MODELING HEAT TRANSFER IN A VERTICAL SILO

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Abstract

The temperature measuring system in vertical silos for storing agricultural seeds can monitor the temperature at a limited number of points along its height. In addition, if some of the sensors fail during seed storage, this leads to no seed temperature data over a period of time. Missing temperature data or malfunctioning of the temperature measuring system is not conducive to proper monitoring of seed storage conditions. This paper aims to use CFD (Computational Fluid Dynamics) simulation to determine the temperature fields in various sections of the silo, using a limited amount of temperature sensor data. The results show that by using CFD simulation to obtain colour thermal fields in the sunflower seed layer in the silo, measures can be taken to combat thermal distribution non-uniformity in the seed mass. This provides a theoretical basis for detecting seed storage condition when grain temperature data are intermittently missing. Periodic analysis of temperature fields and high-temperature surfaces is extremely useful from a technological point of view, as it can accurately estimate the times when seed coat aeration should be started in order to keep the seed safe and avoid seed spoilage.

Key words: heat transfer, sunflower seed, silo

The storage of agricultural flat seeds in vertical silos is widespread throughout the country due to economic advantages. Detecting the condition of seed in silos represent an effective measure to ensure safe storage. The main indicators monitored in silos where agricultural seeds are stored are their temperature and humidity, with the role of monitoring changes that occur during storage (Wenhao 2017). Most vertical silos are equipped with temperature monitoring systems that vary from a few measuring points to several dozens, depending on the size of the silo. Efficient detection and analysis of seed conditions can avoid condensation, mold (Cui 2022; Jingjing 2019; Xiaomeng 2019) and other conditions affecting the quality of agricultural seed and also prevent their overheating affecting the final quality and quantity after storage (Pingyuan 2017). On the other hand, accurate analysis of temperature conditions over time can provide clues for intervention work by aeration and therefore, analysis of agricultural seed storage conditions is important for the management and audit system of seed storage so that it ensures the safety of seed quantity and quality. Currently, stored seed condition detection systems can detect indicators such as temperature, humidity, insect pests, and gas concentrations inside and outside the silo (Xuecang 2018). Based on the detected seed condition data, some researchers have established mathematical models coupled with a certain factor or several factors (Quemada-Villagómez 2020; Panigrahi 2019) and then used the models to predict and analyze temperature, humidity, and other seed volume indicators. Some researchers have used CFD and other simulation software to simulate and analyze the process of changing temperature field, moisture field, and other fields in grain volume (Mengmeng 2020; Libing 2019; Qinqin 2019; Novoa-Muñoz 2018; Chunyun 2017). These provide theoretical models for the analysis of agricultural seed condition. Other researchers have studied the coupling relationship between temperature field, moisture field (Mengmeng 2021), pressure field (Dexian 2017), biological field (Zidan 2020) and other fields in grain volume and proposed a multifield coupling method for grain condition analysis. These methods have proven to be able to perform preliminary analysis and assessment of grain condition with respect to aspects affecting grain quality, such as condensation (Mengmeng 2020), mold, etc., and has been able to perform online grain quantity monitoring and analysis (Dexian 2017). The above-mentioned studies perform detection, prediction and assessment of grain quality and quantity by analyzing seed storage condition data and establishing patterns. However,

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there has been research focused on the analysis of historical seed condition temperature data to propose methods for on-site seed storage monitoring and management. In our research group, some studies have been carried out on using historical sunflower seed temperature data in CFD simulations, in order to obtain maps of temperature fields in the sunflower seed mass that can support the management of the silo-mounted aeration system to avoid the formation of high temperature cores in the seed mass that can lead to seed self-ignition. The main directions investigated include: (a) monitoring storage conditions by acquiring temperature data from the silo and their processing; (b) establishing the optimal mathematical heat transfer model; (c) CFD simulation to obtain colour contour maps of the temperature fields in the stored sunflower seed mass.

MATERIAL AND METHOD

To accurately monitor the temperature of sunflower seeds inside the vertical silo with conical bottom, the temperature sensors are necessary to be placed in the most unfavourable positions in terms of temperature distribution (Fig.1).

