Cool Storage Performance of Integrated Heat Pump System with Triple-Sleeve Energy Storage Exchanger

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Abstract

A new integrated heat pump system with triple-sleeve energy storage exchanger was proposed. Experimental system was designed and developed. The cool storage performance of integrated system was studied. The results showed that evaporating temperature was 1 ℃ which was higher than ice storage. COP of cool storage process at the highest point 2.4 dropped to 1.75. In general, system efficiency kept a high level.

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1. Introduction

With the deterioration of energy shortage and environment pollution energy saving technology, new systems and new equipments emerge continuously in the field of building energy-saving. Solar energy can be used as the substitution of conventional energy for building heating and plays an important role in reducing the dependence on conventional energy resources. Heat pump technology is at high development stage. Many governments spend a large amount of money and make preferential policies to spreading and applying heat pump.

Many scholars have studied on the various solar assisted heat pumps [1-4]. Jiang et al. simulated a solar heat pump heating system with seasonal latent heat storage [5]. Han et al. built up a mathematical model of solar assisted ground source heat pump with a potential energy storage device and obtained the...
effect of the heat conservation device on the performance of solar assisted ground source heat pump [6]. For energy storage exchanger study many scholars researched the mechanism and performance of heat transfer of new type exchangers [7-12].

But all sorts of energy-saving technology usually save energy depending on a single technology, solving the problems also are single. Therefore, system energy saving era is coming. Comprehensive energy-saving technique combining simplex technology could get effective energy utilization. A new integrated heat pump system with triple-sleeve energy storage was proposed. The integrated system which combines cool storage in summer with heat storage in winter by triple-sleeve energy storage exchanger makes extensive use of advantages of heat pump technology and energy storage technology. In summer, cold is discharged in the daytime, accumulated at night. It realizes reducing peak and filling valley to ease the pressure on electricity. In winter, triple-sleeve energy storage exchanger is a heat storage device and acts as evaporator of energy storage heat pump.

2. Integrated heat pump system with triple-sleeve energy storage exchanger

The paper proposes a new integrated heat pump system with triple-sleeve energy storage exchanger. The schematic diagram of the new integrated system was shown in Fig. 1. The integrated system combines cold storage in summer with heat storage in winter, air source heat pump with solar heat pump, and heat pump system with energy storage by triple-sleeve energy storage exchanger. It makes extensive use of advantages of heat pump technology and energy storage technology. In summer, cold is discharged in the daytime, accumulated at night. It realizes reducing peak and filling valley to ease the pressure on electricity. In winter, triple-sleeve energy storage exchanger is a heat storage device and acts as evaporator of energy storage heat pump. The integrated system has eight working modes through valve switching: 1. Solar heat pump heating mode in winter; 2. Solar collecting mode in winter; 3. Energy storage heat pump heating mode in winter; 4. Air source heat pump heating mode in winter; 5. Air source heat pump cooling and solar hot water supplying mode in summer; 6. Cold storage mode at night in summer; 7. Cold discharge mode in the daytime; 8. Air source heat pump cooling and cold discharge mode in summer.

![Schematic diagram of integrated heat pump system with triple-sleeve energy storage exchanger](image)

Triple-sleeve energy storage exchanger is a key equipment for the integrated system which consists of several exchanger unit. Structure of exchanger unit is showed in Fig. 2 which inner pipe is refrigerant, middle pipe is phase change material and outer pipe is water. Triple-sleeve energy storage exchanger acts as evaporator all the time in the heat pump system.
3. Choice of phase-change material

The integrated system used the phase change material which stored heat energy as well as cold energy. So the choice of phase changer material must meet the temperature demands of heat and cold energy storage. Collecting water temperature of solar of design condition was 20°C and supplying cold water temperature of design condition was 7~12°C in summer. The phase change temperature range of material was considered from 5 to 15 °C. For accumulating enough energy and reducing the volume of device latent heat of phase change material should be higher than 100kJ/kg. There were many kinds of materials in the range but a small number are commercialized. According to the principle mentioned above RT6 of Rubitherm GmbH Company was used in the integrated system. The properties of the PCM, RT6, are listed in Table 1.

Table 1 Characteristic parameters of RT6

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase-change temperature</td>
<td>°C</td>
<td>6</td>
</tr>
<tr>
<td>Latent heat</td>
<td>kJ/kg</td>
<td>183</td>
</tr>
<tr>
<td>Solid density</td>
<td>kg/m³</td>
<td>860</td>
</tr>
<tr>
<td>Liquid density</td>
<td>kg/m³</td>
<td>750</td>
</tr>
<tr>
<td>Volume expansibility</td>
<td>%</td>
<td>10</td>
</tr>
<tr>
<td>Specific heat (solid/liquid)</td>
<td>kJ/(kg·K)</td>
<td>1.8 / 2.4</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/(m·K)</td>
<td>0.4</td>
</tr>
<tr>
<td>Corrosivity</td>
<td></td>
<td>Nonreactive with most material</td>
</tr>
</tbody>
</table>

