NUMERICAL SIMULATION AND TEST OF HOT AIR FAN
/
热气流风机的数值模拟及试验

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ABSTRACT
The value of high moisture content crops is higher and the planting area is wider. However, in the harvest process, due to the high moisture content, the cleaning loss is greater. In order to reduce the adhesion between the crop extraction mixtures and improve the cleaning performance, a method of hot air cleaning was proposed. By using the fan design theory and thermodynamics, the prototype design of the hot air fan was completed. Through orthogonal test, the most suitable parameter combination is 1445 r/min fan speed and 85℃ air inlet temperature. Computational fluid dynamics (CFD) was used to observe the air velocity and air temperature of the outlet under the optimal combination of parameters to check whether it meets the requirements of hot air cleaning. The reliability of numerical simulation was tested by bench test. Finally, a field experiment was carried out with the hot air fan to observe the difference between the cleaning effect and the fan under the optimal parameter combination, and compare the cleaning loss rate.

摘要
高含水率农作物的价值较高，种植面积较广。然而，在收获过程中，由于水分含量高，清选损失较大。为了减少农作物脱出混合物之间的粘附，提高清选性能，提出了热风清选方法。利用风机设计理论和热力学，完成了热气流风机的样机设计。通过正交试验，得出最合适参数组合为风机转速 1445r/min，进风口风温 85℃。采用计算流体力学(CFD)观察最佳参数组合下的出风口风速以及风温，检验其是否达到热风清选的要求。用台架试验检验数值模拟的可靠性。最后使用热气流风机进行田间试验，观察在最佳参数组合下的清选效果与普通风机的差别，并对比清选损失率。

INTRODUCTION
In the rape harvesting, a crucial link in the working process of the combine harvester is the cleaning process of the material. If the cleaning effect is not good, it is easy for the grain to adhere to the sieve. As a result, the effective working area of the cleaning device is reduced, the sieve was blocked and the material flow was blocked, and the impurity and loss rate of the cleaning device are generally high. The main function of the cleaning mechanism is to ensure that the impurity content and loss rate of the grain after cleaning meet the specified requirements. The short stalks, weeds and impurities in the extracted mixture after threshing were separated from the seeds. Cleaning device is an important working part of combine harvester, and its excellent performance is the guarantee of efficient operation of the whole machine *(Li et al., 2009; Cheng et al., 1998; Li et al., 2012; Du et al., 2007)*. The cleaning device of the combine harvester is mainly an air sieve cleaning device, which uses airflow and sieve to work together. The fans commonly used in the air sieve cleaning device include centrifugal fans, cross-flow fans, and combined multi-fans *(Li et al., 2020)*. The sieve includes a cylinder sieve and a vibrating sieve, etc. A vibrating sieve is usually composed of a multi-layer sieve, a commonly used sieve has a fish scale sieve, punching sieve, and braid sieve. Different sieves have different working characteristics and are suitable for cleaning different extrusions.

Yuko et al., (2012), studied the effect of the presence of straw in the removed mixture on the cleaning flow of the combine. The results show that the friction of the wall and the friction between the extruded particles are the important reasons for the energy loss of the cleaning air in the combine harvester. *Hyeon et al., (2015),* studied the influence of the combination of working parameters such as the installation Angle of the cleaning sieve, vibration frequency of the vibrating sieve, and speed of the cleaning fan on the cleaning effect of semi-feeding combine harvesting. The optimal combination of working parameters is obtained.

