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Numerical simulation of heat and humidity coupled cooling in Fermentation Room of Daqu

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Abstract

Aiming at the burning Daqu phenomenon in the fermentation process of liquor Daqu, in order to explore the characteristics of the flow field in the Fermentation Room of Daqu when the burning Daqu occurs, and seek prevention methods. The CFD software Fluent was used to numerically simulate the normal fermentation state and the burning state of Daqu, and the flow field characteristics in the Fermentation Room of Daqu under the two conditions were compared. The results show that when the scorching phenomenon occurs, the temperature of the curved block rises, causing the lower air temperature in the c room to rise and the humidity to decrease, and the upper air temperature and humidity of the room do not change significantly. The air internal circulation is used to simulate the cooling of the air in the room. The simulation results show that at the 15th minute, the air temperature in the room can be restored to the normal fermentation temperature, and the humidity is slightly higher than the normal fermentation stage, which provides a basis for further improving the fermentation environment of Fermentation Room of Daqu .

Keywords

Scorching phenomenon; thermal and moisture coupling; UDF; temperature field; humidity field.

1. Introduction

During the fermentation process of liquor Daqu, the change of air temperature in Fermentation Room of Daqu has a significant impact on the fermentation results. The air temperature in different fermentation stages needs to be kept within a certain range. When the temperature exceeds the allowable range of the fermentation stage, the phenomenon of burning Daqu will occur. That is to say, the moisture of the Daqu is quickly lost, and the fermentation of the Daqu is stopped, which seriously affects the quality of Daqu. At present, Huang Aoyun, Gao Yuxiang [1] and others have proposed an intelligent temperature and humidity monitoring system for Fermentation Room of Daqu in response to the cumbersome wiring, high cost, and poor measurement accuracy in Fermentation; Zhao Dianchen, Ma Liansong [2] etc. developed the temperature and humidity for Fermentation Room of Daqu The wireless control of the automatic window opening and closing technology, monitoring the cultivation process of Daqu all-weather, is of great help to the improvement of Daqu quality. Current scholars mainly study the monitoring process of temperature and humidity in the curved room, but no scholar has studied the problem of cooling the curved room. In this paper, by means of numerical analysis, the CFD software Fluent is used to numerically simulate the burning phenomenon, and the cooling process is simulated, the cooling rate of the Fermentation Room of Daqu is studied, and

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the temperature and humidity characteristics in the Fermentation Room of Daqu before and after cooling are compared.

2. Physical Model

A simulation model was established based on the internal flow field of the Fermentation Room of Daqu, and part of the three-way structure of the cooling pipeline was added to the room simulation model. Assuming that the temperature and humidity conditions and speed of each air inlet of the Fermentation Room of Daqu are the same, in order to facilitate the setting of the boundary conditions of the air inlet during the dehumidification process, a pipe tee structure is established for each air inlet and outlet, and the inside of the Fermentation Room of Daqu is established at a ratio of 1:1and 1/2 model, as shown in Figure 2-1. The pipeline model is meshed. The divided mesh model is shown in Figure 2-2. The model has 673,269 mesh units, 17023 nodes, and a mesh quality of 0.85. , Meet the calculation requirements.

