Influence of guide vane angle of circulating hot blast stove sleeve on temperature field and flow field

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Abstract. In order to improve the heating efficiency and uniformity of the hot air circulation heater, a three-dimensional model of a hot blast stove of hot in-place recycling hot air circulating heater was established, based on the finite element method and CFD software ANSYS, the influence of the guide vane angle of the circulating hot blast stove sleeve on the temperature field and flow field of hot blast stove and air distribution pipe was studied by numerical simulation. The results show that the guide vane angle of the hot blast stove sleeve affects the temperature distribution at different positions of the air distribution pipe, has less influence on the internal temperature field of the hot blast stove, and has greater influence on the temperature distribution of the air distribution pipe. With the increase of the guide vane angle of the hot blast stove sleeve, the velocity and flow path of the circulating hot air in the hot blast stove sleeve increases, which improves the hot air distribution uniformity of the heating device. When the guide vane angle of hot blast stove sleeve is 45 °, the hot air transverse distribution uniformity of heating device is the best.

1. Introduction
Asphalt pavement heating is the key part in the hot in-place recycling technology, and the heating uniformity is an important guarantee for the heating quality of asphalt pavement. Hot air circulation heating has good temperature controllability, which can improve heating efficiency and reduce pollution through hot air recycling [1]. It is widely used in the heating equipment of hot in-place recycling [2]. The existing hot in-place recycling heating machine has the problem of uneven heating in horizontal and vertical direction. The concentrated areas of speed and temperature are easy to scorch asphalt, and produce flue gas to pollute the environment. Meanwhile, the leakage of high temperature flue gas is easy to cause the burning damage of vegetation around the equipment. The poor heating uniformity of the heating device will also lead to the decrease of heating efficiency and the deformation or fracture of local materials at high temperature.

The hot air circulating heater mostly recycles the hot flue gas with residual temperature after heat exchange with asphalt pavement into hot blast stove through a circulating fan to reuse to reduce hot air leakage and improve thermal efficiency [3]. The mixed flow hot air generator developed in Reference [4] adopts the decentralized return air to ensure the maximum utilization of waste hot air and improve the heating efficiency. The influence of different parameters of hot air circulation heater on the heat transfer coefficient of asphalt pavement surface was studied in Reference [5]. Literature [6] analyzed the influence of the height of ventilation pipe above the ground, hot air circulation speed and the
number of rows of ventilation holes on the pavement temperature field. In Reference [7], the variation characteristics of temperature of each layer of pavement with heating time, pavement depth, wind speed and mechanical driving speed were studied. The above researches studied the influence of the parameters of the hot air heating plate and below the heating plate on the heating effect of asphalt pavement. There is little research on the distribution of hot air inside heating device, especially the return air system.

In order to increase the speed of circulating air, improve the distribution of circulating air in the hot blast stove sleeve and the uniformity of hot air distribution in the heating device, guide vanes are designed at the inlet of circulating air in the hot blast stove sleeve of a modularized small partition structure hot blast circulating heating device in this paper. The influence of the circulating air on the temperature field and flow field of the hot blast stove and the air distribution pipe under different guide vane angles is studied based on the finite element method and CFD software ANSYS, so as to determine the best vane angle and provide reference for the structural optimization of the hot blast stove and the hot air circulating heater.

2. Numerical simulation process

As a CFD simulation analysis software, ANSYS is widely used to calculate fluid flow, heat transfer and other issues. In this paper, the FLUENT module of ANSYS is used to simulate the influence of the guide vane angle of the hot blast stove sleeve on the uniformity of the temperature field and flow field distribution of the hot blast stove and the air pipe. The combustion is simplified as the flow of high temperature hot air in the inner tube. Based on the conservation of mass, energy and momentum, the mathematical model of hot air flow and heat transfer process is established, and the numerical calculation is carried out. The temperature field and velocity field are obtained by iteration [8].

