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AERATION ANALYSIS OF A REAL GRAIN STORAGE SYSTEM THROUGH MATHEMATICAL MODELING

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Abstract: In bulk warehouses, the conservation of grains for a certain period of time depends mainly on an efficient aeration system, preserving the quantity and quality of the stored grains. To simulate an aeration system, a mathematical model and software were developed to simulate the 3D airflow distribution in horizontal bulk warehouses, under inhomogeneous and anisotropic conditions. The formulated air flow problem was solved using the Finite Element Method, with geometries and tetrahedral meshes of real grain storage systems. With the simulation it was possible to analyze the distribution of air flow at all points of the stored grain mass. To evaluate the effectiveness of air distribution, the local specific flow criterion was used.
Keywords: Airflow Distribution, Computational Modeling, 3D Simulation

INTRODUCTION

According to [11], in recent decades, advances demonstrate that agriculture is in a transformation phase, making intensive use of agricultural equipment and techniques, allowing greater yield in the production process. The grains produced, after going through cleaning and drying processes, are packaged in large warehouses, which must have controlled conditions to maintain the quality of the grain. The main technique used to preserve stored grains is aeration, which aims to preserve the grain mass.

To compensate for the lack of storage capacity in the country, the construction and operation of large horizontal bulk warehouses is widely adopted, reaching significant dimensions, making ventilation of the grain mass difficult and unsafe.

There are several factors that affect the distribution of airflow in bulk warehouses, for example, the filling method, the depth of the grain mass, the morphology of the grains, the speed of the driven fans, etc. In works by [10], [1], [3], [11], [4], [5] and [7] the air flow through the grain mass under the influence of some of these characteristics was studied. In large warehouses, inhomogeneity was studied by [6] and [8] and grain mass anisotropy by [2]. The thermal state of the grain mass in warehouses with an aeration system was studied by [1], [4] and [9].

In the post-harvest period, so that significant grain production is not damaged or even lost, careful storage is essential. The ideal is to obtain storage capable of monitoring all risk domains of the grain mass. Furthermore, an optimized, adequate and efficient aeration system is important, encompassing a uniform air flow throughout the grain mass domain.

The purpose of the work is to computationally model the distribution of air flow during the aeration process in real grain storage systems.

The main objectives of the present study were: i) Collect information from a real grain storage system with aeration; ii) Carry out 3D modeling (mathematically and computationally) of air flow distribution in real storage systems, aiming to analyze pressure and flow; iii) Analysis of the air flow distribution of the real grain storage system.

STUDY OBJECT

To carry out the simulation of air flow in horizontal bulk warehouses, the study object of a real grain storage system from a private company, located in the southern region of Brazil, was adopted. Table 1 presents the characteristics of the bulk warehouse, and Figure 1 shows its structure.

The warehouse has a deep V structure, 121 meters long and 45 meters wide. The aeration system is made up of three air intake systems: 1) Central Aeration, 2) Side Aeration and 3) Aeration at the Ends (front and rear). Figure 1 shows the location of the aeration system's air inlets.

MATHEMATICAL MODELING AND SOFTWARE DESCRIPTION

MATHEMATICAL MODEL

In this study, the mathematical model referred to in work [6] was used, which describes the air flow in particulate media, consisting of a system of two equations:

$$div\, V = 0 \quad (1)$$

$$V = -\frac{gradP}{|gradP|} exp(\{[(1+U) - 2U arctan(U)]/\pi + 3U\}/4a + C) \quad (2)$$

where V is the velocity vector in: ms^{-1}; gradP is the pressure gradient in: Pa; a and b are constants that depend on the type of grain; where: U(P)=aln|gradP|+b is an intermediate argument, corresponding to laminar and turbulent flow; C is the constant of integration.

