Simulation on Positive Temperature Coefficient Heat Ex-changer in Electric Vehicle

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ABSTRACT
Different from the conventional vehicle, there is no low quality heat to be used in the electric vehicle (EV); therefore, additional high efficient heating system is essential for EV. Positive temperature coefficient (PTC) water heater has been widely used as one of the steadiest heating methods. This paper analyzed the performance of series of designed structures by numerical simulation, capacity at different temperature, the heat resistance, flow field and temperature field of flow were obtained and an optimization direction was proposed.

INTRODUCTION

Traditional vehicle use the waste heat for heating in winter, but the pure electric vehicle don’t have engine, so there is no waste heat. PTC is a useful solution and widely used in the pure electric vehicle. Heywang-Jonker model, which is proposed by Heywang[1] and developed by Jonker[2] is widely used microcosmic model; D. Y. Wang and LENG Sen-Lin [3] have done research on the positive temperature coefficient thermistor, both the structure and the characteristics. This paper interacts with the application, research on the heater’s structure, through the CFD simulation, research on different rate of flow, its flow
characteristics and temperature feature, and propose optimization method, points out an ideal for the PTC heater’s structure design.

MODEL SET UP

This paper focuses on a PTC water heating device for the electric vehicle heating supply in winter, the model using the recycle model, including the PTC heating device, hot water heating recycle system, and the fluid reservoir, and add the movement source in the fluid reservoir model instead of the pump. The overside fluid reservoir will prolong the heating time of the whole recycle, and influence the heating efficiency, so a reasonable fluid reservoir is needed. Here we choose the fluid reservoir volume is 2L. The temperature of heating recycle varies from 0℃~60℃, the PTC is made by ceramic plate, whose working curie temperature is 200℃, the liquid in the device is water and glycol which are mixed 1:1 by volume.

![Figure 1. PTC heating recycle diagrammatic sketch.](image)

From Fig1 we can see, the antifreeze fluid flow to the PTC heater by the pressure of pump, heating the antifreeze fluid to a high temperature, then flow to heater (warm air core). If the antifreeze fluid temperature doesn’t achieve to the setting temperature, the recycle will go on until the antifreeze fluid achieve the aim temperature. Then the air door open, heating change, warm up the cold air to hot air. In this paper we simplify the heater and the pump as the fluid reservoir added the movement source model.

SIMULATION

This paper uses the widely used CFD simulation software STAR-CCM+ for simulation. In the process, we use the Navier-Stokes equation set, which is not
only suit for turbulence process in steady state model, but also suit for the transient state. The control equation sets are as follows in equation 1-2:

\[
\frac{\partial u_i}{\partial x_i} + \frac{1}{\rho} \frac{\partial P}{\partial x_j} = \nu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - u_i u_j
\]

ui, uj—Mean velocity component, i,j=1,2,3;

xi, xj—Coordinate component, i,j=1,2,3

P—Mean pressure of fluid, unit Pa

\nu—Coefficient of kinematic viscosity of fluid

\rho—fluid density

uiu_j—The unknown Reynolds stress component

Turbulence model use the standard \( K-\varepsilon \) model. As below:

\[
\rho \frac{dk}{dt} = \frac{\partial}{\partial x_i} \left[ (\mu + \frac{\mu_T}{\sigma_k}) \frac{\partial K}{\partial x_i} \right] + G_K + G_b - \rho \varepsilon - Y_u
\]

\( \mu_T \)—Turbulence dynamic viscosity

\( \sigma_k \)—k’s prandtl constant

\( G_K \)—The turbulent kinetic energy produced by a laminar velocity gradient

\( G_b \)—The turbulent kinetic energy produced by buoyancy

\( Y_u \)—the fluctuations by turbulent transitions in the compressible process

Grid Meshing

For the PTC heater simulation, in catia flow area build the 3D model, which can divide into three parts, duct, fluid reservoir and the PTC heater. From Fig. 2, we can see it’s a whole recycle. In the STAR-CCM+, Import the model to part mode, use the trimmer grid for generating mesh, and refine the grid of the narrow flow road of the PTC heater, the ducts and the fluid reservoir needn’t refine as they are not the main analysis area. The total mesh number is 1,050,000.

Figure 2. The recycle model grid.
Boundary Condition

In the STAR-CCM+ software, use the 3D unsteady model, add the moment source as the power source so that the pump is omitted. The model parameters and the boundary conditions are as table 1.

| Boundary parameter                  | value       |
|-------------------------------------|-------------|
| density (kg/m^3)                    | 1073.5      |
| Flow rate (L/min)                   | 6, 8, 10, 12|
| Basis of reference Temperature (℃) | 0           |
| dynamic viscosity (Pa*s)            | 0.00809     |
| PTC curie temperature (℃)          | 210         |
| Volume of fluid reservoir (L)       | 2           |
| specific heat capacity (J/Kg*K)     | 3100        |

In the transient state, Iteration time the shorter, calculate precision the higher, but that will result in large simulation mission and a long working time. So it is necessary to set a reasonable time step to make sure the quick calculation and convergence result. In STAR-CCM+, the iteration time less than half of the analysis area can meet the requirement. For the precision, this paper use 1/8 time of the liquid flow through the heater as the time step. After calculation, the residual curve converges to 10-5, the pressure drop of the heater tends to be stable, the flow parameters are consistent.

