Experimental Investigation of the Closed Loop Oscillating Heat Pipe Condenser for Vapor Compression Refrigeration

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ABSTRACT
The aim of this paper is to experimentally investigates the applying of the Closed Loop Oscillating Heat Pipe (CLOHP) condenser in vapor compression refrigeration. Split type air conditioner for residence was considered with two disadvantages. Firstly, the large pressure drop in the condenser because refrigerant flows inside very small tube which affects compressor power, resulting in decreasing of the Coefficient of Performance (COP). Secondly, a lot of wasted heat losses to surrounding since the refrigerant has to condense after passing through condenser. To recover pressure drop and heat from the condensing process, this research is pursued to use the CLOHP instead of the conventional condenser in split type air conditioner. The refrigerating capacity and refrigerant were 12,500 Btu/hr and R22, respectively. Size of the CLOHP are 0.08 - meter evaporator section length (L_e), 0.1 - meter condenser section length (L_c), 2.03 - millimeter inner diameter (D_i), 234 turns (N) and working fluids (WF) is R123. The experimental results were obtained then compared with the conventional. It can be seen that COP of the conventional condenser was higher than the CLOHP condenser while EER of the conventional condenser was lower than the CLOHP condenser. In addition, the pressure drop in a refrigerant line of the CLOHP condenser was lower than that of the conventional condenser. Finally, 3 °C increasing of water temperature, which recovers heat from condenser section of CLOHP, was obtained for utilization.

Keywords: closed loop oscillating heat pipe, vapor compression refrigeration, split type air conditioner; conventional condenser, CLOHP condenser

1. INTRODUCTION
Refrigeration is the process of moving heat from one location to another by means of refrigerant in a closed refrigeration cycle. The refrigeration is developed and applied to use in various applications such as food industry, chemical industry and air conditioning for sustainable well-being. The air conditioning is commonly used in a wide range of residential and commercial buildings. Most of the air conditioner types used for this purpose are called “split type”. This type of air conditioner is divided to two parts, a fan coil unit and a condensing unit which the fan coil unit is located inside the room and another one is located outside the room. The split type air conditioner based on the vapor compression refrigeration is shown in Figure 1.

Figure 1. The conventional vapor compression system

It has two disadvantages. First, it has a large pressure drop in the condenser caused by the flow of refrigerant inside a very small tube which affects compressor power and results in a decrease in the coefficient of performance (COP). Second, a large amount of heat is lost to the surroundings.
since the refrigerant has to condense after passing through the condenser. To reduce pressure drop and recover heat from the condensing process, in this investigation we used a Closed Loop Oscillating Heat Pipe (CLOHP) instead of the conventional condenser in split-type air conditioner as shown in Figure 2.

The CLOHP condenser for vapor compression system

The CLOHP is a heat transfer device with very low thermal resistance, high thermal response, and can operate at low temperature difference. Many researchers studied the effects of different working fluids and fluid flow rate on the thermal effectiveness of CLOHP for air-conditioning. The studies showed that the thermal effectiveness decreases when the working fluid was changed from R134a to MP39 or the mass flow rate of cooling fluid was increased (Kammuang-lue et al., 2006). The CLOHP with check valves has been applied for reducing relative humidity in drying system and it can reduce relative humidity and achieve energy thrift (Meena et al., 2007). Heat rejected from a split-type residential air conditioner was recovered for clothes drying in residential buildings. The results indicated that the system was effective for its reasonably short drying duration and high energy use efficiency during air conditioning seasons (Shiming and Han, 2004). From the previous literature it can be seen that, there are no substantial studies on applying the CLOHP as a condenser in the refrigeration system to reduce pressure drop and recover heat from the condensing process. Therefore, the aim of this study is to experimentally investigate the use of a closed loop oscillating heat pipe as the condenser for vapor compression refrigeration system. Our optimization technique will be on the basis of a thermo-economical method (Soylemez, 2000; Soylemez, 2003).

