Research on Temperature Distribution Characteristics and Optimization of PC Component Maintenance Kiln in Prefabricated Building

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Abstract: Aiming at the phenomenon of uneven temperature distribution in the curing kiln of three-dimensional PC components, the temperature field distribution model of the curing kiln was established by using computational fluid dynamics numerical simulation method on the premise of ensuring the curing quality of PC (Precast component) components, and the effects of the location of the spray hole, the presence of fans and the number of fans on the temperature field distribution in the curing kiln were studied.The research shows that when there is no fan, the temperature distribution is very uneven, and the upper and lower temperature difference reaches 26K.By adding the fan simulation experiment, it is found that the temperature distribution of the curing kiln is more uniform and the curing time is shortened when there is one fan.Through the simulation experiment of the position of the spray holes in the curing kiln, it is found that the temperature distribution is the most uniform when the spray holes are located at the front and back of the curing kiln, the direction is inclined down 45°, and the temperature distribution is arranged in 1 column and 9 rows, which shortens the time required for uniform temperature distribution inside the curing kiln.

Keywords: *Three-dimensional PC component curing kiln; Temperature distribution; Numerical simulation; Optimization analysis*

I. INTRODUCTION

With the development of The Times and the progress of science and technology, the traditional construction production mode with poor safety, low efficiency and serious pollution has no longer adapted to the needs of today's rapid development. In this context, prefabricated buildings have been paid more and more attention.In recent years, the Ministry of Housing and Urban-Rural Development has repeatedly issued documents to promote prefabricated buildings, promote the industrialization of the construction industry, and achieve high-quality development of the construction industry[1][2].

PC component production industrialization is an important part of building industrialization.The thermal effect of hydration has a great influence on the quality of PC components. If the temperature rise of concrete hydration heat is too high, cracks will occur in the early stage of PC components, which will affect the subsequent mechanical performance of PC components and reduce their durability [3].The main reason for early cracks is that the early curing method of concrete is unreasonable, or the curing effect is not ideal, and temperature and humidity are the key to concrete curing [4].In order to accelerate the hardening of concrete, improve work efficiency and the quality of PC components, PC component factories usually carry out steam curing of PC components [5].As one of the important equipment of PC component production line, the curing kiln can accelerate the curing time of concrete PC component by injecting steam, so that it can reach the required strength in a short time [6].

Wang et al[7] conducted a study on steam curing with mold in deep pit. Through theoretical analysis and calculation of the curing process, and experimental verification, steam flow will affect the heating efficiency of PC components and the strength of concrete. Therefore, the PC components must be placed separately during steam maintenance, and forced gas supply can also be adopted.

Qi et al[8] conducted a systematic analysis of the maintenance systems of domestic and foreign maintenance kilns. The hot air system was used in foreign maintenance systems, and the fan sent hot and humid air into the maintenance kilns.The domestic maintenance system uses steam maintenance system, through the steam nozzle to send wet heat into the maintenance kiln and fin radiator and maintenance kiln heat exchange to meet the temperature and humidity of the maintenance kiln.The research shows that the hot air system has better curing effect than the steam curing system, but because the steam curing system is widely used in China, it is not only familiar with the process, but also cheap, so the steam curing system is mainly used in China.

Peng[9] mainly analyzed the main parameters of the steaming system, namely resting time, heating rate, constant temperature time and the influence of constant temperature temperature on the physical properties of concrete. Extending the resting time, accelerating the heating rate, extending the constant temperature time and increasing the constant temperature temperature can improve the physical properties of concrete.Li[10] found through the study of concrete that increasing constant temperature is conducive to the improvement of early release strength; When the temperature reaches 80℃, the damage to the concrete micro structure is minimal.Wang et al[11] conducted experiments on three kinds of concrete and concluded that the pre-conditioning time could be shortened by 1h under the condition of 60℃.China Academy of Building Science[12] stipulated in the 2011 concrete quality control standard that the steam curing system includes four stages: static stop, warming, constant temperature and cooling.