Simulation and Analysis of Working Conditions

After set the boundary conditions then start the simulation, in the STAR-CCM+, we can not only finish the grid mesh and the simulation calculation, but also the post processing function. By setting up monitoring points, monitoring planes, etc. in the derivative parts to monitor the objects, monitor the pressure drop of the PTC heater. Furthermore, the STAR-CCM+ can supply the monitor report. This simulation can supply the temperature chart of the inlet and outlet at different flow volume as time pass by. The simulation is a whole recycle process, as time increasing, the inlet and outlet temperature is increasing to the aim temperature (65℃).

Figure 3. Power-Temperature at different flow rate.
From the fig.3, we can see that during the heating process, the mixture liquid in the initial condition at the flow rate is 12l/min needs the maximum operating power, as the flow rate decrease, the operating power decrease. From 10 to 20℃, the operating power is increasing, and reach the peak point. Then the power gradually decrease as the temperature of the heater outlet increase. The operating power at the flow rate of 10L/min exceeds other working condition is the maximum from the peak point and keep the situation to the aim temperature. While the operating power at 6L/min is minimum, which is only 70% of the maximum. This is because in the initial condition, large flow rate can make the liquid temperature per unit rises less, greater heat transfer temperature difference to make the heating power is larger. But as the outlet temperature is rising up, at the maximum flow rate (12L/min), the mix liquid flows too fast, the inside temperature gradient is large, so the near-wall hot liquid can’t transfer the heat to the inside liquid, that will cause the operating energy decrease. The inside temperature gradient of other three condition is better.

Flow Field Distribution

For the PTC heater, the static pressure loss is one of the main inspections during the flow process. The fig.4 lays out the static pressure loss of different flow rate.

From the fig.4, we can see that the flow rate increasing, static pressure loss is increasing. The static pressure loss is 220 Pa at 6L/min, while static pressure loss is 778Pa at 12L/min. The energy loss equation is 3-5:

\[ h_w = \Sigma h_f + \Sigma h_j \]  

\( h_f \)—friction head loss, \( h_j \)—local resistance loss

\[ h_f = \frac{1}{2g} \frac{\nu^2}{D} \]  

\[ h_j = \zeta \frac{\nu^2}{2g} \]
λ — Coefficient of friction head loss, a dimensionless factor
l — pipe length (m)
D — Equivalent diameter of non circular pipe (m)
v — flow velocity of the liquid (m/s)
ξ — Coefficient of local resistance loss, a dimensionless factor

From the equation 3~5, we can have the conclusion, at the same shape, the velocity increases, the friction head loss and local resistance loss increase too, and they are proportional to the square of the velocity. That will result the state pressure loss more and more while increasing the flow rate. Fig.2, section A-A is in the middle of the PTC heater, whose influence of local turbulence by inlet and outlet is little and more stable, is suit for analysing the flow field distribution of the PTC heater. Fig.5~12 show the temperature and flow field velocity distribution at different flow rate.

Figure 5. Temperature distribution at 6L/min.  Figure 6. Temperature distribution at 8L/min.
Figure 7. Temperature distribution at 10L/min.  Figure 8. Temperature distribution at 12L/min.
Figure 5-Figure 8. Temperature distribution.

Figure 9. Velocity distribution at 6L/min.  Figure 10. Velocity distribution at 8L/min.
From the Figs.5~12 the temperature distribution and velocity distribution are all limited by volume. At the small flow rate, the situation is worse, temperature distribution is large, and the high temperature area has the low velocity. The low temperature area has the higher velocity. The flow rate increasing, the temperature and flow rate velocity gradient decrease, and the field are more homogeneity. At the flow rate of 10/min, the temperature and flow rate velocity field is optimum. Keep on increasing the flow rate will get worse. Compared by figs. 6~7, and figs. 11~12, when the flow rate at 12L/min, the temperature and velocity field will get worse, which is accordance with Fig.3. From Fig.9~Fig.12, we can see even at the best condition 10L/min, there are flow blind points in the narrow area of the heater. This is because of the large local resistance.

CONCLUSIONS

We can have the conclusion as below:
1. The pressure loss of the PTC heater inlet and outlet is directly proportion to the flow rate. 6L/min working condition is the minimum, and the 12L/min is the maximum. But it is in acceptable range.
2. Consideration from the heating power, the maximum and minimum flow rate are not the optimize choice. Overall condition, the 10L/min working condition is reasonable.
3. The flow rate in the middle channel is higher than the sides. That is because the side’s local pressure loss is higher than the middle channel. Add the flow rate of the sides’ within the reasonable pressure loss of the inlet and outlet is a way to reduce the pressure loss, e.g. add flow disturbance apparatus. While the flow blind points can be improved by change the shape or enlarge the section of the area.

REFERENCES

1. G. Goodman: 'Electrical conduction anomaly in samarium doped barium titanate', J. Am. Ceram. Soc., 1963, 46(1), 48-54.
2. W. Heywang: 'Resistivity anomaly in doped barium titanate', J. Am. Ceram. Soc., 1964, 47(10), 484-490.
3. D. Y. Wang and K. Umeya: 'Electrical properties of PTCR barium titanate', J. Am. Ceram. Soc., 1990, 73(3), 669-677.