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Simulation of fuel cell plate cooling system

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Abstract

With the vigorous development of new energy vehicles, pure electric vehicles have obtained the opportunity of rapid development, and fuel cell vehicles also have broader development prospects. Based on the working characteristics of fuel cell, there are strict requirements for the structure and cooling mode of cooling system. In this paper, the types of coolant are compared and analyzed, the cooling system structure is simulated and optimized, and the advantages and disadvantages are analyzed based on the simulation cloud pictures of coolant temperature, isotherm, velocity and pressure of different cooling modes.

Keywords

Fuel cell plate, cooling system, coolant, simulation.

1. Introduction

In recent years, the earth's temperature record has reached a new high year after year, and the ecological environment has been deteriorating. For the better development of mankind, environmental protection is an urgent problem to be implemented. The exhaust emissions of fuel vehicles are an important cause of air pollution. The promotion and use of new energy vehicles can effectively reduce air pollution. Since 2020, China has made an international commitment to strive to achieve the goal of carbon neutrality in 2060, relevant policies have been issued, and the voice of "new energy vehicles" has emerged in the society. In addition, the global new energy vehicle market has shown a rapid development trend since 2014, while China has rapidly become the world's first and fastest-growing market in terms of sales volume since 2015. In 2021, China's new energy vehicle sales accounted for 54.8% of the world's total new energy vehicle sales.

The intermediate waste heat released by fuel cells of new energy vehicles contains huge useful energy, which can be recycled for secondary utilization. However, the traditional solid-state equipment used to collect medium waste heat is limited by low power generation and conversion efficiency. This paper presents a hybrid vehicle cooling system composed of new energy vehicle fuel cell and heat recovery battery sleeve. The system cools and absorbs all kinds of heat losses in most devices and fuel cells. The performance characteristics and parametric design strategy of hybrid cooling system are studied. The simulation results show that for pipe cooling, semi cylindrical channel is the better choice in terms of coolant flow uniformity, flow speed, pipe pressure and cooling speed; For plane cooling, the plane cooling with fins is closer to the inlet, reaches the temperature peak earlier, and the cooling effect is better. This paper reveals the potential of the hybrid cooling system of fuel cell thermal radiation device in waste heat recovery, and opens up a new way to improve the energy conversion efficiency of carbon fuel cell.

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2. Analysis of cooling mode of fuel cell plate

In the actual fuel cell vehicle, fuel cell plates are stacked by multiple groups of fuel cell plates. Each plate is connected in series and works in the form of fuel cell group. In this simulation experiment, we do not take the fuel cell stack as the geometric main body, but only one fuel cell plate as the experimental object. While studying the heating and cooling of a single plate, we simplify the experimental steps and shorten the experimental time. In the later calculation and inspection results, it is found that it has no significant impact on the experimental results.

2.1. Geometric modeling

The team collected a large amount of information related to the fuel cell in the early stage and the fuel cell in the market. The selected models include: Toyota Mirai series, honda clarity, BMW I8, Mercedes Benz GLC fuel cell, Audi h-tron Quattro, Hyundai NEXO series, SAIC Maxus G20 FC, Hongqi H5 fecv, Dongfeng Fengshen AX7 FCV, etc. As shown in Figure 1, we use the Toyota Mirai second generation fuel cell plate (1.36mm×85mm×90mm) with cutting-edge technology as the modeling prototype, its size is used to draw more accurate research conclusions, so that the conclusions are more accurate, practical and have reference value and significance.

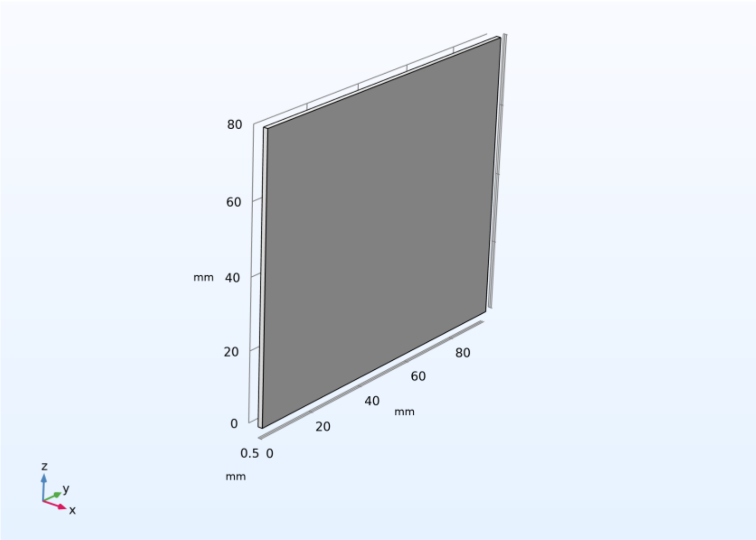

Figure 1 Geometric modeling of fuel cell plate

2.2. Design of cooling channel type of fuel cell plate and selection of coolant material type

There are two kinds of cooling methods in traditional automobile: air cooling and water cooling, while the fuel cell plate is usually cooled by coolant water cooling. After calculating the stacking mode and stacking spacing of fuel cell stack, we arrange the coolant water cooling channel on the side close to the fuel cell plate, which is designed as pipe cooling and plane drainage cooling. The pipe cooling is divided into rectangular channel cooling which is more close to the fuel cell plates on both sides (as shown in Figure 2) and semi cylindrical channel cooling with more sufficient coolant flow (as shown in Figure 3). Planar drainage cooling is divided into planar cooling with larger coolant bonding area (as shown in Figure 4) and planar cooling based on planar cooling with shunt fins (as shown in Figure 5).