The above researches mainly focus on the improvement of the steaming system and the steaming system, and rarely study the temperature field of the curing kiln.If the temperature distribution is not uniform, it may cause cracks in the PC component and make the later strength substandard.Therefore, this paper carried out simulation research on the temperature field of the curing kiln, and carried out research on the optimization of steam injection and fan position.

II. SIMULATION SETTINGS

A. Simulation Area

This paper conducted a survey on a PC component production plant, and studied the temperature field of 8 rows of 1-layer curing kilns under the curing condition of large wall panels, as shown in Figure 1. The kilns are 6.3m long, 4.2m wide and 3m high.9 steam spray holes with diameter of 0.01m are arranged in a single row on two sides of the front and back of the curing kiln with a height of 1m, the spacing is 0.4m, and the spray Angle is horizontal.Injection speed 580m/s, steam temperature 380k, steam humidity 90%; Radiators are located on both sides of the kiln.

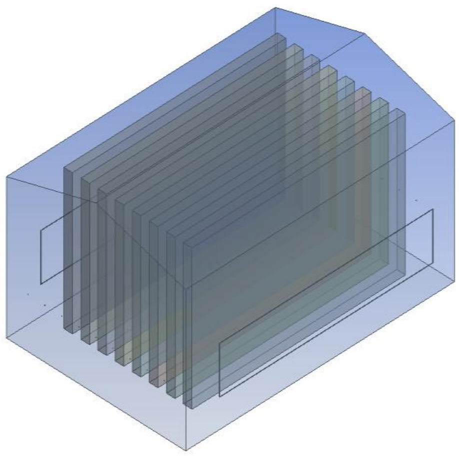


Fig.1 PC component curing kiln diagram

B. Simulation settings

Mesh was used to mesh the calculation model, and the results were shown in Figure 2.The total number of grids is 4.1×10^5. The divided grids are imported into Fluent for transient simulation, and the time is set to 10s.The simulation region is divided into two parts: fluid region and solid region.The fluid region is a mixture of air and water vapor;Considering the influence of gravity on the airflow, the incompressible ideal gas model is selected when setting the density, so that the function of density and temperature, i.e

$$\rho=\frac{P_{OP}}{\frac{R}{M_W}T} \tag{1}$$

Where: R is the gas constant; M_W is the molar mass of the gas mixture. P_{OP} is the operating pressure; T is the temperature.

Specific heat capacity at constant pressure is calculated by mixing law, i.e

$$C_P=\sum_i \omega_i C_{p,i} \tag{2}$$

Where: ω_i is the quality fraction of the i component; $C_{p,i}$ is the specific heat capacity at constant pressure of the i component.

The thermal conductivity is calculated by the ideal gas mixing law,

$$k=\sum_i \frac{x_i k_i}{\sum_j x_j \phi_{ij}} \tag{3}$$

Formula:

$$\phi_{ij}=\frac{\left[1+\left(\frac{\mu_i}{\mu_j}\right)^{1/2}\left(\frac{M_{w,j}}{M_{w,i}}\right)^{1/4}\right]^2}{\left[8\left(1+\frac{M_{w,i}}{M_{w,j}}\right)\right]^{1/2}} \tag{4}$$

x_i and x_j are the molar fractions of the i and j components, respectively. k_i is the thermal conductivity of the i component. μ_i and μ_j are the dynamic viscosity of the i and j components, respectively. $M_{w,i}$ and $M_{w,j}$ are the molar masses of the i and j components, respectively.

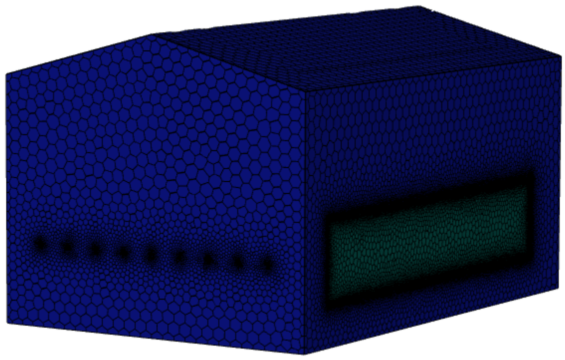


Fig.2 Grid diagram

According to the parameters of C30 concrete, the density of large wall panels in solid areas is 2500kg/m3, the specific heat capacity is 920, and the thermal conductivity is 1.74.Convective heat transfer between solid and fluid regions is calculated by means of coupled interface transfer parameters.

