Pneumatic shock waves utilized for bulk and inbag grains aeration

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Abstract
The paper presents theoretical and experimental interdisciplinary considerations concerning the principle due to the pneumatic shock waves can be utilized for bulk grain disinfection/aeration: working principle for pneumatic shock waves device; pneumatic shock waves velocity/energy; fast velocity imaging.

Keywords: fast velocity imaging, bulk/inbag grains aeration, pneumatic shock waves

1. Introduction
Preventive method for pest and insects control inlet silos bulk grains, to combat or interrupt the biologic cycle of pest/insects, consists in permanent environmental conditions monitoring (temperature, humidity, chemical and biological conditions), too. During medium or longer period of grains’ storage in silos, method recommends ventilation systems and energetically mixing aeration realized in intensive manual operation, or by multiple belt conveyor mixing equipment. Due to the intensive impact and friction phenomena between grain particles during mechanical mixing aeration, the sensible life stage of insects (eggs, larva) are almost killed or inactivated. In the same time, during the mechanical mixing aeration, the bulk grain very short natural ventilation is realized.

The traditional method for bulk grain ventilation stored into large silos in larger farms (Figure 1) is based on artificial ventilation, but no mechanical mixing aeration is possible.¹,¹¹,¹²,¹³

Many years ago, to prevent any problem in bulk materials stored in bunker or silos, in USA and west European countries, discharging equipment (technical and commercial known as Big Blaster), were used. Big Blaster consists of one or more air cannons mounted on the storage vessel.

Air cannons are pneumatic systems, which quickly release compressed air into the storage vessel, to restore bulk material moving/flowing that is clinging, rat-holing, bridging or arching.¹¹,¹³

In Romania there are known several technical applications for solid or powder bulk materials (large electro-thermal plants, cement plants, raw materials for metallurgy, dust filtering system for belt conveyors), and for viscous materials in food industries (Figure 2).¹²

There are known research contributions concerning the effect of shock waves impulsive kinetically energy on plastic deformation of thin metallic parts [²,⁷], on metallic bunker stability [²,⁴,⁸], or for nuts fruits harvesting [⁵,⁶], respectively.

Figure 1. Bulk grain ventilation stored into large silos in larger farms
The experimental equipment consists in a fast discharge device, successively mounted on a vertical wall of an experimental small silo made in plastic material (Figure 4, a), and on the horizontal wall of an experimental small silo made in glass pipe (Figure 5, a), respectively.

Taking into account visual / demonstrative experimental considerations, those bunkers’ walls were made in transparent high density polypropylene (end of life use recyclable plastic material), and high grade shock resistance transparent glass (end of life use transparent glass pipe).

In a previous project, experimental equipment (Modular Equipment for Nuts Harvesting by Pneumatic Impulses - MEHPI) was designed to replace the effect of the wind blasts, with orientated air blaster shock waves, which replace the velocity and orientation of strong winds. The main operational component of MEHPI consists in a fast discharge device (FDD). [5,6]

The same FDD was used for the presented paper. In principle, FDD is composed in 8 dm$^3$ capacity storage vessel with a special fast discharge pneumatic valve (Figure 3).

The FDD operation is based on the effect of the compressed gas discharge with high velocity from a storage vessel. During this fast process, the gas flow is characterized by high rate pressure variation.

Therefore there is no heat exchange with the outside environment, and the flow process can be considered adiabatic. When the compressed gas is discharged from a storing vessel (initial parameter $p_o$, $\rho_o$, $T_o$) through a nozzle in the atmosphere (final parameter $p_{at}$, $\rho_{at}$, $T_{at}$), the gas maximum velocity can be determined taking into account the fluids mechanics applied for specific in impulsive jet theory.

In the minimum cross section of the convergent nozzle / pipe the critical regime is realized and the maximum flow $Q_{max}$ passing through this cross section is obtained.\[8,9\]

Considering the initial and the final parameters of the gas ($p_o = 2 - 5$ bar; $p_{at} = 1$ bar; $k = 1.4$; $T_o = T_{at} = 293^\circ K$), and the cross section area of the convergent nozzle / pipe corresponding for convergent nozzle diameter $D_p = 44$mm, too, the maximum velocity $v_{max}$ and the maximum flow $Q_{max}$ of the compressed air discharged from the storing vessel, was calculated (Table 1).

The medium velocity of shock wave $v_{med}$ was theoretical determined knowing that the medium velocity in a flow section can be determined with relation $v_{med} = 0.2 v_{max}$ (Table 1).

