Grain dryer temperature field analysis

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Abstract: Taking into account the drying process in the hot air temperature on the grain temperature has a great impact, and grain temperature and determines the quality of food after baking, so in order to ensure that the grain drying temperature in the safe range, the use of ANSYS FLUENT module of grain The temperature field was simulated in the drying process. The horizontal spacing of the angle box was 200mm and the vertical spacing was 240mm. At this time, the grain temperature distribution was more uniform and the drying was more adequate.

1. The background and significance
The temperature of the drying dielectric has a very important influence in the process of grain drying. In this article, the drying dielectric of grain drying is hot air. The temperature of hot air not only affects the speed of grain drying to a certain extent, but also determines the quality of grain after drying. If the hot air temperature is too low, it is easy to lead to insufficient food drying; temperature is too high will reduce the quality of grain. Grain temperature is an important parameter affecting the drying process of grain, effectively controlling the drying process by drying temperature, not only can improve the drying rate but also save energy [1]. In the process of drying, the air volume of hot air is kept constant, so this paper mainly analyzes the influence of different hot air temperature on the grain temperature, and studies the influence of the distribution of the drying box on the drying process.

The drying process of grain can be based on computational fluid mechanics and heat and mass transfer as the theoretical basis, using FLUENT software as a tool for analysis. FLUENT can be used for a variety of occasions, such as a variety of fluid flow, heat conduction, solidification melting, electromagnetic and other simulation. FLUENT software can be used to divide the grid, can also import the grid, such as structural meshes and unstructured meshes divided by software Gambit, ICEM, etc. Users can use unstructured meshes such as triangular or quadrilateral meshes, Tetrahedron mesh or hexahedral mesh to solve a variety of more complex flows [2-3].

2. Internal structure of drying tower
In this paper, the design of the grain dryer drying tower part of the mechanical structure shown in Figure 1:
3. Geometric modeling and meshing

In this paper, the size and distribution of the corrugated box in the drying tower are shown in Fig. 3.1. The horizontal spacing of the angle box is 250mm and the vertical spacing is 290mm. The simplified analysis model of the drying section is shown in Fig. The size of the whole grain area model is 1.1m×1.05m×0.9m.

Figure 1. Mechanical structure diagram of drying tower

Figure 2. The size and distribution diagram of the corrugated box

The grid division of the grain area and the ventilation area is shown in Figure 3, a total of 169,004 grid, using the free grid division.

Figure 3. The grain drying section model and grid division
4. Parameters and boundary conditions setting

4.1 Specific heat of grain
Generally speaking, the specific heat of food includes the mechanical mixing of the specific heat of grain moisture and the specific heat of the dry matter of grain. The specific heat of grain moisture \( C_s \) is 4186.8 J/kg.K, and the specific heat of the dry matter of grain \( C_g \) is a range of 1257 ~ 1676 J/kg.K, generally can be taken as 1425 J/kg.K. In this paper, wheat was used as drying medium to analyze the grain drying process. In order to simplify the calculation, the specific calorific value of wheat was 1875 J/kg.K.

4.2 Heat conduction of grain
The heat conduction of grain in general is storage heat conduction rather than a single grain of thermal conductivity, coefficient of thermal conductivity of grain can be obtained by the method of experiment, the measured thermal conductivity range normally wheat is generally 0.133 ~ 0.160 W/m.K [4-5]. Thermal conductivity of grain is generally 0.1163 ~ 0.2326 W/m.K. In this paper, the thermal conductivity of wheat is 0.160 W/m.K.

4.3 Grain porosity
The porosity of grain heap is the proportion of the volume of grain in the grain to the total volume of the bulk, which is an important physical property of studying grain thermal characteristics [6]. In this paper, in order to simplify the calculation, assuming that the porosity of the grain during the drying process is constant, in this take the porosity of wheat 0.4.

Physical properties of air
Under normal temperature and pressure, the density of the air, in fact the density of air is not constant, which changes with the temperature and pressure. In general, the air density can be regarded as fixed. In this paper, the air density is set to 1.225 kg/m³.

