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# Optimal design of the head of a pneumatic pulsator

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In loose material beds above silo outlets or in vertical channels immovable vaults can occur limiting or making imposible the downward movement of the loose material. To prevent vault creation or to destroy vault by aeration and separation of the loose material from encasing walls, a pneumatic pulsator can be applied. The paper summarises design studies leading to the selection of the optimal shape of the head of pneumatic pulsator provided with pressure accumulator. The phases of preliminary design, numerical simulation, experimental investigation and industrial tests are reviewed.

## 1. Introduction

When loose materials attract and arrest moisture, difficulties in material handling in production facilities can arise. In a silo, high humidity can trigger agglutination and agglomeration of the loose material, or material sticking to silo walls possibly leading to stoppages of transportation lines connected with the silo. As typical consequences of such problems, lower efficiency and higher costs of processing, and reduced product quality can be named.

Under certain circumstances, vaults can occur in beds of loose material above silo exits or in vertical channels. This can limit or even totally disable the downward movement of the material.

Depending on the nature of loose material, two kinds of vaults are identified:

a) vaults created by coarse-grained material (Fig. 1a) with random packing of grains,

b) vaults created by fine-grained material with compressive stresses acting in the plane perpendicular to the free surface, while shear stresses in the free surface are equal to zero (Fig. 1b).

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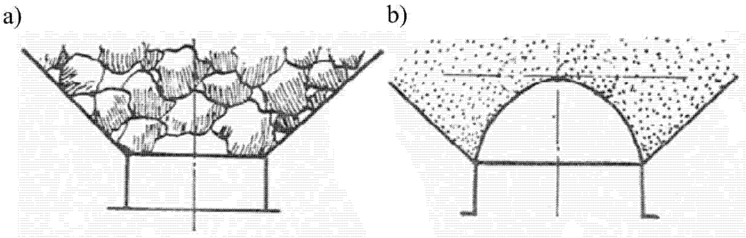


*Fig. 1. Vault creation: a) in coarse-grained material, b) in fine-grained material.*

Vaults can be formed in a fine-grained material when the cross-section area of the vessel outlet is too small. Vault creation is facilitated by the roughness of vessel-wall surfaces in the vicinity of the outlet, but can be avoided by properly choosing the vessel shape and outlet position, or by equipping the vessel with auxiliary vault-preventing devices.

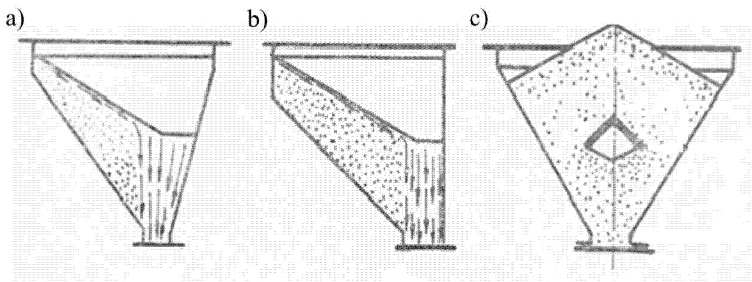


*Fig. 2. Preventing vault creation by proper vessel shaping: a) non-symmetrical shape, b) vertical vessel wall, c) baffles above outlet.*

The preventive measures against vaults creation are following:
1) Vessel wall inclination calculated as:

$$tg\alpha = 1.41 \cdot \frac{\mu_s}{\sin \frac{\psi}{2}}$$

where: $\mu_s$ – wall friction factor at standstill, $\psi$ [grad] – dihedral angle betweeen neighbouring walls.
2) Non-symmetrical shape of the vessel (Fig. 2a),
3) Material outlet positioned close to a vertical vessel wall (Fig. 2b),
4) Baffles placed above the outlet (Fig. 2c),
5) Rotating flat bottom (in cylindrical vessels),
6) Screw conveyor placed in the material outlet,
7) Vibratory, striking or pneumatic equipment, to act on the material bed, attached to the vessel.

In the cement industry and in coal-fired power plants, automated pneumatic pulsators are widely applied for safe and efficient elimination of vaults that may occur above bottom outlets of silos in which loose materials are stored. Bearing in mind large dimensions of the silos in question, in case of lacking preventive equipment, vault removal may require operation breaks and the intervention of staff authorised to work in dangerous conditions, leading to increased production costs.

## 2. Designing a pneumatic pulsator

A pneumatic pulsator consists of two components: a head to control air flow and a cylindrical vessel to act as pressure accumulator. The vessel design is straightforward – it is made of a cylindrical part and two ellipsoidal bottom heads conforming to pressure vessel standards. The vessel volume depends on the silo capacity and type of loose material. In the R&D project reported here, engineering calculations of the vessel were performed using the commercial Visual Vessel Design software (VVD User's Guide, 2002).

The design of pulsator head is more complex. The head includes three channels: inlet channel through which air flows from the pressure accumulator, outlet channel directing air flow to the silo, and control channel to control the air flow. The air flow from the inlet to outlet channels is controlled by valve which openning depends on the pressure difference between inlet and control channels. In order to optimise the head design, the flow phenomena were numerically simulated and the channels were preliminarily designed. The data obtained from simulation were also used as a basis for setting up an experimental stand to validate simulation results.

### 2.1 Numerical simulation

The aim of simulation is to check the shape of pulsator head and its influence on airflow. The channels in the head should allow the pressure accumulator to empty in the shortest possible time thus maximising the total pressure action on the loose material bed. The flow of air through head channels is a transient process brought about by the pressure difference between inlet and outlet while atmospheric pressure governs in the outlet.