Equation (1) is the continuity equation for incompressible fluid whose density remains constant (very small aeration velocity) and isothermal. The proportionality K is expressed by the permeability coefficient for anisotropic medium:

$$K = \frac{exp(\{[ln(1+U^2) - 2U arctan(U)]\pi + 3U\}/4a + C)}{|gradP|} \quad (3)$$

Using equation (2) the velocity components u, v and w for the 3D case, we have:

$$u = -K_x \frac{\partial P}{\partial x};\ v = -K_y \frac{\partial P}{\partial y};\ w = -K_z \frac{\partial P}{\partial z}. \quad (4)$$

Combining equation (4) with equation (1), the non-linear partial differential equation is obtained, for the general case of air flow in a granulated medium, given by:

$$\frac{\partial}{\partial x}\left(-K_x \frac{\partial P}{\partial x}\right) + \frac{\partial}{\partial y}\left(-K_y \frac{\partial P}{\partial y}\right) + \frac{\partial}{\partial z}\left(-K_z \frac{\partial P}{\partial z}\right) = 0 \quad (5)$$

Where: K_z in $m^3kg^{-1}s$. are the permeability coefficients in the main directions:(x, y, z) in $m^3kg^{-1}s$ $m^3kg^{-1}s$.

Equation (5), together with the Dirichlet and Neumann boundary conditions, describe the distribution of air flow in bulk warehouses with an aeration system, under non-uniform and anisotropic grain mass conditions.

To apply the proposed mathematical model, it is assumed that: a) the coefficient: K_z corresponds to the vertical direction is given by equation (3); b) the plane coefficients are equal, ($K_x = K_y$); c) the relationship between the coefficients in the vertical and horizontal direction (degree of anisotropy) is constant at all points of the grain mass. In large warehouses, the K coefficient and pressure gradient vary according to the depth of the grain mass. The a and b and anisotropy coefficients were obtained according to the work [7].

The finite element method was used to solve equation (5). The permeability coefficient matrix K was calculated at each node of the finite element mesh through an iterative process. The software, developed in ANSI C++ and Pascal, uses open source tools whenever possible. A more detailed description of the software can be found in the work [6].

SOFTWARE DESCRIPTION

The finite element method was used to solve equation (1), making it necessary to establish a domain of integration of smaller elements. The software, developed in ANSI C++ and Pascal, uses free software tools whenever possible and consists of the following steps: a) Construction of the geometry: the geometry was built in Open SCAD, defining all the contour information of the study object; b) Mesh generation with dynamic adaptive refinement. The geometry was discretized into smaller tetrahedral volumetric elements in the NetGen software, which contains modules for mesh optimization and refinement; c) Generation of the system matrix using the finite element method; d) Solver of systems obtained from linear algebraic equations using the successive excessive relaxation method; e) Post-processing results and analysis using

Type of Grain	Soy
Warehouse type	Below ground, in V background
Warehouse capacity	60 thousand tons
Central aeration entry number	14 registrations
Number of central aeration fans	14 fanners, DYNT 04, 20 CV
Side aeration input number	8 registrations
Number of side aeration fans	2 fanners: RFS 800, 40 CV
Number of aeration inlets at the ends	8 registrations
Number of aeration fans at the front and rear ends	8 fanners: RLS 450, 4 CV
Central aeration pressure value	1623 Pa
Side aeration pressure value	800 Pa
Aeration pressure value at the front and rear ends	1623 Pa
Warehouse depth	13,4 m

Table 1: Characteristics of the object of study.