2.1. Model and grid generation

A modular small partition structure variable power hot air circulation heating device is shown in Figure 1. The mixed high temperature air is fed into the two symmetrical heating walls by the air distribution pipe, then sprays to the asphalt pavement through the nozzles on the air outlet panel of the heating device to complete heat transfer. To simplify the calculation, the hot air inlet on both sides of the heating wall is taken as the outlet of the hot blast stove device, the structure of the hot blast stove is simulated and analyzed. The hot blast stove device is composed with the inner tube, sleeve and air distribution pipe. The space of inner tube is the hot flue gas, and the space of sleeve is the recovered hot air. Guide vanes are arranged on the circumference of the front end of the sleeve to guide the circulation of the circulating hot air in the hot blast stove sleeve. The physical model of computational domain is shown in Figure 2. Inlet1 is the high temperature hot air inlet with a diameter of 170mm, and the diameter of the inner tube is 450mm. Inlet2 is the circulating hot air inlet with a section size of 170×140mm, and the diameter of the sleeve is 530mm. Outlet1 and outlet2 are the outlet of air distribution pipe with a section size of 310×310mm, respectively connected with the heating wall on both sides.
The model of computational domain is discretized. The whole area is unstructured tetrahedral grid, the mesh at the inlet, outlet, near the vanes and wall are encrypted to improve the mesh quality. When the number of grids increases from 1.56 million to 1.91 million, the temperature of outlet 1 changes by 2.4%. When the number of grids increases from 1.91 million to 2.3 million, the temperature of outlet 1 changes by 0.67%. 1.91 million grids are selected for the next simulations.

2.2. Related parameter setting

In the process of numerical simulation, because the Mach number at the maximum velocity is less than 0.25, the flow of hot flue gas is considered to be stable, viscous and incompressible [9]. In the process of hot air flow, the effect of mass force and thermal radiation is ignored. According to the power of the burner, the hot air after combustion is equivalent to the velocity inlet, the velocity is 31.24 m/s and the temperature is 1373K. The inlet velocity of the circulating hot air is 19.75 m/s and the temperature is 493K. The outlet type selects the pressure outlet condition. The fluid wall is non slip adiabatic wall, and the thermophysical properties of the material are shown in Table 1. The fluid wall of is no slip adiabatic wall, the thermophysical properties of the material are shown in Table 1 [10]. The turbulence model is calculated by standard k-ε model, standard wall function and a pressure-based solver, SIMPLE algorithm of pressure velocity coupling and second-order upwind style solution are used [11]. The convergence criterion of energy equation is 10e-6, and other equations is 10e-3, details are omitted for brevity.

| Material | Density (kg·m⁻³) | Specific heat capacity (J·kg⁻¹·K⁻¹) | Thermal conductivity (W·m⁻¹·K⁻¹) | Viscosity (kg·m⁻¹·s⁻¹) |
|----------|-------------------|-------------------------------------|-----------------------------------|------------------------|
| Air      | 1.225             | 1006                                | 0.0242                            | 1.79e-05               |
| Steel    | 7830              | 460                                 |                                   |                        |

Considering the convenience of processing and manufacturing, the angle of guide vane of hot blast stove sleeve is selected as 0 °, 15 °, 30 ° and 45 ° to analyze the temperature field and flow field distribution of hot blast stove and air distribution pipe.

3. Results and discussion

3.1. Temperature field distribution

Figure 3 shows the temperature field distribution of hot blast stove and air distribution pipe under different guide vane angles of hot blast stove sleeve.

![Temperature field distribution of hot blast stove and air distribution pipe: (a)0°; (b)15°; (c)30°; (d)45°.](image)

Figure 3 shows that the circulating hot air has great influence on the temperature distribution of the air distribution pipe. Under different guide vane angles of hot blast stove sleeve, the mixing degree of high temperature hot air and circulating hot air is different at the different positions in air distribution pipe, and the temperature distribution is different. The high temperature hot air flows along the inner wall of the air distribution pipe, and the circulating air flows along the outer wall of the air distribution
pipe. With the increase of guide vane angle, high temperature hot air and circulating air cross into the air distribution pipe in a spiral shape in the hot blast stove sleeve, resulting in uneven temperature of the air distribution pipe, then the structural of the air distribution pipe will be deformed, which will affect the distribution of hot air in the two heating walls, and eventually lead to poor horizontal heating uniformity of the heating device. The two kinds of hot air continue to mix and transfer heat with each other in the air distribution pipe and heating walls. When the hot air heats the asphalt pavement from the outlet of the heating wall, the two kinds of hot air mix more evenly.