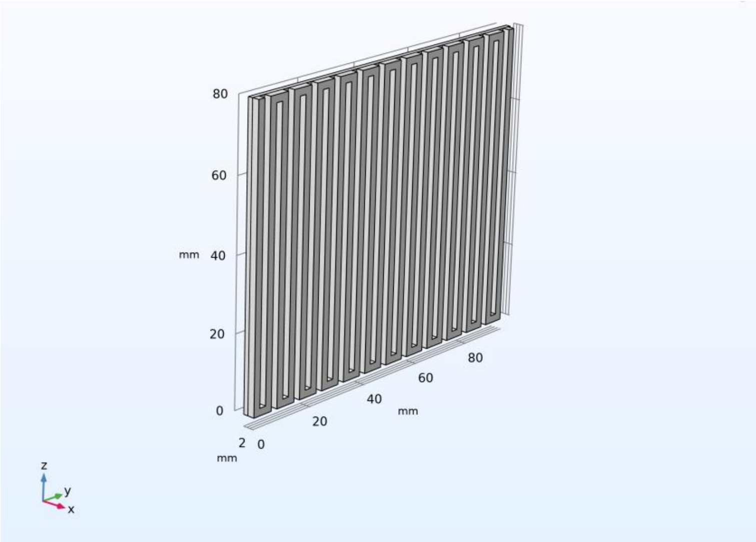

Figure 2 Rectangular channel cooling

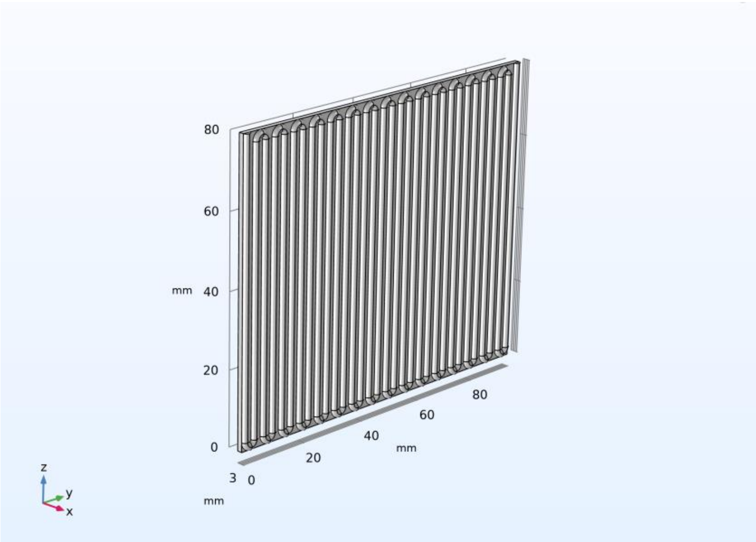

Figure 3 Semi cylindrical channel cooling

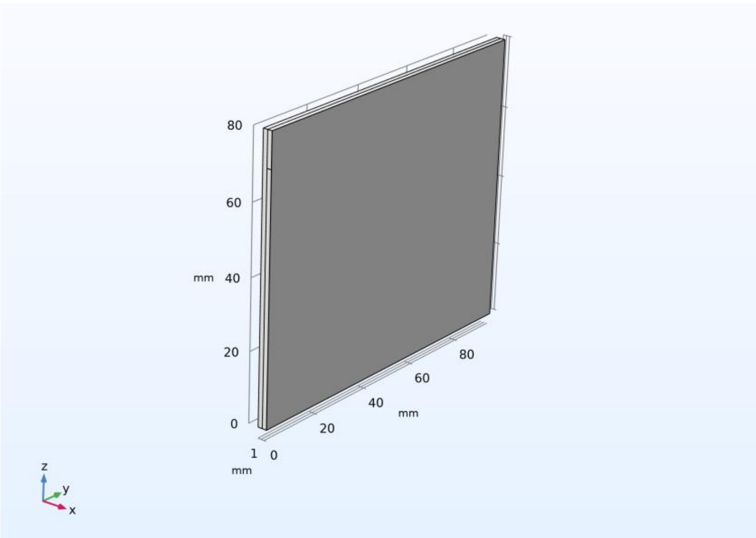

Figure 4 Plane cooling

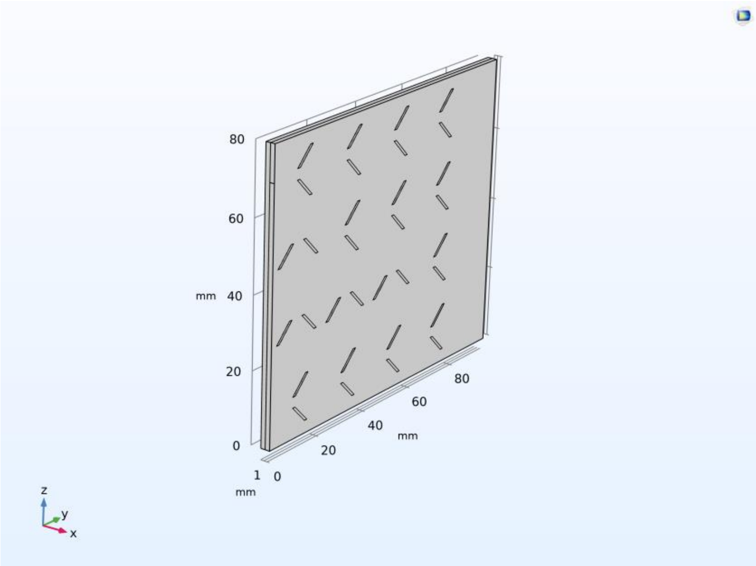

Figure 5 Planar cooling with fins

2.3. Simulation results and analysis

2.3.1. Working medium selection

In the type of coolant, we select water and glycol coolant in the market for simulation and comparison. By taking the steady-state results after the simulation experiment, the temperature, isotherm, streamline, velocity, pressure and two-dimensional temperature nephogram of the simulation situation are obtained. In rectangular channel cooling and semi cylindrical channel cooling, the cooling conditions of water and glycol coolant are simulated.

According to the working conditions of the two working fluids in the rectangular channel cooling (as shown in figures 6 and 7), the cooling effect of using only water as the coolant is worse than that of ethylene glycol coolant.

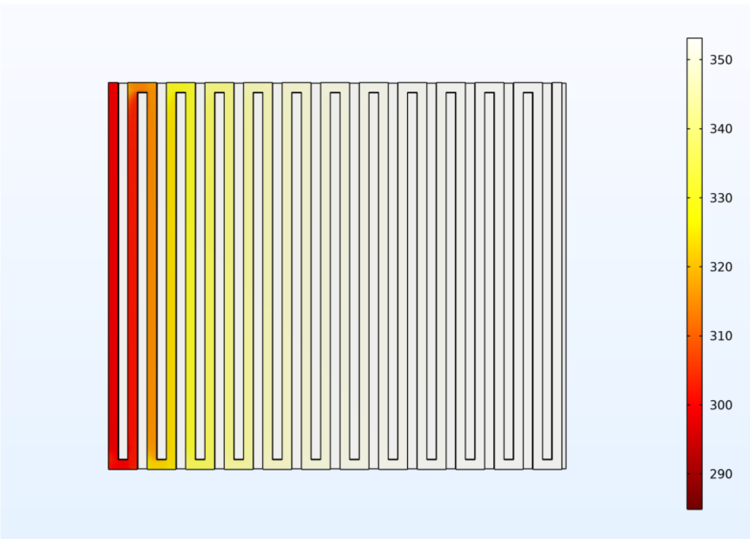

Figure 6 Cloud diagram of cooling temperature in rectangular channel with water as working medium

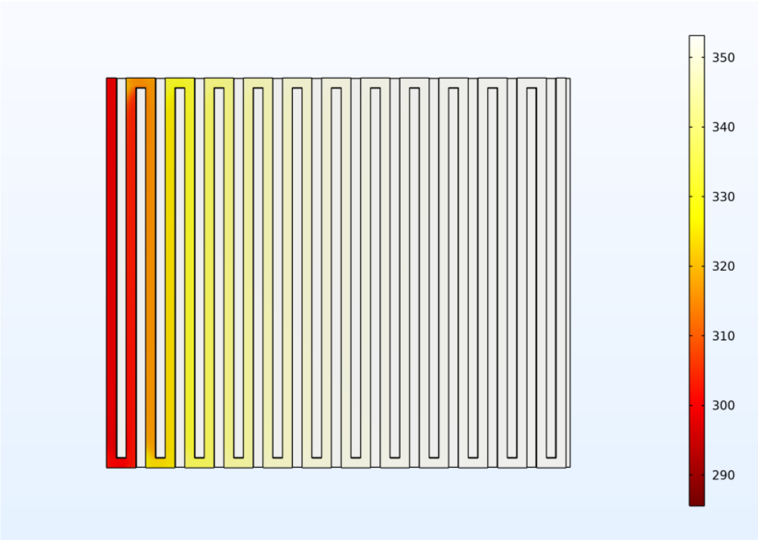

Figure 7 Cloud diagram of cooling temperature in rectangular channel with ethylene glycol coolant as working medium