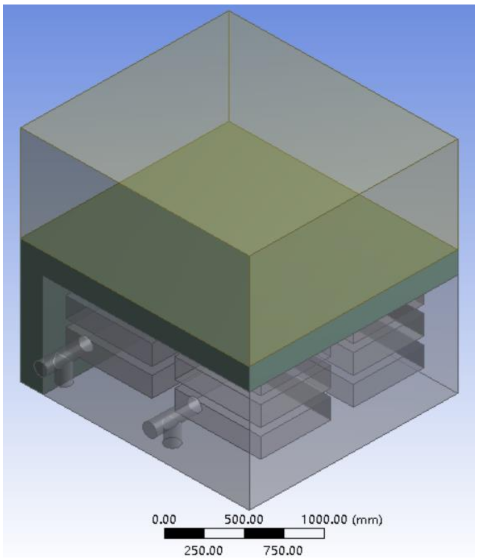

Figure 2-1 Curved room model

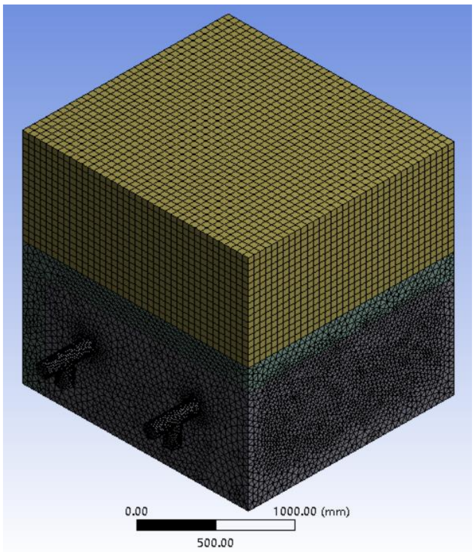

Figure 2-2 Curved room grid model

3. Mathematical Model

The fluid flow in Fluent obeys the law of conservation of mass, law of conservation of momentum, and law of conservation of energy. The governing equations are as follows:

(1) Mass conservation equation

Conservation of mass means that the mass added in the micro-element body per unit time is the same as the mass flowing out. The continuity equation is:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho v_x)}{\partial x}+\frac{\partial(\rho v_y)}{\partial y}+\frac{\partial(\rho v_z)}{\partial z}=0$$

In the formula, v_x, v_y and v_z are the velocity vectors in x, y and z directions respectively; ρ are the density of the fluid flowing through the infinitesimal body, x, y and z are the total Cartesian coordinates; t are the fluid flowing time.

(2) Momentum conservation equation

The conservation of momentum means that the rate of change of the momentum of the fluid in a micro-element body with respect to time is equal to the sum of various forces acting on the micro-element body from the outside world. The momentum conservation N-S equation is:

$$\frac{\partial \rho v_x}{\partial t}+\frac{\partial(\rho v_x v_x)}{\partial x}+\frac{\partial(\rho v_y v_x)}{\partial y}+\frac{\partial(\rho v_z v_x)}{\partial z}$$
$$=\rho g_x-\frac{\partial P}{\partial x}+R_x+\frac{\partial}{\partial x}\left(\mu_\varepsilon\frac{\partial v_x}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_\varepsilon\frac{\partial v_x}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu_\varepsilon\frac{\partial v_x}{\partial z}\right)+T_x$$
$$\frac{\partial \rho v_y}{\partial t}+\frac{\partial(\rho v_x v_y)}{\partial x}+\frac{\partial(\rho v_y v_y)}{\partial y}+\frac{\partial(\rho v_z v_y)}{\partial z}$$
$$=\rho g_y-\frac{\partial P}{\partial y}+R_y+\frac{\partial}{\partial x}\left(\mu_\varepsilon\frac{\partial v_y}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_\varepsilon\frac{\partial v_y}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu_\varepsilon\frac{\partial v_y}{\partial z}\right)+T_y$$
$$\frac{\partial \rho v_z}{\partial t}+\frac{\partial(\rho v_x v_z)}{\partial x}+\frac{\partial(\rho v_y v_z)}{\partial y}+\frac{\partial(\rho v_z v_z)}{\partial z}$$
$$=\rho g_z-\frac{\partial P}{\partial z}+R_z+\frac{\partial}{\partial x}\left(\mu_\varepsilon\frac{\partial v_z}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_\varepsilon\frac{\partial v_z}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu_\varepsilon\frac{\partial v_z}{\partial z}\right)+T_z$$

In the formula, g_x , g_y and g_z are the acceleration components produced by gravity in the x , y and z directions respectively; ρ are the fluid density, μ_ε is the effective viscosity, R_x , R_y and R_z are the distributed resistance in the x , y and z directions; T_x , T_y and T_z 为are the viscous loss terms in the x , y and z directions.

(3) Energy conservation equation

Conservation of energy means that the rate of increase of energy in the micro-element body is equal to the net heat flow into the micro-element body plus the work done to the micro-element body by physical and surface forces. The energy equation is:

$$\frac{\partial}{\partial t}(\rho C_p T_0)+\frac{\partial}{\partial x}(\rho v_x C_p T_0)+\frac{\partial}{\partial y}(\rho v_y C_p T_0)+\frac{\partial}{\partial z}(\rho v_z C_p T_0)$$
$$=\frac{\partial}{\partial x}\left(K\frac{\partial T_0}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial T_0}{\partial y}\right)+\frac{\partial}{\partial z}\left(K\frac{\partial T_0}{\partial z}\right)+W^v+E^k+Q_v+\Phi+\frac{\partial P}{\partial t}$$

Where C_p is the specific heat capacity; T_0 is the total temperature; K is the thermal conductivity; W^v is the viscous work; Q_v is the volume heat source, Φ is the viscous heat generation term; E_k is the kinetic energy.

