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Numerical Simulation of Hot Air Drying Kiln Velocity Field Based on Computational Fluid Dynamics

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Abstract: In this paper, the energy-efficient hot air drying kiln adopts innovative -designed guide air cover to control the speed of airflow velocity and the direction of the air flow in the fan outlet, so that the horizontal airflow in the fan outlet forms a smooth jets transferred to the vertical wind tunnel smoothly, and using computational fluid dynamics (CFD) software SCT/tetra to complete numerical simulation and analysis of air drying kiln flow velocity field , and compares in detail the before and after optimization design in different spatial positions of the velocity distribution in the cross section of drying kiln. The simulation results show that: After the adoption of new technology optimization, the drying kiln improves the uniformity of air flow field distribution, advances the drying efficiency and wood drying quality, also reduces the energy consumption, and lays the foundation of energy-efficient hot air drying kiln applications.

Keywords: drying kiln; guide air cover; air flow; uniformity; numerical simulation

I. Introduction

Drying is the maximum energy consumption process in wood processing, energy consumption accounts for 40% -70% of the company's total energy consumption [1-2]. Hot air drying kiln is the most widely used drying equipment in wood processing enterprises. Cycle characteristics of drying medium heat drying air , especially the distribution uniformity of circulating air flow velocity , is one of the most important factors that affect the drying quality, and it's also the main technical indicators to measure the performance of drying equipment ; However, the wood drying is a complex strongly-coupled nonlinear dynamic system [3-4], it's difficult for the traditional research methods to accurately analyze the motion characteristics of the air drying kiln, using computational fluid dynamics (CFD) techniques for numerical simulation of hot air drying kiln can get more detailed information of airflow velocity field, temperature and humidity, etc. Literature [3-4] uses computational fluid dynamics software Fluent for making wood drying kiln dimensional steady-state CFD model and using numerical simulation to predict the impact of airflow distribution which based on different airflow rate of a given fan. Literature [5] uses Fluent to complete modeling and simulation of the internal flow field of drying kiln with different wall structure, the drying kiln wall was modified to obtain a more uniform flow field. Literature [6-7] uses Fluent to simulate optimized dry kiln with setting diversion baffles under the two-dimensional and three-dimensional structure of the distribution of the flow field, the results show that the diversion baffles improve the uniformity of the velocity field inside the drying kiln.

However, the effect of air flow characteristics in the fan outlet on the wood drying quality also lacks of research, therefore, this paper uses innovative-designed guide air cover of the energy-efficient air drying kiln, and uses computational fluid dynamics (CFD) technology to complete the numerical simulation and analysis of air drying kiln flow velocity field , and compares in detail the before and after optimization design in different spatial positions of the velocity distribution in the cross section of drying kiln, to enhance the quality of wood drying and production efficiency, to reduce energy consumption and make a positive exploration.

II. Design of energy-efficient drying kiln

Energy-efficient hot air drying kiln is shown in figure 1, the wet wood stacking is loaded into drying kiln to dry, level airway formed between the stacking layers of wood. Closing the door15, opening the power distribution cabinet 1, when the fan 9 starts, the air is heated by radiator after it is guided by guide air cover 10, the arc guide plate 12 guide air through 90 degrees to the right side of the vertical wind, and then transferred to horizontal airway between the wood. The hot air absorbed water from the wood and increase the humidity, the temperature is reduced, as the hot air flow through horizontal airway. Then it flow upwards through the left side of the vertical duct, heated on the left side of the radiator before returning to fan inlet, air flow complete a cycle. At the beginning of drying, the moisture from the wood is more, left and right side of the wet mouth 11should be open at the same time, some high humidity hot air in the drying kiln is discharged to the outside in order to take away the wood moisture, at the same time breathing in the dry air from outdoor through the left side of the wet exhaust port, circulate air always maintain a certain dryness, after a certain period of time the wood drying to achieve requirement.

