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PIPE LINE GRAVITY HEAT PIPE HEAT TRANSFER NUMERICAL ANALYSIS RESEARCH

Abstract. *Gravity heat pipe is the most common type of heat pipe without core, it has the characteristics of simple structure, low cost, reliable work and high heat transfer efficiency. Waste heat recovery technology and comprehensive utilization of heat energy in various fields, the gravity heat pipe has reflected the unique superiority, according to the structure characteristics of the pipe line of gravity heat pipe, a mathematic model of the structure of the condenser. On the basis of mathematical model, through the preparation of the program C + + language, the numerical simulation study the communicating pipe type of gravity heat pipe heat transfer performance. A mathematical model is established according to the structural characteristics of the gravity heat pipe of the connected pipe row. Use FLUENT software for internal structure, to simulate the velocity vector according to the results of simulation analysis of pipeline of gravity heat pipe heat within the rationality of the steam and condensate return movement trend.*

Keywords **:** ***Gravity heat pipe*** **;** ***Pipe line of type*** **;** ***C++*** **;** ***Numerical simulation*** **;** ***FLUENT***

The introduction

Gravity heat pipe is the most common type of heat pipe without core, It has the characteristics of simple structure, low cost, reliable work and high heat transfer efficiency , as an efficient heat transfer element. Common waste heat recovery equipment include high temperature heat exchanger, heat storage heat exchanger, fin tube heat exchanger, fluidized bed heat exchanger, waste heat boiler and heat pipe heat exchanger [1-2].

The gravity heat pipe has shown its unique advantages in the technology of waste heat recovery and comprehensive utilization of heat energy in various industries. In 1916, Nusselt [3-4] proposed the vertical flat laminar flow membrane condensation theory. However, the Nusselt theory does not consider the momentum exchange and frictional stress between steam and liquid membrane. In 2004, Shi-mei sun [5-6] is based on the theory of enhanced heat transfer micro-layer evaporation. Inside the heat pipe to set shunt tube structure, and enhanced boiling heat transfer mechanism of this structure is studied based on the theoretical analysis of heat pipe internal boiling heat transfer model [7-8], and the correctness of the model is verified by experiment. At the same time, the finite difference method is used to calculate the energy control equation of the heat pipe, which is in good agreement with the experimental results [9-10]. Using the VOF model in FLUENT software, Asghar conducted numerical simulation of the flow field and temperature field inside the gravity heat pipe, and was verified by experiments. Zhangbo Ye against gravity heat pipe heat transfer heat transfer limits, there are some design three kinds of scheme under different forms of heat pipe, through carries on the numerical simulation, comparison of the heat pipe under different forms of pressure field, velocity field, temperature field and the distribution of phase volume fraction. Because there is some room for improvement in the structure of gravity heat pipe, a new type of structure is put forward in this paper. A mathematical model is established according to the structural characteristics of the gravity heat pipe of the connected pipe row. Based on this model, in order to more intuitive to observe the simulation results, at the same time by using FLUENT software for internal structure, to simulate the velocity vector according to the results of simulation analysis of pipe line of gravity heat pipe heat within the rationality of the steam and condensate return movement trend.

The analysis process

Connected pipe row gravity heat pipe structure

The gravity heat pipe of the tandem pipe is composed of 8 gravity heat pipes with parallel structure. The upper and lower pipes are connected respectively.

The average power output of the heating plate during normal operation of the heat pipe is 7.53kw. The charging rate is between 34% and 40% and the transmission power of the gravity heat pipe of the connected pipe row is about 0.323 kW, and the transmission power per unit area is about 2.679kW/m^2.

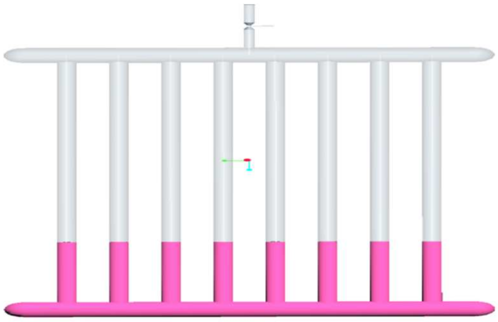

Figure 2-1Connected pipe row gravity heat pipe structure

Heat transfer can be divided into three processes: the membrane condensation process in the condensation stage, the boiling heat transfer process in the liquid pool, and the membrane evaporation process in the above part of the liquid pool. In this section, the membrane condensation theory of the condensing section is deduced.

The model of condensation section was established

According to the characteristics of the gravity heat pipe structure of the connected pipe row,as shown in figure 2-2, assumed under the working condition of the heat pipe heat transfer mass transfer, upper and lower communicating tubes, respectively, to keep the uniformity of heat transfer inside, and the structure size is symmetrical, so only need to consider when establishing mathematical model a can.

