

STRUCTURAL OPTIMIZATION DESIGN AND HEAT TRANSFER CHARACTERISTICS OF MULTI-DEGREE-OF-FREEDOM SPIRAL PLATE TYPE AGRICULTURAL MACHINERY EQUIPMENT HEAT EXCHANGER

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In agricultural equipment, heat exchangers are mainly used for heat exchange and full utilization. Based on the theory of enhanced heat transfer, we establish a reasonable mathematical model and physical model for the multi-degree-of-freedom spiral plate type agricultural machinery heat exchanger, and use the FLUENT numerical simulation software to add the spiral disturbing fluid to the spiral plate heat exchanger flow channel. Numerical simulation and further optimization simulation of the fluid-conducting conditions with poor heat transfer effect were carried out, and an optimal arrangement of two kinds of spiral-shaped turbulent fluids with constant curvature and variable curvature was determined. The heat transfer effect of the fixed-curvature spiral-shaped disturbing fluid is superior. Further optimize the structure of the disturbing fluid. When the diameter of the disturbing fluid increases, the heat transfer can be enhanced; thus, the diameter of the disturbing fluid plays an important role in enhancing the heat transfer effect.

Key words: Spiral plate heat exchanger; structure optimization; heat transfer characteristics; spoilers; numerical simulation

1. Introduction

Heat exchangers are a vital type of heat exchange equipment and occupy a very important position in many fields[1]. They can transfer heat between multiple media at different temperatures, and also improve energy efficiency and save energy. Key equipment. Since the worldwide energy crisis, the enhancement of heat transfer technology and the optimization of heat exchangers have attracted the attention of scholars, which has led to the emergence of new energy-efficient heat exchangers. Among many types of heat exchangers, plate heat exchangers are widely used due to their large heat transfer area and large heat transfer per unit volume[2, 3]. The special form of plate heat exchanger spiral plate heat exchanger, originally proposed by Roseblad, due to its compact structure, high heat transfer coefficient, self-scouring characteristics, low cost, especially in the case of small temperature difference, can be recycled The advantages of low heat and so on have gained more and more attention[4]. During the use of agricultural machinery, the output of heat is very rich. This poses a great challenge to the heat dissipation of agricultural machinery, and how to make reasonable use of

these energy sources is a hot topic of research. The use of heat exchangers enables colleagues who have effective heat dissipation in agricultural machinery to make full use of their heat production[5]. This paper takes the cooling system of a diesel-powered high-power tractor in China as the research object, and takes the tractor hood, the diesel engine cooling system under the hood and related accessories as the whole research object, and uses the computational fluid dynamics CFD software FLUENT to feed the tractor hood[6]. The grille, the air passage under the hood, the accessories of the cooling system such as the cooling fan, the air hood, the intercooler, etc. carry out flow and heat transfer analysis, optimize the design model, and the ambient temperature adaptability of the tractor cooling system meets the development goal[7].

2. Heat exchange problems in agricultural equipment

2.1. Research on dust removal and heat dissipation of agricultural engines

At present, the dust removal and heat dissipation method of the domestic large-scale self-propelled harvesting machinery engine mainly seals the water tank, but the large self-propelled harvesting machine will generate a large amount of dust, grass, fine particles and debris during the field operation, and it is easy to advance. The blockage of the wind components causes poor ventilation, resulting in poor heat dissipation of the water tank and high temperature[8]. In addition, various fine particles enter and remain in the pores of the air intake component, which also causes the heat of the water tank to be not good, resulting in early wear of the engine and seriously affecting the engine. Work efficiency and service life[9-11]. In view of this, some people have designed a dust removal and heat dissipation device for agricultural machinery, which can effectively improve the working efficiency of the engine and prolong the service life of the engine[12]. Compared with the existing heat dissipation and dust removal structure, the dust removal rate of the device can be increased by about 60%. The device has the advantages of simple structure, strong practicability and convenient maintenance[13]. It consists of a water tank, a sealing frame, a fan, a shaft, a pressure reducing plate, a suction nozzle, a suction pipe, and a fan. Among them, the parameters of the fan are as follows:

$$Q = 900\pi D_2^2 g v_2 \phi \quad (1)$$

$$K_p = \frac{\rho_1 v_2^2 \phi}{101300} / \left[\left(\frac{\rho_1 v_2^2 \phi}{354550} + 1 \right)^{35} - 1 \right] \quad (2)$$

