Development of a Novel Structure Rotary Compressor for Separate Sensible and Latent Cooling Air-Conditioning System

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ABSTRACT

The energy efficiency of separate sensible and latent cooling (SSLC) air-conditioning system is higher than traditional one, since SSLC system uses separate cycles which can raise the evaporating temperature of sensible cycle. Separate cycles often include two separate compressors, which makes the initial investment of SSLC cycle too expensive to use in room air conditioning. A novel structure rotary compressor for SSLC system is proposed in this paper. Using just one novel compressor, SSLC system can realize separate cycles. This paper introduces the schematic of new compressor, shows how the compressor works and the good performance of system. Furthermore, the advantage of this novel compressor is used in two evaporating temperature system.

1. INTRODUCTION

The evaporator of conventional air conditioning systems undertakes the load of the cooling,(i.e. meet the sensible load) and removing moisture (i.e. meet the latent load). In order to remove the moisture, the return air temperature has to be below the dew point temperature of the indoor air. And the evaporating temperature has to be much lower than the dew point temperature. The lower evaporator temperature leads to higher pressure ratio of the compressor. Thus, this doesn’t make the running air conditioning systems economical and the supply air of low temperature makes people uncomfortable.

The Constant Temperature and Humidity air-conditioner in present market can meet the demand of constant humidity. The supply air is heated by the condensation part of the indoor after it is dehumidified, and the supply air of higher temperature makes people comfortable, but it isn’t economical.

Some SSLC (separate sensible and latent cooling) system uses two independent Separate cycles with two separate compressors, which makes the initial investment of SSLC cycle too expensive to use in room air conditioning.

In some Multi-split Air-Conditioning systems, for example, one outdoor drives two indoors , it can realize two different room temperature. But there is only one evaporate temperature in this system. The evaporate temperature is low in order to meet the lower room temperature. The higher pressure ratio of the compressor leads to the low COP of the Multi-split Air-Conditioning system.

Ling et al.(2009) proposed an idea of using the separate sensible and latent cooling (SSLC) system. In SSLC system, one of the vapor compressions dealt with sensible load only, and it is operating at a higher evaporating pressure than the conventional air conditioning system, which reduces pressure ratio. The reduced pressure ratio brings the benefit of better compressor efficiency and less power input than the conventional system. The other vapor compression dealt with both latent load and a small amount of sensible load. Under the ASHRAE standard ambient condition (35°C, 44% RH) , the energy consumption of such SSLC system was reduced by 30% compared with that of a conventional system, and the saving was reported to be up to 50% under hot and dry condition (37°C, 15% RH) (Ling et al, 2010).

A novel structure rotary compressor has developed using for the SSLC system, which includes two cylinders and two accumulators, which can meet the sensible load and the latent load separately. It can also apply the two different evaporate temperature at the same time. Its compact structure and high efficiency is suitable for the SSLC system.
2. DESIGN OF SS LC COMPRESSOR

2.1 Compressor structure features

Fig 1: Comparison of compressor structure

(a) SS LC compressor        (b) conventional twin rotary compressor

Fig 1 (b) shows the conventional twin rotary compressor with double suction structure and single accumulator. The flow of refrigerant in the suction side is as follows: First, the refrigerant from one or two evaporators is mixed in the accumulator of the suction side of compressor, and then the refrigerant is evenly distributed into the two cylinders to be compressed. After being compressed, the refrigerant is mixed in the exhaust chamber of the compressor, then it is exhausted from the discharge pipe into the condenser of the air-conditioning system.

The SSLC compressor is different from the conventional twin rotary compressor. Fig 1 (a) shows its structure features with two cylinders, two suction structures of two different sizes of accumulators. The flow of refrigerant distribution in the suction side is as follows: First, the refrigerant from one or two evaporators enters the desired accumulator of the suction side independently, then the refrigerant enters the desired cylinder to be compressed. After being compressed independently, the refrigerant is mixed in the exhaust chamber of the compressor, then it is exhausted from the discharge pipe into the condenser of the air-conditioning system.