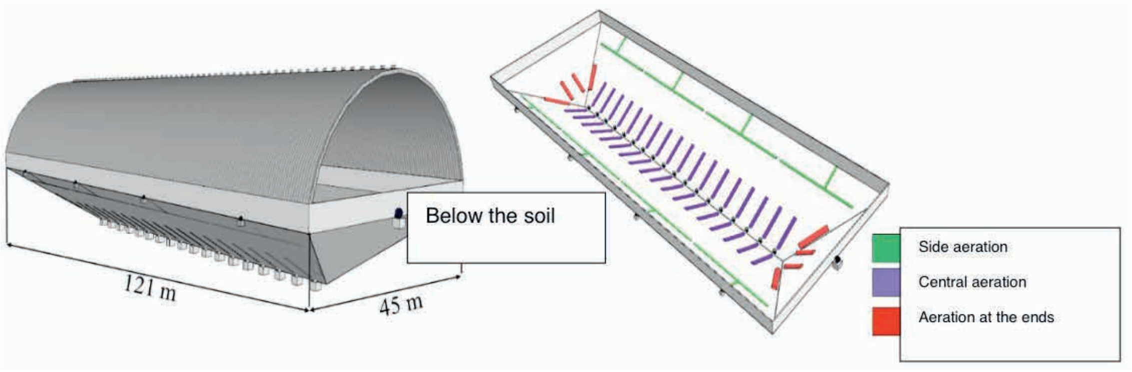

Figure 1: Sketch of the structure of the study object.

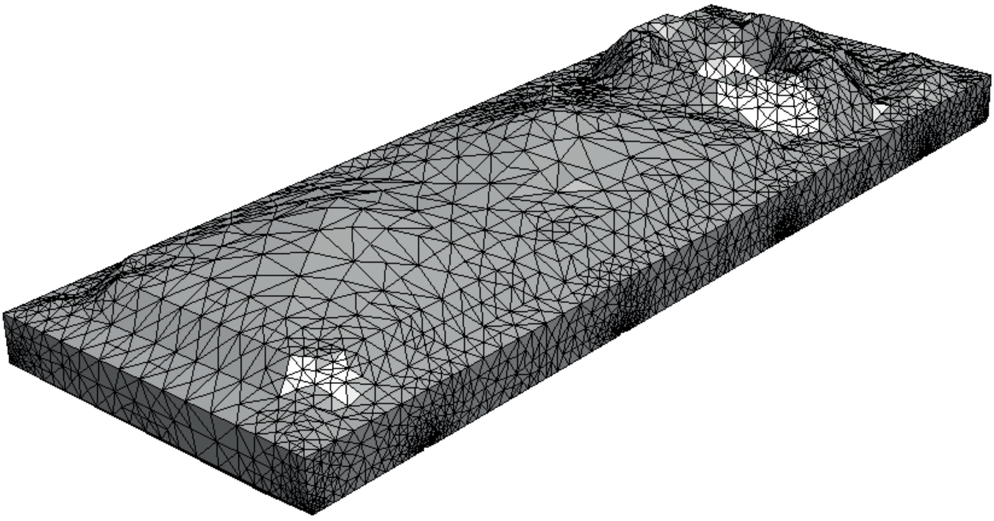

Figure 2: Wireframe of the tetrahedral mesh of the study object, built in NetGen.

Paraview software.

RESULTS AND DISCUSSION

With the characteristics of the study object and the execution of the program, data on the air flow distribution of the formulated problem were obtained. Figure 2 shows the wireframe surface of the tetrahedral mesh used in the simulation. For the problem considered, the mesh was discretized into 850 thousand tetrahedra, according to the real grain storage system, based on the structure of the object and height of the grain mass on the day of data collection.

Figure 3 illustrates the distribution of airflow in the study object. The pressure values in the central and lateral air inlets at the ends (red color) and the pressure values on the side (gray color) are verified, which model the boundary conditions of the study object domain.

Figure 4 demonstrates the location of the isobaric surfaces, the distribution of the air flow in the investigated bulk warehouse, in the pressure layers of 1500Pa, 1250Pa, 800Pa, 400Pa and 200Pa, analyzing what occurs during the system's aeration process. It is possible to perceive the different pressure layers in the grain mass, presenting an idea of the spatial distribution of air pressure.