In order to improve characteristics of airflow in the fan outlet, reduce wood craze, deformed, improve the quality of wood drying. Setting guide air cover in the fan outlet, in accordance with the requirements of different drying processes and rotational positioning nut to adjust guide tongue plate position, change the outlet section area and the jet angle, to control the velocity of the airflow and the jet direction, so that the airflow smooth smoothly into to vertical wind tunnels in the form of attached with a jet [7-8]. Guide air cover three-dimensional view is shown in figure 2.

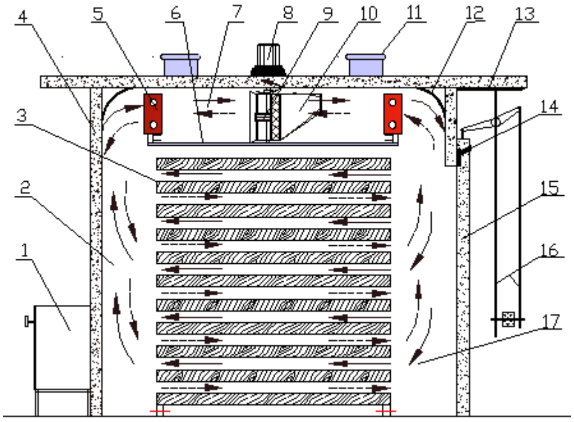

Figure 1 Structure of energy-efficient drying kiln

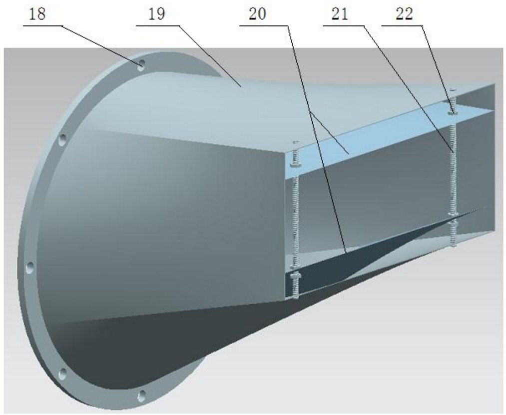

Figure 2 Guide air cover three-dimensional view

1-Power distribution cabinet; 2-The left side of vertical wind duct; 3-Wood stacking; 4-Drying kiln thermal insulation wall; 5-Radiator; 6-Support frame; 7-the level of airway; 8-Motor; 9-Fan; 10-Guide air cover; 11-Outlet for discharging moisture; 12-Arc guiding plate; 13-Lifting shelf guide rail; 14-Lock parts of door; 15-Closed door; 16-Lifting shelf; 17-The right side of the vertical wind duct; 18-Bolt holes; 19- Guide air cover wall; 20-Arc guide tongue; 21-Positioning screw; 22-Positioning nut

III. Numerical simulation of drying kiln velocity field

3.1Establishment of mathematical model

This paper uses computational fluid dynamics (CFD) software SCT/tetra to complete air drying kiln flow velocity field numerical simulation under the condition of isothermal and humidity , depending on the flow characteristics of drying kiln, sees the air flow as incompressible turbulent flow, its density is constant. Equations [8] as follows:

(1) Continuity equation: $\frac{\partial u_i}{\partial x_i}=0$

(2) Momentum equation: $\frac{\partial(\rho u_i u_j)}{\partial x_j}=\frac{\partial P}{\partial x_j}+\frac{\partial}{\partial x_j}[\mu(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})]-\frac{2}{3}\frac{\partial}{\partial x_j}(\mu\frac{\partial u_i}{\partial x_j})+\rho g_i$

In the formula: u is air velocity (m/s); ρ is the density of air (kg/m^3); μ is the dynamic viscosity (Pa · s); P is static air pressure (Pa); g is gravitational acceleration(m/s^2)

(3) Choice of turbulence model for Realizable κ-ε model, the corresponding turbulent kinetic k and energy dissipation rate e transport equations are:

$$\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}[(\mu+\frac{u_i}{\sigma_k})\frac{\partial_k}{\partial x_j}]+\mu_1(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})-\rho\varepsilon$$

$$\frac{\partial(\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}[(\mu+\frac{u_i}{\sigma_\varepsilon})\frac{\partial\varepsilon}{\partial x_j}]+\rho c_1 E_\varepsilon-\rho c_2\frac{\varepsilon^2}{k+\sqrt{v\varepsilon}}$$

$$E=(2E_{ij}E_{ji})^{\frac{1}{2}}\ E=\frac{1}{2}(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})$$