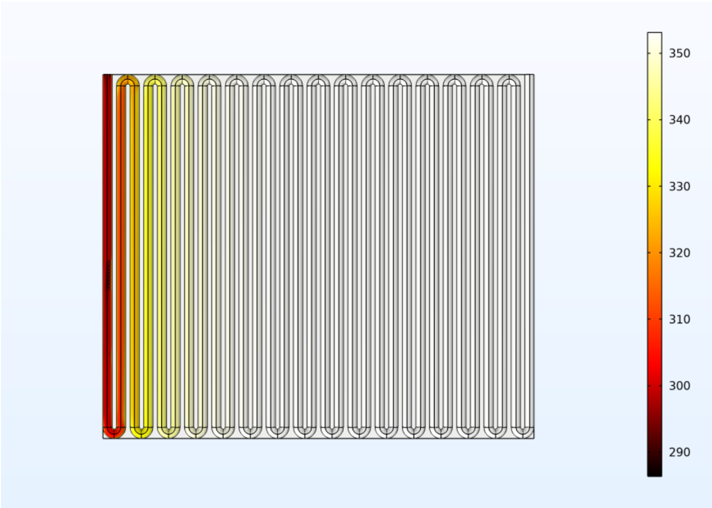

Figure 8 Cloud diagram of cooling temperature of semi cylindrical channel with water as working medium

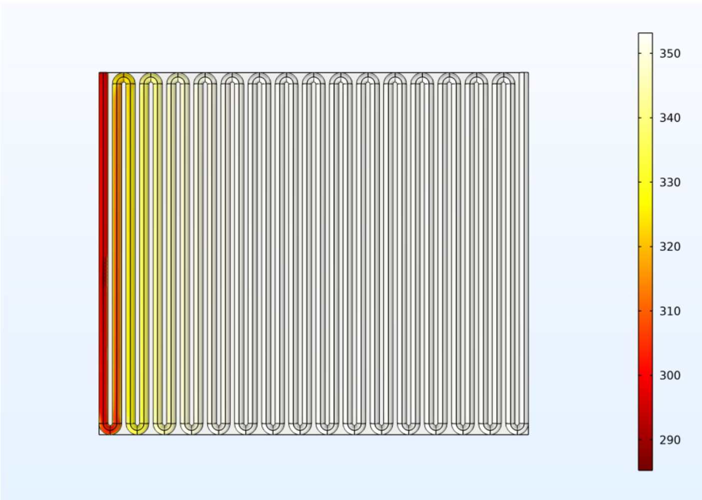

Figure 9 Cooling temperature nephogram of semi cylindrical channel with ethylene glycol coolant as working medium

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Similarly, according to the working conditions of two working fluids in semi cylindrical channel cooling (as shown in Figures 8 and 9), the cooling effect of using only water as coolant is worse than that of ethylene glycol coolant.

Excluding the different shapes of coolant flow channels, glycol coolant is a better working medium choice than water. In real life, the automobile coolant also contains antifreeze, pH regulator and additives, which can not only play a cooling role, but also ensure that the electrochemical corrosion of the electrolyte in the coolant to automobile parts is minimized and prolong the service life of automobile parts. The cooling liquid can not replace the glycol fuel cell. The experimental results show that the suitable working temperature of fuel cell stack is between 70°and 80°. Under the mutual cooperation and control of the water pump and the solenoid valve, the coolant flow increases with the rise of the fuel cell temperature, and the temperature of the fuel cell stack is always controlled within the appropriate temperature threshold. Similarly, for the power cells, motors and electronic control components in fuel cell vehicles, the flow of coolant should be controlled within a certain range to ensure its stable operation within the appropriate operating temperature threshold and provide safety guarantee for the normal driving of fuel cell vehicles.

2.3.2. Pipe cooling

For the cooling effect, ethylene glycol coolant is selected as the working medium. Through the analysis of data results, the following isotherms, velocity and pressure nephograms in rectangular channel cooling, semi cylindrical channel cooling and plane cooling are obtained.

As shown in figures 10 and 11, using the thermal light color legend, it can be concluded that under the conditions of the same working medium and the same cooling results, the cooling isotherm of the semi cylindrical channel is more uniform than that of the rectangular channel. Because the rectangular channel has a right angle, the coolant can not fully flow through the contact surface of the bend for cooling.

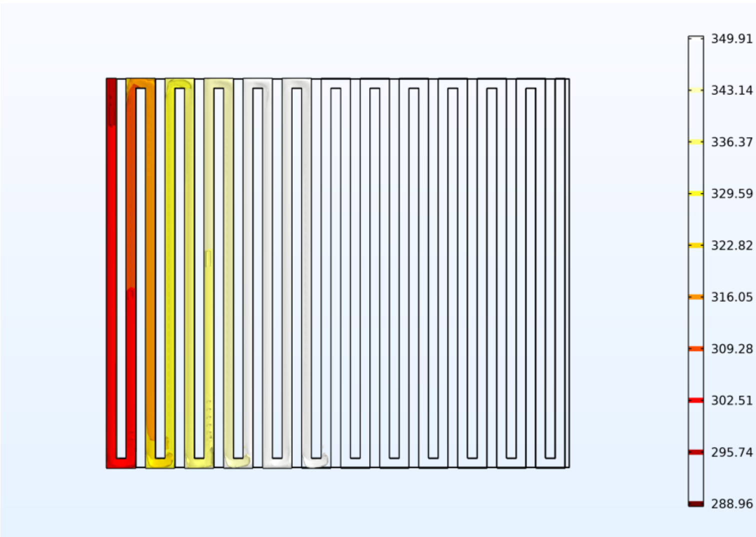

Figure 10 Cloud diagram of cooling isotherm in rectangular channel

As shown in figures 12 and 13, using the rainbow color legend, it can be seen intuitively that the semi cylindrical flow channel can lose less speed because of the smoother angle at the bend of the flow channel, so that the high-temperature coolant in the flow channel flows out faster and the low-temperature coolant flows in faster, which improves the heat dissipation cycle efficiency of the fuel cell plate and ensures the normal operation of the fuel cell stack.