For the pore area formed by curved blocks and rice straw, the porous media model is used to simulate the influence of the resistance of the fluid flowing between pores on the flow field. The governing equation is:

$$S_i=-\left(\sum_{j-1}^{3}D_{ij}\mu v_j+\sum_{j-1}^{3}C_{ij}\frac{1}{2}\rho_{air}|v|v_j\right)$$

Where S_i is the i directional momentum source term; C is the coefficient of inertial resistance; D is the coefficient of viscous resistance; $|v|$ is the air flow rate, in units m/s ; μ is the aerodynamic viscosity, in units $N\bullet s/m^2$; v_j is the air velocity, in units m/s .

Use Ergun equation to calculate viscous resistance coefficient and inertial resistance coefficient, the formula is as follows:

$$\frac{1}{\alpha}=\frac{150}{D_p^2}\frac{(1-\varepsilon)^2}{\varepsilon^3}$$

$$C_2=\frac{3.5}{D_p}\frac{(1-\varepsilon)}{\varepsilon^3}$$

Where $1/\alpha$ is the viscous resistance coefficient; D_p is the equivalent diameter; C_2 is the inertial resistance coefficient; ε is the porosity of the porous medium. According to the ratio of the total volume of the unsimplified single-layer curve to the volume of the simplified single-layer curve, the porosity is 0.26

Take the straw porosity to be 0.15, check the data, and get the physical properties of the straw, as shown in the following table 3-1:

Table 3-1 Physical parameters of rice straw

Density (kg/m3)	Specific heat capacity (J/kg•K)	Thermal Conductivity (W/m·K)
150	2010	0.06

4. Parameter Setting

If you According to the data measured at a certain moment of normal fermentation during the tidal period of a winery in Yibin, the temperature sensor measured that the temperature of the Daqu rose to 51℃, and the relative humidity of the air in the fermentation area of the room was 85%. As shown in Table 4-1.

Table 4-1 Normal fermentation parameter setting table during tidal fire period

name	Parameter value
Initial air temperature outside the straw/℃	41
Initial temperature of straw/℃	41
Initial temperature of curve/℃	51
The initial relative humidity of the air in the fermentation area/%	85
Heat transfer coefficient of room wall W/m2·K	2.207

At this time, the curved block in the room is the heat source, and the heat transfer method in the room is mainly the convective heat transfer between the curved block and the porous medium of the air and the heat conduction of the porous medium between the Daqu and the straw. The transient simulation of the model is performed for 10 minutes, and the extraction The cloud diagram of normal fermentation temperature is shown in Figure 4-1, and the cloud diagram of normal fermentation humidity is shown in Figure 4-2.

Comprehensive analysis of the temperature and humidity cloud map in the room at that time shows that the air temperature distribution in the room shows that the upper air temperature is lower than the lower air temperature, and the air humidity distribution shows that the upper humidity is higher than the lower humidity, and the upper air temperature and humidity are more evenly distributed. , The lower air temperature distribution shows that the air temperature near the Daqu is high, and the air temperature through the floor is low, and the humidity distribution trend is opposite to the temperature distribution. Extracting the air temperature and humidity data of the upper and lower layers respectively, it can be seen that the average temperature of the upper air is 314.15K, the average humidity is 85%, the average temperature of the lower air is 323.01K, and the average humidity is 53.6%. The temperature distribution trend in the room is opposite to the humidity distribution trend. .

After 10 minutes, the temperature sensor detected that the temperature of the slab rose by 5 degrees Celsius, resulting in a burning phenomenon, and the temperature reached 56 degrees Celsius. Set the temperature of the Daqu at this moment to 56 ℃, continue the transient simulation of the normal fermentation model during the damp and fire period for 10 minutes, and extract the Daqu temperature cloud diagram of the burning phenomenon as shown in Figure 4-3, and the humidity cloud diagram is shown in Figure 4-4. Shown.