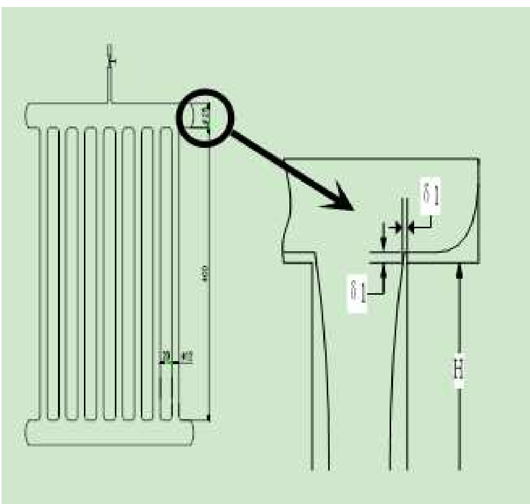

Figure 2-2 model simplification diagram

According to the structural characteristics of the gravity heat pipe of the connected pipe, at H on the top of the condensation section, the return velocity of the condensate is not zero, and the liquid film has a certain thickness.When the heating time t = 0, the thickness of liquid film δ = 0, When heating time t = t_1, $\delta=\delta_1$.

The model is simplified by analyzing one of the pipes and assuming that the thickness of the liquid film is continuously and uniformly changing, the thickness of the liquid film of the tube wall is equal to the thickness of the liquid film at the top of the condensing section. The mathematical model and parameter coordinates of the gravity heat pipe of the tandem pipe are established, as shown in Figure 2-3.

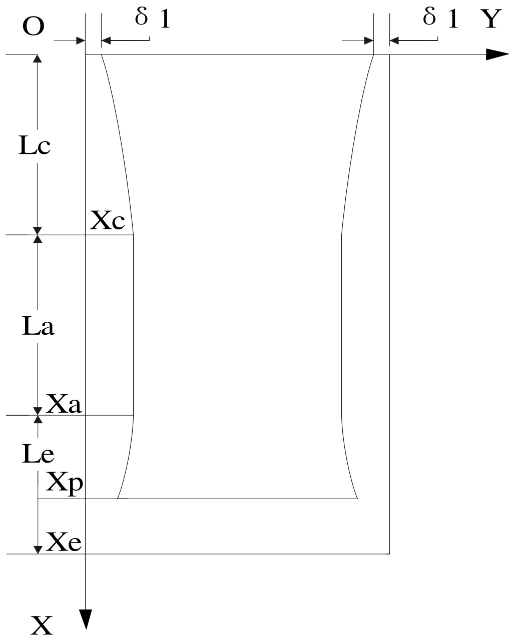

Figure 2-3 model of gravity heat pipe condensation section

C++ programming route

In the application of the above theoretical analysis, deduces the relation between the use of c + + language to write, the heat transfer model in Nusselt pure saturated steam laminar filmwise condensation theory, considering the influence of the gas-liquid interface shear stress, N – S equation and liquid membrane elements are applied to solve the physical quantity conservation equation and get the thickness of liquid film speed, temperature, distribution. In this program, set the various physical parameters is very physical, according to the iterative calculation for different saturation temperature, the saturation temperature physical parameters obtained by means of program automatic look-up table, the table without physical parameters will be calculated by the method of linear interpolation, this makes the calculation more accurate. In the calculation of liquid film thickness, discrete calculation method is adopted.

C++ programming framework

The concrete calculation is carried out in the following steps:

1. Given heat pipe length L, length of condensation Lc, inner diameter d, assumed saturation temperature Tsat parameters.
2. Calculated mean temperature t = Tsat+Twcc/2, the average temperature was used to check the physical parameters of gas and liquid, and the data not found in the table were obtained linearly according to the temperature range, and the A and C constants derived from the theory in the correction model were initialized.
3. The step length dz was defined, and the iterative precision e of saturation temperature was calculated.
4. The liquid film thickness of each micro-segment was calculated iteratively and its precision was set up.
5. Calculate the local heat transfer coefficient hx and the average heat transfer coefficient of the condensing section h.
6. Calculate the new saturation temperature, compare the saturation temperature with the assumed saturation temperature, if not, repeat steps 2 to 6 using the saturation temperature instead of the assumed saturation temperature.
7. If meet the accuracy requirement, output at the entrance of condenser, 0.05 m, 0.10 m, 0.15 m, 0.2 m, 0.25 m in, such as key points at the end of the condenser liquid film thickness, and shear force, the actual parameters such as saturation temperature and liquid membrane velocity.