2. DESIGN CONDITION AND PERFORMANCE CALCULATION

2.1. Design conditions
- Dimensions of test room were 2.5×4×3 m (Width×Length×Height).
- Cooling capacity of the air conditioning unit was determined by the cooling load calculation.
- The entire test room was insulated by polystyrene to control heating load and the test room was closed while experiments were performed.
- The CLOHP condenser was designed on the basis of the optimization technique by using thermo-economical method. The optimum size of the system with water as the working fluid are 0.08 meter of evaporator section length ($L_e$), 0.1 meter of condenser section length ($L_c$), 2.03 millimeter of inner diameter ($D_i$) and 234 number of turns (N).

2.2. Performance calculations

The locations of the components shown in Figure 3 correspond to those shown in Figure 1 and each process was calculated as follows:

- Pressure drop in the condenser,
  \[ \Delta P_c = P_2 - P_3 \]  

- Cooling capacity,
  \[ \dot{Q}_c = \dot{m}_c (h_1 - h_6) \]  

- Heat rejection rate,
  \[ \dot{Q}_e = \dot{m}_e (h_2 - h_5) \]  

- Isentropic compression power,
  \[ W_{comp, isen} = \dot{m}_r (h_2 - h_1) \]  

- Coefficient of performance,
\[ \text{COP} = \frac{Q_c}{P_{\text{comp}}} \]  

(5)

- Energy efficiency rating,
- 

\[ \text{EER} = \frac{Q_c \text{ (Btu/h)}}{\text{Power input the system (Watt)}} \]  

(6)

- Electrical power input to the compressor was directly measured and also computed as,

\[ W_{\text{comp}} = \frac{\eta \times W_{\text{comp}}}{\eta_{\text{SEN}}} \]  

(7)

3. EXPERIMENTAL SETUP AND MEASURING EQUIPMENT

3.1 Experimental setup

The experimental setup was divided to two main parts: the conventional condenser system and the CLOHP condenser system, as shown in Figure 4, while specifications are given in Table 1 and 2.

The conventional condenser system consists of four major components of the system, namely compressor, condenser, capillary tube and evaporator. The CLOHP condenser system uses CLOHP instead of the conventional condenser in the same refrigeration system.

3.2 Air conditioning unit

Cooling capacity of the air conditioning unit is 12,500 Btu/h (3.663 kW). The compressor is of reciprocating type and R22 is used as the refrigerant.

3.3 Heating loads

The test room was subjected to heating loads of 1,000 W by means of an I-type electric heater.

3.4 Cooling unit

The conventional condenser was cooled by air, while the CLOHP condenser was cooled by water. Cooling water was circulated by a water pump and
the temperature of water was controlled by a cold bath. A factory calibrated rotameter was used to measure the volume flow rate of water.

3.5 Refrigerant temperature measurements
Refrigerant temperatures were measured by K-type thermocouples at four locations at the inlet of compressor, condenser, capillary tube and evaporator, respectively. The thermocouples were installed on the outside of the refrigerant copper tube surface using thermal paste to ensure good contact. Thermocouples were calibrated in a water bath with an accuracy of ±0.5°C (5-90°C) and connected to data logger interface with a desktop computer.

3.6 Electrical power input measurement
Power input of the entire system was measured by a digital power clamp meter.

3.7 Refrigerant pressure measurements
Pressure of the refrigerant was measured by Bourdon pressure gauges at the same four locations that the refrigerant temperature was measured by the thermocouples. The pressure gauges were factory calibrated with an accuracy of ±1% (-30-120 psi for low pressure and 0-500 psi for high pressure).

3.8 Refrigerant mass flow rate measurement
The refrigerant mass flow rate was measured by a factory calibrated orifice flow meter for R22 refrigerant with an accuracy of ±5% (5-35 g/s). The mass flow rate meter was installed in the liquid line for liquid phase measurements. To ensure that the refrigerant was in the liquid phase, a sight glass was installed before orifice flow meter.

4. EXPERIMENTAL PROCEDURE
The experiments were divided to two main parts: one with the conventional condenser and the other with the CLOHP condenser. Each main experiment was conducted at the heat loads of 1,000 W. In each sub-experiment, all of the data were recorded at an interval of ten minutes and a period of 7.5 hours.