$$P = \rho_1 v_2^2 \phi / K_p \text{ (Pa)} \quad (3)$$

$$N_m = \frac{\pi D_2^2}{4000} \rho_1 v_2^3 \lambda \text{ (kW)} \quad (4)$$

Q-flow, m³/h; P-full pressure, Pa; v₂ impeller blade outer circular velocity, m/s; p, - intake density, kg/m³; K_p - full compression coefficient; N_m- Required power, kW; D₂ - impeller blade outer diameter, m. Determine the parameters according to the operating conditions of the fan: $\phi = 0.25; \psi = 0.39; \lambda = 0.1126$. After several field test adjustments and subsequent field tests, the relevant data of the vacuum structure was finally determined, as shown in Table 1.

Table 1. Data related to dust absorption structure

Dust removal pipe	Boquilla aspiradora		Draught fan		Fan blade
Inner diameter (mm)	blast capacity (m ³ /h)	rotate speed (r/min)	wind pressure (Pa)	blast capacity ((m ³ /h))	diameter (mm)
85	828	2500	2495.7	300	

After several site tests, the device was fully configured to the product prototype, and several field trials were conducted in the Communist Youth League Farm, Miquan, Wusu and other places. The test results show that the device can achieve all-weather trouble-free operation of the engine, the engine water temperature is maintained between 80 °C and 95 °C, no weeds are trapped at the air inlet of the sealing box, and the dust removal heat dissipation effect meets the expected design requirements. The approval of agricultural machinery users. At present, this automatic dust removal and heat dissipation device has been deployed in various harvesting machines of our company.

2.2. Tractor diesel engine cooling and cooling system

The tractor cooling system is similar in structure to the car cooling system. The pump is used to increase the coolant pressure, and the coolant is forced to flow in the diesel water jacket and the accessory passage. The conventional forced circulation water cooling system includes a cooling fan, a water pump, a thermostat, a radiator of a water tank, an expansion tank, a water jacket of the engine cylinder head and the cylinder block, and an attachment device[14]. The diesel engine cooling system for tractors is designed to ensure that the diesel engine operates at a reasonable temperature range under all operating conditions. After the diesel engine is started in the cold state, the diesel engine should be heated up quickly to reach the ideal working temperature quickly[15]. The correct fluid mechanics equation must be used when conducting CFD analysis. The focus is on the basic equations of fluid mechanics and the system of partial differential equations. The flow control equation uses numerical solutions, such as split method, finite volume method, boundary method, spectral (meta) method, particle method, etc., and numerical solution can be realized by means of computer.

The basic equation derivation is based on the assumption of continuous medium, following the law of macro conservation, including conservation of mass, conservation of kinetic energy, and conservation of energy.

(1) Conservation of quality. Its mathematical expression is as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0; \quad \nabla \cdot (\rho \vec{V}) = \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} \quad (5)$$

Where ρ is the fluid density, t is the time, v is the velocity vector, and u , v , and w are the components of the velocity vector V in the x , y , and z directions, respectively.

Assuming that the fluid is incompressible within the control body, the density is constant:

$$\frac{\partial(u)}{\partial x} + \frac{\partial(v)}{\partial y} + \frac{\partial(w)}{\partial z} = 0 \quad (6)$$

Assuming that the fluid is in steady flow, the density does not change over time:

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \quad (7)$$

(2) Conservation of kinetic energy. The law of conservation of kinetic energy indicates that the momentum of the inflow of the body, the impulse of the surface force, and the impulse of the mass force are equal. The formula is expressed as follows:

$$\begin{aligned} \frac{\partial(\rho u)}{\partial x} + \nabla(\rho uu) &= -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + F \\ \frac{\partial(\rho v)}{\partial y} + \nabla(\rho vu) &= -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + F \\ \frac{\partial(\rho w)}{\partial z} + \nabla(\rho wu) &= -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + F \end{aligned} \quad (8)$$

(3) Energy conservation. The law of conservation of energy means that the energy change in the body is controlled by the sum of the inflowing energy, the surface force work, the volume force work, and the incoming heat. These energy can be converted but not increased or decreased.

