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Simulation and Experiment of Small Pepper Drying Box Structure Optimization

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Abstract: ***Firstly, through simulation analysis, that the current small pepper drying box in Zunyi area with a stacking height of 900mm had uneven flow field distribution, local low temperature zone and local high temperature zone. The lowest temperature was 26.8 ℃, and the maximum temperature difference was 104 ℃. Secondly, the flow field distribution of the existing drying box was simulated by adding one baffle and two baffle panels vertically. The local maximum temperature of one baffle was 130.85 ℃,and the maximum temperature difference of the baking area was 63 ℃; And the minimum temperature of the two baffle panels was 26.85 ℃, and the maximum temperature difference of the two baffle panels was 29 ℃. It can be seen that adding baffle could effectively improve the flow field distribution of the drying box, reduce the local low temperature area, eliminate the obvious high temperature area, and improve the temperature distribution uniformity of the baking area. Thirdly, the flow field distribution of three baffles placed vertically and horizontally in the existing drying box was analyzed by simulation. The maximum temperature difference of single layer of the baking area was 2.5 ℃-7.5 ℃, the maximum temperature difference between the upper and lower plane was 2 ℃-7.5 ℃, and the temperature was stable at about 67 ℃. It can be seen that the flow field distribution of the scheme with three baffles was more uniform and could completely eliminate the high temperature zone and low temperature zone. Finally, through the prototype experiment, the maximum temperature difference of the single layer with two baffles placed vertically in the existing drying box was 4 ℃-11.5 ℃, and the maximum temperature difference of the upper and lower layers was 10 ℃-16 ℃; The single-layer temperature difference of three baffles placed vertically and horizontally was 4.5°C-6.5°C, and the upper and lower temperature difference was 10.2 ℃-11.2 ℃, which was basically consistent with the simulation data. It could be seen that the scheme completely eliminated the local low temperature zone and local high temperature zone, so that the flow field distribution of the drying box was more uniform, the temperature difference was smaller, and the drying effect was better. In addition, it was proved by experiments that it was feasible to simulate the resistance of pepper by using the viscosity of sand and to simulate the flow field in the baking area. At the same time, the experimental optimization scheme will can provide guidance for enterprises to improve their products.***

Keywords: pepper drying box CFD flow field analysis, structural optimization

0 Introduction

The excellent ecological environment in Guizhou provides an ideal place for the development of organic and green pepper. Pepper has become one of the traditional characteristic and advantageous industries in Guizhou Province. In recent 3 years, the planting area of pepper in Guizhou province has maintained over 5 million mu [1].Most of the famous domestic pepper products are from Guizhou, such as Laoganma and Laogandad, etc. Oil pepper products have accounted for more than 60% of the national market share [2].Because guizhou area is mainly mountainous, so that the chili drying in Guizhou area is mainly by small chili dryer, mainly because of its installation, cheap price, low baking cost. However, after investigation, it is found that the current use of small pepper dryers in Guizhou province, there is a widespread problem of inadequate local pepper drying, the need for secondary drying, resulting in increased drying costs. According to literature review, there are many domestic papers on the structural optimization of pepper drying box. Literature [3] analyzes the velocity distribution of flow field with different baffle sizes and inlet angles. Literature [4] analyzed the effects of different hot air drying temperature, wind speed, thickness and drying speed on the quality of pepper. Literature [5] studied the effects of hot air temperature, wind speed and loading thickness on the drying quality of pepper.In literature [6], Workbench software was used to simulate and analyze the drying effect of different flow fields, temperature, flow rate and hot air entry Angle in the drying box, but no prototype was made to verify the simulation data.Literature [7] studied the distribution of heat airflow field in tunnel drying kiln under different air intake schemes. Literature [8] studied the influence of additional air baffle on temperature field distribution of drying chamber. Literature [9] studied the influence of fan frequency and material layer thickness on the flow field distribution inside the dryer. Literature [10] has studied the addition of a deflector device on the air aid of a sprayer with a small velocity variation area. There are some foreign studies on the influence of hot air temperature on the drying quality of pepper [11-13].However, the above paper mainly studied the flow field distribution in the air inlet chamber below the pepper when the thickness of the pepper stack was less than 100mm, but did not study the flow field distribution in the pepper baking area when the thickness of the pepper stack was 900mm.In addition, because of the different structure of the drying box, different baking conditions, different drying box need different optimization scheme, need to be studied and analyzed separately. Therefore, it is necessary to study and analyze the problems of uneven baking and timely drying in small chili drying boxes in Zunyi area. This paper on the small dryer drying box now Fluent simulation analysis, found that the existing drying box structure design of flow field distribution, can lead to dry the local hot pepper in a set time in the oven can't drying problems on time, and then to the existing small chili dryer drying box structure optimization simulation analysis, In order to reduce the uneven distribution of the flow field in the drying box, the Fluent simulation and prototype experiment proved that adding baffle in the drying box and optimizing the position of the stall can effectively improve the uniformity of the distribution of the flow field in the drying box and improve the uniformity and consistency of pepper drying.

1 Method

In this paper, simulation is combined with prototype experiments. First of all, the flow field distribution of the drying box without baffle is simulated and analyzed. Secondly, simulation analysis was conducted on the flow field distribution of 1 baffle, 2 baffle and 3 baffle in the drying box[3],and the baffle position was determined through simulation optimization to obtain the best flow field distribution effect. Finally, through the prototype experiment, the effectiveness of the improved drying box is proved.