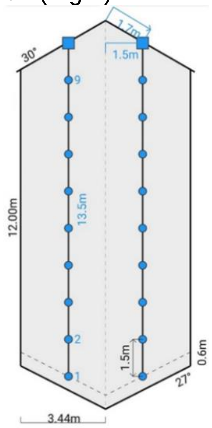

Figure 1 **Positioning of temperature sensors in vertical silo with conical bottom**

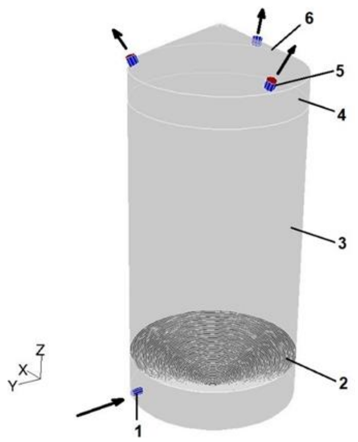

Figure 2 **Geometry of the silo with conical bottom 1 air duct, 2 conical bottom with air holes, 3 sunflower seed area, 4 air area, 5 air holes, 6 silo roof**

The number of temperature sensors in the silo is 27 and their numbering is from bottom to top. They are positioned at an angle of 120º in rows of nine sensors. The temperature sensors are digital type Ds18b20 with stainless steel protection, operating in the range -55 to +125°C and an accuracy of ±0.5°C in the range -10°C to +85°C.

The resolution of the temperature sensors is 12 bits, with an accuracy of 0.0625°C. The 3D geometric model of the conical bottom silo (Fig. 2) has a vent at the bottom, consisting of a duct positioned axially and perpendicular to the cylindrical geometry of the silo.

This duct has a diameter of 300 mm and a length of 460 mm and is connected at one end to a fan with a maximum flow rate of 9500 m^3/h. On the silo roof there are three vents positioned at an angle of 120º.The sunflower seeds used for the experiment were cleaned and selected before being placed in the silo, having the following thermo-physical characteristics. The porosity of the seeds in the vertical silo has an average value of 63%, the bulk density at storage is 438 kg/m^3, the average specific heat of the sunflower seeds is 656.28 J/kgK, the average conductivity of the seeds is 0.088 W/mK, and the thermal diffusivity has an average value of 10.15-10-8 m^2/s. All these parameters took into account the limits of variation of temperature, humidity, density and fat content of the product.

RESULTS AND DISCUSSIONS

The raw experimental results obtained from all temperature sensors placed inside the silo over a period of about one month were processed by applying their median rather than their mean (Table 1).

The average temperature measured over the height of the seed layer at the silo wall was 18°C. The temperature field and isothermal surfaces in the silo in the horizontal plane (XOY) as shown in Fig. 3. From the analysis of the temperature field on the 9 sections (S1...S9), maximum temperatures between 22°C and 24°C varying in circumference are observed from the isothermal surfaces. Thus, in section S9, S7, S4, S3, S2 and S1 these maximum temperature isotherms are positioned at the bottom of the section (bright red colour). In the remaining sections, these maximum temperature isotherms in S5, S6 and S8 have a different orientation. The areas with minimum temperature isotherms have values between 15°C and 18°C for the nine sections. The minimum values are positioned in section S8 at the bottom of the silo and in section S1 oriented at 30° clockwise.

For a complete analysis of the heat transfer in the sunflower seed layer, temperature fields were also taken on vertical sections in the silo, which are positioned at an angle of 120° to each other in the same direction as the temperature sensors (Fig. 4). From the analysis of the temperature field isotherm surfaces, the maximum temperature values range between 23°C and 24°C and the minimum values between 15 and 16°C. In section V1 the maximum temperature isotherm surface is concentrated between 5 and 10 m vertically and between 1 and 2 m horizontally, with a tendency towards the central region of the silo. In section V2 the area of the maximum temperature isotherm is between 6 and 8 m vertically and between 1 and 2 m horizontally, and in section V3 the distribution of maximum temperatures is non-uniform along the vertical of the silo. The minimum temperatures in the isotherms have values between 15°C and 18°C which are positioned at the bottom of the silo and towards the outer wall of the silo, with two small cores in sections V1 and V3 at the top.

By correlating the temperature fields in the horizontal sections (S1...S9) with those in the vertical sections (V1..V3) it can be concluded that the temperature distribution is non-uniform in the product mass.

One explanation for this non-uniformity can be related to uneven aeration starting from the base of the silo and the creation of preferential airflow paths in the heterogeneous porous medium of the sunflower seeds, a trend that is maintained over time even after ventilation has stopped. Taking into account temperature sensor errors of ±0.5°C, the maximum temperature variations inside the silo can reach 8.5°C and the minimum 7.5°C.