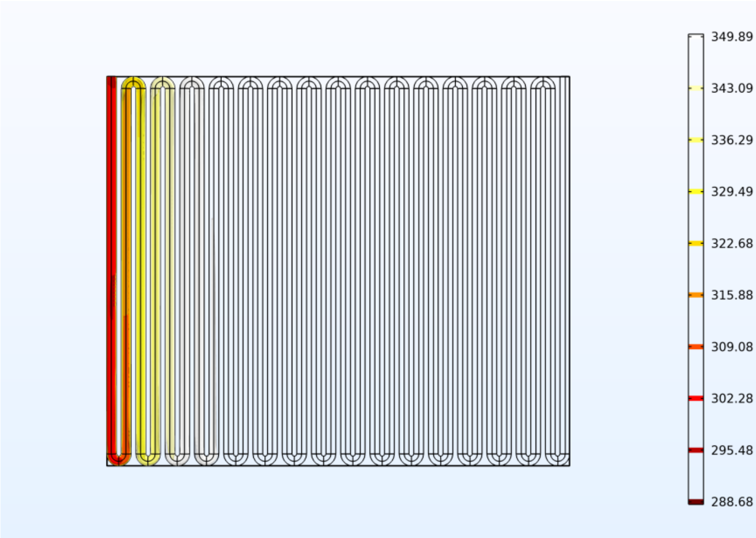

Figure 11 Half-cylindrical runner cooling isotherm cloud map

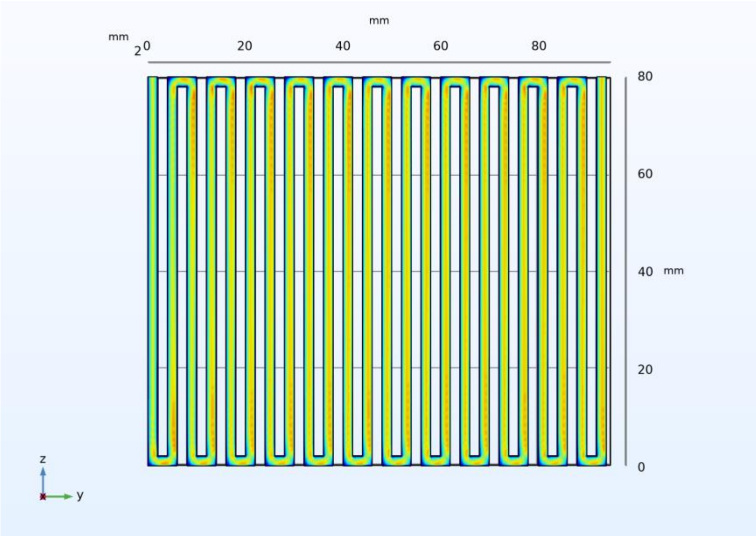

Figure 12 Nephogram of cooling rate in rectangular channel

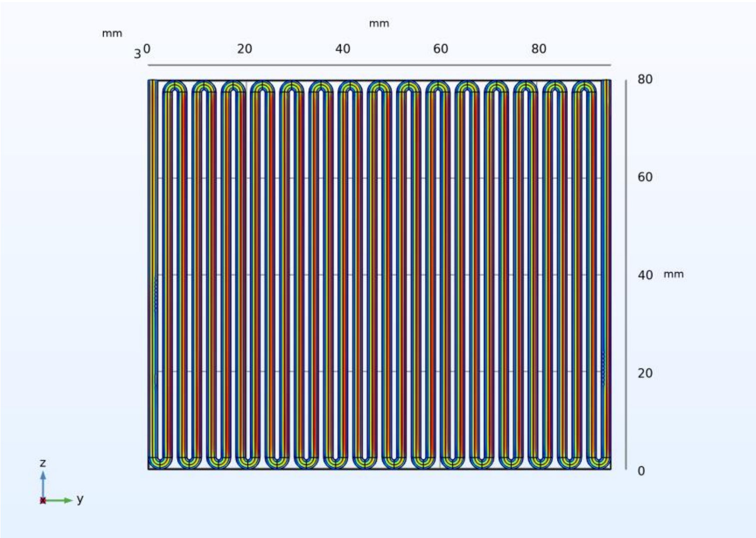

Figure 13 Nephogram of cooling rate of semi cylindrical runner

As shown in figures 14 and 15, using the rainbow color legend, it can be concluded that the pressure isolines in the rectangular channel cooling are mostly distributed at the bend, and only a few isolines are distributed in the straight pipe, while more pressure isolines in the semi cylindrical channel cooling are distributed in the straight pipe. Further, it can be deduced that the pressure at the bend of the rectangular channel is large, and the pressure at the bend of the semi cylindrical channel is small. The distribution of pressure isoline is closely related to the channel shape and coolant flow rate. Combined with the analysis of the above speed results, it is not difficult to see that the rectangular channel causes more loss of coolant speed and greater pressure at the bend joint, which is not conducive to the long-term use of coolant pipeline, and the service life of this type of channel shape will be greatly shortened.

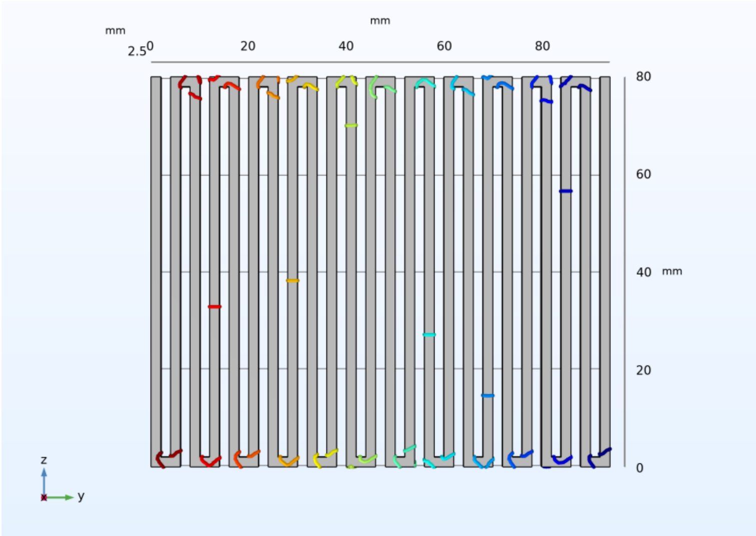

Figure 14 Cooling pressure nephogram of rectangular channel

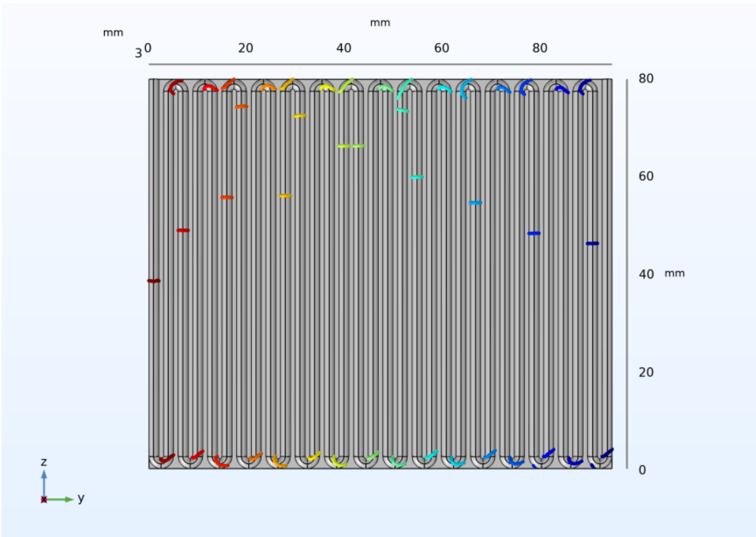

Figure 15 Nephogram of cooling pressure in semi cylindrical channel

As shown in figures 16 and 17, using the rainbow color legend, the steady-state study of glycol coolant flow is carried out when the heat source is stable at 80°. The glycol coolant in the semi cylindrical channel reaches 80°faster and absorbs heat faster, which has better cooling effect than the rectangular channel.

