A energy saving methodology for legacy air-conditioning systems - Performance of an additional condenser and its application to a hot-water supply

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Abstract: By installing an additional condenser on a legacy air-conditioning system designed for HCFC22, a more efficient heat pump system could be operated with HFC134a as well as HCFC22 without changing the mineral lubricant oil. It was shown that COP for cooling operation was improved when operating with both HCFC22 and HFC134a. In order to demonstrate performances of the additional condenser, a hot-water supply system was constructed to utilize wasted heat of an air-conditioning system with HFC134a refrigerant. The additional condenser working as a desuperheater was equipped ahead of the condenser of an air-conditioning system to extract thermal energy of compressed high-temperature refrigerant. HFC134a was selected as a refrigerant because its pressure was relatively lower at a higher temperature. It was shown that cooling COP decreased 15% by installing desuperheater, because the work done by the compressor increased, but the overall energy efficiency including cooling and hot-water supply increased 34%.

Keywords: Desuperheater, Hot-water supply system, Air-conditioning system, HFC134a

1. INTRODUCTION

The impact on global warming by energy consumption of air-conditioning systems is so large that various research and development is performed aiming at high efficiency and energy saving of air-conditioning systems. Irrespective of this efforts, it is usual that the heat rejected form air-conditioning systems is merely discharged in the atmosphere and never recovered. As a result, this is not only a waste of energy but also a causes of a “heat island phenomenon” in the central area of big cities where buildings are overcrowded. The heat island phenomenon is a phenomenon that makes the temperature of the atmosphere several degrees higher than that of surrounding suburbs, where the temperature distribution is isolated like an island[1]. Once the heat island phenomenon occurs, in addition that energy consumption of air-conditioning systems increases, ambient temperature does not fall even at night when air-conditioning systems stop working and thus we would be forced to live unpleasant life.

In this research, a desuperheater was installed on the air-conditioning system to supply hot water by regenerating heat rejected from air-conditioning systems instead of being discharged in the atmosphere, and performance of supplying hot water was evaluated. A desuperheater is a heat exchanger that collects heat rejected from air-conditioning systems during condensation of refrigerant and makes water hot. It is usually set separately at the former steps of the condenser with the separate cooling water system. Due to this, the water flow rate of a desuperheater can be independently changed from that of the condenser so that high temperature water can supplied by adjusting the water flow rate.

Major contribution on research and development of a desuperheater was achieved mainly in the house equipment field. There exist some research papers on desuperheaters[2,3]. However; regarding refrigerant, HCFC22 was only applied to all research projects. Authors have been studying efficiencies of air-conditioning systems using HFC134a refrigerant and additional condensers[4,5]. HFC134a refrigerant has an advantage that it has zero ozone depleting potential and smaller global warming potential compared with HCFC22 refrigerant[6]. HFC134a is also more appropriate to apply for high temperature water heaters because it has more excellent high temperature and pressure characteristics. Therefore in this research, we evaluated the effect of the quantity of charged refrigerant on performance of the system and performance change induced by installing a desuperheater (energy efficiency of heat exchange due to air-conditioning, COP, and overall energy efficiency due to both supplying hot water and air-conditioning) by adopting HFC134a as refrigerant and applying an water-cooled additional condenser as a desuperheater[7].

2. EXPERIMENTAL METHOD

The air-conditioning system made by A company (Specifications: Refrigerant: HCFC22; Compressor power output: 3.75 kW; Air-conditioning output: 14.5 kW) was used as a main experimental device. The major dimensions of the condenser are: fin pitch:1.8mm (slit fin); inner tube: φ 7.94mm × 0.3mm (bear tube), 2 arrays – 48 stages, frontal width: 832.4mm, frontal area:

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Regarding the evaporator: fin pitch: 1.6mm (rover fin); inner tube: \( \phi 9.4 \text{mm} \times 0.41 \text{mm} \) (channel tube), 3 arrays – 11 stages, frontal width: 1270mm, frontal area: 0.355m\(^2\); array pitch: 19.04mm. Regarding the capillary tube for cooling: inner diameter: 1.4 mm; length: about 400mm.

