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Exergy destruction in the pneumatic pulsator system during one working cycle

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ABSTRACT

Energy efficiency tends to be a crucial issue in engineering since energy costs have started permanent growth. Because of that exergy analyses are applied in the fields where they have not been utilized so far. In this study energy efficiency is determined by calculation of exergy destruction during transient and compressible flow phenomena. The investigated object is a pneumatic pulsator system which utilizes energy of compressed air for destruction of agglutinations, which come from cohesion forces, in loose materials and make the outlets of silos unobstructed. A type of pneumatic pulsator was developed during an R&D project in which fast effect of a pulsator performance was in focus. The results of this study show how much energy can be converted into work during the pulsator operating. A method was developed for exergy destruction calculation during one work cycle of pulsator. The method was based on the validated simulation results. The flow proceeded within less than 0.4 s with the highest Mach number $M = 3$. It has been found that 11.4% of accumulated energy, which equals 2160 MWh for one silo in heavy industry, is irreversibly lost. It is a significant amount of energy by which the pneumatic pulsator efficiency is reduced.

1. Introduction

Raising energy costs make the exergy analyses necessary in fields where they have not been considered so far. The present study is one of a series of articles which opens energy and exergy analyses in an area where systems for unclogging outlets of silos for loose materials are applied. In the study, a pneumatic pulsator system is considered.

The main task of the article is to present the method to calculate exergy destruction for transient phenomenon of fast vessel evacuation which occurs while a pneumatic pulsator is working. The issue is important because of possibility of a determining amount of energy which can be transferred into work. Exergy and energy analyses have not been taken into account by researchers in this field of action for the time being.

Pneumatic pulsators are a type of a system which is used for making silos outlets clear. These systems utilize air which is compressed in a pressure accumulator for generation a pneumatic impact. The impact destroys adverse structures of loose material which are: arching, ratholing, clinging, and bridging. The structures are created while cohesion forces are much larger than the gravity. Pneumatic impact defeats the cohesion forces and moves the loose material towards the silo outlet. The pneumatic pulsators work in cycles, they strike loose material beds every several or several dozens of seconds, and destroy adverse phenomena or prevent them from creation. Because of the impact and periodical characteristic, the pulsator are often named as “air cannons” or “air blasters”. The pneumatic pulsators are mainly used in facilities which are related to cement and power plants, mines, and other heavy industry. A lesser scale pulsators are used in pharmaceutical and food industry. Exemplary visualisation of the pneumatic pulsator system which is mounted on the silo walls is presented in Fig. 1.

The pneumatic pulsator consists of three basic parts: a pressure accumulator, a head, an auxiliary nozzle. During a work cycle, the pneumatic pulsator utilizes energy which is accumulated in pressure accumulator with compressed air. The amount of energy strictly depends on the size of the accumulator but energy which can be converged to work on the loose material bed depends on losses which occurs while air flows. These losses are:

1. Friction loss inside the pulsator head, mostly caused by air viscosity and roughness of walls. The heads are mostly made with

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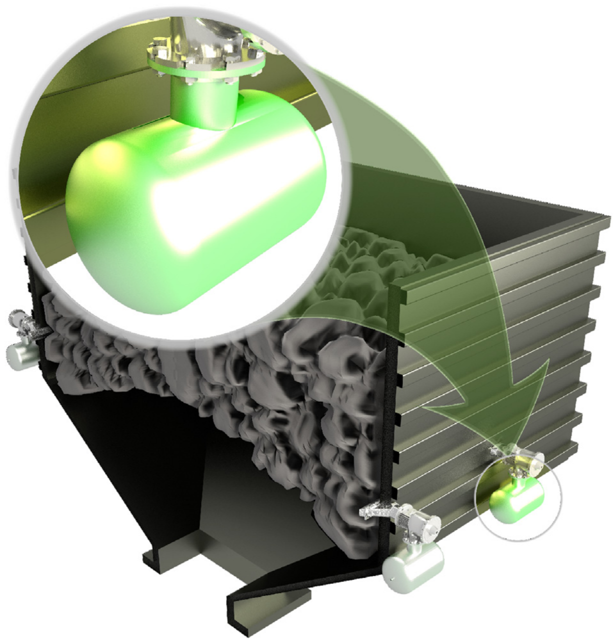

Fig. 1. Visualisation of pneumatic pulsator system and its location on a silo walls.

aluminium alloys without any kind of finishing. Because of it, the friction could be an issue.

2. Energy dissipation loss in turbulent flow. The loss is caused by dissipation of energy in vortices while turbulence flow occurs. The amount of this loss is calculated during numerical simulation when a proper turbulence model is applied.
3. Exergy destruction which is a part of energy which cannot be transferred into work. It comes from irreversibility of the thermodynamic gas conversions [1]. That issue is the main purpose of the study presented in this article.

Each of aforementioned losses is visualized in Fig. 2. Besides issues mentioned in point 3, the study has one more aim. It is determining the maximal amount of energy which could be transferred onto the work on condition that the losses mentioned in points 1 and 2 are not taken into account. In another words, the physical model used in the study is the pressure accumulator with the head of the pulsator taken off. The results will allow to determine an amount of friction losses (1), and, therefore, efficiency of the pneumatic pulsator system in future investigations. Visualisation of the geometry of the model is shown in Fig. 3 altogether with a numerical mesh.

The industrial pulsators were investigated during R&D project of development and application of them. Basic functions and a principal of operation of the pulsator were published in Ref. [2] whereas authors of [3] focused on flow matter of pulsator and its working.

Analytical model for outlet velocity of pulsator (air cannon) was investigated in Ref. [4]. The study consists of calculation and experimental measurement. Only laboratory scale models were studied but pressure was applied the same as for industrial pulsators. It has been shown that pulsator flow parameters differ from the analytical calculation of simple vessel evacuation.

Besides the pulsator, flow phenomena during the pressure accumulator evacuation have been investigated in Ref. [5] and then the first energy analysis has been undertaken in Ref. [6], but the exergy and changes of energy in time have not been studied. A part of pulsator system, i.e. a directional heat-resisting nozzle, has been balanced in respect of energy consumption and results has been reported in Ref. [7].

Fig. 2. Distribution of energy losses in a pneumatic pulsator.

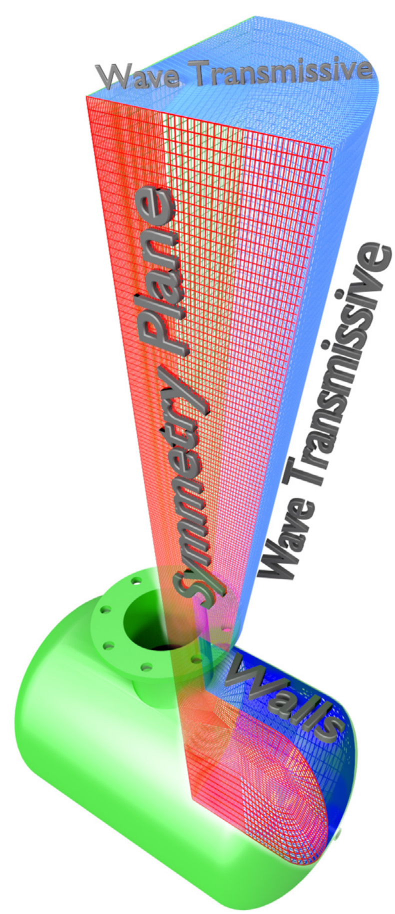

Fig. 3. Structured mesh with boundary conditions on the background of the vessel.

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