In the formula: u_i 、 u_j represent average velocity per hour in the direction of x_i 、 x_j ; x_i is Cartesian coordinates of three axes; μ is turbulent viscosity (Pa/s); v is kinematic viscosity (m^2/s); E is strain tension per hour, c1 = 1．44，c2 =1.92，σ_k = 1.0，σ_ε = 1.2。

3.2 Establishment of physical model

This paper studies the Laboratory used head wind type hot air drying kiln , the drying kiln model dimensions are: the width of X-direction is 4.4m, the length of Y-direction is 3.6m, the height of Z-direction is 3.2m, the upper part of drying kiln configures 2 fans, the support frame of fans are in the middle position. The inlet and outlet of conventional drying kiln fan are 480mm diameter circular; Energy-efficient drying kiln sets guide air cover at the fan outlet, rectangular air outlet dimensions is of 600mm width, 300mm height , two drying kiln have considerable size of outlet. Wood chip thickness is 50mm in drying kiln wood stacking, the thickness of sticker placed among pieces of wood is 40mm, and the height of entire wood stacking is 2000mm.

3.3 Boundary conditions and parameter settings

In the use of SCT/tetra pretreatment software, the boundary conditions set for: fan axial wind speed 2m/s, the fan inlet and outlet use pressure boundary condition, drying kiln wall and wood surface with no-slip and insulation boundary condition, turn off all wet exhaust port, meshing results is shown in figure 3, and finally, the mesh file and boundary conditions are introduced into the SCT/tetra solver for calculations.

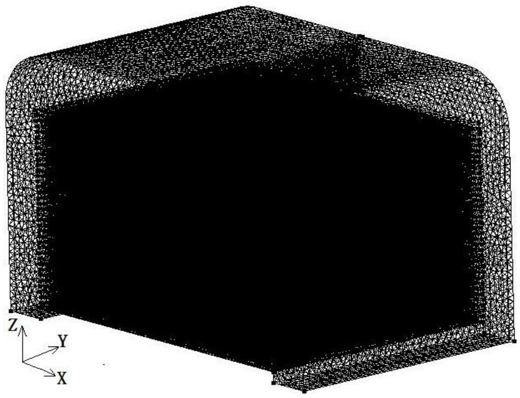

Figure 3 Drying kiln meshing results

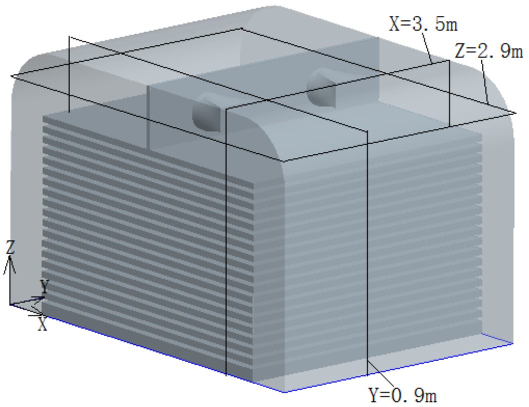

Figure 4 Diagram of each section in drying kiln

IV. Airflow simulation results

This paper mainly aims at a detailed analysis of the internal velocity field of drying kiln, through the numerical simulation of airflow contours; we can visually observe the air distribution rule and the situation of uniformity in drying kiln. For a detailed comparison of the airflow velocity field characteristics of drying kiln with before and after optimization design , we choose X = 3.5 m, Y = 0.9m, Z = 2.9m, 3 groups of section in different spatial locations for a detailed analysis, the location of each section is shown in Figure 4.

