Research on Structural Optimization of Spiral Array Heat Exchanger Based on Exhaust Heat Recovery

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Abstract. With the development and advancement of technology, modern industry has made rapid progress in improving the combustion performance of automobile exhaust heat in improving the combustion performance of automobile engines and reducing harmful emissions of automobile engines. This technology can not only improve the energy utilization of vehicle fuels. Efficiency can also reduce environmental pollution. The spiral array heat exchanger is an important equipment for waste heat recovery of automobile exhaust gas, which can fully recycle this waste heat energy. Therefore, this paper studies the structure optimization of spiral array heat exchangers, and plays an important role in the recovery of exhaust gas heat recovery, optimization of structure and enhancement of its comprehensive heat transfer performance. It improves fuel economy, saves energy and protects the environment. Great significance.

1. Introduction
The heat exchanger is the core of waste heat recovery. The key factor of low recovery rate of vehicle exhaust heat is the low heat exchange capacity of the heat exchanger. Optimizing the structure of the heat exchanger is the key to improve the recovery rate of waste heat. The rotary array heat exchanger is a new type of high efficiency heat exchanger developed on the basis of the traditional tubular heat exchanger. It is widely used in refrigeration air conditioners, heat pumps and waste heat due to its excellent structural characteristics and efficient heat transfer efficiency. Recycling and other systems.

With the rapid development of China's economy, the number of cars has exceeded 250 million, and the number of engines is huge, causing a sharp increase in oil consumption. Due to the limited amount of fossil energy, how to improve the energy efficiency of automobile engines has attracted widespread attention. Studies have shown that the energy efficiency of automobile engines is generally low, and only about one-third of the chemical energy released by engine fuel is effectively utilized. Most of the energy is lost or discharged into the atmosphere as waste heat, which causes great energy. The waste also has a negative impact on the environment. If the waste heat in the automobile exhaust gas can be effectively utilized, this will be an effective way to reduce the energy consumption of the automobile and improve the energy utilization efficiency of the automobile, especially the optimization of the structure of the spiral array heat exchanger, which is also the focus of the study [1].

2. Tail gas waste heat recovery technology
The exhaust heat recovery technology of automobile engine exhaust gas is a means for recycling the heat contained in the engine exhaust gas through waste heat recovery equipment, turning it into a
usable energy source, and realizing turning waste into treasure. This technology is one of the most effective and direct ways to improve energy efficiency, reduce production costs, and protect the environment [2].

According to the current displacement and fuel of different types of automobile engines, the exhaust temperature of the automobile is different, generally 400-600℃, and this part of the heat in the exhaust gas has great utility value. At present, there are many kinds of exhaust heat recovery technologies for automobiles, among which the widely used technologies include cabin heating, refrigeration, power generation, heating diet and hot showers. However, these technologies are only limited to improving the riding environment and have higher requirements for models. If the exhaust gas waste heat recovery technology can be applied to improve the combustion performance of automobile engines and reduce the harmful emissions of automobile engines, then this technology can not only improve the energy utilization efficiency of vehicle fuels, but also reduce environmental pollution, so the spiral array heat exchanger The optimization of the structure is the optimal technique. But at present, the technology still has certain advantages and disadvantages [3].

2.1. The main advantages are as follows
(1) Spiral coil tube can resist thermal strain and mechanical vibration based on its own special structure; (2) Perforated plate and perforated tube are provided between the tube shell, which has certain noise elimination effect; (3) Simple manufacturing and low cost.

2.2. The main disadvantages are as follows
(1) Waste space: When processing the spiral coil, in order to avoid local deformation of the coil, the straight tube with outer diameter 20mm and wall thickness 2mm should be at least 140mm when the spiral tube is spirally wound on the rounding machine, otherwise the coil is easy. Damage, reducing its shock resistance and temperature resistance. Therefore, when the coil is arranged in the heat exchanger, the volume of the outer casing also increases, and many spaces in the middle cannot be utilized; (2) the heat exchange efficiency is not high: the coil type exhaust heat exchanger relies on increasing the volume of the coil to satisfy the change The heat is wasted, but the space in the middle of the heat exchanger is wasted, and the heat exchange per unit volume is not high. When used on a vehicle in a cold area, a coil of 15 m length is required. (3) Large water resistance: Due to the poor heat exchange effect of the coil, a long spiral coil is required to meet the heat requirement. When the coolant flows in a plurality of coiled coils, the resistance loss and local resistance along the path the loss is large [4].