The actual curing kiln uses aerogel felt as insulation material; Based on the thickness (10mm) and thermal conductivity (0.02 $W/(m\cdot K)$) of the aerogel felt, the heat flux of the insulation wall is 342.6W/m^2.The heat sink in the curing kiln is simplified into a heating surface, and its temperature is set to 440K, and the heat transfer with the air is treated according to the second type of boundary condition.Other setup conditions used in the simulation are shown in Table 1.

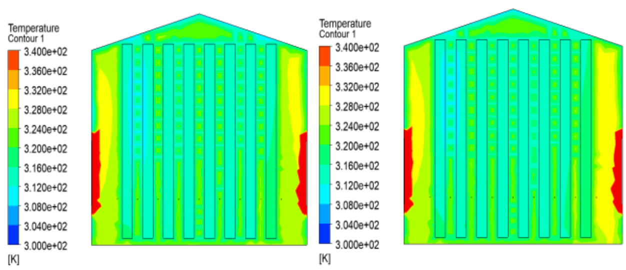
Table 1: Fluent Simulation conditions

Set type	Mock name
Turbulence model	k-omega
Convective term discrete scheme	QUICK format
Diffusion term discrete format	Central difference scheme
Solution algorithm	SIMPLE algorithm (transient)

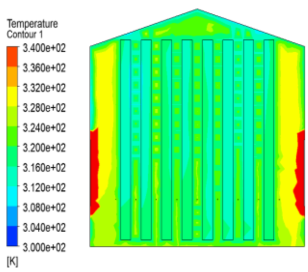
III. ANALYSIS OF CALCULATION RESULTS

A. Temperature analysis characteristic

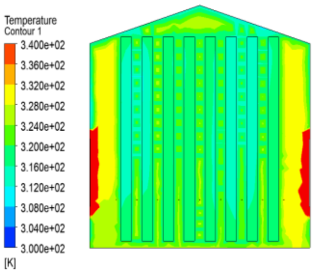
By simulating the curing process of existing curing kilns, the internal temperature distribution characteristics of PC component curing kilns during t=10, 20, 30, 40, 50 and 60min were selected for analysis in order to display the simulation results more intuitively. The specific temperature distribution diagram is shown in Figure 3.



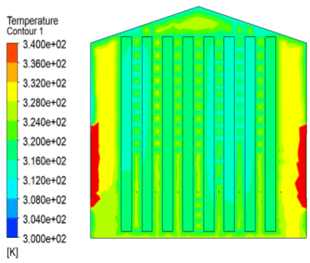
t=10min t=20min



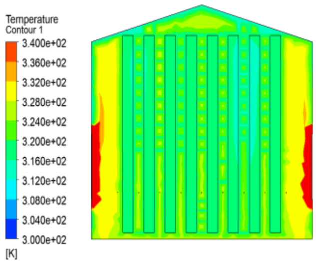
t=30min



t=40min



t=50min



t=60min

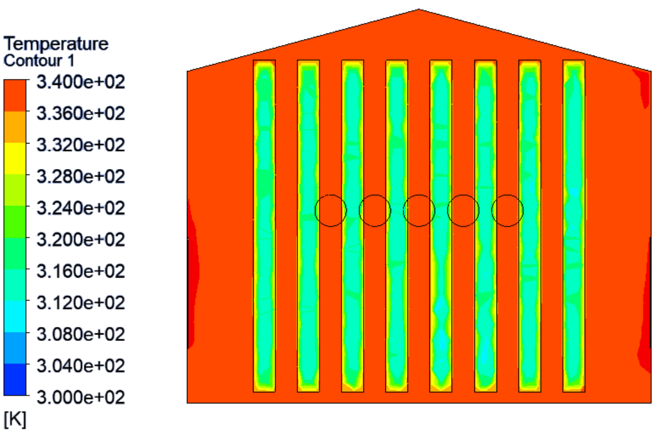
Fig.3 Temperature distribution (x=0m) at different time

Figure 3 shows the temperature cloud map at x=0m. At the beginning, the heating on both sides has obvious heating effect on the air inside the curing kiln, and the hot air floats upward and diffuses to the middle of the curing kiln. As the steam from the steam nozzle gradually increases, the steam diffuses throughout the curing kiln, and the overall temperature inside the curing kiln rises.