Liang et al., (2014), developed a grain loss monitoring sensor and established an adaptive fuzzy control system. Through the feedback signal of the loss monitoring sensor, the fan speed, the angle of the air distributor and the opening of the air intake can be adjusted in real time, which can effectively reduce the cleaning loss. *Casarsa et al., (2011),* studied the influence of volute wall position on the flow field distribution inside the fan by using numerical simulation methods and verified the reliability of the simulation results through tests. *Vasudeva et al., (2009),* studied the influence of radial spacing on the internal flow of the centrifugal fan, and obtained the first-rate radial spacing value. *Raftery et al., (2019),* used full-scale laboratory measurements of the airspeed generated by ceiling fans to predict indoor air movement. Thus, previous investigations have demonstrated the relationship between internal flow field of the impeller and the performance of the entire fan, but the impact of impeller on internal airflow field has not specifically been studied. *(Lee et al., 2016)* evaluated factors, such as inlet and outlet pressures, flow rate, torque and power, aiming at the optimal design of the centrifugal fan. Compared with most optimization studies, there are fewer studies examining outlet airflow distribution. The cleaning device of Yanma YH880(4LZ-3.5A) fully fed into the combine *(Gebrehiwot et al., 2010)* has the characteristics of wide width, multi-layer segment, secondary cleaning, etc. *Kwang et al., (2004),* selected several factors, such as the location of the blade cut-off, the radius of the cut off, expansion angle of scroll and impeller width, to optimize the velocity distribution of a centrifugal fan. *Cui Junwei et al., (2015),* designed a double-fan air sieve cleaning device. The front fan adopted a three-outlet structure, and the rear fan was placed in front of the miscellaneous auger, and the air generated was used to assist the discharge of short culm at the tail of the sieve. *Chai et al., (2020),* added a polytetrafluoroethylene coating to the surface of the vibrating screen to achieve the hydrophobic effect.

At present, most cleaning fans at home and abroad are simulated from the parameter and improved from the structure. Only the influence of air velocity and volume on the cleaning effect is studied. During cleaning, there is still a lot of residues on the vibrating sieve and shaking plate, resulting in sieve blockage. There is no further improvement of the fan, the cleaning effect has not been greatly improved, and the hot air technology is also mostly used for drying wet crops, without considering the combination with cleaning. At present, there are no hot air fan products at home or abroad. To improve the cleaning efficiency, reduce the cleaning loss rate, and reduce the problem of sieve plugging and material obstruction, the study and design of the hot air fan are presented. The air distribution, heat change, and air velocity change of the hot air in the fan, as well as the heat loss and air distribution in the cleaning room are studied. This helps to reveal the characteristics of the hot air fan and to improve the cleaning performance of the combine.

MATERIALS AND METHODS

The working principle of the hot air fan is that the heating device was installed at the inlet of the fan to provide hot air. The hot air is rotated by the fan, and the air at normal temperature is replaced by the hot air to complete the cleaning.

Electric heaters were used to provide imported heat. The action principle of the electric heater is mainly to use the thermal effect of electricity, the current passes through the heating element of the electric heater, so that it heats up so that the temperature of the liquid substance or other substances rises. The heating element of the electric heater can be a resistance wire, a metal sheet, or an electric heat pipe, etc., which can emit a lot of heat to heat the object. The working process is that the internal electric heating device was energized and heated, and the air was inhaled by the fan in front of the electric heating device. The air was heated by the electric heating device and discharged from the outlet to provide hot air.

The structure of the electric heater is shown in Figure 1.

The calculation formula of the heat emitted by the electric heater is:

$$Q = \Delta T \times \lambda \times \delta \times S \tag{1}$$

where:

Q represent heat dissipating capacity (W/m^2);

ΔT represent temperature difference (℃);

λ represent heat conductivity coefficient (W/mK);

δ represent thickness of thermal conductivity material (mm);

S represent heat radiating area (m^2).

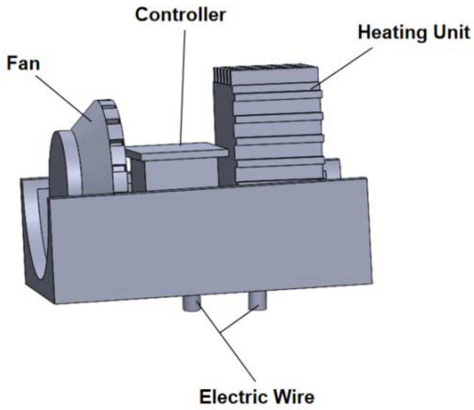


Fig. 1 - Internal structure of electric heater

Compared with the agricultural centrifugal fans commonly used now, the hot air fan can provide high heat flow without affecting the performance of the fan. The air temperature can be adjusted according to the humidity in the cleaning room so that the moisture extract with large material amount, high moisture content, and high grain content has a better separation effect without changing the structure or working parameters of the fan. It can meet or even improve the cleaning efficiency. The main improvement point is to change the original agricultural centrifugal fan into a hot air fan and connect the fan inlet with the electric heater. The optimized fan is installed on the Combine Harvester, which operates at a full load with an impeller speed of 1600 r/min.