There is a direct mathematical relationship between temperature T and internal energy i . The energy conservation equation for T is:

$$\frac{\partial(\rho T)}{\partial t} + \nabla(\rho u T) = \nabla\left(\frac{k}{c_p} \text{grad} T\right) + S_T \quad (9)$$

We use YC6105 6-cylinder supercharged intercooled diesel engine as the research object, which is a mature product, the main parameters are shown in Table 2.

Table 2. The basic parameters of diesel engines

project	parameter
type	Straight line, water cooling, four stroke
Cylinder number - cylinder diameter×stroke/mm	6-105×125
Displacement/L	6.494
Air inlet	Pressurized and cold in air
rated power/kw·ps ⁻¹ /	128/175
rated speed /r/min	2300
maximum torque/N·m	710
maximum torque rotate speed/r/min	1625
fuel system	Mechanical list
Calibrate fuel consumption rate/g/kw·h	225
External characteristic minimum fuel consumption /g/kw·h	198

When the diesel engine is running, the fuel is burned in the sealed combustion chamber by compression ignition, which converts the chemical energy of the diesel into heat energy, thereby releasing a large amount of heat. About two-thirds of the heat energy is converted into kinetic energy, about one-third. Thermal energy is taken away by the tractor cooling system. If the tractor cooling system can not effectively cool the diesel engine in time, the diesel engine temperature will be too high, and the diesel engine reliability will decrease, the power will be reduced, the parts will be hot and the lubrication performance will be deteriorated.

According to the CFD analysis and comparison results of the tractor cooling system, the tractor cooling system test plan is developed in a targeted manner. as shown in Table 3.

Table 3. Tractor cooling system test program

NUM	FAN SCHEME	FAN DISTANCE FROM RADIATOR(MM)
STEP1	pressure angle40°,power4kW	80
STEP2	pressure angle40°	80
STEP3	pressure angle40°	70
STEP4	pressure angle40°	70

For the radiator, the performance is tested. The test method is: at the ambient temperature, the pressure and temperature sensors are arranged at the inlet and outlet of the radiator, the full load and part load, the torque point full load and the medium speed torque at the engine calibration point. Point the full load to measure the differential pressure and temperature difference between the inlet and outlet of the radiator, and evaluate the heat sink capacity. Engine water temperature comparison as shown in Figure 1.

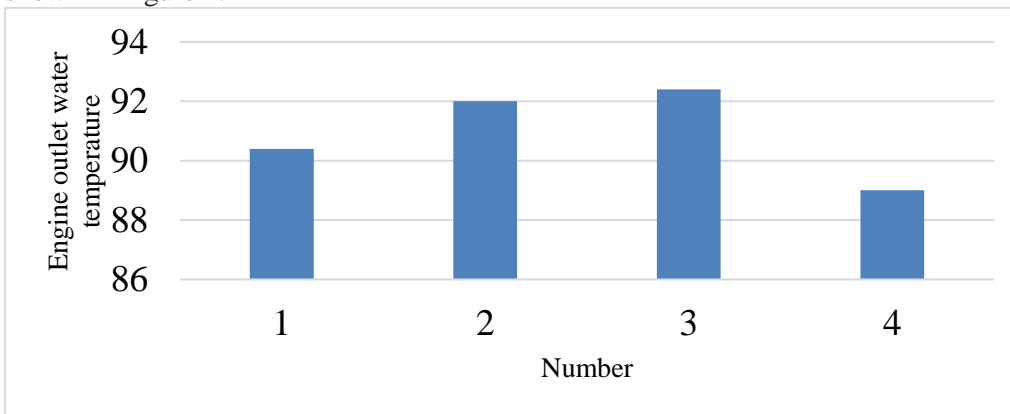


Figure 1. Engine outlet water temperature

Under the design requirements of the extreme use environment temperature $LAT \geq 45^{\circ} C$, the engine outlet water temperature of each scheme does not exceed the limit value of $95^{\circ} C$, and the scheme 4 is the best.

Test the ultimate ambient temperature. The pressure difference and temperature difference between the inlet and outlet water are converted into the extreme use ambient temperature, as shown in Figure 2. And thereby assess the ability of the cooling system.