Assuming fast and complete discharge of the all pressured gas weight initial contained into 8 dm$^3$ capacity storage vessel, the kinetically/dynamic energy $E_{K, dyn}$ determined with well-known relation $E_{K, dyn} = (W_{sv} \times v_{med}) / 2$, is presented in Table 1.

The aim of this paper is to realize the bulk grain aeration, and bulk grain moving, too. Thus, the kinetically/dynamic energy $E_{K, dyn}$ must be greater then the potential energy $E_{pot}$ of the bulk grain column weight $W_{bg}$ that exist above the FDD discharge pipe axis ($E_{pot} = W_{bg} \times g \times H$).[9]

<table>
<thead>
<tr>
<th>$\rho_o$ (bar)</th>
<th>$\rho_{at}$ (bar)</th>
<th>$v_{max}$ (m/s)</th>
<th>$Q_{max}$ (kg/s)</th>
<th>$\rho_{at}$ (kg/m$^3$)</th>
<th>$W_{bg}$ (kg)</th>
<th>$H$ (m)</th>
<th>$E_{K, dyn}$ (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.34</td>
<td>246.2</td>
<td>6.94</td>
<td>61.1</td>
<td>15.72</td>
<td>41.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.43</td>
<td>395.5</td>
<td>1.010</td>
<td>73.2</td>
<td>27.35</td>
<td>65.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.53</td>
<td>407.6</td>
<td>1.344</td>
<td>81.5</td>
<td>36.48</td>
<td>104.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.72</td>
<td>430.7</td>
<td>1.709</td>
<td>87.4</td>
<td>43.36</td>
<td>146.48</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The experimental method to determine the shock wave velocity proposed Fastec Imaging high velocity camera. To determine the effective shock wave velocity for compressed air fast discharging (initial pressure $p_o = 2...5$ bar), a contrast colored fine powder was introduced into FDD convergent nozzle.
A modular panel with 0.1m horizontal and vertical grids was used. [9,10]

According the shock wave theoretical velocity value’, the high speed camera image capturing sequence was set for 500 fps. The high speed camera MiDAS 4.0 Express Control Software start was simultaneous triggered with the FDD’s fast discharge pneumatical valve. The values obtained by using the experimental method are up to 10% smaller then those obtained by using theoretical method (viscosity force that occurred due to high velocity shock wave, in the front and at the border of the shock wave, the turbulent flow determines smaller values then the theoretical shock wave velocity).[9,10]

During the high velocity discharge, both the bulk material into the silo and the silo’ walls too, are stressed by impulsive loads. Before recycling, to determine static and impulsive dynamic stability, both silos made in plastic material parts, and high grade shock resistance transparent glass pipe was necessary to be verified by using finite elements method and von Mises method.

3. Results and discussion

In the first step, in order to increase the visibility during the experiment efficiency tests, the plastic transparent bunker was filled with successive layers of bulk grains (wheat and corn). The FDD was activated by four consecutive pressures (2, 3, 4, 5 bar). During these experiments it was observed that the shock wave kinetically/dynamic energy realize each time the bulk grains mixing and in the same time, the aeration, too.

In Figure 4 are presented four stages (during 0.294s total timing - Fastec Imaging high velocity camera) of the bulk grains mixing and aeration process.

In the second step, the experiment efficiency tests were realized by using 50 liters capacity plastic bag, and 200 liters capacity plastic big-bag, respectively, filled with grains.

![Figure 4. Shock wave dynamic energy realize bulk grains mixing and aeration](image1)

After each of these experiments it was observed that the dynamic shock wave energy realize the intensive grains mixing and in the same time, the aeration, too. Inside the bags, the intensive grains mixing process and the simultaneous aeration process are difficult / impossible to be observed; just the shock wave effect can be finally evaluated.

![Figure 5. Shock wave dynamic energy realize grains mixing and aeration inside plastic storing bags](image2)
Taking into account only experimental demonstrative considerations, in Figure 5 are presented six consecutive stages (during 0.676s total timing - Fastec Imaging high velocity camera) of the simultaneous grains mixing and aeration processes.

4. Conclusion
Dynamic shock wave energy realizes the simultaneous intensive grains mixing and aeration processes.

The equipment can be modular mounted, when mixing and aeration are necessary, for bulk grains and for in-bag stored grains in any small farm.

Further experiments are necessary to observe the influence of discharged CO$_2$ shock wave on grains preservation.

Compliance with Ethics Requirements
Authors declare that they respect the journal’s ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human and/or animal subjects (if exists) respect the specific regulations and standards.

References
10. Roşca A.; Olaru, N., Experimental equipment for bulk grain aeration in small farms, The VIIIth National Student Symposium IF-IM-CAD, University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Land Reclamation and Environmental Engineering, 19-20 April 2013.