Grain resistance
Because of the porosity in the process of grain accumulation, In this paper, the accumulated grain is simplified into the porous medium model, and the viscous drag coefficient and inertia resistance coefficient are calculated by formula (3.1) (3.2):

\[
\begin{align*}
D_{ij} &= \begin{cases} 
R_h/\mu; & i = j = 1,2, \\
R_v/\mu; & i = j = 3, \\
0; & i \neq j, i = 1,2,3, j = 1,2,3,
\end{cases} \\
C_{ij} &= \begin{cases} 
2S_h/\rho_a; & i = j = 1,2, \\
2S_v/\rho_a; & i = j = 3, \\
0; & i \neq j, i = 1,2,3, j = 1,2,3,
\end{cases}
\end{align*}
\]

(3.1) (3.2)

In the above formula: \( R_h, R_v \) are the viscous resistance of the airflow across the porous medium in the horizontal and vertical directions, respectively; \( S_h, S_v \) are the horizontal and vertical inertial resistance, respectively; \( \mu, \rho_a \) are the gas viscosity and density, respectively.

5. Boundary conditions setting
WALL wall boundary: the wall is set to non-slip boundary conditions, due to the grain drying process, the heat convection in the drying section has a great influence on the temperature of the grain, and the heat transfer between the grain and the angular box is secondary. Therefore, the wall of the corner box can be set into a constant temperature, as shown in figure 4.

Interface: for different regions and fluid is the same as the interface, since the hot air flows out from
the bottom of the horn box, the inside of the horn box and the outside food area of the horn box belong to different fluid areas, so the bottom surface of the horn box is set as Interface, can correctly simulate the hot air flow through the food situation, as shown in Figure 5.

Inlet: the hot air inlet can be set as the velocity inlet, which is velocity inlet, which is suitable to be used in the case of incompressible flow, and the speed of the hot air should be set during the process, as shown in Figure 6.

Outlet: the hot air outlet can be set to pressure outlet the export pressure, conditions in the process of using, it must be noted that should be set on the gauge, as shown in Figure 7.

6. Simulation result analysis
The temperature distribution of the grain is simulated when the hot air temperature is 65°C, 75°C, 85°C, 95°C, and the simulation results are shown in Fig. 8 - Fig. 11:
It can be seen from the chart, the upper grain temperature in the grain drying zone was almost unchanged. Considering the influence of angular spacing on the vertical box grain temperature field, the angular vertical spacing box instead of 240mm to simulate the effects on grain temperature field at different locations under the same conditions, horn shaped box, the simulation results are shown in figure 12—figure 15.
It can be seen from the simulation results that when the vertical interval of the angle box is reduced to 240mm, the grain temperature in the upper part of the drying section is larger than before, indicating that this part of grain contact with the hot air is more, the heat exchange takes place more. And the grain temperature in the vertical direction away from the angle box between the air inlet angle boxes is higher than that in the vertical direction by 290 mm because the vertical distance between corners of the box is reduced and the same drying time, the total amount of hot air with the former has increased compared to the drying section of the upper part of the hot air enough to dry the grain, and the overall average temperature of grain, grain drying is more adequate. Therefore, the vertical direction of the angle box can be optimized to 240mm, the temperature of the grain under different hot air temperature is shown in Table 1.

### Table 1. the grain temperature under different hot air temperature (when the vertical angle of the box is 240mm)

| Hot Air Temperature (℃) | 65  | 75  | 85  | 95  |
|-------------------------|-----|-----|-----|-----|
| Grain Temperature (℃)   | 41.1| 43.3| 49.7| 55.6|

In order to consider the effect of the horizontal spacing of angle boxes on the grain temperature field, the horizontal spacing of horn boxes was changed to 200mm to simulate the effect of different positions of the angle boxes on the grain temperature field at 65 ℃, 75 ℃, 85 ℃ and 95 ℃, respectively. The simulation results are shown in Fig.16-Fig.19.
Fig. 18 Temperature field of grain drying section (T=85℃)

It can be seen from the simulation results that when the horizontal distance of the horn box is reduced to 200mm, the grain temperature distribution is more evenly distributed between the horn boxes compared with the horizontal distance of 250mm in the horizontal direction of the drying section, the grain can get better drying, so the horizontal distance of the angle box should not be too large. In this paper, the spacing of the horn boxes in the horizontal direction is optimized to 200mm, and the average temperature of grain is shown in Table 2.

| Hot Air Temperature (℃) | 65  | 75  | 85  | 95  |
|-------------------------|-----|-----|-----|-----|
| Grain Temperature (℃)   | 40.4| 46.8| 48.6| 54.7|

From the above analysis, the temperature field was simulated by changing the dimension of the corrugated box of the drying section to 200mm in the horizontal direction and 240mm in the vertical direction. The results showed that the hot air temperature was 65 ℃, 75 ℃, 85 ℃, the grain temperature distribution in the drying section is shown in Fig. 20 - Fig. 23.