Figure 1. Research on Automotive Heat Exchanger System

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3. Improvement scheme of spiral array heat exchanger structure

The coil-type exhaust gas spiral pitch and the heat exchange area of the coil have a great influence on the heat transfer performance. When the coil area is constant, the increase of the helical pitch can increase the wall heat transfer coefficient; when the coil occupies the same space, the spiral pitch increases, the coil length decreases, and the heat exchange amount decreases; In terms of water flow resistance, the water resistance of the coiled-type exhaust gas heat exchanger is relatively high and is basically linear with the number of coils; the spiral pitch has little effect on the exhaust pressure loss, and the exhaust back pressure is still controlled within the scientific scope[5]. In summary, the applicable conditions of the coil type exhaust gas heat exchanger:

In this paper, the performance of the spiral coiled vehicle exhaust heat recovery heat exchanger of the vehicle is studied by means of experiment and simulation. On this basis, an optimized structure and spiral array heat exchanger are proposed. Then the numerical simulation method is used to further optimize the spiral array heat exchanger, and an optimized structure, spiral array heat exchanger is proposed. The effect of the change of the taper angle on the heat exchange and resistance characteristics of VSE under the same helical coil length L was studied. The research results provide a theoretical basis for the optimization of the spiral coiled vehicle exhaust gas heat recovery device.

3.1. Analysis of the transformation process of spiral array heat exchanger

The spiral array heat exchanger consists of a housing, a shell side and a spiral coil. The housing and shell are connected by flanges for easy disassembly, repair and cleaning. The fluid inlet and outlet of the coil outside is located on both sides of the shell side, and the fluid inlet and outlet in the coil is located on the side wall of the shell, and the fluid outside the tube and the fluid in the tube are countercurrently exchanged.
3.1.1. The test is as follows. When the exhaust gas temperature is 300℃ and the circulating water supply temperature is 40℃, the waste heat recovery is 2010 W, the waste heat recovery rate is 8.5%, the waste heat recovery amount is increased by 19.4%, and the waste heat recovery rate is increased by 7.1%. When the exhaust gas temperature is 350℃ and the circulating water supply temperature is 40℃, the residual heat recovery is 2780 W, the waste heat recovery rate is 10.02%, the waste heat recovery amount is increased by 27.7%, and the waste heat recovery rate is increased by 15.2%. It can be seen that the amount of waste heat recovery increases first, then decreases, and then increases. From the above conclusions, it can be concluded that when the exhaust gas temperature is 350℃, the residual heat recovery amount and the residual heat recovery rate are the largest. As the engine exhaust temperature increases, the temperature difference between the circulating water supply temperature and the engine exhaust temperature becomes larger and larger. The exhaust heat recovery heat exchanger, the circulating water absorbs more and more heat from the exhaust gas, so the effect of different exhaust temperatures on the system is that the waste heat recovery and waste heat recovery increase with increasing exhaust gas temperature.

3.1.2. The spiral coil D5 of the spiral array heat exchanger is constantly changing. To create a suitable mesh for this complex model, it is divided into two parts, the inner and outer parts of the coil and the near wall portion of the coil. The internal and external models of the coil create a hexahedral core mesh, and the coil is continuously spiraled near the wall to create a prism layer boundary layer that better accommodates the change in the helix angle. In order to reduce the influence of the grid on the simulation results, the grid is checked for independence when the air side inlet wind speed is 1.5m/s. As the number of grids increases, the values of j and f gradually become stable. When the number of grids is about 2.8 million, the values of j and f are basically no longer changed. It can be considered that the grid-independent verification meets the requirements and the simulation results are reliable.

![Figure 4. Study on waste heat recovery process of tail gas](image)