Compared with the traditional twin rotary compressor, the two cylinders of SSLC compressor use independent suction structures which can control two different evaporating temperatures independently because of the same exhaust chamber, the two cylinders may have different suction pressure but the same discharge pressure. Each cylinder’s displacement is determined by its cooling capacity requirement and operation condition, so they are maybe different. The two cylinders use the same crankshaft as shown in Fig 1 (a), so they work in the same time and have the same rotational speed.

In SSLC (separate sensible and latent cooling) system, the SSLC compressor uses the two cylinders to deal with the sensible load and the latent load independently. We can raise the evaporate temperature of the sensible load after meeting the latent load, which can improve the overall energy efficiency of the air conditioning system.

2.2. Theoretical performance analysis of SSLC compressor
Fig 2: the enthalpy-pressure diagram of SSLC compressor

Fig 2 shows the enthalpy-pressure diagram of the vapor compression cycle of SSLC compressor and conventional compressor.

The cycle of the conventional air conditioning system is as follows: the suction 1l--the discharge 2l--the outlet of condenser 3-- the outlet of throttle 4l-- the suction 1l. The evaporate temperature of the VCC (Vapor Compression Cycle) is set 5℃ in order to meet the need of dehumidification.

In SSLC system, the sensible evaporate temperature is set 15℃ in order to meet the thermal comfort of human body, which mainly deals with the sensible load of the room air conditioner. The latent evaporate temperature is set 5℃ in order to meet the need of dehumidification, which mainly deals with both the latent load and a small amount of sensible load.

The cycle of the sensible VCC of higher evaporate temperature as follows: the mixture of 2s and 2l of discharge -- the outlet of condenser 3-- one of the outlets of throttle 4s— one of the suctions 1s— discharge 2s. The cycle of the latent VCC of lower evaporate temperature as follow: the mixture of 2s and 2l of discharge -- the outlet of condenser 3-- one of the outlets of throttle 4l— one of the suctions 1l— discharge 2l.

The operating conditions are listed in the table 1.

According to the ratio of sensible load and latent load under most conditions for room air conditioners, the volume ratio of the two cylinders of Compressor is set to 1.5:1. That is to say, the displacement of the sensible cylinder is 15.2cc and the displacement of the latent cylinder is 10.0cc.

The calculating formulas for cooling capacity and power are as follows:

\[ Q_0 = q_m \times (h_1 - h_3) \]  
\[ W_0 = q_m \times (h_2 - h_1) \]  
\[ q_m = \rho \times v \times n / 60 / 1000 \]  
\[ Q_0 \quad \text{cooling capacity} \quad \text{W} \]  
\[ W_0 \quad \text{Power} \quad \text{W} \]  
\[ q_m \quad \text{mass flow rate} \quad \text{kg/s} \]  
\[ h_1 \quad \text{enthalpy at suction status} \quad \text{kJ/kg} \]  
\[ h_2 \quad \text{enthalpy at discharge status} \quad \text{kJ/kg} \]
\[ h_3 \] --- enthalpy before expansion throttling valve kJ/kg
\[ \rho_1 \] --- density at suction status kg/m³
\[ v \] --- displacement of compressor cylinder dm³
\[ n \] --- speed of compressor rpm

The Comprehensive cooling capacity is the total of the capacity of the two cylinders.

The Comprehensive power is the total of the compression work of the two cylinders.

The performance calculation result of the theoretical cycle is list in the Table 1.

**Table 1:** Comparison of performance calculation result of the theoretical VCC of SSLC compressor and conventional compressor

