

## CFD SIMULATION OF THE HOT AIR FLOW USED FOR CEREAL SEED DRYING

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**Abstract:** Artificially cereal seed drying is widespread in order to ensure their conservation, because by reducing the water content, a loss in microbial activity is achieved and that allows storage of long periods of time without the need for complex storage installations. The thermal conductivity of the seeds increases with the growth of the humidity. That is why the cereal seed mass stores about 85% of the heat resulting through self-heating, this leading to a rapid temperature increase. The transfer of heat is one of the most common ways of energy change between two systems that present a difference of temperature, the mechanisms of transfer being the thermal conduction, the thermal convection and the thermal radiation.

This paper proposes a mathematical model for the convection drying of seed in two different drying boxes and achieving the CFD simulation for both of them. Due to the CFD simulation of the drying process of seeds, the time evolution of the temperature and humidity fields at any point in the product layer can be viewed in a graphical form. By means of the CFD simulation was optimized the construction of the drying boxes so that one could obtain a uniform distribution of the air currents and of the temperature fields in the cereal seed layers.

**Keywords:** CFD simulation, air flow, cereal seeds

### 1. Introduction

Drying cereal grains removes many dangers of harvesting and storage of agricultural products with high humidity. Processed cereals can often be considered as solid foams and their constitutive walls, mostly a blend of starch and proteins, may be envisioned like a composite material. The change between cellular intermediate scale and composite micro-scale may be achieved by mechanical modelling using numerical methods.

For both scales, imaging methods (microscopy and tomography) provide relevant description of product structure, which can be meshed and used in computer software for mechanical simulation [1]. The mechanical properties of cereals are essential to define their texture which is linked to sensory attributes, such as firmness, crispiness, crunchiness [2, 3]. Differences of mechanical properties may also be of nutritional consequence [4].

The need for rigorous stewardship of thermal regime of grain dryers requires technical-functional knowledge of plants used for drying seeds and presents a great importance because it allows to obtain a global picture regarding certain categories of performance. After the drying process, grain seeds for consumption or for animal feeding, are able to be stored and to respond properly to processing and handling.

The proposed small capacity drying plant is a pilot one, which can modify and monitor in real time several important parameters such as the drying agent speed, air temperature and humidity, product temperature and humidity. These physical parameters are useful in order to achieve the process modelling and simulation.

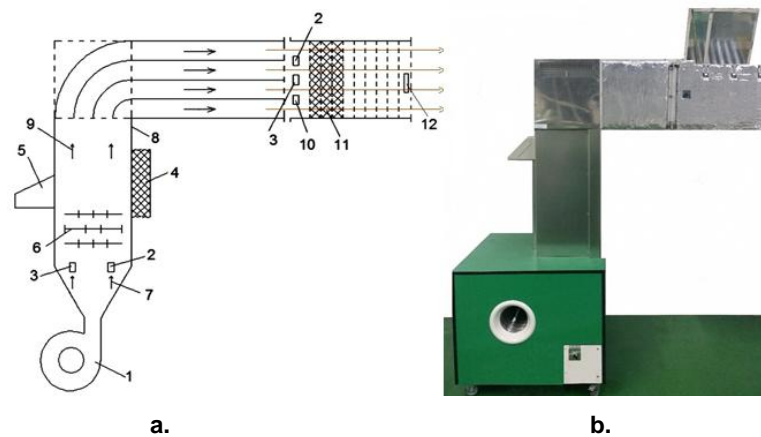
The model concept has many meanings that can refer to a machine, a concept, an equation, a person etc. In the most general sense, the model is a material construction, depending on the purpose, having a likeness or similar behaviour like the model object.

The model is a representation of reality used to analyse the original behaviour under different conditions. The model is, in most cases, a simplification of the original, while maintaining only the essential elements of this significant [5].