The impeller structure parameters of the hot gas centrifugal fan are shown in Table 1, and in Figure 2.

Table 1

Structural parameters of four-blade centrifugal fan

Parameter	Number
Number of blades	4
Impeller outer diameter	556 mm
Impeller bore diameter	278 mm
Blade inlet mounting Angle	74°
Blade outlet mounting Angle	83°
Blade length	900 mm
Blade width	127 mm

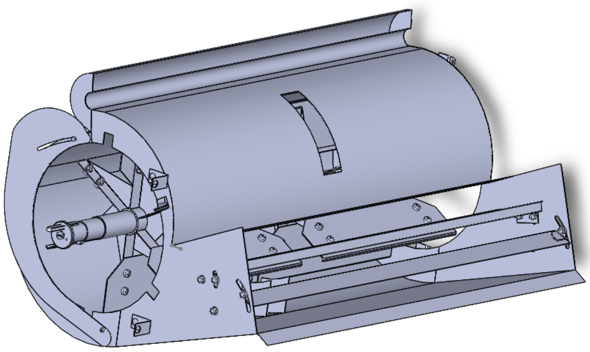


Fig. 2 - Fan model

Based on the designed 3D model, part module of SolidWorks software is used to model the simulated fluid domain, as shown in Figure 3. The flow field was numerically simulated by using FLUENT software. By analyzing the simulated air velocity and air temperature contour, it is verified whether the optimized fan can generate sufficient air velocity and temperature for separating the rape extraction mixture and whether the distribution of airflow is uniform and reasonable to ensure the cleaning effect.

The established model is imported into FLUENT software for preliminary treatment, tetrahedral unstructured Mesh is used in the mesh module to mesh the established airfield model, and all surfaces of thin-plate structures mesh to ensure that the average Element Quality of the mesh is above 0.8. The average distortion is less than 0.3. After partitioning, the model of the cleaning device generated a total of 20858413, 20957776 and 21039651 grids, respectively. The preparation work before calculation was carried out in the Setup module. The dynamic coordinate system method was adopted to set the fan impeller part in the airfield model as the dynamic coordinate system, and its center of rotation was the impeller axis.

The calculation model was selected as the Standard k-e model 23 with a wide range of applications, and the equation was solved by the SIMPLEC. The residual is set to 0.000 1 and the number of iteration steps is set to 20,000. This completes the preliminary treatment processing. Set the fan speed of 1445 r/min, the air inlet temperature of 85℃.

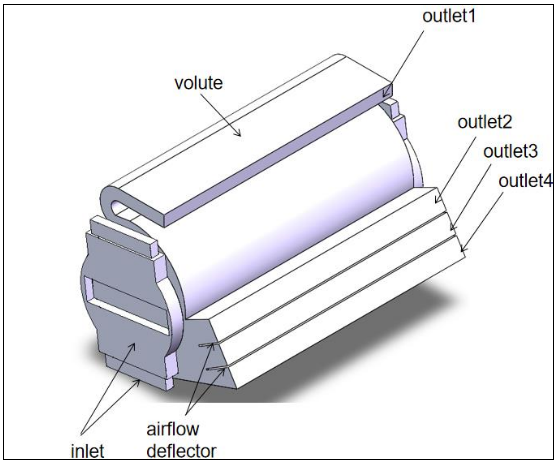


Fig. 3 - Airflow field model

A response surface analysis was conducted to examine the impact of fan speed, inlet air temperature, on the fan outlet air velocity and temperature.

A response surface analysis design was conducted using the Box–Behnken, the specific operations are as follows: first, Design-expert13 software was opened to set up the three-factor and three-level test *(Asad et al., 2021)*. Then, the air average velocity and average temperature at the upper and lower outlets were set as the response surface. Input the maximum and minimum values of the three factors.

The appropriate numerical combinations of factors were selected to verify their impact on cleaning performance.