It can be seen that the maximum temperature of the cooling liquid passing through the rectangular or semi cylindrical channel 17 does not appear in the subsequent channel, that is, it can be seen that the temperature of the cooling liquid passing through the rectangular or semi cylindrical channel has not changed much. Based on this defect, the current cooling mode is further optimized. According to the size of fuel cell plate, multiple flow channels are arranged on one side to produce better cooling effect on the premise of constant coolant flow. In order to avoid the mutual influence of temperature between coolant channels, the inlet is adjacent to the inlet and the outlet is adjacent to the outlet.

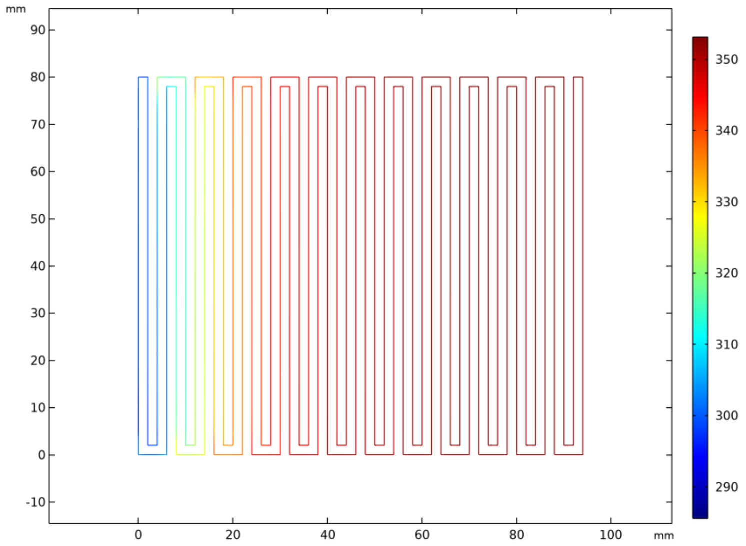

Figure 16 Two dimensional drawing of cooling temperature in rectangular channel

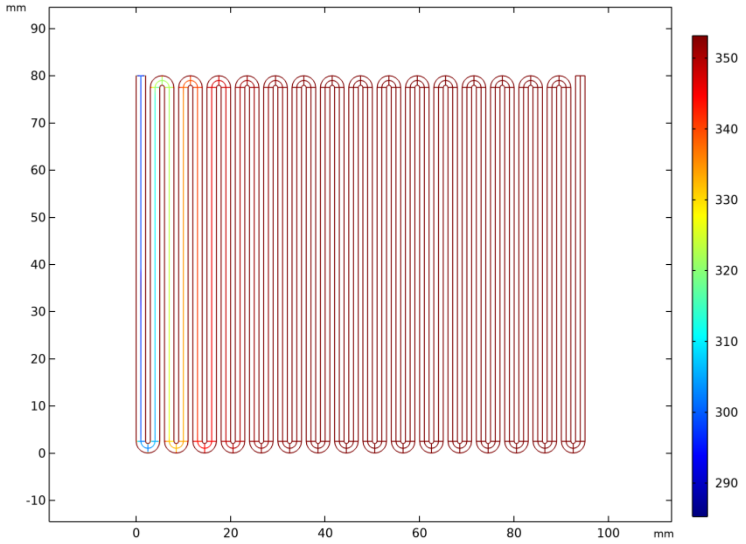

Figure 17 Two dimensional drawing of semi cylindrical runner temperature

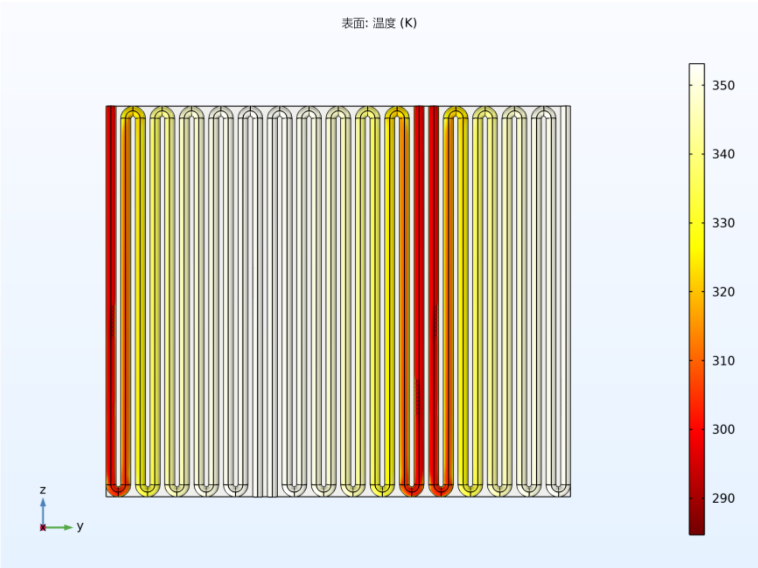

Figure 18 Semi cylindrical optimized runner temperature

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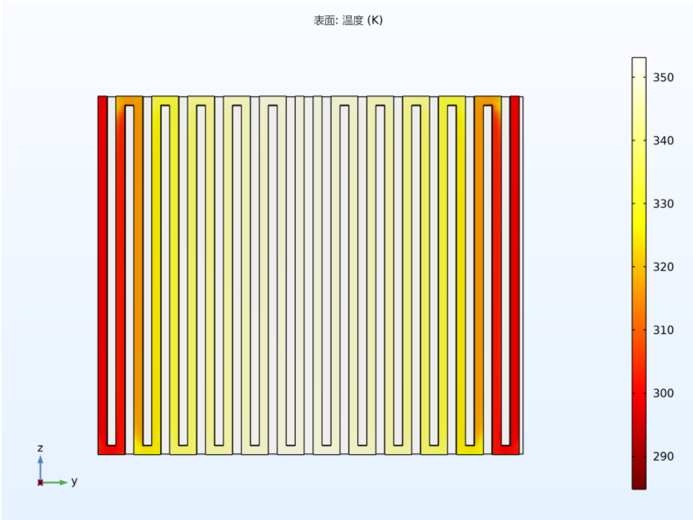

Figure 19 Semi cylindrical optimized runner temperature

To sum up, semi cylindrical channel is the better choice in terms of coolant flow uniformity, flow speed, pipe pressure and cooling speed. On the contrary, this type of coolant channel shape is not often found in practical application. Because of its precision processing technology, manufacturing technology and high production cost, it can not be widely used in all kinds of fuel cell stacks. Because of its own plane, the rectangular channel can cool the fuel cell plates on both sides at the same time, which simplifies the manufacturing process and reduces the production cost.

