Study on energy saving effect of IHX on vehicle air conditioning system

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Abstract. In this paper, the performance of Internal Heat Exchanger (IHX) air conditioning system for R134a is investigated in bench test and vehicle test. Comparison for cooling capacity and energy consumption between IHX air conditioning system and traditional tube air conditioning system are conducted. The suction temperature and discharge temperature of compressor is also recorded. The results show that IHX air conditioning system has higher cooling capacity, the vent temperature decrease 2.3 °C in idle condition. But the suction temperature and discharge temperature of compressor increase 10 °C. IHX air conditioning system has lower energy consumption than traditional tube air conditioning system. Under the experimental conditions in this paper, the application of IHX can significantly reduce the energy consumption of air conditioning system. At 25 °C of environment temperature, AC system energy consumption decrease 14%, compressor energy consumption decrease 16%. At 37 °C of environment temperature, AC system energy consumption decrease 16%, compressor energy consumption decrease 13%.

1. Introduction
According to the latest statistics of China Association of Automobile Manufacturers, vehicle sales exceeded 28 million in China in 2016, energy saving and emission reduction of automobiles have become increasingly prominent. According to the relevant provisions of GB 27999-2014 Evaluation method and index of passenger vehicle fuel consumption : "For vehicles with one or more off-cycle technologies/devices (efficient air conditioning, idle start and stop), the vehicle fuel consumption can be subtracted by a certain amount, but not more than 0.5L/100km." In response to the call of energy-saving and emission reduction, the use of efficient air-conditioning technology is the direction of the development of automotive air conditioning industry. Xiang L and Cao X et al. [1] theoretically analyzed the improvement of the refrigeration cycle performance for R134a with the use of Internal Heat Exchanger (IHX) technology. Wu X et al. [2] discussed the influence to IHX system by inlet and outlet status. Qian R et al. [3] found from experiments that, IHX sometimes brought negative influence to the system. Liao D et al. [4] found that, discharge temperature of compressor rose evidently when IHX was applied, and brought a risk of invalidation to the oil. More ever, Mota-Babiloni A [5] and Navarro E J [6] researched that the IHX can increase the cooling capacity of the AC system with R1234yf. Kwon Y C, Kim D H [7] got the same result by researching the AC system with CO₂. Therefore, IHX has become a high efficiency air conditioning technology, but to a new AC system, it is necessary to pay attention to the negative influence, and minimize it. This paper will discuss the specific application of the vehicle in FAW car Co., Ltd. with IHX technology.
2. IHX system principles
As shown in Figure 1, IHX also called the Suction Line Heat Exchanger or Coaxial Tube, which is a heat exchange device, composed of two separate circulation areas by inner tube and outer tube. Low-temperature gas refrigerant flowing out of the evaporator and high-temperature liquid refrigerant flowing out of the condenser pass through the two separate areas respectively, so that sufficient heat exchange is performed on both sides.

As the structure of IHX is relatively compact, it can be used to replace the Suction tube and liquid tube air conditioning system directly. Figure 2 is a schematic diagram of IHX and traditional tube.

![Figure 1. Schematic diagram of IHX cross section.](image1)

![Figure 2. Schematic diagram of IHX and traditional tube.](image2)

![Figure 3. Schematic diagram of IHX air conditioning system](image3)

![Figure 4. Pressure-enthalpy diagram of traditional tube air conditioning system and IHX air conditioning system.](image4)
As shown in Figure 3, the principle of the IHX air conditioning system is that the high temperature liquid refrigerant at the outlet of the condenser and the low temperature gas refrigerant at the outlet of the evaporator are heat-exchanged so that the subcooling degree in the refrigeration cycle is increased and the superheat degree of the intake air of the compressor is increased.

Figure 4 is a pressure-enthalpy diagram with traditional tube air conditioning system and IHX air conditioning system. The 1-2-3-4 represents the cycle of traditional tube air conditioning system, 1'-2'-3'-4' represents the cycle of IHX air conditioning system. For the unit mass of refrigerant, the cooling capacity of a refrigeration cycle in the traditional tube air conditioning system is the enthalpy difference from 4 to 1. The cooling capacity of a refrigeration cycle in the IHX air conditioning system is the enthalpy difference from 4' to 1. IHX is good for increasing cooling capacity of the air conditioning system.