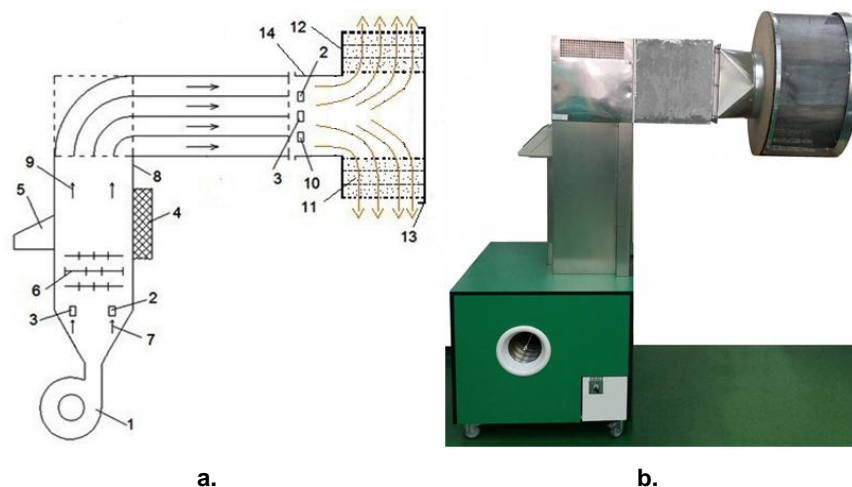
## 2. Materials and methods

The heat is brought into the product layer by means of hot air (convection). Water vapour produced are taken out of the air, which is the mass transfer medium. Once the heat penetrates the grain mass, the mass transfer (water) starts inside the product to its surface. The water can easily reach the surface of the product or product easily occurs the phenomenon of evaporation. The water then moves under the influence of capillary forces and due to shrinkage of the product during dehydration. Towards the end of the drying process, the water transfer is slower because of the dried layer formed on the surface of the product.

The experiences of drying products were made in the Department of Agricultural Mechanization of the University of Agricultural Sciences and Veterinary Medicine "Ion Ionescu de la Brad", Iași, Romania, using laboratory facilities for drying agricultural products. The laboratory dryer allows control and monitoring of the drying process parameters that can be chosen by the user before or during the drying process. The dryer can be equipped with a rectangular box (fig. 1) or a cylindrical box (fig. 2).



**Fig. 1.** Laboratory dryer scheme with rectangular box: a – functional scheme; b – general view; 1 – fan; 2 – temperature sensor; 3 – humidity sensor; 4 – isolating layer; 5 – control panel; 6 – electrical resistances; 7 – cold air; 8 – body; 9 – hot air; 10 – velocity sensor; 11 – drying cells; 12 – humidity sensor for the used drying agent.



**Fig. 2.** Laboratory dryer scheme with cylindrical box: a – functional scheme; b – general view; 1 – fan; 2 – temperature sensor; 3 – humidity sensor; 4 – isolating layer; 5 – control panel; 6 – electrical resistances; 7 – cold air; 8 – body; 9 – hot air; 10 – velocity sensor; 11 – drying cells; 12 – fixed cover; 13 – mobile cover; 14 – change of section.

Mathematical modelling is used in design, in the operational and optimization work. For the same process (physical, technological) or object models are possible, depending on the purpose, the available data, the degree of abstraction etc.

The mathematical model of the convective drying process is based on the theory of fluid dynamics, mass balance and energy. Mathematical model equations on the movement of air flow are presented below.

The differential equation of continuity is obtained by applying the principle of conservation of total mass to a fixed volume element using the formula:

$$\frac{\partial \rho}{\partial \tau} + v_x \frac{\partial \rho}{\partial x} + v_y \frac{\partial \rho}{\partial y} + v_z \frac{\partial \rho}{\partial z} = -\rho \left( \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} \right) \quad (1)$$

in which:  $\rho$  – fluid density,  $\tau$  – time,  $v$  – fluid velocity with the three components ( $v_x, v_y, v_z$ ).

Mass transfer equation from the cereal grains to the intergranular space is described mathematically by partial derivative:

$$\frac{(\rho_a \times X_a)}{\partial \tau} + \nabla \times (\rho_a \times \vec{u} \times X_a) = \nabla \times (\rho_a \times D_{eff} \times \nabla X_a) + S_x \quad (2)$$

in which *Nabla* operator ( $\nabla$ ) is:

$$\nabla = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z} \quad (3)$$

in which:  $\rho_a$  – air density,  $X_a$  – air absolute humidity,  $\tau$  – time,  $u$  – air velocity vector,  $D_{eff}$  – diffusion coefficient of water in the product.