RESULTS

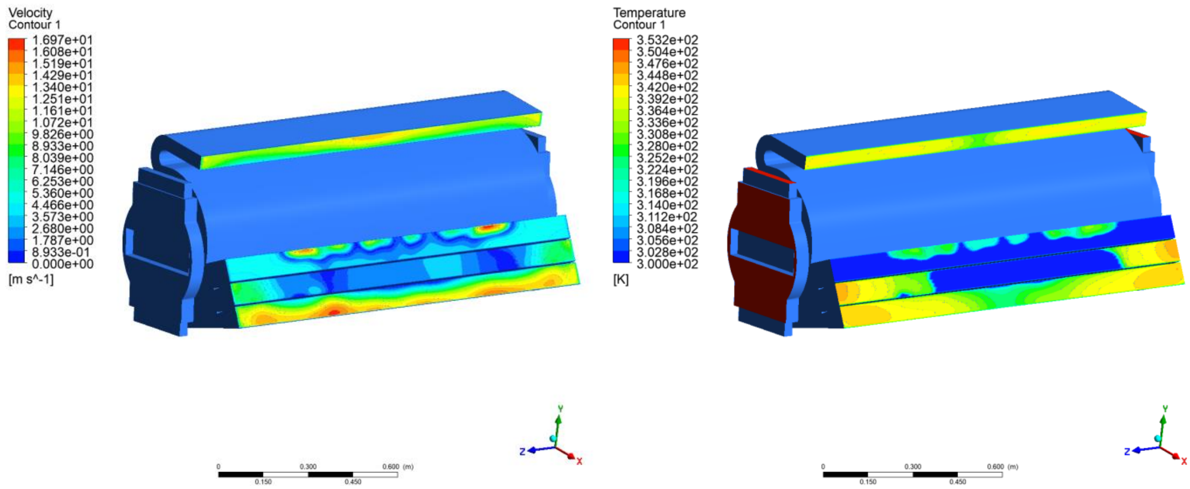
The response surface test table was obtained using Design-Expert13, and the experimental parameters satisfying the hot air cleaning were determined according to the simulation table. The experimental table is shown in the table 2.

Table 2

Test results of response surface of Hot-air fan cleaning performance.

	Fan speed	Inlet air temperature	Average air temperature at the upper outlet	Average air temperature at the lower outlet	Average air velocity at the upper outlet	Average air velocity at the lower outlet
	[rev/min]	[ºC]	[ºC]	[ºC]	[m/s]	[m/s]
1	1200	80	67.88	46.63	9.15	5.28
2	800	80	67.04	56.22	7.33	4.96
3	1200	80	67.88	46.63	9.15	5.28
4	1200	120	89.56	60.22	9.15	5.28
5	1200	80	67.88	46.63	9.15	5.28
6	1200	80	67.88	46.63	9.15	5.28
7	800	40	43.55	42.62	7.32	4.96
8	1200	80	67.88	46.63	9.15	5.28
9	1600	120	86.15	56.659	11.01	6.57
10	1600	80	55.65	41.22	11.01	6.57
11	1200	40	37.66	30.22	9.15	5.28
12	1600	40	30.69	26.64	11.01	6.57
13	800	120	97.46	72.31	7.32	4.96

The air velocity required for hot air cleaning is 7.6 m/s, and the air temperature is 60 ºC *(Zhang et al., 2022)*. The optimal combination of parameters to satisfy the hot air cleaning is the fan speed of 1445 r/min, the air inlet temperature of 85 ºC. The simulation results are shown in Figure 4.



a) Velocity Contour of at the outlet **b) Temperature Contour of at the outlet**

Fig. 4 - Simulation results

As can be seen from Figure 4, where the air velocity is higher, the air temperature is also higher. This is because the air velocity is larger, the hot air volume is also larger, so the air temperature is higher.

According to the simulation results, the average air temperature and average air velocity of each outlet are calculated to check whether the effect of hot air cleaning can be achieved. The air velocity and temperature of each outlet are shown in the Table 3.

Table 3

SIMULATION RESULTS

	Velocity [m/s]	**Temperature [ºC]**
Outlet 1	10.6	65.2
Outlet 2	6.7	51.2
Outlet 3	5.3	57.6
Outlet 4	10.6	72.2

It can be seen from Table 3 that the average wind speed and wind temperature of the upper and lower outlet can meet the conditions of hot air cleaning. In particular, the air velocity and air temperature at outlet 1 and outlet 4 are large enough to effectively separate the impurity adhesion and improve the cleaning efficiency.