3. Test results and analysis

3.1. IHX part test
In order to verify the performance and pressure drop of IHX, IHX with length of 500mm was tested according to the test conditions in Table 1.

According to the tests, under the condition 1, the heat exchange of the low pressure side is 277W, the pressure drop of the high pressure side is 1.6kPa, the pressure drop of the low pressure side is 1.2kPa; under the condition 2, the heat exchange of the low pressure side is 391W, the pressure drop of the high pressure side is 3.7kPa, the pressure drop of the low pressure side is 2.9kPa. Under the condition 3, the heat exchange of the low pressure side is 619W, the pressure drop of the high pressure side is 7.5kPa, and the pressure drop of the low pressure side is 7.0kPa.

| Table 1. Performance test conditions of IHX. |
|---------------------------------------------|
| Test condition | Unit | Condition 1 | Condition 2 | Condition 3 |
|----------------|------|-------------|-------------|-------------|
| 1              | Refrigerant pressure at high pressure inlet | kPaA | 1600 | 1300 | 1600 |
| 2              | Refrigerant pressure at low pressure inlet | kPaA | 350 | 300 | 300 |
| 3              | Refrigerant temperature at high pressure inlet | ℃ | 50 | 45 | 50 |
| 4              | Refrigerant temperature at low pressure inlet | ℃ | 15 | 10 | 10 |
| 5              | Refrigerant mass flow rate | kg/h | 100 | 160 | 230 |

3.2. System bench test

| Table 2. Components parameter list of air conditioning system. |
|---------------------------------------------------------------|
| Number | Part              | Specifications          |
|--------|-------------------|-------------------------|
| 1      | compressor        | 106CC (scroll)          |
| 2      | condenser         | 6.4kW (37℃, 1.5m/s)    |
| 3      | evaporator        | 4.9kW (27℃, 450m³/h)   |
| 4      | expansion valve   | 1tons of cold           |
| 5      | IHX               | 450mm long*             |
| 6      | refrigerant       | R134a                   |

* Due to the vehicle space limitation, the actual length of IHX is 450mm.
In this paper, bench test of the air conditioning system for real vehicle pipeline is built. On the air conditioning system of a certain type of First Automobile Work shop (FAW) vehicle, comparison for cooling capacity and energy consumption between IHX air conditioning system and traditional tube air conditioning system are conducted. Specific air conditioning system components are shown in Table 2.

3.2.1. **Evaluation of cooling performance** The test conditions for the evaluation of the cooling performance are shown in Table 3. The test results of the evaluation of the cooling performance are shown in Table 4.

| Table 3. Test conditions of refrigeration performance of air conditioning system. |
| --- |
| Project | Condition 1 | Condition 2 | Condition 3 |
| Intake air temperature of condenser (℃) | 35 | 35 | 35 |
| Intake air temperature of evaporator (℃) | 27 | 27 | 27 |
| Evaporator relative humidity (%) | 50 | 50 | 50 |
| Compressor speed (rpm) | 1000 | 1800 | 3600 |

| Table 4. Comparison of the cooling performance of air conditioning systems. |
| --- |
| Condition | Project | Traditional system | IHX system |
| Condition 1 | Outlet temperature (℃) | 13.09 | 12.26 |
| | Cooling capacity (kW) | 5.47 | 5.72 |
| Condition 2 | Outlet temperature (℃) | 10.01 | 9.21 |
| | Cooling capacity (kW) | 8.65 | 8.9 |
| Condition 3 | Outlet temperature (℃) | 7.51 | 7.18 |
| | Cooling capacity (kW) | 10.34 | 10.73 |

Under the test conditions in Table 3, the application of IHX can improve the cooling effect of the system. When the compressor speed is 1000rpm, the outlet temperature is reduced by 0.8℃, the cooling capacity is increased by 4.6%; when the compressor speed is 1800rpm, the outlet temperature is reduced by 0.8℃, the cooling capacity is increased by 2.9%; when the compressor speed is 3600rpm, the outlet temperature is reduced by 0.3℃, the cooling capacity is increased by 3.8%.

3.2.2. **Energy consumption evaluation**

At the same time, comparison for energy consumption between IHX air conditioning system and traditional tube air conditioning system were carried out. The energy consumption was measured under two conditions of environmental temperature of 25℃, relative humidity of 40%, and environmental temperature of 37℃, relative humidity of 40%. The evaluation time is 636s.