3.2. Flow field distribution
Figure 4 is the velocity vector diagram of the hot blast stove and the air distribution pipe under different guide vane angles of the hot blast stove sleeve. The flow process and velocity distribution of circulating hot air in hot blast stove can be seen.

![Velocity vector diagram of hot blast stove and air distribution pipe](image)

**Figure 4.** Velocity vector diagram of hot blast stove and air distribution pipe: (a)0°; (b)15°; (c)30°; (d)45°.

It can be seen from Figure 4 that the flow direction and velocity distribution of circulating hot air in the hot blast stove sleeve are affected by the guide vane angle. When the vane angle is 0°, the circulating hot air enters the air distribution pipe along the hot blast stove pipe wall straightly, and there are obvious differences in the air volume and velocity of circulating hot air entering the heating wall on both sides, which affect the distribution of hot air. With the increase of the vane angle, the circulating hot air spirals into the air distribution pipe in the hot blast stove sleeve, which not only prolongs the heat exchange time between the circulating hot air and the inner wall of the hot blast stove, increases the circulating wind velocity, improves the uniformity of velocity distribution of circulating air at the inlet of air distribution pipe, but also reduces the air volume difference of the circulating hot air flow into the heating walls on both sides. The distribution uniformity of the mixing hot air in the heating walls on both sides was improved, and the transverse heating uniformity of the heating device was improved, too.

The results of numerical simulation under different guide vane angles are shown in Figure 5. The temperature in the table is the average temperature of the exit plane.

![Numerical simulation results](image)

**Figure 5.** Numerical simulation results: (a)Temperature; (b)Volumetric flow rate.
Figure 5 shows that with the increase of guide vane angle, the difference of hot air flow rate in the two heating walls decreases. Because the circulating air enters the hot blast stove sleeve from the side, the flow direction and distribution of the circulating air in the sleeve are changed by adjusting the angle of the guide vane. The circulating air can be more evenly distributed to both sides of the air distribution pipe, and then mixed with the high temperature hot air and fed into the heating wall to complete the heating of the asphalt pavement.

The distribution of temperature field and flow field are considered comprehensively, when the guide vane angle is 45°, the difference of heat air distributed to the two sides of the hot air heating device is the smallest, and the hot air transverse distribution uniformity of the heating device is the best. The transverse heating uniformity of asphalt pavement is also good.

3.3. Validation of results
Figure 6 and Figure 7 are the heating effect pictures of the hot air circulation heating device before the improvement of the hot air stove sleeve and after the adjustment of the guide vane angle. Through the test, it is found that the transverse uniformity of the heating device is better by setting 45° guide vanes at the circulating air inlet of the hot blast stove sleeve, which is consistent with the simulation results.

4. Conclusions
In this paper, the influence of the guide vane angle of the sleeve on the temperature field and flow field of the hot blast stove and the air distribution pipe is simulated by the numerical simulation method. The conclusion is as follows.

The guide vane angle of hot blast stove sleeve affects the temperature distribution of the air distribution pipe. It has little influence on the temperature field of hot blast stove inner tube, and has great influence on the temperature field of air distribution pipe. With the increase of the guide vane angle, the heat transfer time between the circulating hot air and the inner wall of the hot blast stove and the wind velocity increases, and the distribution of the circulating hot air entering the heating wall on both sides is more uniform. When the guide vane angle is 45°, the difference of hot air distributed to the two sides of the hot air heating device is the smallest, and the hot air transverse distribution uniformity of the heating device is the best.

The circulating hot air has a great influence on the temperature field of the air distribution pipe, which may cause the uneven temperature distribution in the air distribution pipe, and further lead to the structural deformation of the air distribution pipe. It is necessary to continue to study the influence of the sleeve structure of hot blast stove on the thermal stress and deformation of the air distribution pipe.
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