The equation for heat transfer between the drying agent and the seed grain is described mathematically by the equation:

$$(\rho_a \cdot c_{p(a)} + \rho_p \cdot c_p + c_{pH_2O} \cdot X) \cdot \frac{\partial T}{\partial \tau} + c_{p(a)} \cdot \nabla \cdot (\rho_a \cdot \vec{u} \cdot T) = k \cdot \nabla^2 \cdot T + S_h \quad (4)$$

in which:  $\rho_a$  – air density,  $\rho_p$  – product density,  $c_{p(a)}$  – air specific heat,  $c_p$  – product specific heat,  $c_{pH_2O}$  – product water specific heat,  $X$  – absolute humidity of seeds at a specific point  $\tau$ ,  $T$  – absolute temperature,  $u$  – air velocity by three directions,  $k$  – product termic conductivity,  $S_h$  ( $W/m^3$ ) – termic source term.

The geometry meshing of the cylindrical box is hybrid. The cylindrical tubing meshing is structured and in the region of the three seed layers, an unstructured mesh is achieved (fig. 3).

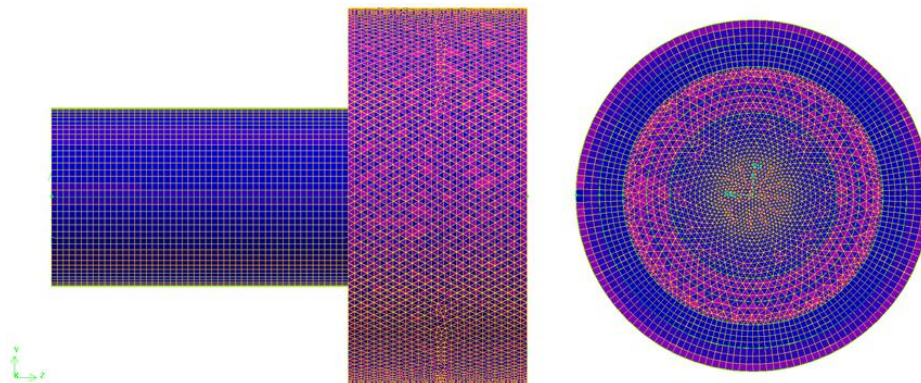
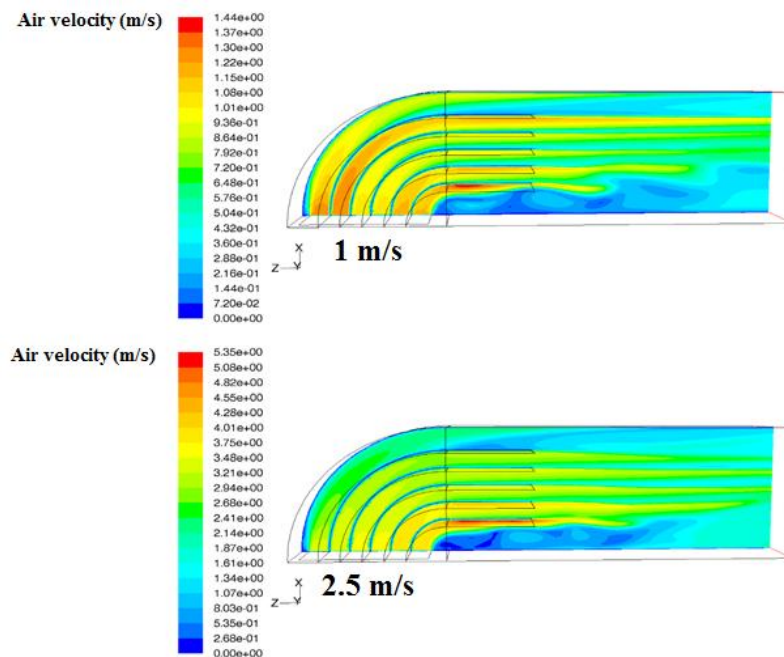