<table>
<thead>
<tr>
<th>Theoretical calculation conditions</th>
<th>Mode of AC system</th>
<th>Conventional AC system</th>
<th>SSLC AC system with two evaporate temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporate temperature °C</td>
<td>5</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Suction temperature °C</td>
<td>10</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Condensation temperature °C</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Inlet temperature of expansion valve °C</td>
<td>36.7</td>
<td>36.7</td>
<td>36.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>theoretical calculation performance of vapor compression cycle</th>
<th>Unit mass cooling capacity kJ/kg</th>
<th>168.61</th>
<th>171.33</th>
<th>168.61</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit mass compression work kJ/kg</td>
<td>30.06</td>
<td>21.21</td>
<td>30.06</td>
<td></td>
</tr>
<tr>
<td>Unit volume cooling capacity kJ/m³</td>
<td>5853.40</td>
<td>8067.30</td>
<td>5853.40</td>
<td></td>
</tr>
<tr>
<td>Unit volume compression work kJ/m³</td>
<td>1043.50</td>
<td>998.90</td>
<td>1043.50</td>
<td></td>
</tr>
<tr>
<td>Speed rpm</td>
<td>3500</td>
<td>3500</td>
<td>3500</td>
<td></td>
</tr>
<tr>
<td>Displacement cc</td>
<td>25.2</td>
<td>15.2</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Theoretical cooling capacity W</td>
<td>8604.427</td>
<td>7153.001</td>
<td>3414.46</td>
<td></td>
</tr>
<tr>
<td>Comprehensive cooling capacity W</td>
<td>10567.46 (↑22.8%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power W</td>
<td>1534.014</td>
<td>885.7144</td>
<td>608.736</td>
<td></td>
</tr>
<tr>
<td>Comprehensive power W</td>
<td></td>
<td>1494.4504</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comprehensive COP</td>
<td>5.61</td>
<td>7.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison of COP</td>
<td></td>
<td>↑26.02%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

According to calculated result in Table 1, it can be seen that the cooling capacity of the SSLC system is increased by 22.8% than that of the conventional compressor. The theoretical COP of the SSLC system is increased by 26.02% than that of the conventional compressor. The energy saving effect is remarkable.

2.3. Analysis of test result of SSLC compressor
SSLC compressor can achieve two different evaporation temperature at the same time. But the conventional performance test equipment of compressor provides only one evaporation temperature. Therefore, we have developed the multifunctional performance test equipment for SSLC compressor.

Fig 3 shows the principle of the performance test equipment for SSLC compressor:

We adopt two sets of separate calorimeter system at the part of evaporation side, which can test the two parts of cooling capacity under two different evaporation temperatures respectively.

Using the multifunctional performance test equipment for SSLC compressor, we get the performance of the SSLC compressor listed in Fig 4.

Fig 4 shows the cooling capacity of the SSLC compressor is increased by 26.4% than that of the conventional compressor with the same displacement under the rated cooling conditions listed in table 1, and the COP of the SSLC compressor is increased by 29.5%. The efficiency gains of the SSLC compressor is consistent with the theoretical performance of SSLC compressor calculated in table 1 under the rated cooling conditions.

![SSLC compressor VS conventional compressor](image)

**Fig 4:** comparison of the performance of compressor

### 3. TEST AND ANALYSIS OF PERFORMANCE OF SSLC COMPRESSOR USED IN AIR CONDITIONING SYSTEM
According to the structural characteristics of SSLC compressor, two different evaporation temperatures can be realized in the air conditioning system. We used a one-driving-two air conditioning system to evaluate the performance of the SSLC compressor. The capacity of the one-driving-two air conditioning unit is 7500W. The capacity of the indoor unit 1 is 5000W (cooling capacity), and the capacity of the indoor unit 2 is 2500W (cooling capacity).

First, we made the test of baseline using the conventional compressor in order to compare with the SSLC system. There is only one evaporation temperature in the one-driving-two air conditioning system using the conventional compressor. Then we replaced the SSLC compressor to test the performance of the one-driving-two air conditioning system with two different evaporation temperatures. The illustration of the air conditioning system using SSLC compressor is shown in Fig 5.

The cooling mode of the AC system using SSLC compressor is as follows: In order to meet both cooling and dehumidification, two different evaporation temperatures should be adopted. The refrigerant divided into two parts enters into the respective four-way reversing valve after being exhausted from the SSLC compressor. Then the refrigerant converges before the outdoor condenser. The refrigerant is divided into two parts again from the outdoor condenser in order to enter into the respective electronic expansion throttling valve. The two parts of the refrigerant enter into the respective indoor unit with different evaporation temperature after being throttled. The refrigerant enters into the respective four-way reversing valve after being evaporated from the different indoor unit. Finally, the refrigerant return to the respective accumulator to enter the respective cylinder to be compressed.