4.1 The conventional condenser experiment
Before each sub-experiment was conducted, the data logger and the desk top computer were turned on to make sure all the measuring equipments were ready. Initial operating condition was a heat load of 1,000 W. The experimental set-up was turned on for twenty minutes to ensure that the system has reached steady state, and then all data were recorded. The refrigerant pressure, the refrigerant mass flow rate and the power input were recorded for all the locations at the same interval of 7.5 hours.

4.2 The CLOHP condenser experiment
In case of the CLOHP condenser experiment, only the conventional condenser was changed in the CLOHP condenser while other components were kept the same. The mass flow rate and inlet temperature of cooling water was fixed at 5 LPM and 25°C, respectively. Before all data were recorded, the sight glass was observed to ensure that the refrigerant was in the liquid phase. Then, the experimental procedure described for the conventional condenser experiments were followed.

5. RESULTS AND DISCUSSION
Figures 5 to 7 show the results of experiments conducted on the conventional vapor compression system and the one with CLOHP condenser for 1,000 W as heat load.

Figure 5. Comparison of the Ph-diagram between with and without CLOHP

Figure 5. compares of the Ph-diagram between with and without CLOHP. From the figure, it was found that the condensing and evaporating evaporator of the CLOHP condenser system was sharply decreased. The very low evaporating temperature of the CLOHP condenser system causes an increase in the specific volume of refrigerant for a constant compressor speed. This in turn for a constant volume flow rate of refrigerant would lead to a decrease in the refrigerant mass flow rate of the CLOHP condenser system. This observation agrees with the findings of Cabello et al. (2004). They experimented on a vapor compression system using R22 as the refrigerant and a condensing temperature of 45°C. Cabello et al. (2004) in their
experiments observed that the mass flow rate of refrigerant was slightly decreased when the evaporating temperature was significantly decreased. From the same figure, it was found that the pressure ratio of the CLOHP condenser system was increased, the mass flow rate was decreased (Cabello et al., 2004) because the volumetric efficiency of the compressor was decreased when the pressure ratio was increased (Gosney, 1982; Stoecker and Jones, 1982). Therefore, the cooling capacity of the CLOHP condenser system was decreased when the pressure ratio was increased (Cabello et al., 2004).

However, as shown in Figure 7, it can be seen that the CLOHP condenser system saved more electrical power for the system, the water pump power was much less than the condenser fan power, the EER of the CLOHP condenser system with 1,000 W as heat loads was increased. In addition, the pressure drop during the condensation process in the CLOHP condenser was sharply decreased because the refrigerant flows through a large tube during the condensing process. This decrement of pressure drop in the condenser caused a decrease in the compressor power consumption.

6. CONCLUSIONS

From this study the following can be concluded:

- The COP of the CLOHP condenser system was obviously lower than the conventional system.
- The CLOHP condenser can definitely reduce the pressure drop when compare with the conventional system.
- The outlet temperature of the cooling water which recovers heat from the condenser section of CLOHP, was increased by about 3 °C showing the possibility of recovering heat for future utilization.

To improve the COP, heat rejection rate and increase the outlet temperature of the cooling water which recover heat from the condenser section of CLOHP, in our future work will change the working fluid from R123 with other working fluids which have higher thermal efficiency and are environmentally safe, for example R134a.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
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<tbody>
<tr>
<td>COP</td>
<td>coefficient of performance</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>diameter</td>
<td>(mm)</td>
</tr>
<tr>
<td>EER</td>
<td>energy efficiency rating</td>
<td>(Btu/h/Watt)</td>
</tr>
<tr>
<td>L</td>
<td>length</td>
<td>(m)</td>
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<tr>
<td>m</td>
<td>mass flow rate</td>
<td>(kg/s)</td>
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<tr>
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<td>number of turn</td>
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<tr>
<td>P</td>
<td>pressure</td>
<td>(Pa)</td>
</tr>
<tr>
<td>Q</td>
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<td>(Watt)</td>
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<tr>
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<tr>
<td>η</td>
<td>efficiency</td>
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Subscripts

a adiabatic section
b condenser section, condenser
c comp compressor
de evaporator section
i    inner
isen    isentropic
r    refrigerant

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REFERENCES