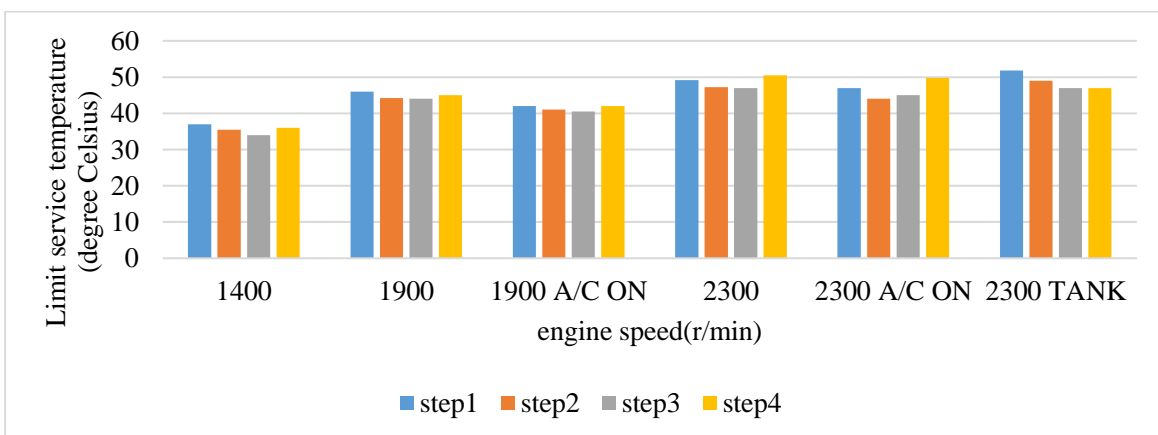


Figure 2. Engine outlet water temperature

From the test results, the ambient temperature of the limit of each working condition of the scheme 1 is up to standard, and the ambient temperature of the limit of the torque point of the scheme 4 is close to the standard.

Test the performance of the expansion tank: Use the heat engine emergency stop test method. Test method: In the tractor PTO gantry, according to the full-speed full-load working condition, the engine water temperature is quickly raised to 105 °C by blocking the hood vent of the tractor hood, then the engine is stopped urgently, the pressure and temperature of the radiator inlet are detected, and the inspection is carried out. The liquid level in the expansion tank and whether there is leakage.

In this paper, the tractor cooling system is made of 8L plastic expansion tank with an expansion volume of 2.5L. The test results show that after the emergency stop of the heat engine, the maximum liquid level of the coolant does not exceed the maximum scale of the expansion tank, and the pressure and temperature at the inlet of the radiator are shown in Figure 3.

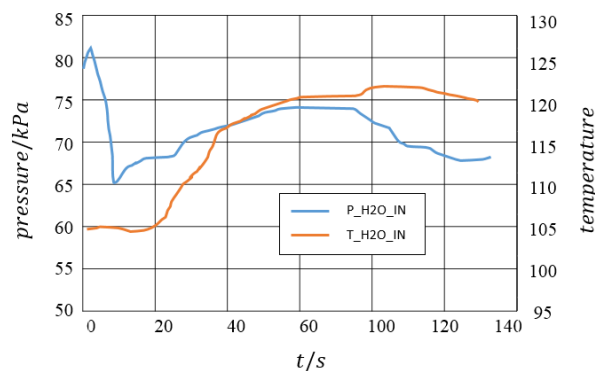


Figure 3. The temperature and pressure of the cooling fluid of the engine stopped rapidly

Comprehensively balance the dynamics of the vehicle and the temperature of the extreme use environment, and finally choose option 3 as the shaping plan. At present, this series of tractors has been put on the market in batches.

According to the results of 3D simulation analysis of the tractor cooling system, the test verification scheme was selected and the multi-program tractor cooling system was compared and verified. Comprehensive balance of power, fuel economy and cooling system performance, determine the third option is the final setting.

3. Intensive heat transfer theory and introduction of FLUENT

Intensified heat transfer technology is classified according to whether there is an external power source attached. It is generally divided into Passive Enhancement Techniques, Active Enhancement Techniques, and Compound Enhancement Techniques.) three categories. This topic adopts the form of installing passive enhanced heat transfer elements, which is arranged as a disturbing fluid on the heat exchanger plates of the spiral plate heat exchanger, and seeks suitable fluid disturbance parameters by studying the heat transfer performance of the heat exchanger. And positional parameters, a new and efficient spiral plate heat exchanger was developed.