The heating mode of the AC system using SSLC compressor is as follows: The dehumidification needn’t be considered in heating mode. So there is only one evaporation temperature in the one-driving-two air conditioning system. The refrigerant divided into two parts enters into the respective four-way reversing valve after being exhausted from the SSLC compressor. Then the refrigerant enters into the respective indoor unit to be condensed. The refrigerant converges before the outdoor evaporator after being throttled in the respective electronic expansion throttling valve. Then the refrigerant enters the outdoor evaporator to be evaporated. The refrigerant is divided into two parts again from the outdoor unit to enter into the respective four-way reversing valve. Finally, the refrigerant return to the respective accumulator to enter the respective cylinder to be compressed.

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The refrigerant converges before the outdoor condenser. The refrigerant is divided into two parts from the outdoor condenser in order to enter into the respective electronic expansion throttling valve. The two parts of the refrigerant enter into the respective indoor unit with different evaporation temperature after being throttled. The refrigerant enters into the respective four-way reversing valve after being evaporated from the different indoor unit. Finally, the refrigerant returns to the respective accumulator to enter the respective cylinder to be compressed.
The heating mode is the same as that of the conventional AC system. We only evaluate the performance of the cooling mode of the one-driving-two air conditioning system using the SSLC compressor. The rated cooling condition is as follows: outdoor dry bulb 35°C/ wet bulb 24°C, indoor dry bulb 27°C/ wet bulb 19°C. The test results of the performance of the SSLC system are shown in Figure 6-7.

![Fig 6: comparison of performance of cooling mode](image1)

![Fig 7: comparison of the shift of sensible cooling and latent cooling](image2)

### 3.1 Higher efficiency in the SSLC (separate sensible and latent cooling) mode

Fig 6 shows that the two indoor units undertake the sensible load and latent load respectively by adopting the SSLC mode with two different evaporation temperatures. The indoor unit 1 undertakes the main sensible load due to the more corporation of the total load. The comprehensive efficiency of the SSLC system is much higher in SSLC mode because of the higher evaporation temperature of the indoor unit 1. The cooling capacity is increased by 1.70% in SSLC mode. And the energy efficiency is increase by 8.40% in SSLC mode.
These results are only the drop-in tests. Though the energy efficiency of the SSLC system is higher than that of the conventional AC system, there is a wide gap between the theoretical calculation results and actual test results. We will optimize the SSLC system in the next work in order to achieve the full energy efficiency.

3.2 Achieving the effect of SSLC (separate sensible and latent cooling) by the one-driving-two air conditioning unit

Fig 7 shows the latent load of the indoor unit 1 is decreased by 58.6% in SSLC mode than in conventional mode under rated cooling conditions. And the latent load of the indoor unit 2 is increased by 52.7% in SSLC mode than in conventional mode. That is to say, the shift of the part of the latent load from indoor unit 1 to indoor unit 2 can be realized in SSLC mode. The temperature difference between sensible load and latent load can be realized by adjusting the air volume of the indoor units and the refrigerant flow. Thus the control of the separate sensible and latent cooling can be achieved.

4. CONCLUSIONS

(1) The SSLC compressor adopts the novel structure with two cylinders, two suction structures of two different sizes of accumulators to realize the two different evaporation temperatures independently. The energy efficiency of the air conditioning system using the SSLC compressor is much higher than that of the conventional air conditioning system.

(2) According to the structural characteristics of SSLC compressor, we have developed a multifunctional performance test equipment for SSLC compressor. The test results show the cooling capacity of the SSLC compressor is increased by 26.4% than that of the conventional compressor under the rated cooling conditions and the COP of the SSLC compressor is increased by 29.5%. The energy efficiency is much more remarkable.

(3) Test and analysis of performance of SSLC compressor used in air conditioning system:
   - The energy efficiency is increase by 8.40% in SSLC mode than that of the conventional mode under rated cooling conditions. We will optimize the SSLC system in the next work in order to achieve the full energy efficiency.
   - The indoor unit 1 undertakes the main sensible load. The indoor unit 2 undertakes the main latent load. The shift of the part of the latent load from indoor unit 1 to indoor unit 2 can be realized in SSLC mode.

5. REFERENCES