2 Pepper Drying Box Cfd Modeling and Optimization Process

The structure of the small dryer, the heating tube and the parameters of the circulating fan are: The length, width and height of the drying box are 2200mm×1400mm×1800 respectively. The air volume of the circulating fan is 5000m3/h and the pressure is 270Pa. Three single cylindrical heating tubes of 2kW with length of 1300mm and diameter of 30mm are placed on the bottom plate as the heat source. Located in the front of the drying box above the two sides of the square plane 150mm long for the air outlet, the lower 300mm round hole for the air inlet, the baking area is 1050mm high, the height of the pile of pepper is 900mm, the distance between the support surface and the bottom of the oven is 750mm. According to the experience of pepper farmers, the drying temperature of Zunyi zhaotian pepper is about 52 ℃.

2.1 Bezel-less Simulation Analysis

Firstly, the structure size of the existing dryer is measured, and the rod structure with little influence on the flow field distribution is ignored. Then, a THREE-DIMENSIONAL fluid calculation model [14-16] is established by using the modeling component DesignModeler of ANSYS, as shown in Fig. 1.

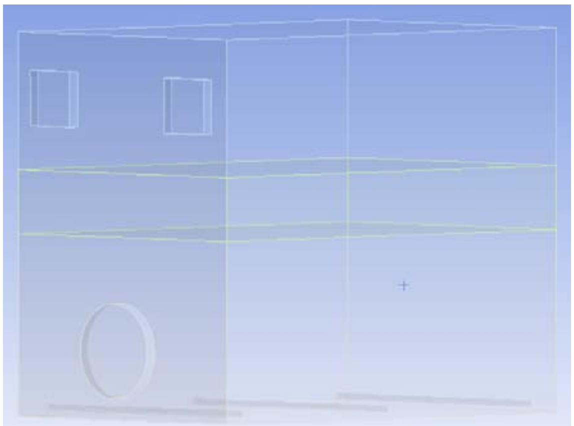

Fig. 1 Three-dimensional fluid model of a pepper dryer

Select the three heating tubes and name them as Conduit. The middle cuboid part is named as LJ and the rest is named as Air. Set relevant parameters and obtain the grid distribution as shown in Fig.2. Due to the small size of the heating tube relative to the whole model, the software automatically encrypts the grid at the position close to the bottom of the heating tube. It can be seen from Fig. 2 that the grid is significantly denser than other parts.

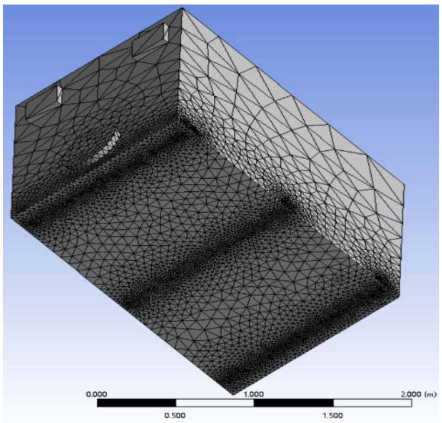

Fig. 2 Grid distribution

2.1.1 Cell Zone Condition Settings

The distribution of hot Air in hot pepper is studied by CFD-DEM gas-solid two-phase flow coupling [17]. The standard K-Epsilon turbulence model for solid and gas two-phase flow is selected in Fluent fluid calculation model [18-19]. The fluid material used in the part named Air is Air. LJ area for pepper stacked area, LaJiaoDui together, there is a certain gap between the air circulation, but chili itself is solid, so it is difficult to define it as a simple solid or fluid, so this article will bake area defined as the coefficient of viscosity of fluid but increase it, to the simulation of air through the baking area resistance, because of the sand like chili, so in this paper The viscosity coefficient of the baking area in is 10Pa s of sand (obtained by enlarging the viscosity of water-sand mixture in reference [20]).

This model needs to set three boundary conditions, inlet, outlet and heat source. The circular area below the drying box is set as the air inlet, and the initial pressure is 101kPa standard atmospheric pressure, and the fan flow is 5000m^3/h and the inlet speed is 19.6m/s. The upper two outlets are set as the natural flow outlet,and the outlet pressure is 101kPa standard atmospheric pressure. The three heating tubes below are set as the heat source. The heating power of a single heating tube is 2kW, and the remaining external planes are all set as walls. The internal interface will be automatically marked out in Fluent. The initial temperature of air and other materials is uniformly set as 300K. In this paper, coupling analysis of air and heat source is required, and Coupled is selected in the solution, and the calculation is initialized, iterated 100 times and started [21].

2.1.2 Simulation Result Analysis

After the calculation, a plane was created in the axis direction of the drying box. The model was symmetrical about this plane, and the height of the drying area of pepper was 900mm. The following simulation and experiment focused on analyzing the flow field distribution of the section of 2200mm×900mm. The obtained velocity trace distribution is shown in Fig. 3, the velocity cloud is shown in Fig. 4, the temperature distribution cloud is shown in Fig. 5, and the temperature distribution cloud in the section of pepper baking area is shown in Fig. 6.

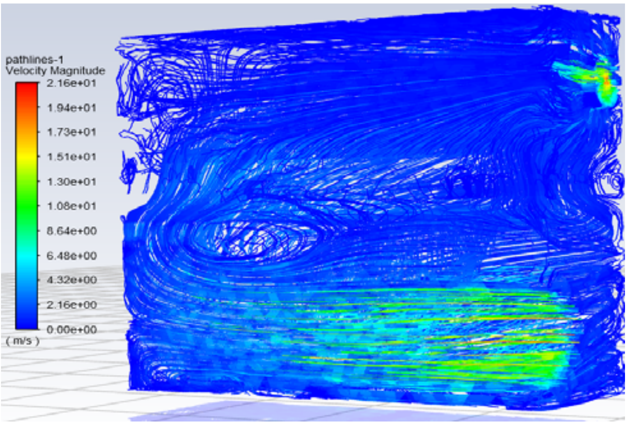

Fig. 3 Drying box speed trace distribution map

Heating of the air and the air stream from the entrance into the mix, and then sent to the baking area, observation can be seen in Fig. 3, Fig. 4, the wind speed distribution of local vortex. As can be seen from the Fig. 5 and Fig. 6, in the middle of the chili baking area is low temperature zone and the tail local high temperature, will lead to the rear of the pepper drying temperature significantly higher than the middle and the first half. The drying time of peppers is inconsistent; The lowest temperature of pepper baking area is 299.8975K and the highest temperature is 403.5333K, and the maximum temperature difference is 103.6355℃. In practical application, temperature sensors and controllers will be used to control the highest temperature, but there will still be a large local low temperature area.