The flow lines on the longitudinal axis of the study object are shown in figure 5, illustrating the movement of the air flow from the bulk warehouse during flow in the porous medium. Note that the lines seek the shortest path of the free surface of the grain mass.

To evaluate the efficiency of the aeration system in bulk warehouses with complex geometry, the criterion created by [6] called local specific flow rate was used. In [8] the criterion proved to be a good parameter for analyzing aeration efficiency. The distribution of the local specific flow of the study object is expressed in Figure 6.

With the local specific flow (q_L) it is possible to evaluate the air flow in m^3 of air every hour per ton of grain at all points of the study object. The overall air flow rate was Q=15,5 $m^3h^{-1}t^{-1}$, the value of q_L varies from 0 to 150 $m^3h^{-1}t^{-1}$. This difference occurs due to the structure of the object of study, influenced by the pressure value in each air inlet, as well as the height of the grain column.

The study of the three-dimensional simulation of air flow in bulk warehouses is of paramount importance, as it can help engineers design more efficient aeration systems suited to the dimensions of the storage structures, thus guaranteeing the proper functioning of the system. In practice, knowledge of the ideal inlet pressure distribution can be useful for selecting the location and number of air inlets, their size, and the corresponding initial pressure for each inlet.

CONCLUSIONS

In this work, modeling (mathematically and computationally) of the air flow distribution of a real grain storage system was carried out, with non-uniform grain mass conditions. To obtain a solution to the problem formulated by the model, discretization domains of a real grain storage system (object of study) were created. It was possible to analyze the performance of the distribution of this air flow at all points of the grain mass domain of the study object.

The results of the simulation of the object of study, using the local specific air flow criterion, demonstrated that the air flow can be optimized so that the energy spent on aeration brings better benefits for storage.

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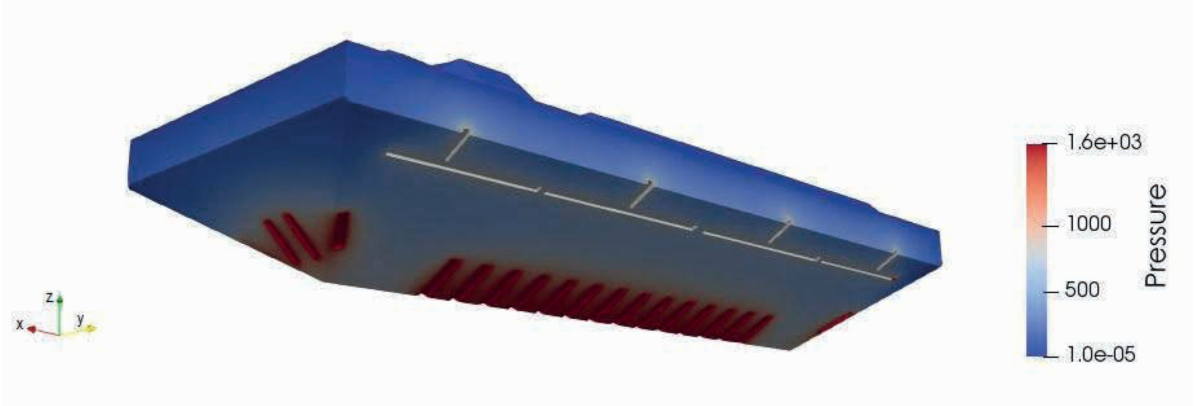

Figure 3: Simulation of the air flow of the aeration system of the study object.

Figure 4: Simulation of the air flow of the aeration system of the study object, isobaric surfaces.