Fig. 3. Cylindrical box meshing

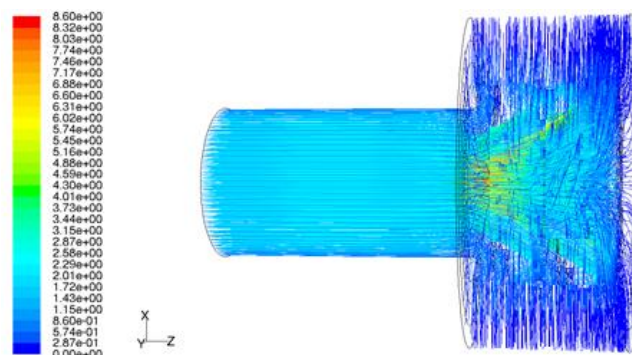
### 3. Results and discussion

The influence of heat can be favorable only if applied wisely regarding the correlation of the following three factors: the temperature of the drying agent, its speed and temperature of the grain seed. During the drying process, humidity vary continuously downwards after complex laws. In order to maintain a high proportion of the qualities as the initial seed is required a close correlation between the temperature and humidity of the drying agent. The air flow was numerical simulated in both the rectangular and the cylindrical drying boxes. Because the velocity profile doesn't cover corners, in the middle section of the air flow, for the rectangular box, turbulences occur both for low and high air velocities (*fig. 4*).



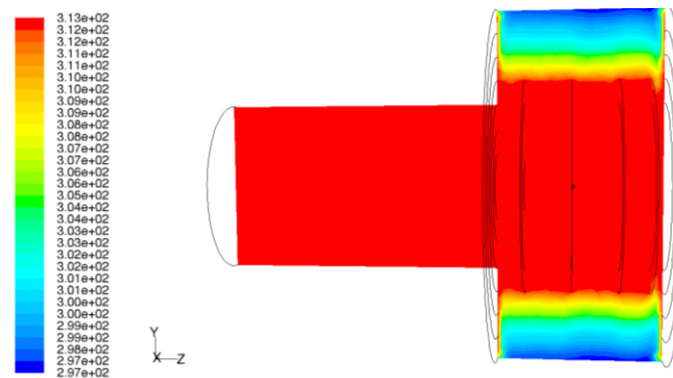
**Fig. 4.** The current velocity lines field inside the rectangular box for the air temperature of 313 K (40°C) and air velocities of 1 m/s and 2.5 m/s

The air field lines obtained in the cylindrical case with three layers of seeds have a laminar flow at the entrance of the box and along the cylindrical sieve can be seen a uniform distribution of hot air throughout the surface layers of seeds subjected to drying (*fig. 5*).

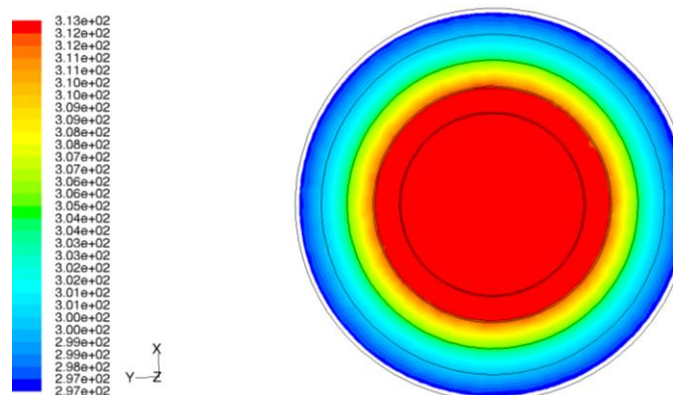


**Fig. 5.** The current velocity lines field inside the cylindrical box for the air temperature of 313 K (40°C) and air velocity of 2 m/s

In *fig. 6* and *fig. 7* are presented the longitudinal and cross section representations of the temperature field (K) for the air velocity of 2 m/s and the air temperature of 313 K (40°C) in the three seed layers.



**Fig. 6.** The longitudinal section representation of the temperature field (K) for the air velocity of 2 m/s and the air temperature of 313 K (40°C)



**Fig. 7.** The cross section representation of the temperature field (K) for the air velocity of 2 m/s and the air temperature of 313 K (40°C)

#### 4. Conclusions

After the drying process mathematical modeling, CFD simulations have been made for the two boxes with three seed layers. The results regarding the distribution of the seed temperature, in the three layers of the cylindrical box, had medium values that varied from the first to the last layer as it follows: the medium value reached was 311 K (38°C) in the first layer, 305 K (32°C) in the second, and 301 K (28°C) in the third one. By means of these CFD simulations calibrated with the experiment, one can make a sufficiently exact model, so that it could be used for other types of seeds too. The main condition is that the entry data introduced in the simulation and obtained experimentally should be as exact as possible. By means of the CFD simulation one can optimize the working process in the cereal seed drying.

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