Therefore, the drying box has a serious problem of uneven temperature distribution, which will lead to slow local drying of peppers in the drying box, causing secondary drying and increasing drying costs.

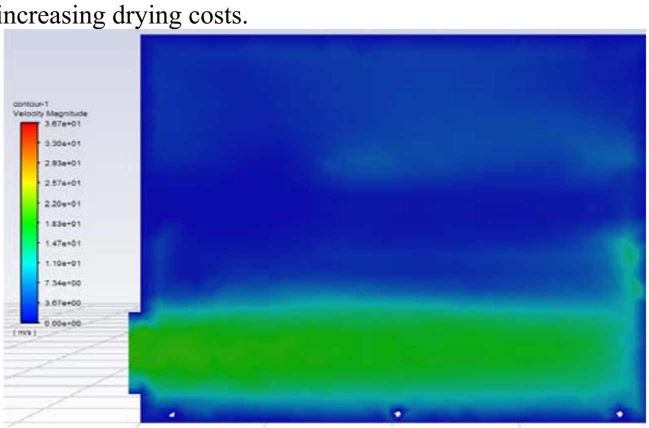

Fig. 4 Speed cloud diagram of the drying box

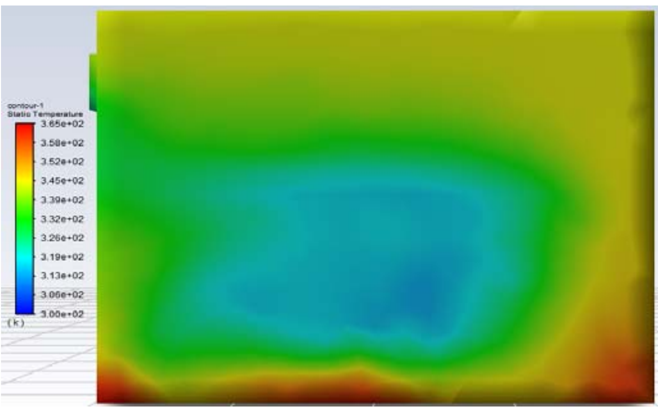

Fig. 5 Temperature distribution cloud diagram of the drying box

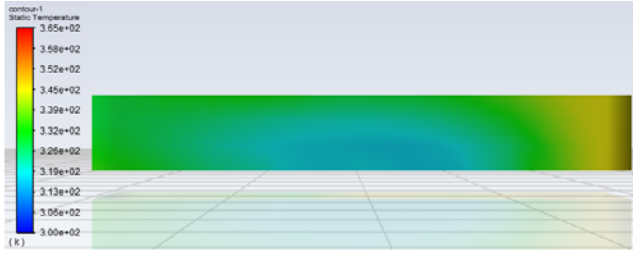

Fig. 6 Temperature distribution of cross-sectional temperature in pepper baking area

2.2 Model Optimization

2.2.1 Added Bezel Simulation Analysis

Scheme 1: a piece of iron baffle with a length of 1400mm, a width of 350mm and a thickness of 10mm is placed below the chili drying area and 1000mm away from the air inlet; Scheme two: two baffles are placed below, and the first one is the same size and position as the baffle placed in scheme one, and the second baffle is 150mm wider than the first one, and the position is 600mm behind the first one, and the other parameters are the same as the first baffle; Model 1 is shown in Fig. 7, model 2 in Fig. 8.

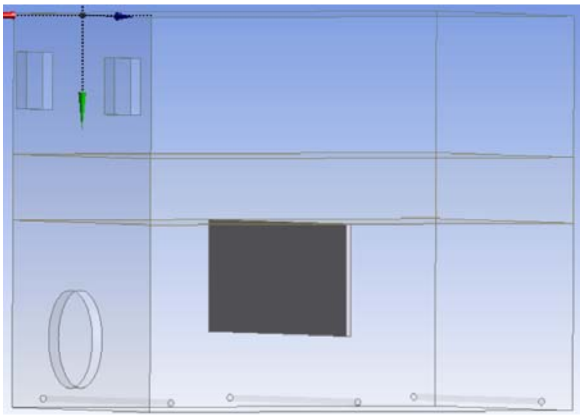

Fig. 7 Scheme 1 bezel model diagram

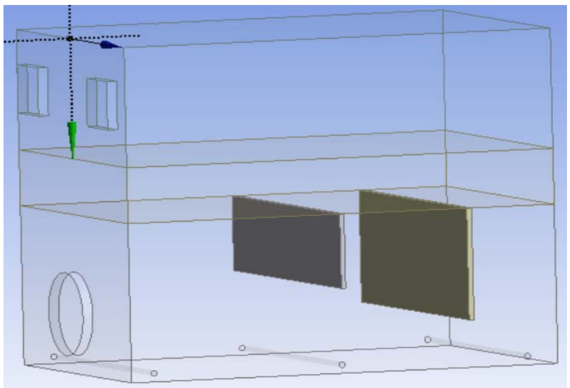

Fig. 8 Schematic second bezel model diagram

The velocity distribution trace diagram and velocity cloud diagram in the drying box obtained in scheme 1 are shown in FIG. 9 and 10, and the temperature cloud diagram and temperature cloud diagram in the baking area are shown in FIG. 11 and 12.