Under the experimental conditions in this paper, the application of IHX can significantly reduce the energy consumption of air conditioning system. The results are shown in Table 5. Under the condition of environment temperature of 25℃, AC system energy consumption decrease 14%, compressor energy consumption decrease 16%. Under the condition of environment temperature of 37℃, AC system energy consumption decrease 16%, compressor energy consumption decrease 13%.
Table 5. Comparison of energy consumption in air conditioning systems.

| Condition                      | Type                                      | unit | Traditional system | IHX system | Incremental percentage(%) |
|--------------------------------|-------------------------------------------|------|--------------------|------------|---------------------------|
| environmental temperature 25℃, relative humidity 40% | Energy consumption value of air conditioning system | kJ   | 775.6              | 670.7      | -14                       |
|                                | 1 Energy consumption value of compressor | kJ   | 636.3              | 531.3      | -16                       |
|                                | Indoor Blower, Actuator Motor energy consumption value | kJ   | 139.3              | 139.3      | 0                         |
| environmental temperature 37℃, relative humidity 40% | Energy consumption value of air conditioning system | kJ   | 1048.4             | 876        | -16                       |
|                                | 1 Energy consumption value of compressor | kJ   | 835.1              | 729.4      | -13                       |
|                                | Indoor Blower, Actuator Motor Energy Consumption Value | kJ   | 213.4              | 146.6      | -31                       |

3.3. Vehicle test in environmental chamber

In order to truly reflect the improvement of work efficiency on the passenger vehicle’s air conditioning system with the use of IHX, a plan concerning IHX was carried out and the comparative evaluation was performed with traditional tube air conditioning system on a certain type of FAW vehicle. The continuous evaluation conditions were as follows: environmental temperature is 45℃, relative humidity is 50%, solar radiation is 1000W/m², vehicle speed is 40km/h (evaluation time is 45min), 60km/h (evaluation time is 30min), 100km/h (evaluation time is 30min) and idle speed (evaluation time is 45min). Specific vehicle test results were shown in Figure 5 and Figure 9.

It can be seen from the comparison of the average temperature of the outlet in Figure 5, the cooling rate of IHX air conditioning system was significantly faster than the traditional tube air conditioning system in the first 30 minutes. At the speed of 40km/h (30 minutes later), 60km/h, 100km/h etc., the compressor was cut off in both tests, so the cooling effect is not obvious. In the idle condition, the improvement of refrigeration performance of IHX air conditioning system is obvious, the average temperature of the outlet is reduced by about 2.3℃. It can be seen from Figure 6 and Figure 7, compressor suction pressure, discharge pressure changes little between IHX air conditioning system and traditional tube air conditioning system. It can be seen from Figure 8 and Figure 9, the discharge and suction temperature of IHX air conditioning system is higher than the traditional tube air conditioning system in all operating conditions, the average increase is about 10℃.

Figure 5. Comparison of the average temperature of the outlet.
Figure 6. Comparison of compressor discharge pressure.

Figure 7. Comparison of compressor suction pressure.

Figure 8. Comparison of compressor discharge temperature.

Figure 9. Comparison of compressor suction temperature.
4. Conclusions

Through the bench test and vehicle test, the performance of IHX air conditioning system and traditional tube air conditioning system are compared:

- Cooling performance of the air conditioning system increased with application of IHX. In the bench test, the outlet temperature decreases 0.3~0.8°C, in the vehicle test, the cooling rate of IHX air conditioning system was significantly faster than the traditional tube air conditioning system in the first 30 minutes. In the idle condition, the improvement of refrigeration performance of IHX air conditioning system is obvious, and the average temperature of the outlet is reduced by about 2.3°C.
- With the application of IHX, the suction temperature of the compressor increases, this leads to the increase of discharge temperature. In this experiment, the temperature of suction and discharge of compressor increases about 10°C, and the maximum discharge temperature reaches 95.89°C, which satisfies the requirements of the compressor allowable discharge temperature (110°C).
- In the practical application of IHX, the compressor discharge temperature should be within the allowable operating temperature range.
- Under the experimental conditions in this paper, the application of IHX can significantly reduce the energy consumption of air conditioning system. The results are shown in Table 5.In the condition of 25°C of environment temperature, AC system energy consumption decrease 14%, compressor energy consumption decrease 16%. In the condition of 37°C of environment temperature, AC system energy consumption decrease 16%, compressor energy consumption decrease 13%.

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