To verify the reliability of the numerical simulation, the fan speed is adjusted to 1435 r/min on the solid fan, the air inlet temperature is 88 ºC. The average value of the sample points at the same position is compared with the numerical simulation, and the difference is observed. The experimental results are shown in the Figure 5.

It can be seen from Figure 5 that the changing trend of air velocity and temperature measured values of each outlet of the fan is generally the same as that of the numerical simulation values. The maximum error between the numerical simulation value of air velocity and temperature of each outlet and the measured value of the anemometer is <10%. On the one hand, the reason for the above measurement error is that the fan has only four blades, and the pressure pulsation occurs when the fan blades rotate, which makes the air velocity fluctuate periodically. In addition, due to the deviation of the boundary conditions used in the numerical simulation and the limitation of the calculation model, the error is further increased. Numerical simulation cannot completely replace the actual measurement to guide the design of the fan structure. Given the small difference between the numerical simulation results of air velocity and temperature of each outlet and the actual measurement results, it is reasonable to use the numerical simulation parameters to study the air distribution inside the fan.

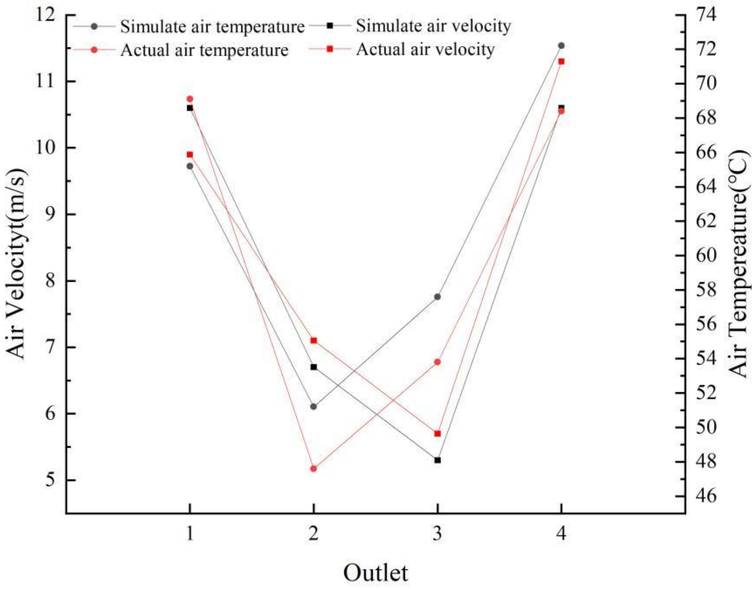


Fig. 5 - Simulation and bench comparison

The reliability of the numerical simulation was verified by bench test. A hot fan was installed on the harvester to harvest the rape. The cleaning effect of the specific heat airflow fan and the fan were tested in the field. In the process of harvesting, adjust the working parameter 1, Fan speed 1445 r/min for normal temperature wind harvesting, working parameter 2, Fan speed 1445 r/min, air inlet temperature 85℃. The model of the harvester is the Ward prime version, and the cleaning shoes are opened every 20 meters to compare the sieve surface blockage of the fan and the hot air fan. The test result is shown in Figure 6.

a. Cleaning shoes without hot air
b.

b. Cleaning shoes with hot air

Fig. 6 - Cleaning shoes comparison

As can be seen from Figure 6, the residual stems in the shoes cleaned by the hot air fan at A area are significantly less than that by the fan. At B area, the adhesion of wet crops to the screen surface was also significantly reduced. It can be seen that the hot air fan has a greater improvement in cleaning than the fan.

CONCLUSIONS

To improve the cleaning rate, different from changing the structure of the fan in the past, the fan is improved from the function for the first time. The heating device and fan type were selected, and a suitable fluid model was established.

The optimal parameters obtained by Design-expert are fan speed 1445 rev/min and inlet temperature 85 ºC. The simulation was carried out with the best parameters, and the reliability of the simulation was verified by bench test.

The difference between the fan and the hot air fan is compared by field experiment. According to the observation of the cleaning shoes, the residual stem of the cleaning shoes of the hot air fan is less than that of the general fan cleaning shoes, and the adhesion of wet crops on the sieve surface is also less than that of the fan. The cleaning rate has been greatly improved.

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