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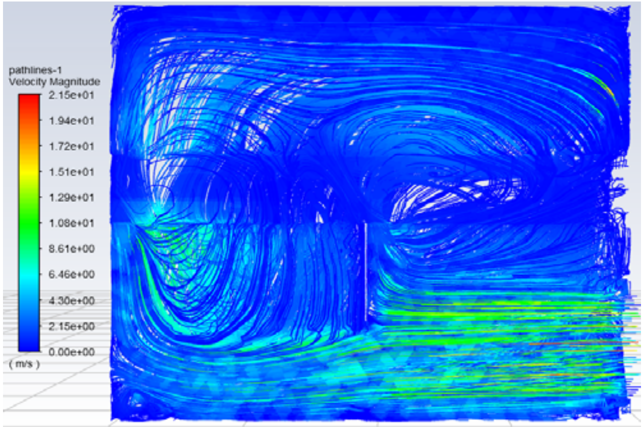

Fig. 9 Scheme 1 Drying Box Speed Trace Diagram

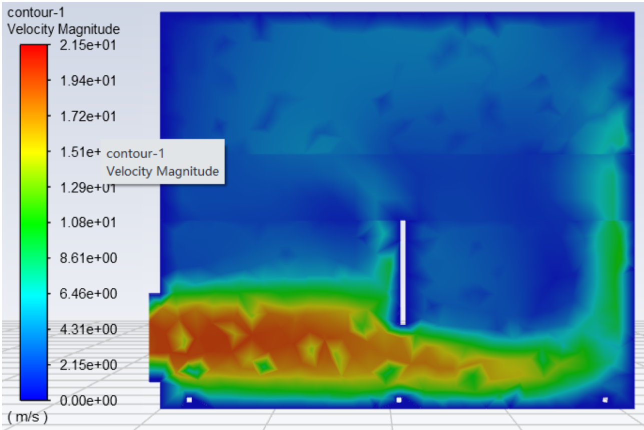

Fig. 10 Scheme 1 Drying box speed cloud diagram

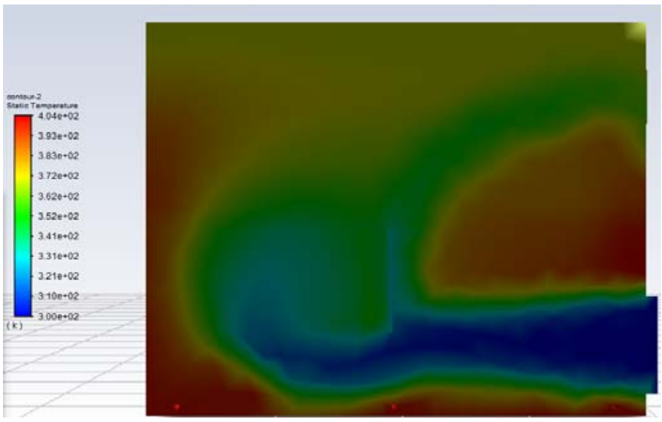

Fig. 11 Cloud diagram of the temperature of the drying box in scheme 1

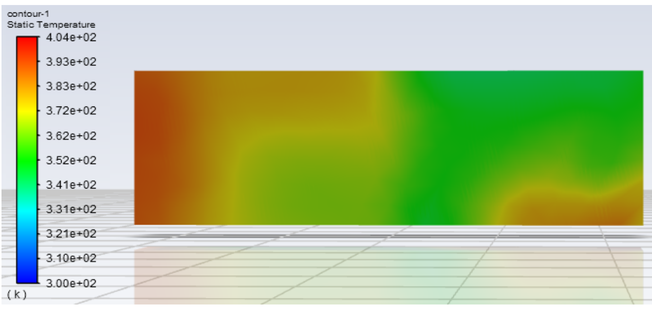

Fig. 12 Cloud map of the temperature distribution of the cross-section of the LJ region in scheme 13

It can be seen from FIG. 9 and 10 that, by adding a baffle plate, part of the air is blocked and allowed to pass through the front half of the baking area, directing part of the heat to the front side of the drying box. It can be seen from FIG. 11 and 12 that, with the addition of a baffle, the temperature of the baking area near the upper part of the entrance side rises significantly, which improves the baking effect of this part. Compared with the no-baffle scheme, the low-temperature area is significantly reduced, while the area of the high-temperature area is increased, and the minimum temperature is also increased. However, it can be seen from Fig. 12 that there are still large local high temperature zone and local low temperature zone in the baking area. The maximum high temperature is 130.85 ℃, and the maximum temperature difference is 63℃.FIG. 13, FIG. 14, FIG. 15 and FIG. 16 show the velocity and temperature distribution of scheme 2.