A water-cooled additional condenser was installed between the compressor and condenser of the air-conditioning system as a desuperheater. Figure 1 shows the circuit chart of the experimental equipment. The mineral oil (Barrel Freeze 32s) was used for the lubricating oil of the compressor. As shown in former reports [4,5], it was confirmed that the air-conditioning system worked properly even if the HCFC22 was just replaced to HFC134a. In this system, the refrigerant flown out from the compressor flows into the desuperheater, the condenser and the evaporator in order. The valve was set between the condenser and the desuperheater so that the modes could be switched to with/without the desuperheater.

The detailed structure of the desuperheater is shown in Figure 2 and the set up configuration on the outdoor unit is shown in Figure 3. The length of the helicoidal tube is about 19m and the inner diameter of the tube is 7.93mm. The high temperature refrigerant gets cooler flowing from the upper side of the helicoidal tube to the lower side and the low temperature water gets warmer flowing from the lower side of the container to the upper side so that the heat exchange occurs through the counter flow condition.

The data are measured as follows: The outdoor unit and the indoor unit are set up in each laboratory room where the wall, the ceiling, and the floor are insulated. The temperature of the refrigerant is measured by T type thermocouples attached on the tube of the compressor, the condenser, the desuperheater, the capillary tube, and the evaporator. The temperature of the air is measured by the dry and wet thermometer in each suction opening and the supply opening of the condenser and the evaporator. The hot water temperature in the desuperheater was measured by T type sheathed thermocouples inserted into the flowfield in the tube. The pressure of the refrigerant was measured at the inlet and the outlet of the compressor by the pressure gauge.

During the test, the room temperature of the indoor unit side was kept 27°C and that of the outdoor unit side was kept 35°C using an extra air-conditioner for room temperature adjustment. This is the performance test method of the air-conditioning equipment according as the Japanese Industrial Standards (JIS B 8615-1) [8]. The water temperature at the inlet of the desuperheater was kept 24°C through the temperature controlled bath and that at the exit was kept 65°C by adjusting the water flow rate. This is the test method for the residential heat pump water heater according as Japan Refrigeration and Air Conditioning Industry Association standard (JRA 4050) [9]. The current value and the integral of the electric power of the compressor were also measured during the test.

3. RESULTS AND DISCUSSION
Firstly, the performance of supplying hot water
was evaluated by changing the quantity of the charged refrigerant from 2.5 to 4.5kg. Figure 4 shows the relation between the quantity of the charged refrigerant and the performance of hot water supply. As the quantity of the refrigerant increases, the performance improves until reaching 7.4 kW with 4.1 kg of the refrigerant quantity. At this point, the flow rate of supplying hot water of 65°C is about 2.6 l/min. Beyond this point, the performance would decrease even if the refrigerant quantity was increased.

The relation between the refrigerant quantity and the performance of air-conditioning heat exchange is shown in Figure 5 with comparison of with/without the desuperheater. The refrigerant quantity was changed from 2.5 to 4.5kg in the case with the desuperheater and from 1.3 to 3.7kg in the case without the desuperheater. For both cases, as the refrigerant quantity increases, the performance of air-conditioning heat exchange improves until reaching 13.4 kW with 3.7 kg of the refrigerant quantity in the case without the desuperheater and 13.0 kW with 4.1kg in the case with the desuperheater. Beyond this point, the performance would decrease for both cases. Therefore, it is understood that the required refrigerant quantity would increase when the desuperheater is installed.

The relation between the refrigerant quantity and cooling COP is shown in Figure 6 with comparison of with/without the desuperheater. Cooling COP is defined as the ratio between a amount of cooling heat exchange and input electric power. Similarly to Figure 5 for both cases, as the refrigerant quantity increases, COP improves until reaching 3.25 with 3.7kg of the refrigerant quantity in the case without the desuperheater and 2.77 with 4.1kg of the refrigerant quantity in the case with the desuperheater. Beyond this point, COP would decrease for both cases. It would be discussed later in this section why cooling COP is lower in the case with the desuperheater.