2.3.3. Plane cooling

The plane cooling will pave the pipeline into a flow channel with the size of 1:1 with the fuel cell plate. The upper left corner is the coolant inlet and the lower right corner is the coolant outlet, which greatly increases the contact area between the coolant and the fuel cell plate and greatly improves the cooling efficiency. However, due to the significant reduction of the coolant flow path, the contact time between the coolant and the fuel cell plate is shortened and the heat conduction time is reduced, which has a negative impact on the heat dissipation efficiency. Therefore, in the simulation, appropriately reduce the normal flow rate at the inlet of ethylene glycol coolant and simulate the water pump and solenoid valve to control the coolant flow, so as to make the simulation results more real and effective, which has reference value and significance. The plane cooling temperature, isotherm, velocity, pressure and flow direction are simulated as follows.

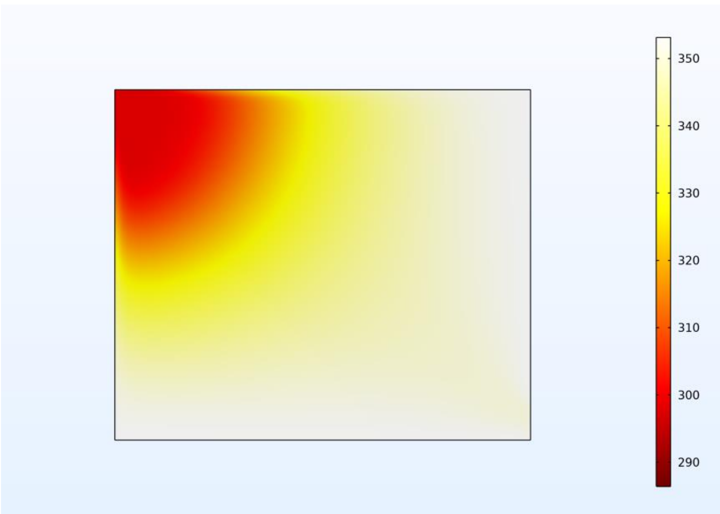

Figure 20 Plane cooling temperature nephogram

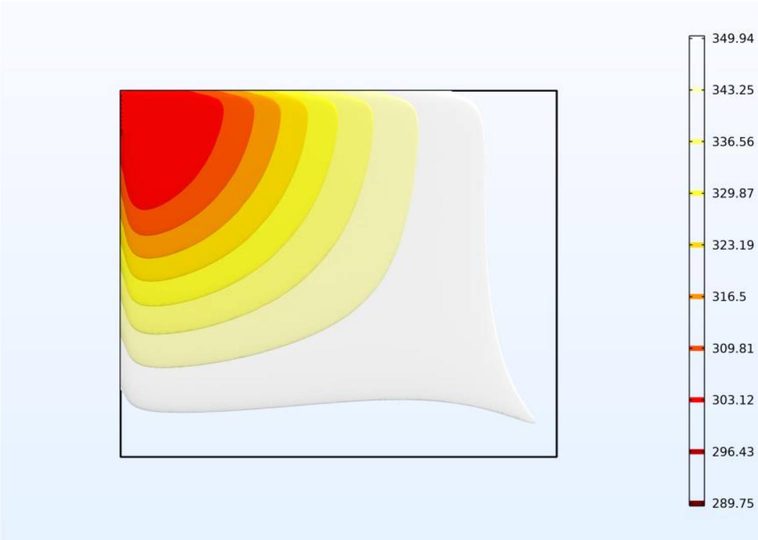

Figure 21 Cloud diagram of plane cooling isotherm

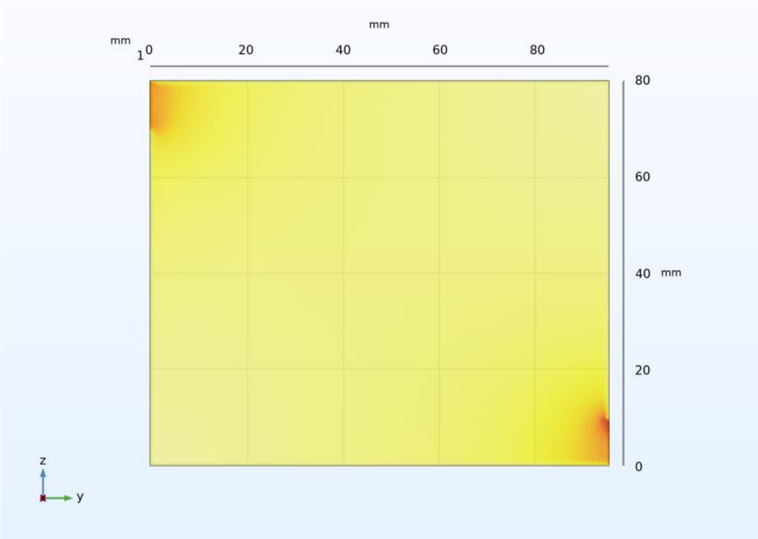

Figure 22 Plane coolant velocity nephogram

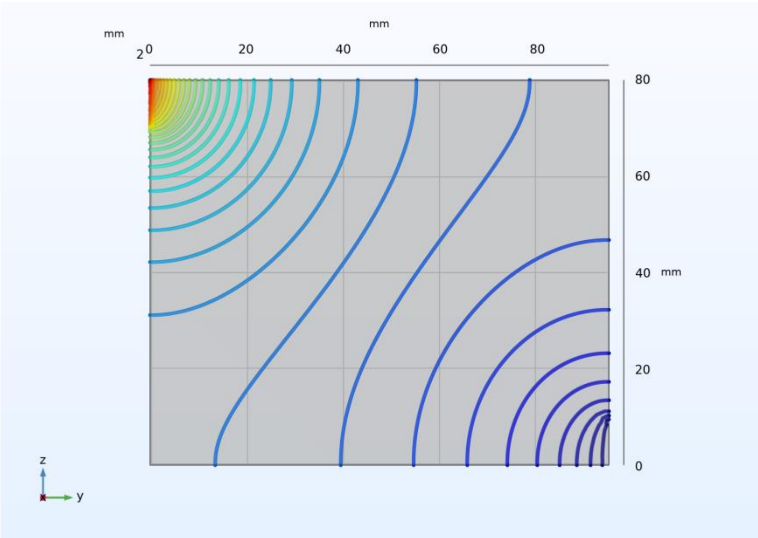

Figure 23 Plane cooling pressure nephogram

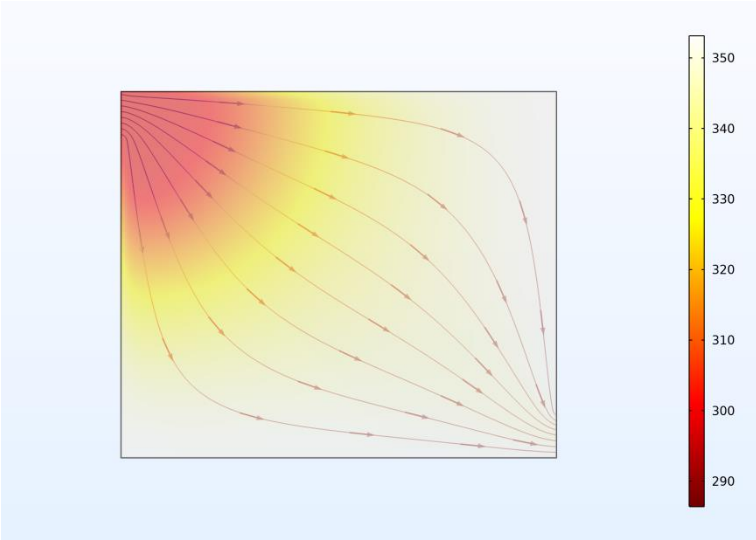

Figure 24 Plane coolant flow line

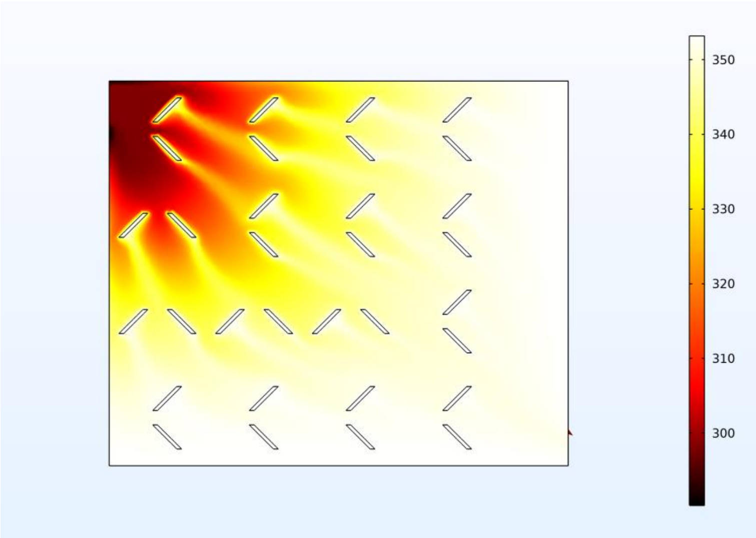

Figure 25 Cloud diagram of plane cooling temperature with fins

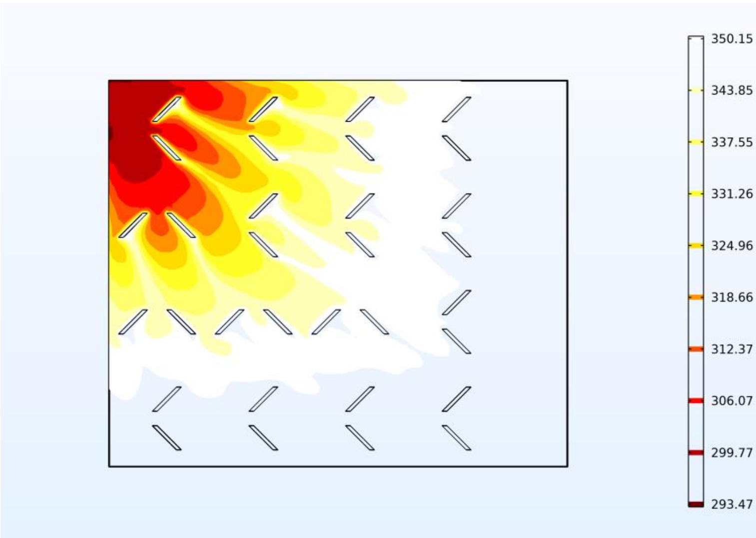

Figure 26 Cloud diagram of plane cooling isotherm with fins

In order to maximize the coolant flow through all edge positions, increase the contact time between the coolant and the fuel cell plate and improve the heat exchange efficiency, the interference flow fins are arranged in the plane flow channel according to the plane cooling flow line, so as to change the flow direction of the coolant, increase its flow distance and time, more fully contact with the fuel cell plate and improve the heat exchange efficiency. The fins are made of the same material as the fuel cell plate, so that the fins also have the function of heat conduction and indirectly increase the heat transfer area.

After 32 fins are arranged at a certain angle to the streamline, the coolant flow path is more uniform. Due to the influence of fins, the speed of coolant flow will slow down at the fins. At the same time, the pressure on the cooling channel with fins will be more uneven, which will shorten the service life of cooling flow to a certain extent. The design of fins will also increase the overall cost, and its manufacturing process is also difficult, but there is still room for further optimization of the design scheme. Combining the temperature nephogram (Fig. 18, 23) and isotherm nephogram (Fig. 19, 24), the plane with fins cools closer to the inlet, reaches the temperature peak earlier, and the cooling effect is better. As shown in Figure 30, after optimizing the size and number of fins, the plane cooling mode with fins has better cooling effect.

