximate method [15,16], proved sufficient reliability of the results of this method when modeling devices.

The main results of the experimental studies were used to determine the parameters of the pneumatic fracture system on cylindro-conical tanks from 25 to 120 tons. The implementation of the developed system under production conditions was carried out at the cement warehouse of a concrete product plant in the city of Cheboksary. The deflectors of this system were located on the forming conical bottom, the angle in the plan between which is 45 °. The number of deflectors located on two adjacent generators and included in one group was 8 pcs. Distribution headers with high-speed valves controlled by an electromagnetic actuator were provided to supply compressed air to the deflectors.

In order to determine the effectiveness of the collapse system and to measure the parameters of compressed air under production conditions, an experimental test was carried out using strain gauge equipment.

Cement before unloading was stored in the tank for a month. After the termination of the free flow of compressed cement, a consistent supply of compressed air to the groups of deflectors was carried out. At the same time, after each collapse of the sector of the frozen material, unloading of the collapsed mass of cement was performed. The complete collapse of the suspended material was achieved in four cycles of compressed air supply to the groups of deflectors along the perimeter of the conical bottom of the tank.

2. Conclusion
Experimental studies of the cement unloading process on a large-scale model made it possible to establish the nature of the outflow and the formation of cement hovering on the bottom of the tank. As a result of studies of the proposed system of pneumatic collapse of suspended cement at the experimental unit, rational values of its parameters (consumption characteristics, clearance of the air-reflecting screen) were determined. On the basis of the application of the theory of similarity and analysis of dimensions, analytical dependences are established that allow the transition from the parameters of the pneumatic fracture system obtained on a large-scale model to the parameters of industrial pneumatic fracture systems. Verification of the effectiveness of the developed system of pneumatic destruction was carried out under production conditions for a capacity of 120 tons.
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