Figure 7 shows the relation between the refrigerant quantity and the energy efficiency. The energy efficiency is defined as the ratio between the sum of the heat exchange of both the hot water supply and air-conditioning and the consumed electric power. It is seen from Figure 7 that the energy efficiency improves as the refrigerant quantity increases until reaching 4.35 with 4.1kg of the refrigerant quantity.

Based on the above results, it may be summarized that the performance would decrease beyond the certain refrigerant quantity which would be defined as the optimal refrigerant quantity. The optimal refrigerant quantity was 3.7kg in the case without the desuperheater and 4.1kg in the case with the desuperheater. Table.1 lists the characteristics at the optimal refrigerant quantity.
It is seen from Table 1 that cooling COP of the case with the desuperheater is lower by about 15% than that of the case without the desuperheater although the performance of the air-conditioning heat exchange is almost same. Figure 8 shows the Mollier diagram predicted from measured temperature and pressure of the refrigerant. It is seen from this figure that the amount of heat exchange in the evaporator is almost same for with and without the desuperheater although larger work needs to be done by the compressor for the case with the desuperheater due to higher temperature and pressure after compression resulting from larger amount of heat exchange for condensation. This is the reason why cooling COP decreases when the desuperheater is installed.

On the other hand, it is also seen from Table 1 that the energy efficiency of the case with the desuperheater is higher by about 34% than that of the case without the desuperheater. Since the heat rejected during the air-conditioning was regenerated for supplying hot water, the energy efficiency is greatly improved by installing the desuperheater. It is understood that installing the desuperheater enables to improve the energy efficiency without deteriorating the performance of the air-conditioning. This indicates that supplying hot-water by regenerating heat from the air-conditioning system using the desuperheater could be the crucial key technology for energy saving of air-conditioning systems especially in the tropical area where air-conditioning systems are indispensable all the year round.

4. CONCLUSION
In this paper, hot water was supplied by regenerating the heat rejected from the air-conditioning system with the refrigerant of HFC134a by installing the desuperheater, and the performance of the system was evaluated. The obtained findings are listed as follows:
1. Installing a desuperheater requires an additional quantity of refrigerant for the optimal condition.
2. The performance of the air-conditioning heat exchange is almost same for both with and without installing a desuperheater.
3. COP becomes lowers by about 15% when a desuperheater is installed. This is because installing a desuperheater requires larger work of the compressor due to higher temperature and pressure after compression.
4. However, the energy efficiency including heat exchange for both air-conditioning and supplying hot water becomes higher by about 34% than the case without a desuperheater. Thus we may conclude that the energy efficiency of the air-conditioning

Table 1 Characteristics of hot-water supply system for optimal refrigerant charges

<table>
<thead>
<tr>
<th>Case</th>
<th>Amount of hot water supply [kW] (max)</th>
<th>Amount of heat exchange [kW] (max)</th>
<th>Cooling COP (max)</th>
<th>Overall energy efficiency (max)</th>
<th>Refrigerant temperature [°C]</th>
<th>Refrigerant pressure [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compressor Inlet</td>
<td>Outlet</td>
<td>Condenser inlet</td>
<td>Outlet</td>
<td>Compressor Inlet</td>
<td>Outlet</td>
</tr>
<tr>
<td>Without desuperheater</td>
<td>—</td>
<td>13.4 (14.2)</td>
<td>3.25 (3.31)</td>
<td>3.25 (3.31)</td>
<td>9.5</td>
<td>71.5</td>
</tr>
<tr>
<td>With desuperheater</td>
<td>7.40 (7.56)</td>
<td>13.0 (13.6)</td>
<td>2.77 (3.08)</td>
<td>4.35 (4.73)</td>
<td>10.4</td>
<td>94.3</td>
</tr>
</tbody>
</table>
system is greatly improved by supplying hot water using a desuperheater.

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REFERENCES