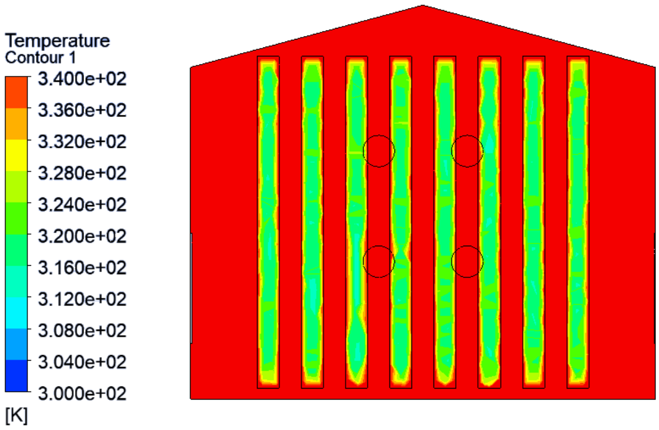
B. *Optimization analysis of temperature field of curing kiln*

1) *Additional fan*

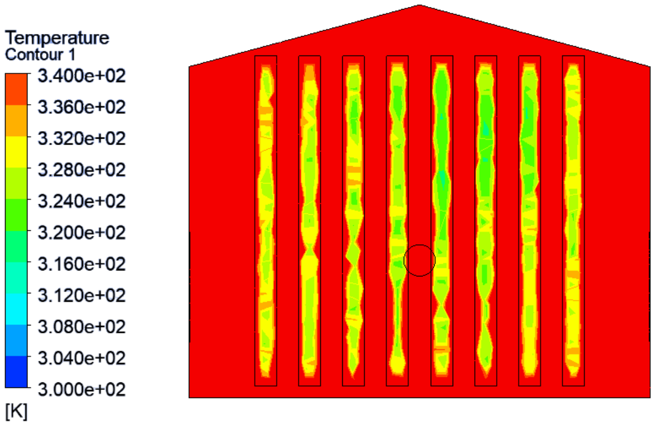
From the above analysis, it can be seen that the main problem in the original curing kiln is the uneven temperature distribution due to the slow air flow caused by the PC component being too close.To optimize the problem. In this paper, the fan (equivalent diameter 0.285m, total pressure 140mbar) was first added for simulation. The fan layout was shown in Figure 4, and the temperature field distribution cloud image when X=0m and t=60min was shown in Figure 4.When 5 fans are arranged in 5 rows, the heat transfer efficiency is low. When the number of fans is reduced and 4 fans are arranged in 2 rows and 2 rows, the heat transfer efficiency is improved to some extent. With one fan, the heat transfer efficiency is the fastest, and the temperature field is evenly distributed, and the temperature of each layer PC component basically meets the maintenance requirements.