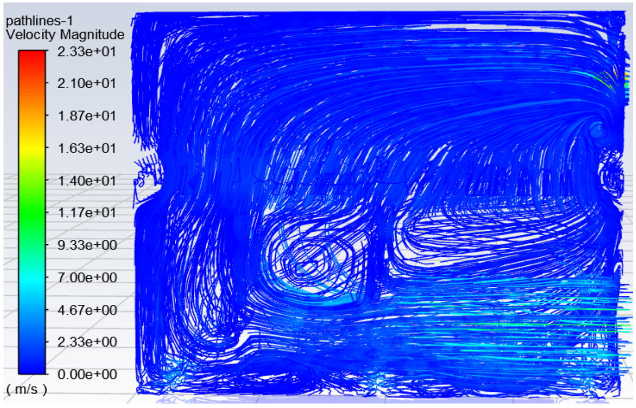

Fig. 13 Scheme 2 Drying Box Speed Trace Diagram

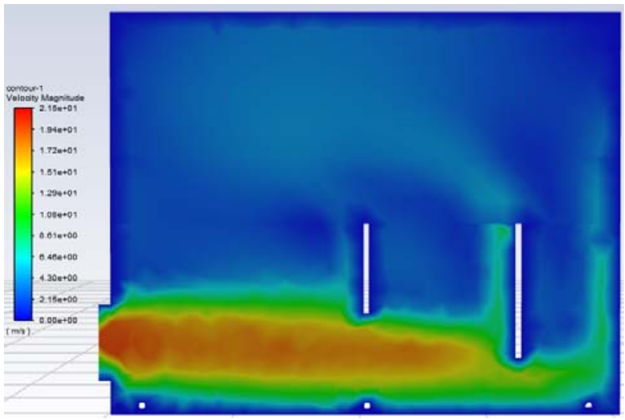

Fig. 14 Cloud diagram of the velocity distribution of scheme 2

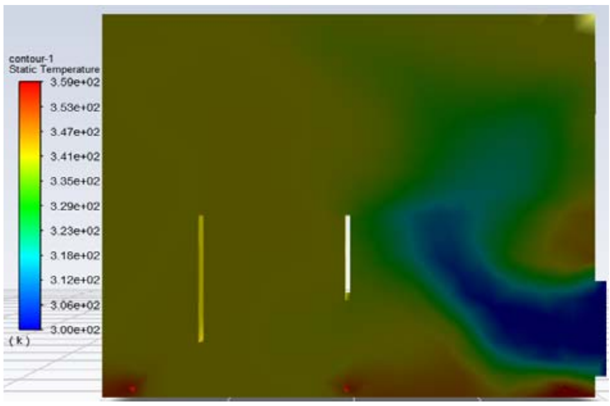

Fig. 15 Cloud diagram of temperature distribution in scheme 2

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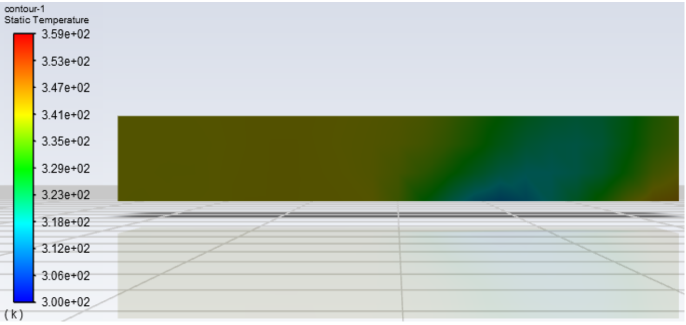

Fig. 16 Cloud map of temperature distribution in the baking area of scheme 2

It can be seen from FIG. 13 and 14 that compared with one baffle plate, the distribution of wind speed and temperature of two baffle plates is more uniform, and some small areas with low velocity in scheme 1 are eliminated. It can be seen from Fig. 15 and 16, compared with Plan 1, that Plan 2 significantly reduces the low temperature zone and eliminates the high temperature zone. Only 0.4m2 area of the baking area has a local low temperature zone, with the lowest temperature of 26.85℃ and the maximum temperature difference of 29℃. The temperature of other baking areas remains at about 67℃. Therefore, it can be seen that scheme 2 is significantly better than Scheme 1, but there are still local low temperature areas, which need to be further improved.

2.2.2 Optimize Bezel Simulation Analysis

Plan 3 is obtained by adding the third baffle and optimizing the tap position, as shown in Fig. 17. Simulation results are shown in FIG. 18, 19 and 20. As can be seen from FIG. 18 and 19, scheme 3 completely eliminates local low temperature zone and local high temperature zone in the baking area. In Fig. 20, 21 points are set in the upper plane, middle plane and lower plane of the baking area, among which points 1, 2, 3 and 4 are located in the upper plane, points 5, 6, 7 and 8 are located in the middle plane, and points 9, 10, 11 and 12 are located in the lower plane. The temperature of these 12 points is counted, as shown in Fig. 21. As can be seen from the Fig. 21, The maximum temperature difference of single-layer plane is 2.5℃-7.5℃, and the maximum temperature difference of upper and lower plane is 2℃-7.5℃, and the temperature is stable at about 67℃. It can be seen that the flow field distribution of scheme 3 is more uniform, the local high temperature zone and local low temperature zone are completely eliminated, and the temperature uniformity of baking area is greatly improved. At the same time, the temperature difference in the drying area without baffle, one baffle, two baffle and three baffle is compared, as shown in Table 1. It can be seen that the baking effect of scheme 3 is ideal.

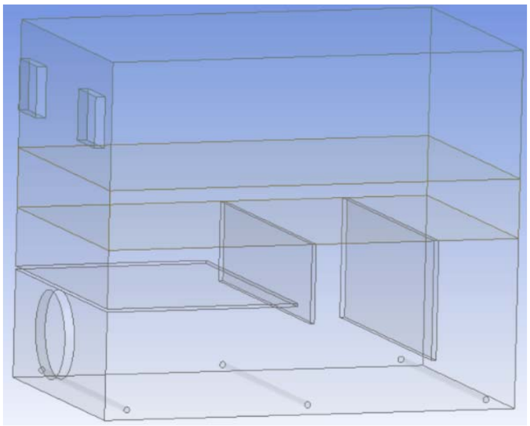
Fig. 17 Scheme three-bezel model diagram