3.2. Analysis of circulating water temperature of spiral array heat exchanger after transformation
The residual heat recovery heat and heat recovery rate decrease as the circulating water supply temperature increases. When the circulating water supply temperature is 50℃, when the exhaust gas temperature is 210℃, the waste heat recovery is 1200 W, the waste heat recovery rate is 8.3%; when the circulating water supply temperature is 60℃, when the exhaust gas temperature is 220℃, the waste heat recovery was 1100W, the waste heat recovery rate was 6.32%, the waste heat recovery was reduced by 12%, and the waste heat recovery rate was reduced by 12%. When the circulating water supply temperature is 65℃, when the exhaust gas temperature is 210℃, the waste heat recovery is 900 W, the waste heat recovery rate is 5.99%, the waste heat recovery amount is reduced by 15.6%,
and the waste heat recovery rate is decreased by 11.2%. When the circulating water supply temperature is 75℃, when the exhaust temperature is 210℃, the waste heat recovery is 660 W, the waste heat recovery rate is 4.3%, the waste heat recovery is reduced by 25.8%, and the waste heat recovery rate is reduced by 35%. As the water supply temperature increases, the amount of waste heat recovery gradually decreases, and the extent of the decrease is increasing. The recovery rate of residual heat is gradually reduced, and the decrease is gradually increased. The waste heat recovery and heat recovery rate increase as the exhaust gas temperature increases. When the exhaust gas temperature is 210℃ and the circulating water supply temperature is 45℃, the residual heat recovery is 1200 W, and the waste heat recovery rate is 7.23%. When the exhaust gas temperature is 260℃ and the circulating water supply temperature is 45℃, the waste heat recovery amount at 1700W, the waste heat recovery rate is increased by 35%, and the waste heat recovery rate is increased.

It can be concluded that when the exhaust gas temperature is 360℃, the residual heat recovery amount and the residual heat recovery rate are the largest. As the engine exhaust temperature increases, the temperature difference between the circulating water supply temperature and the engine exhaust temperature becomes larger and larger. The exhaust heat recovery heat exchanger, the circulating water absorbs more and more heat from the exhaust gas, so the effect of different exhaust temperatures on the system is that the waste heat recovery and waste heat recovery increase with increasing exhaust gas temperature.

In this paper, the experimental conditions are verified to verify the reliability of different flow rates, temperature and water flow and temperature simulation on the air side. Under the different inlet flow conditions on the air side, the experimental values of the air side outlet temperature agree well with the simulated values, the change trend is basically the same, and the error is within 5%. The problem of the model is verified to be reliability.

3.3. Analysis of spiral array heat exchanger from Reynolds number
With the increase of Reynolds number, the exhaust heat recovery of spiral array heat exchangers tends to increase as a whole, and the Reynolds number increases, that is, the speed increases, which increases the shear force and turbulence of the fluid surface, and the boundary disturbance energy is strong. The heat transfer effect is enhanced. From the overall point of view, when L is equal, the larger the enthalpy, the greater the amount of waste heat recovery. The cone angle is VSE in the range of 40. The residual heat recovery of all VSEs is higher than the FSE of 12℃. When the enthalpy is 50℃, the residual heat recovery is the largest, followed by 45℃, and the minimum heat transfer occurs at 10℃. When the Reynolds number is 12000, the residual heat recovery of 46℃VSE is higher than 5℃FSE, and the increase is 35%. Since the change of the taper angle is not large in the range of 10℃ to 30℃, the increase of the residual heat recovery of the VSE compared with the FSE is not obvious, and the apparent increase from 35℃ is large, and the increase is larger at 45℃. Since the fluid outside the tube directly sweeps the spiral coil from 45℃, the fluid outside the tube directly contacts the coil tube, and the curvature of the coil at both ends of the variable curvature spiral coil gradually increases, effectively preventing the front pipeline from obstructing the rear pipeline. Prevent the fluid outside the pipe from flowing directly along the axial direction of the heat exchanger, so that most of the fluid needs to pass through each spiral coil to increase the heat exchange area between the fluid outside the pipe and the fluid inside the pipe, so that the fluid outside the pipe and the fluid in the pipe are in full contact. Moreover, the spiral coil has a diversion function, guiding the hot fluid to diffuse to both sides of the heat exchanger, further contacting the coils on both sides, increasing the flow path and contact area of the fluid in the heat exchanger, and improving the heat exchange efficiency of the heat exchanger. Then we draw the corresponding Reynolds number.
Table 1. Study on the performance of spiral array type heat exchanger

| Number of networks | T℃ deviation | %J | F Deviation of F% |
|-------------------|--------------|----|------------------|
| 1                 | 5            | 12 | 8000             | 0.386 |
| 2                 | 10           | 15 | 10000            | 0.462 |
| 3                 | 20           | 20 | 11000            | 0.569 |
| 4                 | 30           | 30 | 12000            | 0.758 |
| 5                 | 40           | 45 | 14000            | 0.986 |