Simulation results analysis

Liquid film thickness distribution

In the liquid rate was 35%, under the condition of constant heat flux, from numerical simulation. In the cooling section is at the top of the liquid membrane drop height is zero, the thickness of liquid film is, but is very small, 0.02 mm, in the condenser outlet the drop height is 250 mm in the liquid film thickness of 0.274 mm. Also can get from the table, the falling height of 0 ~ 50 mm section, liquid film thickness increases by 0.02 mm to 0.02 mm, in this phase the thickness of liquid film growth rate is large, this is because the high temperature steam cooled wall, temperature difference is big, and the contact area is large, steam condensation quickly, in the liquid film under the action of its own gravity, drops rapidly. Between 50 mm to 250 mm, the thickness of liquid film growth rate decreases, it is because at this stage mainly steam and liquid membrane surface contact, rather than the cold wall, smaller temperature difference, make the liquid film cooling rate is smaller, which leads to the thickness of liquid film growth rate gradually decreases.

Coefficient of condensation heat transfer

Under the condition of different filling rate and constant heat flux, the condensation heat transfer coefficient changes with the falling height of the liquid film.

Above we can see that with the increase of liquid membrane drop height in the condenser, the condensation heat transfer coefficient is more and more small, this is because as the falling liquid film, liquid film thickness increasing, the thermal resistance increase, make tube steam and condensate wall can not be very good heat transfer. At the drop height of 0~ 50mm, the liquid film was just formed at this stage, and the liquid film decreased rapidly and the coagulation efficiency was also high, so the rate of reduction of the condensation heat transfer coefficient changed greatly. After 50 mm, the reduction rate of condensation heat transfer coefficient gradually decreases and becomes flat, because the growth rate of liquid film thickness tends to decrease.

It can be concluded from the figure that under the same heating condition, the condensation heat transfer coefficient of different filling rate is different. Three charging rate of the condensation heat transfer coefficient of the overall trend is down, but at the top of the condenser liquid rate 45% of the heat transfer effect is better than the other two charging rate lower operating mode, condensation heat transfer coefficient of 7423 W/m^2. The K, the heat transfer effect is best, in the condenser outlet charging rate was 25% and 35% of the working conditions are better heat transfer effect, only the charging rate of 45% of the heat transfer effect is a bit poor working conditions. Because of the excess liquid filling rate, a large amount of liquid film formed at the outlet of the condensing section leads to the increase of thermal resistance, so a good heat transfer cannot be achieved. Because of the high filling rate, the thermal resistance is increased and the heat exchange effect is reduced. Therefore, the optimal liquid filling rate of the gravity heat pipe with continuous pipe row in this paper is 35%.

FLUENT simulation

The physical model

New pipe line of gravity heat pipe heat is composed of 8 parallel structure with the gravity heat pipe, up and down, respectively, by connecting pipe connection, due to the rules of the entire model structure is symmetrical, so using two-dimensional model to calculate.

As shown in figure 4-1, in the middle of the eight root heat pipe heat exchanger is 12 mm in diameter, ignore wall thickness in this calculation, the use of grid for quadrilateral mesh, in order to ensure the accuracy of calculation, and boundary layer near the wall of the encryption.

The boundary conditions

Water is used in the gravity heat pipe of the continuous pipe row. In the analysis, some reasonable simplifying assumptions are made. In this simulation, the height of the heating section is set to 150 mm and the condensing section is 250 mm. In the condition setting, the filling height is 125 mm, which is equivalent to the filling rate of 35.8%. In the boundary condition setting, the heat flux of the heat pipe in the heating section is set to 20 kW/m^2. The structural parameters of the heat pipe model are shown in table 4-1.

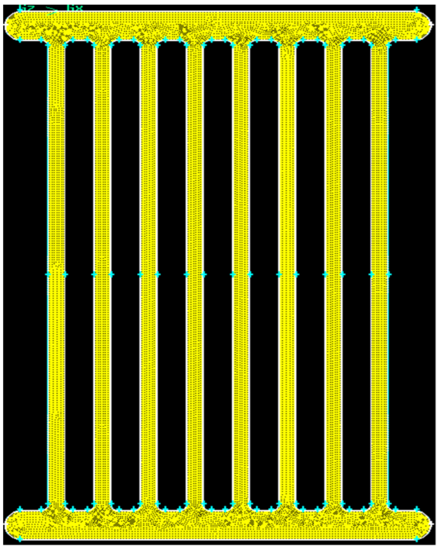

Figure 4-1 model establishment

Because of negative pressure inside the heat pipe, setting the boiling point of 353. 15 K, but in the FLUENT software to simulate the multiphase flow and not directly to the calculation of mass and energy transfer, so need through user-defined functions to implement alternate with of transportation of the mass and energy, so as to realize evaporation condensation heat transfer process. UDF customization through FLUENT: when the liquid phase temperature is greater than 353.15k, evaporation begins. When the gas phase temperature is less than 353.15k, condensation begins. Set the solver, selection pressure solver, transient simulation at the same time, considering the influence of gravity acceleration, activation energy equation, set the liquid phase, steam for the second phase, the diameter of the bubble was 0.0002 m, and the iteration time step length is 0.0001 s.