4.1 The X-Y sectional flow velocity contours when Z= 2.9m

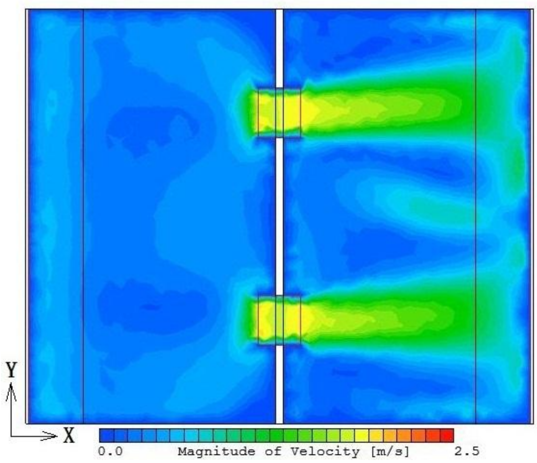

Figure 5 Airflow velocity contours on the X-Y section of conventional drying kiln

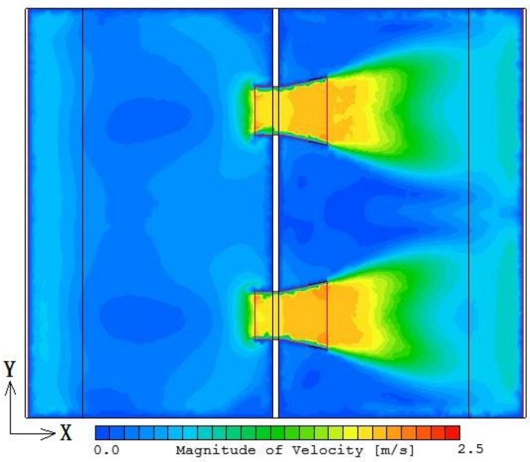

Figure 6 Airflow velocity contours on the X-Y section of energy-efficient drying kiln

As shown in Figure 5 and 6, the airflow of conventional drying kiln fan outlet is emitted in the X-Y plane, which is long and narrow like a single beam, when the middle of the two beams forms a vortex flow, the wind velocity along the Y direction is not serious uniformity when the airflow turns into the above entrance of vertical wind road , then the airflow collides with the outer sidewall and loses part of its energy; air flow can be regulated because of the guide air cover, which has a leading role in energy-efficient drying kiln, the fan outlet forms a suitable dispersion angle, so that the air flow injects as fan-shaped uniformly , the airflow covers with vertical wind duct inlet along the Y direction when it reaches the top of a vertical wind duct, the air flow velocity distributes uniformly along the Y direction.

4.2 The X-Z sectional flow velocity contours when Y= 0.9m

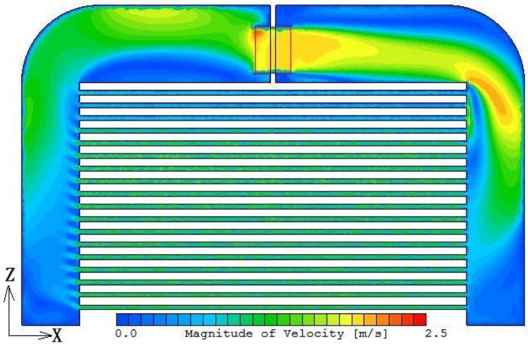

Figure 7 Airflow velocity contours on the X-Z section of conventional drying kiln

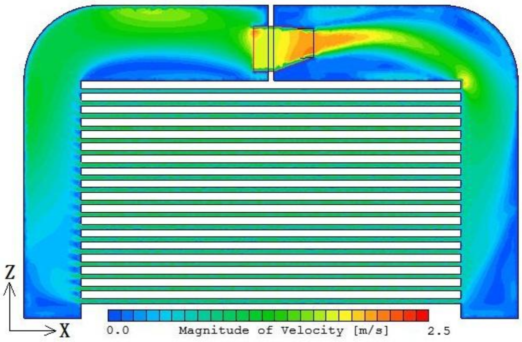

Figure 8 Airflow velocity contours on the X-Z section of energy-efficient drying kiln