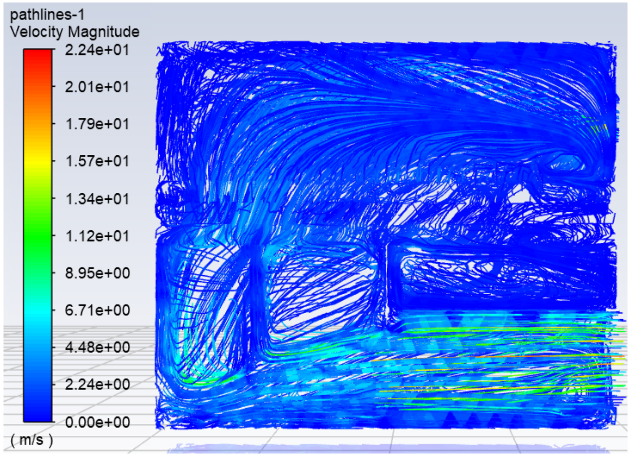

Fig. 18 Scheme 3 velocity trace diagram

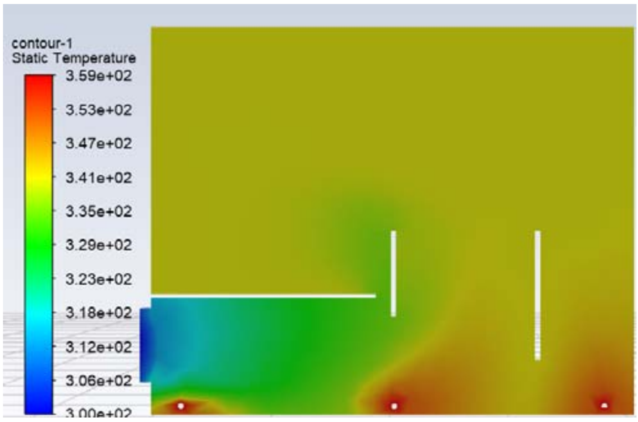

Fig. 19 Cloud diagram of temperature distribution in scheme 3

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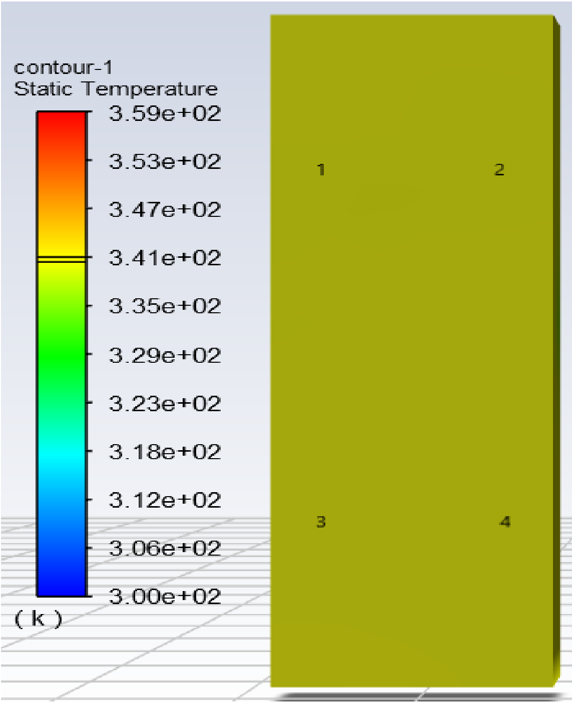

Fig. 20 Scheme 3 Flat temperature distribution in the baking area

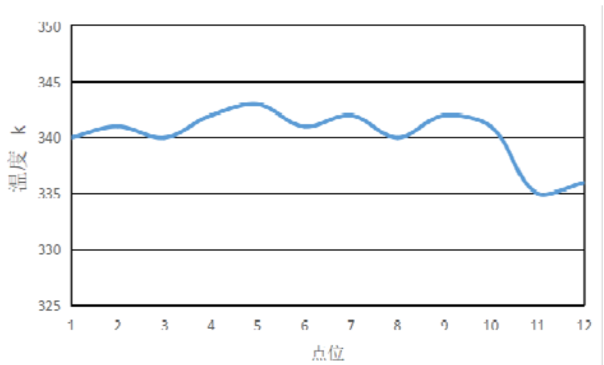

Fig. 21 Temperature distribution of different points in the baking area of scheme 22

Table 1 Temperature difference statistics of drying area under non-working conditions

Working conditions	Baking area	°C	Maximum temperature difference /°C
No bezel	Maximum temperature	130.85	104
	Minimum temperature	26.85	
A baffle	Maximum temperature	130.85	63
	Minimum temperature	67.85	
Two baffles	Maximum temperature	67.85	29
	Minimum temperature	38.85	
Three bezels	Maximum temperature	69.85	8
	Minimum temperature	61.85	

3 Pepper Drying Box Prototype Experiment

According to the drying box parameters of the above simulation study, a prototype was made. Zunyi Chao Tian pepper was used for drying experiment. Huata HIGH temperature and high humidity GKF-F-4 fan was used for circulating fan (air volume 5000m3/h, speed 2900r/min, pressure 270Pa, power 1.1KW). The weight is 1300Kg, and the picture of the prototype is shown in Fig. 22 and 23. PT100 temperature sensor is used to collect the temperature, and M2100 temperature data acquisition card module recorder is used to record the data, and NI VI Logger software is used for data acquisition and storage, and the temperature acquisition box is shown in Fig. 24. During the prototype experiment, 27 PT100 temperature sensors were arranged in three layers in the pepper baking area, and 9 sensors were evenly arranged in each layer. The sensor layout is shown in Fig. 25. Temperature changes at 26 positions in the drying area were tested. The target temperatures were set as 40℃, 45℃ and 49℃ respectively..