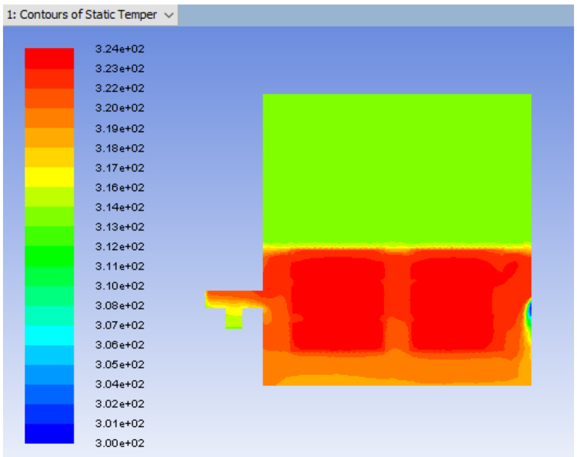

Figure 4-1 Normal fermentation temperature

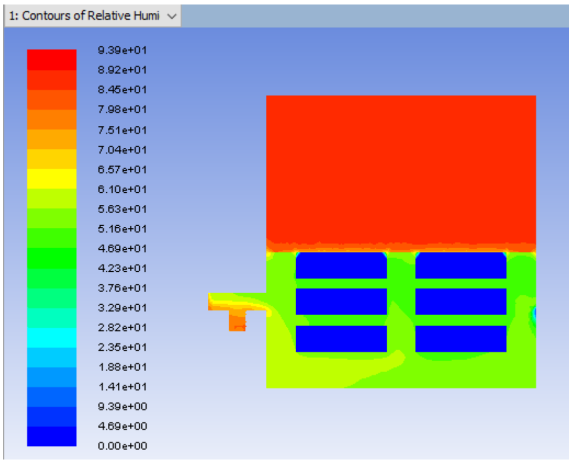

Figure 4-2 Normal fermentation humidity

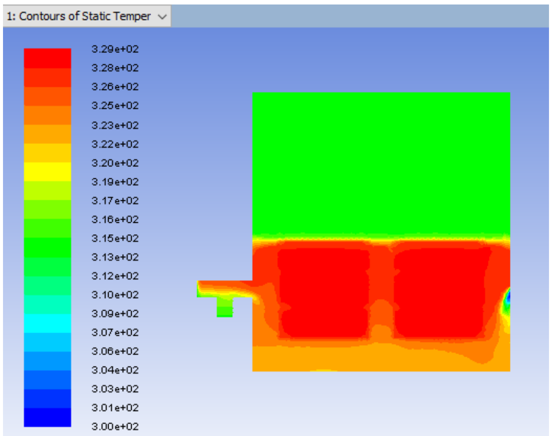

Figure 4-3 Burning phenomenon temperature

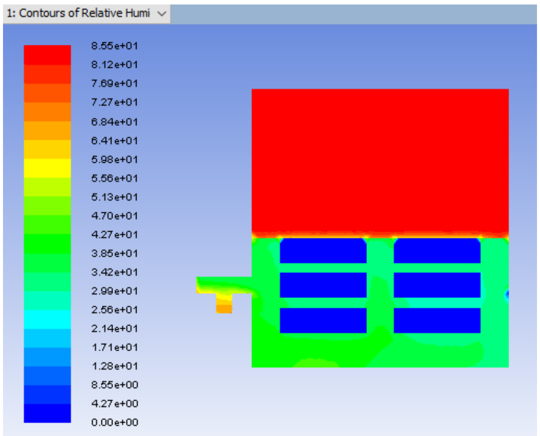

Figure 4-4 Humidity of burning phenomenon

It can be seen from the figure that at this moment, the lower air temperature in the room increases significantly and the air humidity decreases. The reason for this is that the increase in air temperature leads to an increase in the saturated vapor pressure of the air and a decrease in the relative humidity of the air. Extracting the upper and lower air temperature and humidity values at this moment shows that the average temperature of the upper air is 314.15K and the average humidity is 85%, which is almost unchanged from the normal fermentation stage. This is because the heat preservation and moisturizing effect of the straw isolates the temperature and humidity transmission of the lower air in a short period of time. . The average temperature of the lower air is 326.64K, and the average humidity is 32.61%. Compared with the normal

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fermentation stage, the average temperature has increased by 3.63℃ and the average humidity has been reduced by 20.99%. The lower air needs to be cooled in time.

The pipeline heat-humidity coupling cycle cooling system is used to circulate the lower air temperature of the room, that is, the air in the room is led out of the room by a pipe, and is connected with a humidifier to cool down, and then return to the room. In Fluent, the Mix Plans module can be used to connect the inlet and outlet pipelines, with the outlet face as the upstream and the inlet face as the downstream, that is, the temperature of the outlet face is transferred to the inlet face to simulate the pipeline cycle process. However, for the transmission of humidity, there is no usable module in Fluent. Therefore, the humidity transmission UDF is written to transfer the humidity of the outlet surface to the inlet surface.