The numerical simulation is carried out using the finite volume method based on solving the governing equations in a single cell and then transferring the results into a neighbouring cell. The governing equations describe mass conservation (continuity equation) and momentum conservation (Navier-Stokes equation). Taking flow characteristics and expected velocities into account, the classical k-ε model for transient flow is assumed.

The numerical model was prepared using SolidWorks software. The resulting file and flow data were subsequently imported to FLUENT pre-processor for mesh generation using tetrahedral cells. Because of complex geometry the mesh was unstructured.

As a sample of simulation results, those obtained when checking the correctness of flow geometry and boundary conditions can be summarised. Constant fluid properties and a constant valve opening were assumed, and the boundary conditions were: $6 \cdot 10^5$ Pa gauge pressure at inlet and zero gauge pressure at outlet, zero airflow velocity at the surface of channel walls.

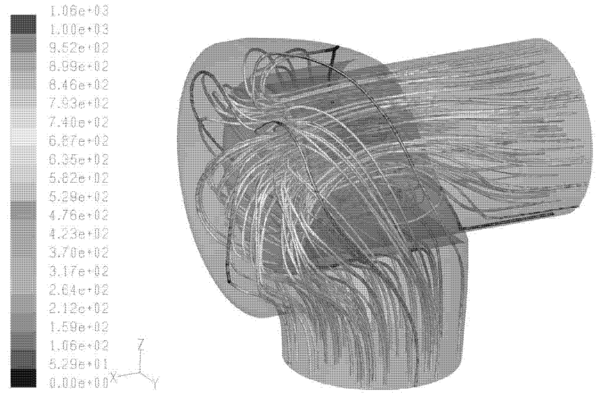


*Fig. 3. Airflow pathlines coloured by velocity magnitude.*

The calculation was carried out using a time step of 0.001 s with end of calculation assumed after 0.7 s. The resulting maps of the velocity vector field and pressure field (Fig. 3) indicated the presence of a large vortical area in the lower part of the outlet channel, and outlet velocity changing between 0 and 500 m/s.

**2.2 Experimental investigation**

The experimental model of the pulsator head is shown in Fig. 4. The model was made of a transparent material making it possible to investigate the flow using Digital Particle Image Velocimetry (Willert et al., 1991; Raffel et al, 1998). In order to obtain experimental flow images, the flowing fluid was lightened with a “light sheet” generated by Solo 120XT laser (impulse energy 129 mJ at wave length 532 nm). Two-dimensional flow images were collected and recorded using Prosilica EC 1600 CCD camera at the resolution of 1392×1040 pixels. As each pair of consecutively collected images allows to determine the flow velocity field if the time step between the recording of the images is known, the maps of velocity field were generated using in-house software (Suchecki et al., 2006; Wernik and Wolosz, 2008).

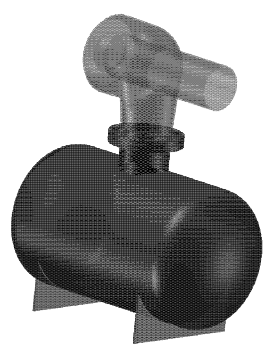

*Fig. 4. Pulsator model used in the experiments.*

In the course of experimental investigation no irregularities in the flow patterns were detected and thus the preliminarily designed shape of the pulsator head was found to be correct.

**2.3 Prototype tests**

On the basis of simulation and experimental results, the final design of the pneumatic pulsator was developed (Fig. 5). 150 mm diameter of the outlet of pulsator head was found to ensure the outflow time of 0.02 s.

In the final design, account was taken of the influence of harsh industrial environment and heat generation in the pulsator head due to rapid flow of compressed air though the channels. To avoid overheating, rectangular fins were attached to the outer surface of the pulsator head. The fins considerably increase the intensity of heat exchange with the environment improving also the stiffness of pulsator casing.

A number of prototypes of the pulsator head were made of aluminium alloy. At the moment, tests are carried out at several industrial sites to evaluate pulsator performance under real operating conditions. User comments and remarks will be collected to assess the quality of pulsator design.

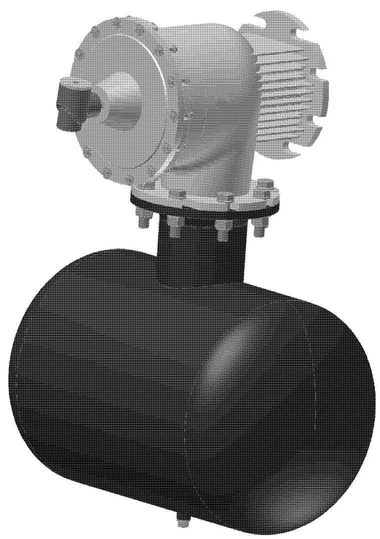

*Fig.5. 3D model of the pneumatic pulsator.*

## 3. Concluding remarks

In order to develop the pneumatic pulsator, it was necessary to combine engineering design with applied research. Preliminary numerical simulations of air flow made it possible to select a correct design of the pulsator head, rejecting other designs that were less efficient with respect to the total pressure available for acting on the loose material bed. The application of SolidWorks modeling software in connection with COMSOL

Multiphysics mesh generation software facilitated smooth and efficient transfer of data between equipment modeling and flow analysis. This allowed to determine the details of the experimental setup and arrive at the final pulsator design within a relatively short time.

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