Fig. 22 Prototype of pepper dryer

Fig. 23 The pepper and sensor arrangement in the drying box are physically arranged

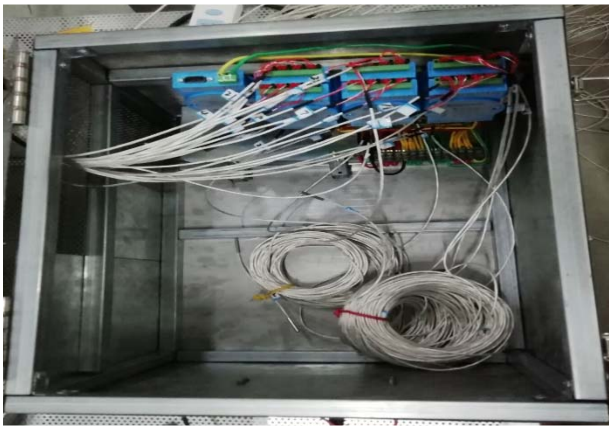

Fig. 24 Temperature collection box

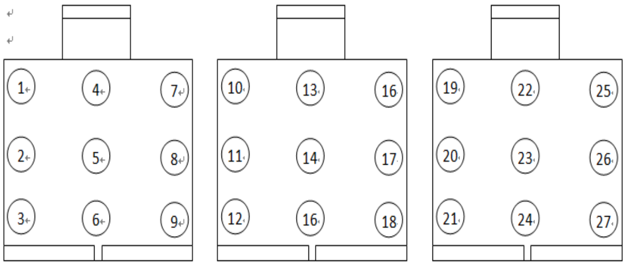

Fig. 25 Lower middle and upper three-layer sensor layout location diagram

Fig. 26 Temperature and heating controller

The temperature was collected for three times in total. Two baffles were set in the drying box to collect 241 groups and 295 groups of temperature data under the target temperature of 40℃ and 45℃ for 56 minutes and 143 minutes respectively, as shown in Fig. 27 and Fig. 29. The three baffles collected 316 groups of data under the target temperature of 49℃ for 156 minutes in total. As shown in Fig. 31; It can be seen from Fig. 28 and 30 that the single-layer plane temperature difference range of the baking area with two baffles designed in this paper is 4-11.5℃, and the temperature difference between the upper and lower planes is 10-16 ℃. As can be seen from Fig. 32, the temperature difference of single layer in the baking area with three baffle plates designed in this paper is 4.5-6.5℃, and the temperature difference between upper and lower layers is 10.2℃-11.2℃. It can be seen from the data that the three baffle scheme designed in this paper eliminates the local low temperature area and local high temperature area of the drying box, reduces the temperature difference in the baking area, and improves the temperature uniformity of the baking area. After 72 hours of baking, all the peppers are dried at the same time. As can be seen from Fig. 33, the roasted peppers have brighter color and better taste, achieving a very good drying effect.

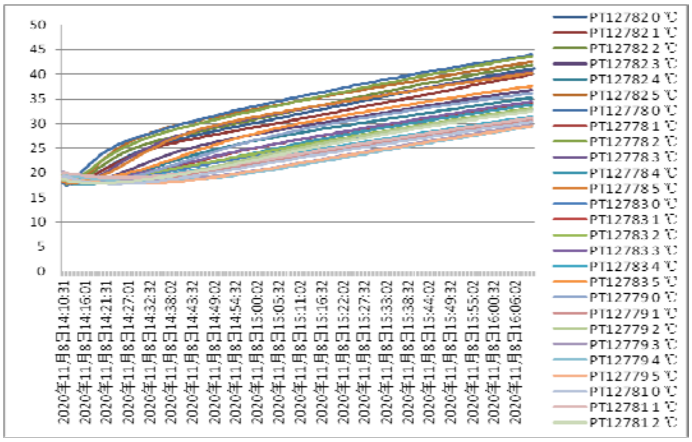

Fig. 27 Temperature curve of two baffles (set temperature 40°C).

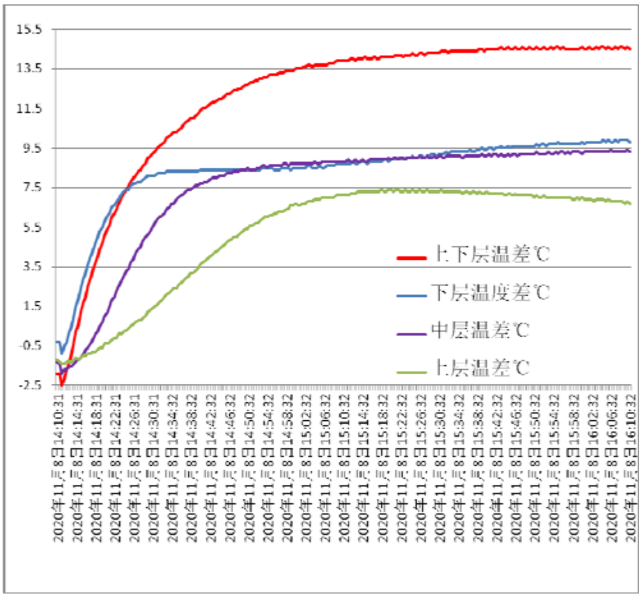

Fig. 28 Comparison curve of three layers of temperature difference between two baffles

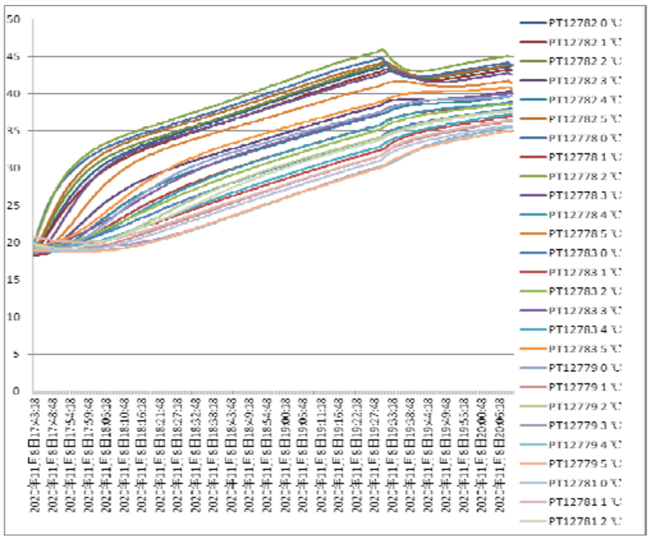

Fig. 29 Temperature data curve of two baffles (set temperature 45°C).