As shown in Figure 7, the conventional drying kiln air velocity distribution contours in the X-Z plane is shown: 1.Air flow divergences with low velocity in the fan outlet, and hit the top of the wood stacking on the horizontal plane before reaching the right side of the vertical wind duct, a part of it drops down to the upper right corner of the wood stacking, a part shots directly to the outer wall of the vertical wind duct, resulting in energy loss and causing vortex at the top right corner of the wood stacking; 2.The velocity of air flow in four horizontal airway is low at the top of wood stacking, and the air flow velocity distribution of the wood stacking is not uniform along the height direction. As shown in Figure 8, the energy-efficient drying kiln air velocity distribution contours in the X-Z plane is shown: air flow rate increases in guide air cover outlet, the jet can be smoothly delivered to vertical wind duct, the vortex disappears around the corner of horizontal and vertical, the velocity of air flow in four horizontal airway is increased at the top of wood stacking, the air flow velocity tends to be uniform along the wood stacking height direction.

4.3 The Y-Z sectional flow velocity contours when X= 3.5m

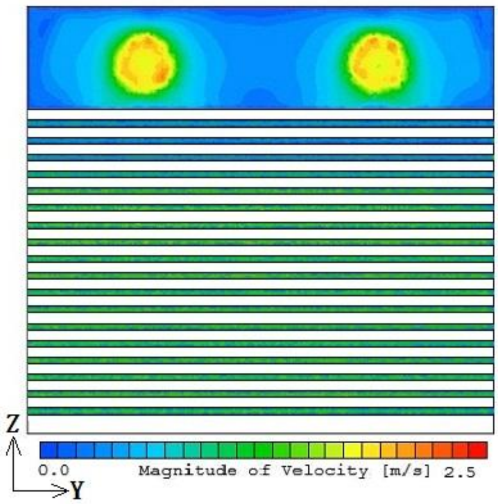

Figure 9 Airflow velocity contours on the Y-Z section of conventional drying kiln

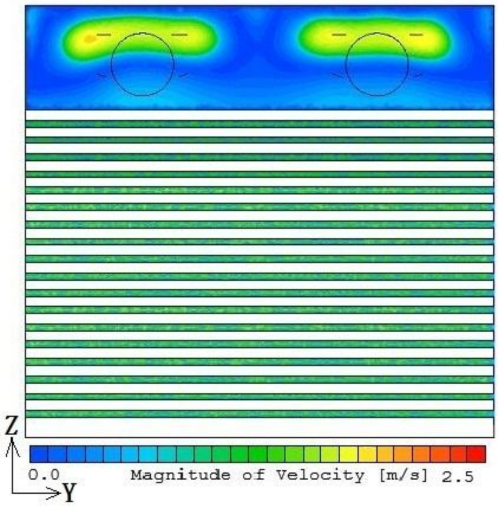

Figure 10 Airflow velocity contours on the Y-Z section of energy-efficient drying kiln

As shown in Figure 9, the velocity of air flow in four horizontal airway is low at the top of wood stacking in the conventional drying kiln, air flow velocity distribution is not uniform from top to bottom along the wood stacking Z direction, the air flow increases when the jet stream distance increases in the fan outlet, and the diameter of the circular formed by air flow jet diffusion is within a small change , that is , air flow beam diameter and fan outlet have the same-sized circular , it is no reasonable spread along the Y direction. As shown in Figure 10, the air flow velocity tends to be uniform from top to bottom along the wood stacking Z direction in energy-efficient drying kiln, the guide air cover leads the air flow evenly diffuses upwards, and along the right and left sides of the fan in the Y direction, finally jets are formed in uniformly distribution along the Y-direction.

V. Conclusion

Energy-efficient air drying kiln adopts guide air cover with innovative design , and uses computational fluid dynamics (CFD) software SCT/tetra to complete numerical simulation and analysis of air drying kiln flow velocity field , then compares in detail the before and after optimization design in different spatial positions of the velocity distribution in the cross section of two types of drying kiln. Simulation results show that: airflow can be reasonably spread in energy-efficient drying kiln fan outlet, the air flow velocity distribution tends to be uniform along wood stacking Z direction, so that to improve the quality of wood drying and drying efficiency.

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