UDF mainly executes functions through the Define macro function in Fluent, or extracts the data generated by the calculation process. Its writing rules completely follow the C language programming rules. Therefore, you can define sub-functions that do not belong to the Define function in the UDF, and use the Define macro function to call ,Calculation.

Since Fluent's own model cannot perform humidity transfer calculations, this paper uses UDF to implement the humidity cycle transfer process. The UDF program needs to extract the water vapor component content of the outlet surface of the calculation result of each time step, average the content of all the output components and assign it to the inlet, so as to realize the circulating calculation of water vapor.

The commonly used Define macros are DEFINE_EXECUTE_AT_END, DEFINE_ADJUT, GET_Domain and DEFINE_PROFILE. Among them, DEFINE_EXECUTE_AT_END is a general macro, which is executed at the end of the last iterative step of steady-state calculation or at the end of a time step in transient calculation. This article uses this function for transient calculation to calculate the outlet water vapor after each time step. flow. Unlike DEFINE_ADJUT, DEFINE_EXECUTE_AT_END does not pass the domain pointer and cannot identify the export domain value. Therefore, it is necessary to use GET_Domain to obtain the domain value ID of the import and export. DEFINE_PROFILE can customize the boundary profile or cell area conditions. The conditions change with spatial coordinates or time. Variables that can be defined are speed, pressure, mass flow, species mass fraction, volume fraction, etc. This article uses this function to export The average water vapor component mass fraction after extraction is defined as the component mass fraction of the inlet boundary condition.

5. Simulation Results

Set the parameters on the basis of the simulation results of the burning curve model. Set the air inlet velocity of the curve room to 1.5m/s, which is the maximum wind speed of soft wind. In the cyclic adjustment during the simulation adjustment process, the humidifier inlet is the mass flow inlet, and the boundary conditions are the same as the previous parameters.

Perform a transient simulation on the model for 20 minutes. In order to more intuitively observe the change of the air temperature in the curved room at different times, the average temperature of the lower air in the curved room at different times is extracted as shown in Table 5-1.

Table 5-1 Air temperature table at each time

Time (min)	5	10	15	20
Average temperature (K)	327.1368	325.7727	324.0354	322.0891

It can be seen from the data in the table that the lower air temperature of the curved room reaches 324.04K during the 15-minute cycle of cooling, which is close to the temperature of the lower air of normal fermentation. At this time, the humidity cloud at X=0.38m in the curved room is shown in Figure 5-1. Show.

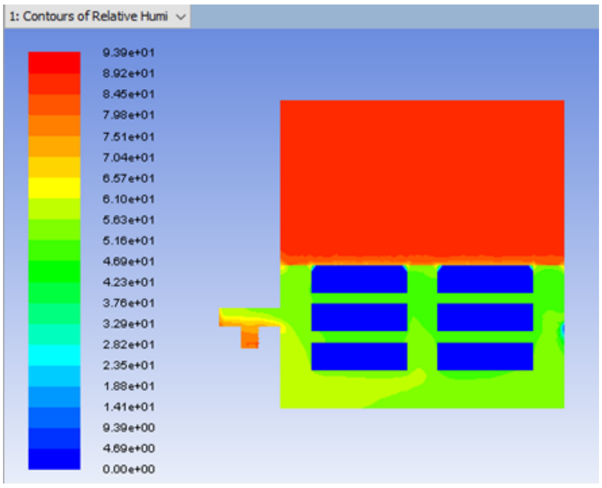

Figure 5-1 Cooling temperature and humidity

At this moment, the average humidity of the lower air in the curved room is 55.6%, and the average humidity of the upper air is 85%. It can be seen that due to the moisture retention of the straw, the temperature of the upper air remains basically unchanged in a short period of time, and the humidity of the lower air is relatively humid. The humidity in the normal fermentation stage during the fire period increases by 2%. The main reason for the increase in humidity is that the humidifier is turned on during the cooling process, which increases the humidity in the air in the koji room.

6. Conclusion

This chapter simulates the scorching phenomenon. It can be seen that when the scorching phenomenon occurs, the lower air humidity in the squiggly room decreases, the temperature increases, and the upper air temperature and humidity do not change much. During the process of cooling the squeeze room, in the 15th Minutes, the average temperature of the lower air in the room reaches the normal fermentation temperature during the damp fire period, and the cooling is over.

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