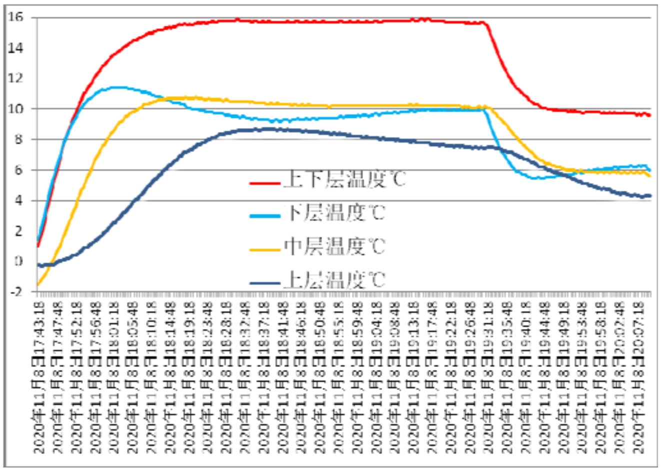

Fig. 30 Comparison curve of temperature difference between two baffles

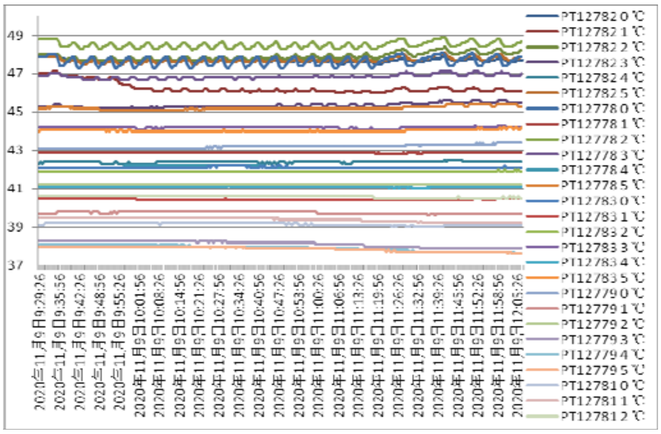

Fig. 31 Temperature data curve of three baffles (set temperature 49°C).

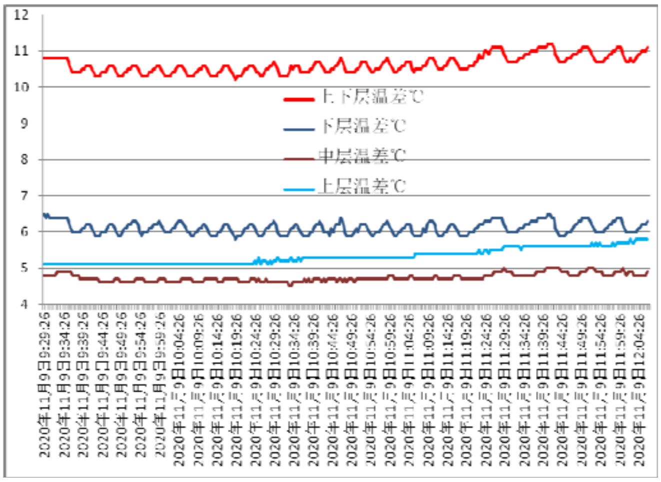

Fig. 32 Maximum temperature difference curve of three baffles (set temperature 49°C).

Fig. 33 Dried Zunyi Chaotian pepper product

4 Conclusion

1) Through simulation, it is verified that there are uneven flow field distribution, local low temperature area and local high temperature area in the small pepper drying box with 900mm stacking height in Zunyi area at present. The lowest temperature is 26.8 ℃, and the maximum temperature difference is 104℃, so local drying cannot be done on time.

2) The flow field distribution of the existing drying box was simulated by adding one baffle and two baffle vertically. The local maximum temperature of one baffle was 130.85℃ and the maximum temperature difference in the baking area was 63 ℃, and the lowest temperature of the two baffle was 26.85℃ and the maximum temperature difference was 29℃. It can be seen that by adding baffle can effectively improve the flow field distribution of the drying box, reduce the local low temperature area, eliminate the obvious high temperature area, improve the temperature distribution uniformity of the baking area.

3) simulation analysis of the existing drying box in the vertical and horizontal placed three of the baffle flow field distribution of single plane on the maximum temperature of 2.5 ℃ to 7.5 ℃, the lower plane of maximum temperature difference of 2 ℃ to 7.5 ℃, temperature stabilized at about 67 ℃. It can be seen that three damper solutions enable drying in the flow field distribution is more even, can completely eliminate the high temperature and low temperature area.

4) Through prototype experiment, the maximum temperature difference of single layer plane with two baffles placed vertically in the existing drying box is between 4℃ and 11.5℃, and the maximum temperature difference of upper and lower layers is between 10℃ and 16℃; The single-layer temperature difference of three baffles placed vertically and horizontally is 4.5℃-6.5℃, and the temperature difference between the upper and lower layers is 10.2℃-11.2℃. It can be seen that the scheme completely eliminates the local low temperature area and local high temperature area, the flow field distribution of the drying box is more uniform, the temperature difference is smaller, and the drying effect is very good.

5) Through experiments, this paper has verified that it is feasible to use the viscosity of sand to simulate the resistance of pepper and carry out simulation analysis of the flow field in the baking area.

6) The experimental optimization scheme in this paper can provide product improvement guidance for enterprises.
7) This paper only analyzed the use of rectangular baffles, and the temperature difference between the upper, middle and lower floors is 11.2℃, the subsequent analysis will continue to reduce the temperature difference between floors.
8) This paper has not analyzed the influence of different stacking heights on the flow field distribution and the flow field distribution of multi-layer drying.

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