Table 1

Temperatures (°C) obtained from the three sensor lines (V1, V2, V3) in the silo

Sensor's position	V1	V2	V3
L9	21,7±0,5	20,8±0,5	24,3±0,5
L8	16,0±0,5	21,2±0,5	15,8±0,5
L7	24,8±0,5	21,2±0,5	24,2±0,5
L6	23,7±0,5	24,7±0,5	21,8±0,5
L5	23,6±0,5	23,8±0,5	21,7±0,5
L4	22,2±0,5	23,4±0,5	23,0±0,5
L3	22,0±0,5	22,1±0,5	22,9±0,5
L2	21,8±0,5	23,6±0,5	23,9±0,5
L1	21,6±0,5	16,8±0,5	22,4±0,5

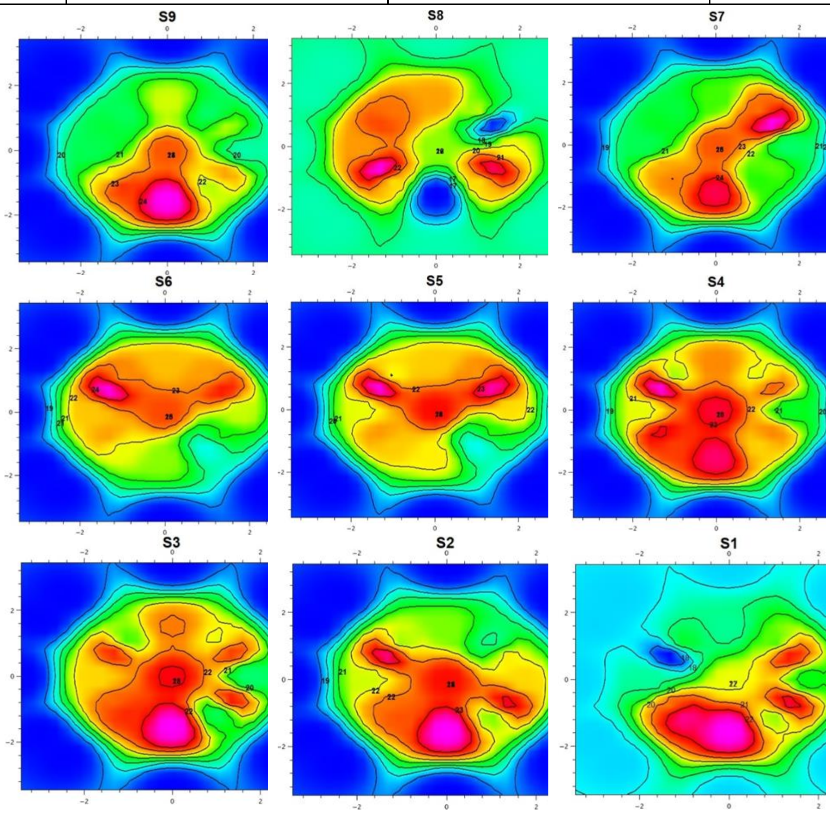

Figure 3 **Isothermal areas in the sunflower seed layer in the silo with T(°C),** (XOY)

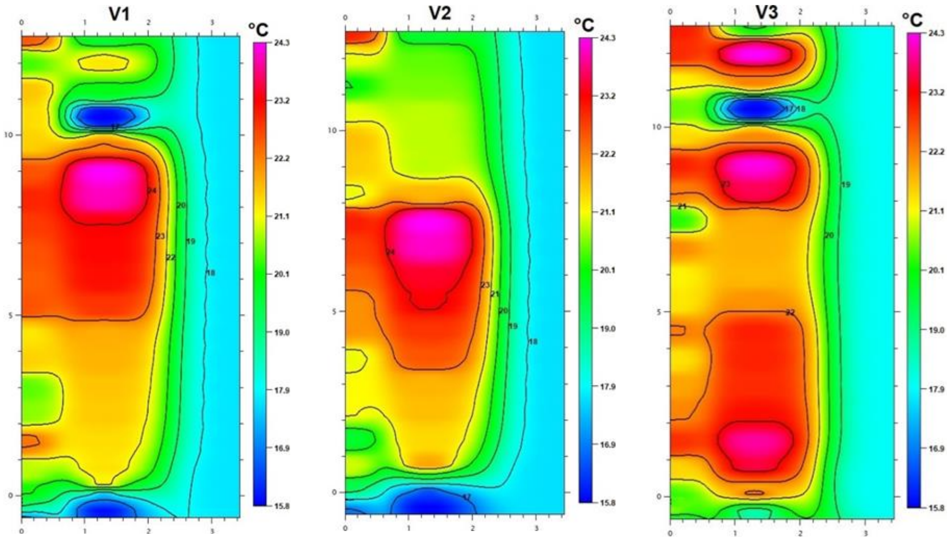

Figure 4 **Isothermal areas in the sunflower seed layer in the silo with T(°C),** (XOY)

CONCLUSIONS

The use of simulation to obtain colour thermal fields in the sunflower seed layer in the silo is important in preventing thermal distribution non-uniformity in the seed mass. Regular analysis of temperature fields and high temperature surfaces is extremely useful from a technological point of view.

Through this research, by analysing the percentage of the high-temperature region of the isothermal surfaces, it is possible to precisely estimate when it is useful to aerate the seed coat.

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