With CFD and Reynolds number in the range of 12000, the influence of the residual heat recovery of the spiral-arc heat exchanger on the residual heat recovery and resistance performance of the spiral-arc heat exchanger is analyzed. Conclusion: (1) The air side outlet temperature obtained by numerical simulation is basically the same as the experimental result, and the results are relatively close. The error is less than 15%, which is within the allowable range of error, thus proving the correctness of the simulation method. (2) When the length L of the spiral coil is the same, the recovery of exhaust heat of the exhaust gas gradually increases with the increase of the taper angle, and the heat exchange capacity of the spiral array heat exchanger is higher than that of the spiral array type heat exchanger; The resistance increase increases as the taper angle increases. (3) When the length L of the spiral coil is the same, the spiral array heat exchanger has a cone angle of 15 and the comprehensive factor is higher than that of the spiral array type heat exchanger, and the comprehensive performance is best at 20℃. (4) When the number of turns is the same, that is, the length of the spiral coil is the same, the taper angle is increased, and the flow resistance increase increases with the increase of the taper angle. When the taper angle is 50℃, the flow resistance increases the most. The recovery of waste heat from the exhaust gas increases with the increase of the taper angle. When the taper angle is 50℃, the exhaust heat recovery is the largest. The comprehensive factor decreases as the cone angle increases. In the scope of the study, the combination factor is the best when the cone angle is 40℃ under the same number of turns. (5) When the taper angle is the same, the number of spiral coils is changed, and the flow resistance increase increases with the number of coil coils. When the number of turns is 12, the flow resistance increases the most. The amount of exhaust heat recovery increases with the number of coils. When the number of turns is 12, the exhaust heat recovery is the largest. The comprehensive factor increases first and then decreases with the increase of the number of coils. When the number of turns is 10, the comprehensive factor is the largest.

4. Conclusion

In this paper, the performance of array heat exchangers for vehicle exhaust heat recovery is studied. On the one hand, the experimental method is adopted, and the remaining heat recovery capacity is tested by changing the fluid medium parameters entering the array type exhaust gas heat exchanger based on the waste heat recovery amount and the residual heat recovery rate; on the other hand, by means of numerical simulation means, by changing the array type The structural parameters of the exhaust gas heat exchanger were studied for its heat transfer performance. The conclusions of the research are as follows:

The experimental method was applied to study the fixed-curvature spiral coil automobile exhaust heat recovery heat exchanger. When the circulating water supply temperature is changed, the heat recovery heat and heat recovery rate decrease with the increase of the water supply temperature. In the research range, when the circulating water supply temperature is 45℃, the heat recovery heat and heat recovery rate are the largest; changing the engine exhaust temperature, the residual heat recovery heat and heat recovery rate increase with the increase of exhaust gas temperature. In the research range, when the engine exhaust temperature is 400 ℃, the heat recovery heat and heat recovery rate are the largest; change the circulating water supply, heat recovery heat and the heat recovery rate increases with the increase of circulating water supply.
At present, the field of numerical simulation is constantly developing, and the accuracy and accuracy of simulation are continuously improved. To simulate a precise model, the configuration requirements of the computer equipment are high, the basic professional knowledge is firm, the use of the simulation software is mastered, and a new and efficient optimization model is continuously proposed, and a more efficient product is developed for this research field. When arranged in a row, the high-temperature air enters the heat exchanger, first flushing the spiral array heat exchanger on the head, and the airflow is separated behind the pipe. Since the flow channel is straight, most of the air flows along the flow direction and the next row of spiral arrays. The flow field in front of the heat exchanger is connected to form a flow dead zone between adjacent spiral array heat exchangers, which limits heat exchange. When arranged in tandem, between the first row of spiral array heat exchangers and the second row of spiral array heat exchangers, between the second row of spiral array heat exchangers and the third row of spiral array heat exchangers and the flow dead zone. The transposed heat exchanger rotates in a row, the high temperature air enters the heat exchanger and flows around the oncoming spiral array heat exchanger, and after the flow direction is separated, the spiral spiral heat exchanger flows again. After the speed separation, the flow field in front of the remaining spiral array heat exchanger is connected to generate a flow dead zone. The area of the flow dead zone between adjacent spiral array heat exchangers in the transposed arrangement is greatly reduced compared to the alignment. Therefore, the spiral array heat exchanger type exhaust gas heat exchanger has better heat exchange effect.

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