Results analysis

The velocity vector graphs of different positions are simulated, as shown in figure 4-2:

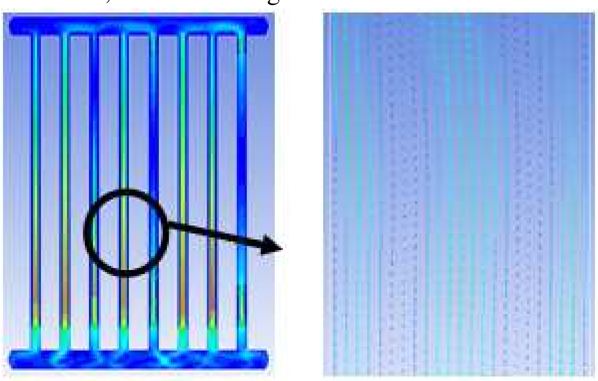

Figure 4-2 velocity cloud diagram and vector diagram

It can be seen from the velocity vector diagram that the maximum velocity of steam reaches 0.511 m/s, and the minimum velocity reaches 10-5, which can be considered as static.

Conclusion

1. Considering gas-liquid interface shear stress influence on condensation heat transfer, established the mathematical model of this structure condenser of the saturated temperature physical parameters of the model were set according to the saturation temperature obtained by iteration.
2. Through numerical calculation, at the top of the condenser liquid film thickness of 0.02 mm, thickness of liquid film on the condenser outlet is 0.274 mm, the thickness of liquid film growth rate increased with the increase of liquid membrane drop height reduced, and the thickness of liquid film growth trend and the trend of Nusselt theoretical calculation value is the same.
3. Under different filling rates, through the study on the local heat transfer coefficient of the condensing section, it is concluded that the optimal liquid filling rate of the gravity heat pipe with continuous pipe row is 35%.
4. By FLUENT software to simulate the pipe line of gravity heat pipe heat pipe, according to the velocity vector diagram in heat pipe work, maximum speed in the cooling and heat insulation, and the maximum speed of 0.511 m/s, the condensation and adiabatic trend of gas liquid two phase velocity vector is in line with the gravity heat pipe in the trend of the velocity vector.

The innovation points

The structural characteristics of the gravity heat pipe with continuous pipe row are as follows:

5. In the case of heat pipe heat transfer, the upper and lower connecting pipes maintain the uniformity of heat transfer in the pipe respectively;
6. The lower connecting pipe can keep the liquid level balance in each pipe. When the condensate returns, the lower connecting pipe distributes the returned liquid evenly to each heat pipe;
7. To prevent the occurrence of the limit, ensure the continuity of the normal operation of the heat pipe after the connection of the pipe, and greatly improve the working efficiency.
8. Compared with the ordinary gravity heat pipe, the gravity heat pipe with continuous pipe is more convenient in discharging non-condensable gas and installing and distributing, which greatly improves the efficiency.

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ЧИСЕЛЬНИЙ МЕТОД ДОСЛІДЖЕННЯ ЦИРКУЛЯЦІЇ ТЕПЛА В ТЕПЛОВИХ ТРУБАХ З ВИКОРИСТАННЯМ ГРАВІТАЦІЇ

Анотація. *Гравітаційна теплова труба є найпоширенішим типом теплових труб без сердечника, має характеристики простої конструкції, низької вартості, надійної роботи та високої ефективності теплопередачі. Технологія вилучення відпрацьованого тепла та повна утилізація теплової енергії у різних галузях, гравітаційна теплова труба відображає унікальну перевагу, відповідно до структурних характеристик трубної лінії гравітаційної теплової труби, математичної моделі структури конденсатора. На підставі математичної моделі, шляхом підготовки програми мовою C++, чисельне моделювання вивчає характеристику передачі теплотворної здатності теплових трубок через контактну трубку. Математична модель встановлюється відповідно до структурних характеристик теплової трубки підключеного трубопроводу. Використовується програма FLUENT для внутрішньої структури, щоб імітувати вектор швидкості відповідно до результатів симуляційного аналізу теплоти трубопроводу в межах раціональності закономірностей пари та повернення конденсату.*

Keywords **:** ***Трубопровідна труба; Трубопровід типу; C ++; Чисельне моделювання; FLUENT***

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