In 1904, Prandtl proposed the concept of boundary layer. The velocity boundary layer and the temperature boundary layer are ubiquitous in various flows and heat transfer in nature. The schematic diagrams of the two are shown in Figure 4:

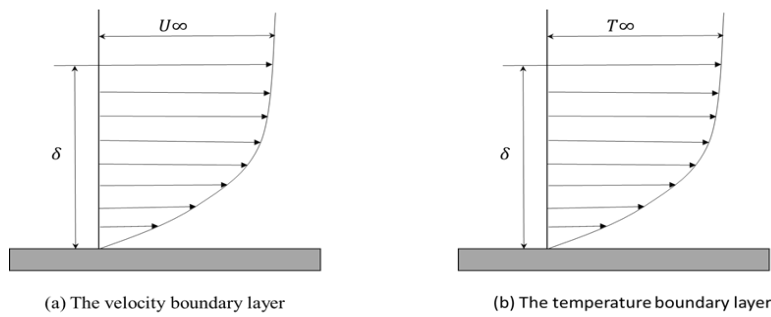


Figure 4. Boundary layer diagram

Now, it has been found that expanding the heat transfer area, controlling the boundary layer, and reducing the coordination angle are effective ways to enhance heat transfer. Therefore, this topic chooses to add the disturbing fluid to enhance the disturbance of the fluid and control the boundary layer. At the same time, the fluid disturbance is enhanced, the temperature field of the hot and cold watershed will be more uniform, and the temperature field synergy will be better.

4. Structural optimization design of spiral plate heat exchanger

4.1. Spiral plate heat exchanger model

The spiral plate heat exchanger model studied in this paper is BLC1.6-6-0.5/500-10, and the material of the plate is 304 stainless steel. The relevant structural parameters of the heat exchanger are: heat exchanger tube height 500mm, spiral body outer diameter 500mm, fixed distance column diameter 30mm, spiral plate thickness 4mm, cold fluid channel width 10mm, thermal fluid channel width 10mm. Using the Computational Fluid Dynamics (CFD) software FLUENT pre-processing GAMBIT software, the overall geometric model of the spiral plate heat exchanger is meshed. The spiral body and the inlet and outlet nozzles are both unstructured meshes, and are locally close to the heat transfer surface area. Encryption, and through grid-independent verification, the final selection of the grid number is about 2.95 million can meet the requirements of calculation time and calculation accuracy. Related boundary conditions are shown in Table 4.

Table 4. Boundary condition parameter

fluid	entrance velocity/ $m \cdot s^{-1}$	inlet temperature/K	Export pressure
The cold fluid	0.03	310	atmospheric pressure
The hot fluid	0.03	350	atmospheric pressure

4.2. Structural optimization simulation of spiral plate heat exchanger

We use a fixed-curvature spiral scrambling fluid to simulate, the upper layer is the hot watershed, and the lower layer is the cold watershed. Five arrangements are used. The detailed parameters are shown in Table 5.

Table 5. The specific layout of disturbing fluid

Arrangement form	Specify
1	The distance between the disturbed fluid in the cold and hot drainage area is 50mm, and the distance between the upper and lower left side is 25mm
2	The distance between the disturbed fluid in the hot drainage area is 50mm, and the distance between the upper and lower left side is 25mm, The perturbed fluid was 12.5mm away from

	the edge, and the perturbed fluid was staggered in the cold and hot drainage area
3	The distance between the disturbed fluid in the hot drainage area is 50mm, The distance from the bottom distance is 1/3 of the width of the simulation unit, the left and right edge distance is 25mm, and the cold and hot disturbing fluid is arranged in parallel lines
4	The distance between the disturbed fluid in the heat flow domain is 1/3 of the width of the simulation unit, and the distance between the left and right sides is 25mm. The hot and cold disturbed fluid is arranged diagonally
5	In the heat flow domain, the distance between the disturbed fluid and the bottom distance is 1/3 of the width of the simulation unit, the left and right side distance is 25mm, and the cold and hot disturbed fluid is arranged in parallel lines

The Nu distribution diagram of the spiral spoiler in different arrangements is shown in Fig. 5.