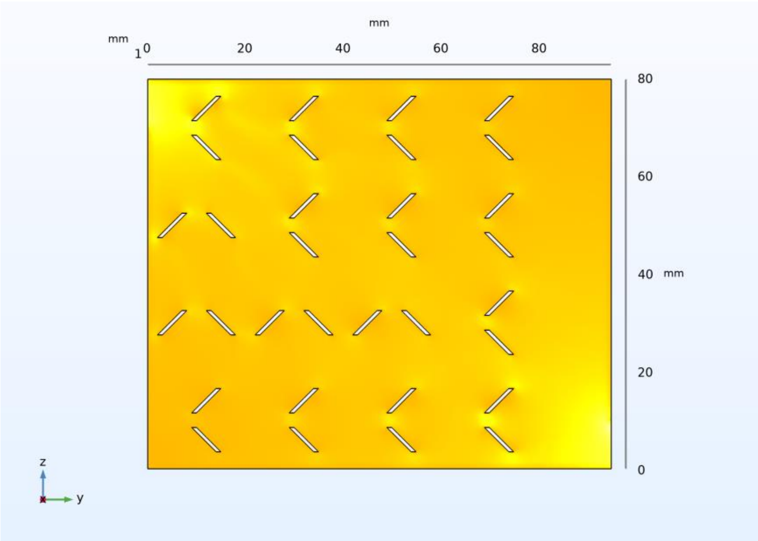

Figure 27 Cloud diagram of plane coolant velocity with fins

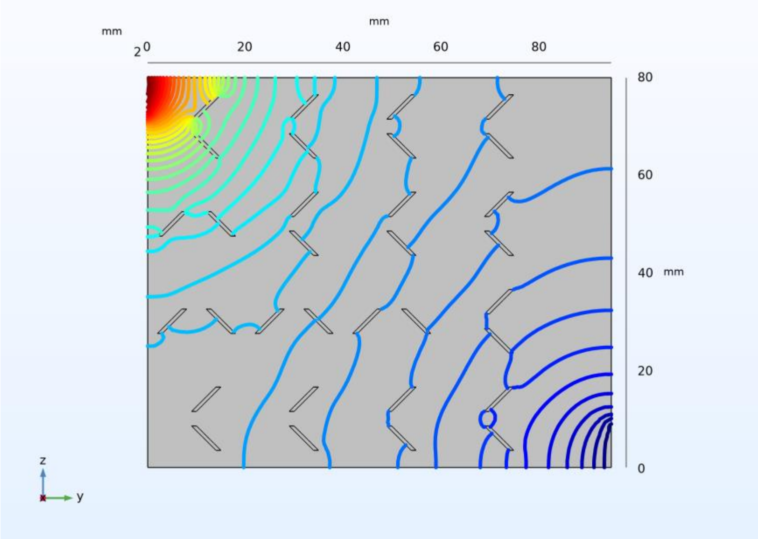

Figure 28 Nephogram of plane cooling pressure with fins

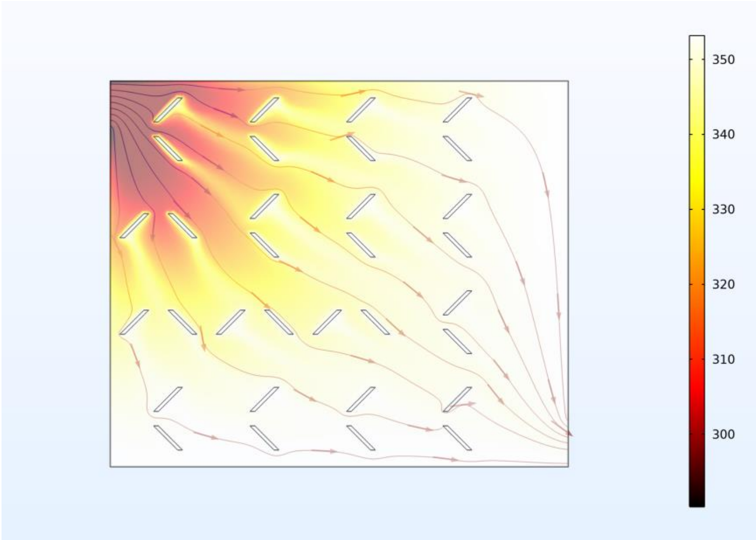

Figure 29 Planar coolant flow line with fins

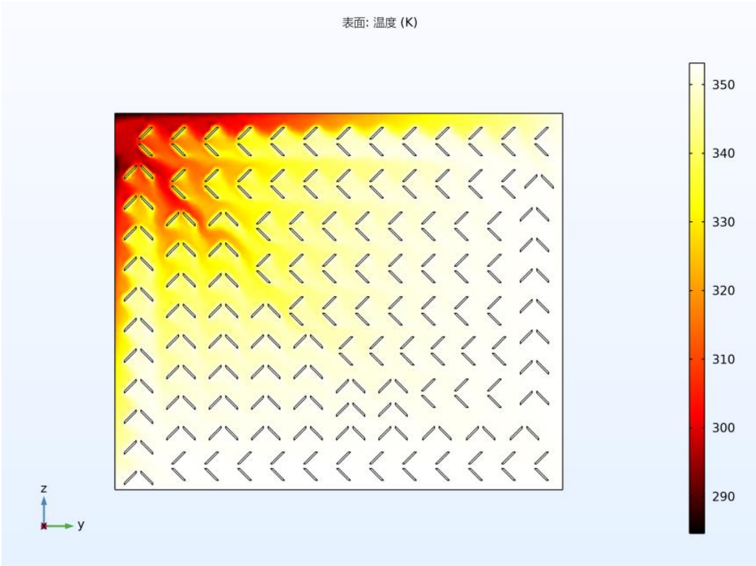

Figure 30 Optimized temperature of plane cooling with fins

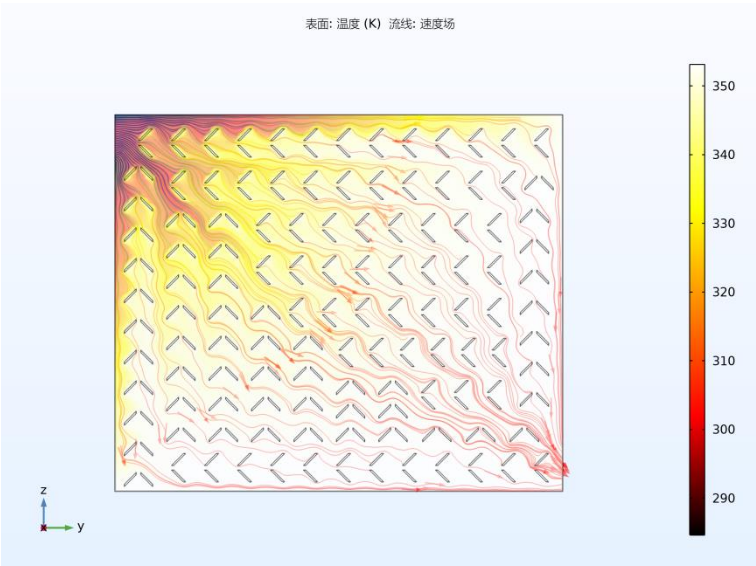

Figure 31 Optimized coolant flow line of plane cooling with fins

It can be seen that the optimized cooling effect is better, but the temperature cloud diagram shows that the cooling effect of the coolant decreases in the latter half of the flow. It is believed that through further research, better heat dissipation effect can be achieved and higher requirements can be met by adjusting the angle, position and quantity of fins.

3. Summary and Prospect

In short, this paper proposes a new concept of fuel cell hybrid cooling system for new energy vehicles, and constructs a comprehensive model. The model can capture a variety of important non ideal states, and the cooling mode is divided into pipe cooling and plane cooling. In the mode of pipe cooling, by comparing the cooling effect of the fuel cell of new energy vehicles when the cross-section of the channel in pipe cooling is rectangular and semi cylindrical, it is concluded that compared with the rectangular channel, the semi cylindrical channel can lose less speed because of its smoother angle at the bend of the channel, so that the high-temperature coolant in the channel flows out faster and the low-temperature coolant flows in faster, It can also improve the cooling cycle efficiency of fuel cell plate. For the plane cooling mode, the simulation and performance comparison between the ordinary plane heat exchange plate and the fin heat exchange plate are carried out. The research shows that the fin heat exchange plate changes the flow direction of the coolant, increases its flow distance and time, makes more full contact with the fuel cell plate, and improves the heat exchange efficiency. Therefore, the cooling system designed in this paper is a promising secondary component of waste heat recovery, which can significantly improve the heat conversion efficiency and take an important step in the development of environment-friendly energy conversion system.

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