4. Introduction of experimental system

The integrated system was complex. A simplified experimentation was designed and developed. Performance of cool storage process was researched by the simplified system. The schematic diagram of experimental system is showed in Fig.3. The compressor of the unit was a rotary compressor of model AEZ3440E. The refrigerant of heat pump was R22. The main parameters of the compressor are shown in Table 2.
1 triple-sleeve energy storage exchanger; 2 triple-sleeve energy storage exchanger unit; 3 compressor; 4 condenser; 5 throttle valve; 6 capillary; 7 hot water tank; 8 cooling water tank; 9 electric heater; 10 cooling water unit compressor; 11 air condenser; 12 flow meter

Table 2 Performance parameters of the compressor

<table>
<thead>
<tr>
<th>Model</th>
<th>Cylinder capacity (cm³)</th>
<th>ARI working condition 7.2°C/54.4°C</th>
<th>Refrigeration capacity (W)</th>
<th>Rated voltage (V)</th>
<th>Rated load current (RLA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEZ3440E</td>
<td>7.6</td>
<td>980</td>
<td>250</td>
<td>220</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Three-dimensional structure of triple-sleeve energy storage exchanger is shown in Fig. 4 which consists of four units. The main configuration parameters of the energy storage exchanger are shown in Table 3.

Table 3 Configuration of the energy storage tank

<table>
<thead>
<tr>
<th>Material</th>
<th>Inner pipe (mm)</th>
<th>Middle pipe (mm)</th>
<th>Outer pipe (mm)</th>
<th>Energy storage volume (ml)</th>
<th>Pipe length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>copper</td>
<td>Φ8×0.5</td>
<td>Φ28×1.0</td>
<td>Φ40×1.3</td>
<td>11500</td>
<td>24</td>
</tr>
</tbody>
</table>

5. Results and discussion

Curves of pressure of cool storage mode are shown in Fig. 5. The system comes into steady running process after 100 seconds. Condensing pressure rises rapid to 1.5MPa and during the mid and later stage
of cool storage process condensing pressure has a little increase. Evaporating pressure reduces slowly after entering the steady running process. Evaporating pressure is about 0.5MPa. By pressure of measurement between outlet and inlet of evaporator pressure loss of triple-sleeve energy storage exchanger is 10kPa. Fig.6 shows the curve of ratio of compression of cool storage mode. As can be seen from the figure, ratio of compression keeps invariant during 500 seconds after entering steady running. After that, ratio of compression rises continuous from 2.75 to 3.25.

Fig.5 Curves of pressure of cool storage mode

Fig.6 Curve of ratio of compression of cool storage mode

Fig.7 shows the refrigerant temperature of cool storage mode. Average condensing temperature is 38 °C and average evaporating temperature is 1 °C. At the beginning of 800 seconds refrigerant temperature difference between inlet and outlet of evaporator is large. Because the process is at stage of sensible heat transfer with large temperature difference and heat transfer. Curves of water temperature of inlet and outlet of condenser are shown in Fig.8. From the figure, water temperature difference of inlet and outlet reduces continuously from 4.5 °C to 3 °C.

Fig.7 Curves of refrigerant temperature of cool storage mode

Fig.8 Curves of water temperature of inlet and outlet of condenser

Fig.9 and 10 show the Curves of energy and COP of cool storage mode. At the beginning of 500 seconds condenser heat, capacity of cool storage and COP rise. COP rises to 2.4. Initial stage heat transfer difference and evaporator temperature is large. So efficiency of system keeps a high level. When entering stage of the phase-change heat transfer coefficient and heat transfer reducing ratio of compression rising
efficiency and COP of system reduces continuously. But COP keeps a high value because of high phase transition temperature and small evaporator temperature reducing. Average COP of system is about 2.

Curves of temperature of phase-change material of cool storage process are shown in Fig. 11. In this figure, temperature of two points A and B (a distal and a proximal end of evaporator inlet) phase-change material has two stages: rapid decline stage and gentle decline stage. Temperature of two points C and D (a distal and a proximal end of evaporator outlet) phase-change material has three stages: decline buffer stage; rapid decline stage; gentle decline stage. Temperature of A and B reduce rapidly in initial stage. After 800 seconds coming into phase-change transfer stage temperature of A and B reduce slowly. Temperature of C and D reduce slowly at the beginning because of length of triple-sleeve energy storage exchanger. With the temperature reducing of refrigerant of energy storage exchanger end temperature of C and D reduce rapid. At 2800 seconds heat transfer enter solid sensible heat transfer stage.

6. Conclusions

The paper proposes a new integrated heat pump system with triple-sleeve energy storage exchanger, and introduces different running modes. A simplified experimentation is designed and developed to simulate the performance of cool storage process. The following conclusions can be drawn:
1) Ratio of compression of cool storage process rises from 2.75 to 3.25. Evaporator pressure loss of triple-sleeve energy storage exchanger is 10kPa.

2) Water temperature difference of inlet and outlet reduces continuously from 4.5°C to 3°C. COP of cool storage process rises to the highest 2.4 then reduces down to 1.75. Average COP of cool storage process can reach up 2.

3) Temperature of two points A and B phase-change material has two stages: rapid decline stage and gentle decline stage. Temperature of two points C and D has three stages: decline buffer stage; rapid decline stage; gentle decline stage.

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References