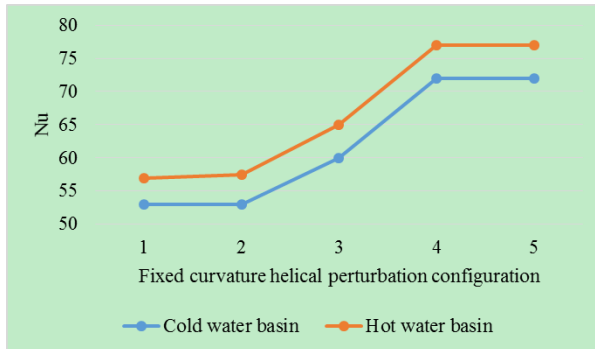


Figure 5, Different layout Nu number distribution diagram

Simulate the temperature difference between the inlet and outlet of the hot and cold waters in the unit, as shown in Figure 6.

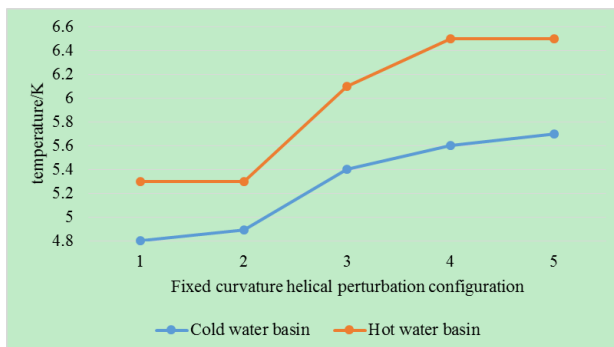


Figure 6. Temperature difference distribution map of different arrangements

The pressure drop inside the unit is simulated, and the simulation results are shown in Fig. 7.

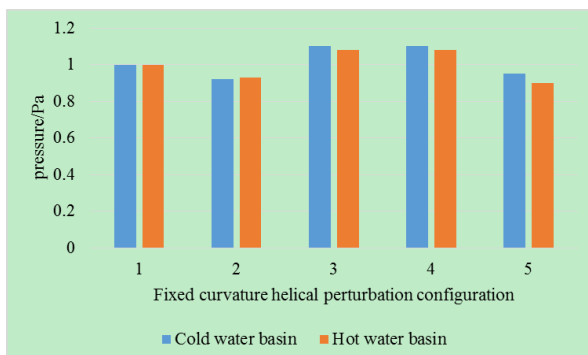


Figure 7. Temperature differential pressure drop chart of different layout

The vortex intensity of the five arrangements was analyzed and the results are shown in figure 8.

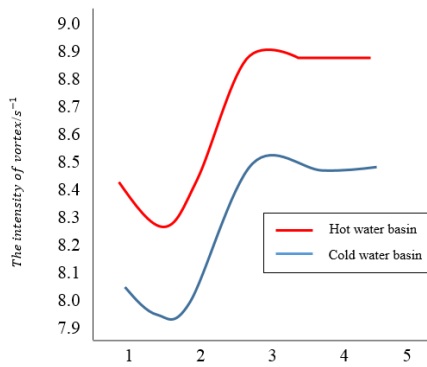


Figure 8. Fixed curvature helical perturbation configuration

It can be seen from the fixed curvature spiral disturbing fluid layout diagram that the vortex intensity is the largest when the mode 5 is arranged in the hot and cold water flow, and the vortex intensity is the smallest when the mode 2 is arranged. The vortex intensity is large, so that the liquid is easily disturbed during the flow process, so that the liquid is likely to reflow in this part and enhance heat exchange.

5. Conclusion

In this paper, the multi-degree-of-freedom spiral plate heat exchanger in agricultural machinery is taken as the research object, and the heat exchange problem that needs to be solved urgently in the current agricultural machinery equipment is studied. The FLUENT software was used to simulate the disturbance fluid distribution of the plate heat exchanger. The results show that the heat transfer effect is not improved when the height of the disturbing fluid changes and the diameter is constant. When the height of the disturbing fluid is constant and the diameter is reduced, the heat transfer is performed. The effect is also not improved; the heat transfer effect is improved when the height of the disturbing fluid is constant and the diameter is increased. Among them, the fixed-curvature spiral-shaped disturbing fluid has the best heat dissipation effect and can be further studied. In the future, we will study the multi-channel spiral plate heat exchanger, and improve and further simulate the structure of the disturbing fluid in order to optimize the heat exchanger structure more accurately.

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Remarks:

Nearby the capital of the country do not write the name of the country.

For the states in USA, Canada, and other countries use abbreviations (*e. g.* Penn. for Pennsylvania, Ont. for Ontario).