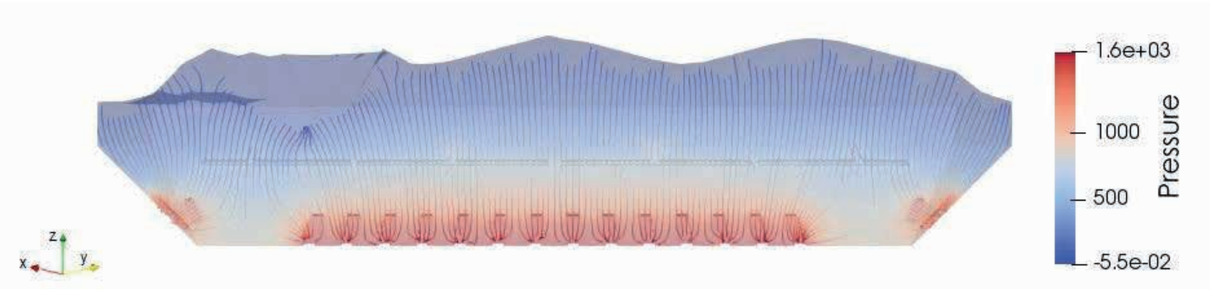

Figure 5: Simulation of the air flow of the aeration system of study object 03, flow lines on the longitudinal axis.

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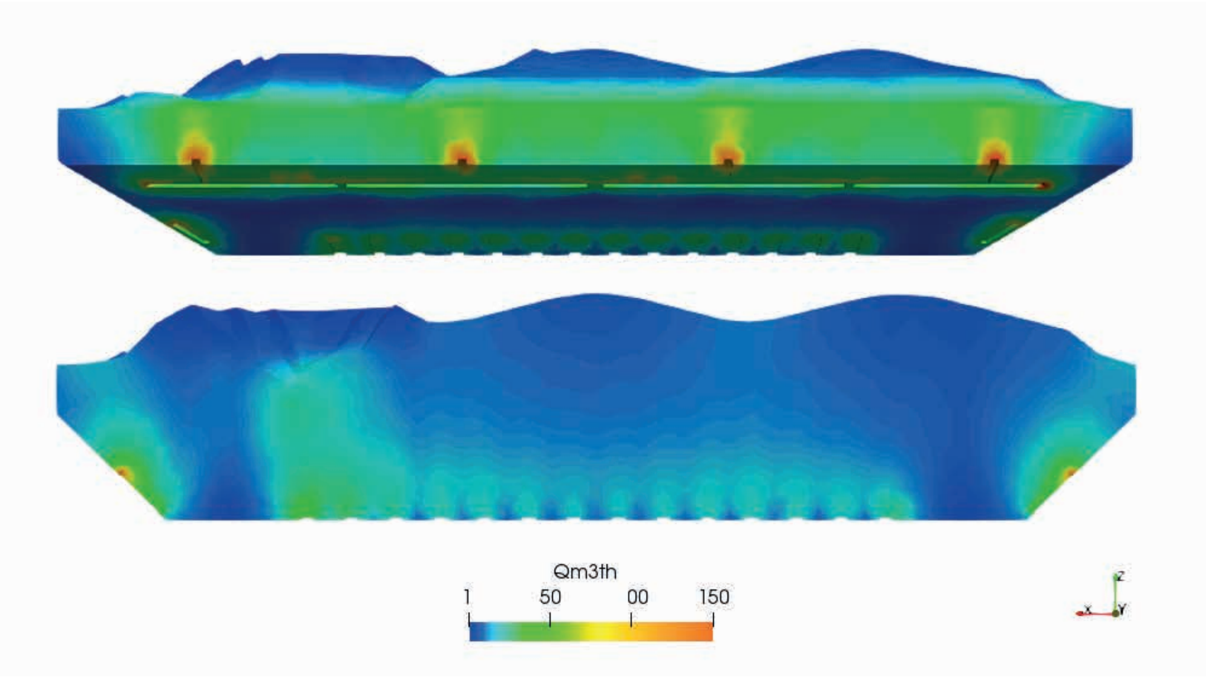

Figure 6: Distribution of the local specific flow of the study object. Global specific flow rate Q=15,5 $m^3h^{-1}t^{-1}$.

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