A.5 fans



B.4 fans



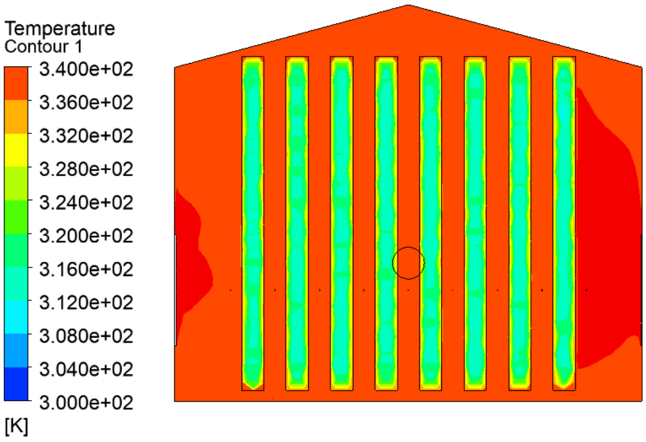
C.1 fan

Fig.4 Temperature distribution cloud picture of different number of fans

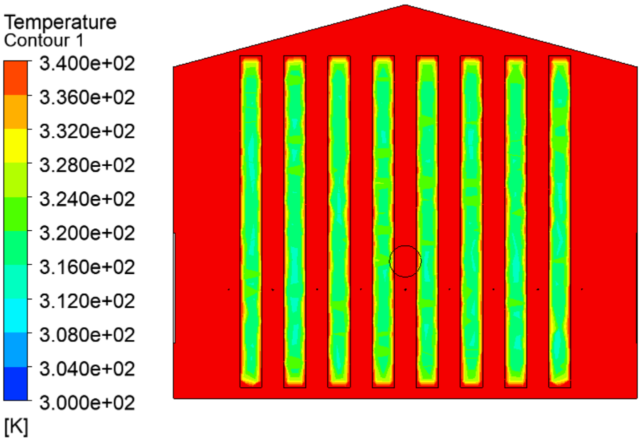
2) *Steam hole optimization*

Water vapor has an important influence on the temperature distribution. By adjusting the Angle and position of the spray hole, the activity trajectory of the heat transfer medium in the curing kiln is optimized, so that it can effectively enter the interlayer area of the prefabricated component, improve the temperature distribution in the curing kiln and improve the curing quality.

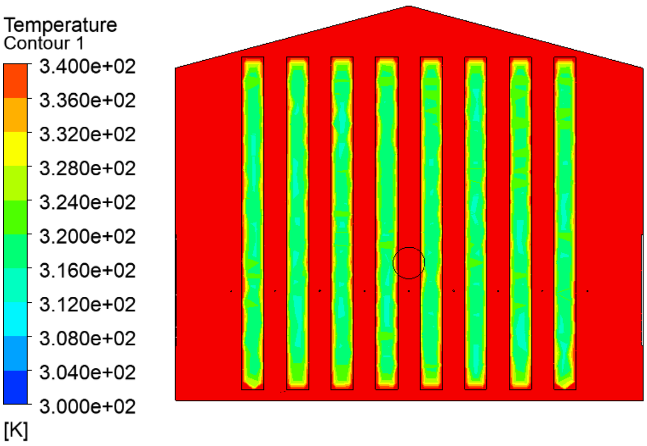
When the fan arrangement mode is determined, the position of the spray hole is adjusted and 60 minutes is selected, the temperature distribution cloud diagram inside the maintenance kiln at X=0 is shown in Figure 5.When there are 9 holes on each side of the front and back, and the direction is horizontal, the overall temperature ranges from 332K to 336K, and there is a local high temperature on both sides of the heating surface, which is significantly different from the overall temperature. When the injection direction is inclined up 45° and inclined down 45°, the internal temperature distribution of the curing kiln is uniform and the curing environment is stable. The overall temperature of the PC component is within the range of 336K to 340K, both of which meet the temperature curing requirements. In contrast, when the spray hole is inclined down 45°, the temperature control accuracy of the PC component is higher, which is more conducive to the improvement of the curing quality.



A.The jet direction is horizontal



B.The injection direction is 45° oblique upward



C. The injection direction is inclined down 45°

Fig.5 Temperature distribution in different jet directions

CONCLUSION

This paper takes PC component as the research object, combines the on-site production process with the temperature field calculation theory, and uses ANSYS finite element analysis software to simulate and analyze the temperature field during the maintenance process of PC component, and draws the following conclusions:

1) The whole process of engineering curing was simulated. Because the distance between PC components is too close, the air flow is slow, and the temperature distribution of PC components is very uneven.

2) The fan is added, and the layout of the fan is simulated. When a fan supplies air in the negative direction of Z axis, the flow of steam between the layers of PC components is enhanced, the heat transfer efficiency of steam is improved, and the temperature field of PC components is evenly distributed.

3) The simulation study was carried out by adjusting the arrangement of steam jet holes. When the steam nozzle is at both ends of the front and back of the maintenance kiln, the direction is inclined down 45°, and the temperature distribution inside the maintenance kiln is the most uniform, and the maintenance requirements are met in all working conditions.

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