It can be seen from the chart: in the process of grain drying, hot air temperature decreased gradually in the process of moving forward; with hot air diffusing into the grain bulk, occurrence of convective heat transfer of grain in the temperature rising; in the vertical section, the grain temperature of closing to the angular box is higher, and the temperature decreases gradually from the inlet angle box; The temperature at the inlet of the air inlet box is higher than that of the grain next to it. In the air inlet angle box, most of the hot air enters the grain heap, and a small amount of the hot air coming out of the air inlet angle box is diffused to enter the grain heap above the air inlet box. In general, the grain temperature distribution is more evenly distributed and the drying is more adequate than the initial design. Therefore, the size of the angular box in the drying section can be optimized to be 200mm in the horizontal direction and 240mm in the vertical direction, and the average grain temperature as shown in Table 3.

| Hot Air Temperature (℃) | 65  | 75  | 85  | 95  |
|-------------------------|-----|-----|-----|-----|
| Grain Temperature (℃)   | 44.3| 47.6| 52.7| 58.9|

It can be seen from Table 3 that the temperature of grain increased with the temperature of hot air, when the temperature of hot air was 95 ℃, the temperature of grain was 58.9 ℃. When the grain temperature was 75 ℃, the temperature of hot air was 47.6 ℃. Too high temperature of hot air will lead to the high temperature of the grain in the drying process, so that the quality of grain will decrease. Although the hot air temperature keep the temperature of grain in the safe range, it will shorten the
drying time and reduce the drying efficiency. Therefore, the hot air temperature of the drying grain can be set to 85°C, the upper limit is set at a temperature of 95°C, and the lower limit is set at a temperature of 75°C.

Fig.20 Temperature field of grain drying section (T=65°C)

Fig.21 Temperature field of grain drying section (T=75°C)

Fig.22 Temperature field of grain drying section (T=85°C)
7. Summary
Considering that the hot air temperature has a great influence on the grain temperature in the drying process, and the grain temperature determines the quality of grain after drying, so in order to ensure that in the process of drying temperature of grain in the safe range. In this chapter, ANSYS FLUENT module is used to simulate the grain drying process, through the analysis of the influence of different angular the box position on the grain drying process, to optimize the structure of grain drying machine. When the horizontal spacing of the horn box is 250mm and the vertical spacing is 290mm, the temperature distribution of the grain will be uneven and the local drying will be insufficient. After the optimization, the horizontal spacing of the angle box is 200mm and the vertical spacing is 240mm, grain temperature distribution is more uniform, more fully dry. Through the analysis of the temperature field, the upper and lower limits of the hot air temperature required for the grain dryer were determined, which provided the basis for the control target of hot air temperature in the control system.

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References
[1] Zhang Yaqiu Moisture Detection and Automatic Control of Grain Drying Process[D]. Changchun: Jilin University, 2012.
[2] D.B.Funk, Z.Gillay, P.Meszaros. Unified moisture algorithm for improved RF dielectric grain moisture measurement [J]. Measurement Science and Technology 2007, (18): 1004-1015.
[3] Zhang Q, Lithfield J B. Knowledge representation in a grain drier fuzzy logic controller. J. Agric. Engng. Res, 2004, 57(18): 269-278.
[4] Zhang Lilin, Li Yanfeng, Mao Guangqing and so on. Determination of Thermal Conductivity of Grain by Hot - wire Method[J]. Food and Feed Industry 2010 (7): 12-14.
[5] Yang Li, Tao Binbin qualitative drying of porous media [J]. Journal of Heat and Mass Transfer of Agricultural Engineering, 2005, 01: 27-31.
[6] Wang Xue. Study on grain heat transfer model [D]. Zhengzhou: Henan Polytechnic University, 2013.