Condensate water as a compressor discharge cooler to generate subcooling on the residential air conditioning using R32 as refrigerant

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Abstract. In residential sector, air conditioning (A/C) system contributes the largest power consumption. As a result, several methods have been developed to improve the system performance. Subcooling is a method to improve the performance of A/C by increasing the cooling capacity. Because R32 has much lower global warming potential (GWP) than that of R22 and R410A, this refrigerant is projected as a substitute of R22 and R410A. This study investigates the performance improvement of residential (A/C) using condensate water as a compressor discharge cooler to generate subcooling. In present study, the experiment was carried out on a split-type A/C using R32 as working fluid. During the experiment, the indoor and outdoor temperatures were controlled at 20°C and 33°C, respectively. The experimental results showed that the average decrease in refrigerant temperature at the condenser outlet was 4.5°C. The decrease in temperature at the condenser outlet indicated that the subcooling occurred on the system. The subcooling on the condenser outlet resulted in increase in cooling capacity by 12.1%. In addition, the use of condensate water as a compressor discharge cooler increased the COP by 21.7%.

Keywords: Condensate water, subcooling, refrigerant, R32.

1. Introduction
Split-type A/C is widely used in residential sector as air conditioner. During operating, the A/C generate condensate water. The condensate water is formed from air condensation on the evaporator surface. Generally, the evaporator temperature of A/C is approximately 5-7°C, as a result the condensate temperature is slightly above the evaporator temperature. In the current practice,
condensate water is discharged and not utilized. On the other hand, the temperature of compressor discharge is typically above 70°C [1], consequently there is a considerable temperature difference between condensate and compressor discharge temperatures. By lowering the compressor discharge temperature using condensate yields subcooling on the condenser outlet, because some of the heat in the refrigerant has been absorbed by condensate before entering the condenser. The subcooling causes the increase in cooling capacity of the A/C. The refrigerant cycle in P-h (pressure vs. enthalpy) diagram of A/C without and with condensate as a discharge cooler is shown in Fig. 1. The figure shows that the outlet condenser temperatures of without and with discharge cooler are point 3 and point 3’, respectively. It can be seen that temperature of point 3’ is lower than that of point 3. It means that the use of condensate water as a compressor discharge cooler will generate subcooling on the outlet condenser. Using Fig. 1, the cooling capacities of the A/C without and with discharge cooler are determined using Eq. (1) and (2), respectively.

\[
Q_{\text{without}} = m_{\text{without}}(h_1 - h_4) \\
Q_{\text{with}} = m_{\text{with}}(h_1 - h_4')
\]

where, \( Q \) = cooling capacity (W), \( m \) = mass flow rate of refrigerant, \( h \) = specific enthalpy (kJ/kg).

The use of discharge cooler will not change the mass flow rate, as a result \( m_{\text{without}} = m_{\text{with}} \). Based on Fig. 1,

\[
(h_1 - h_4) < (h_1 - h_4')
\]

so,

\[
Q_{\text{without}} < Q_{\text{with}}
\]  

It can be seen from Eq. (4) that the cooling capacity with discharge cooler is higher than that of without discharge cooler.

Fig. 1. Refrigerant cycle of A/C without and with discharge cooler in P-h diagram.

Because A/C consumes the highest energy in buildings, several methodologies have been developed to enhance the system performance, such as subcooling using liquid suction heat exchanger [2-4], the ejector as an expansion device [5-7] and inserting nanoparticles in the compressor lubricants [8-10]. At the time of writing of paper, the authors have not found references that discuss the use of condensate water as a compressor discharge cooler. Some topics that discussed the utilization of
condensate water are carried out by Delfani et al. [11], Sawant et al. [12], Britto and Vasanthanathan [13], Sawan et al. [14], Tissot et al. [15] and Ibrahim et al. [16].

Delfani et al. [11] investigated the use of condensate water to lower air temperature entering the condenser on the packaged air conditioning system. They employed indirect evaporative cooling to decrease the air temperature entering the condenser. Based on their experimental investigation, they reported that the method could reduce the power consumption up to 55%. In the same year, Sawant et al. [12] carried out experiment on a window air conditioner using condensate water to lower the air temperature before entering the condenser. The results showed that the use of condensate water on the direct evaporative cooling decreased air temperature entering the condenser. They reported that by employing direct evaporative cooling using condensate decreased power consumption up to 10%.

Another experimental investigation using a window air conditioner was performed by Britto and Vasanthanathan [13]. They still used the same method as Sawant et al. [12], that is using direct evaporative cooling to lower air temperature entering the condenser. Their experimental investigation showed that the method increased the COP by 14.4% and decreased the power consumption by about 8%.

Sawan et al. [14] employed evaporative cooling using condensate water as media for absorbing heat from the air before entering the condenser on a split-type A/C in Beirut. The results showed that the power consumption reduction on June and August are slightly difference, that is 5% and 4.5%, respectively. Tissote et al. [15] carried out experimental investigation on a heat pump operated in cooling mode using water spray to reduce air temperature before entering the condenser. They reported that for hot and dry weather conditions, that is RH = 19.7% and T = 35°C, the COP of a heat pump system increased by 28.9%. Similar to the Sawan et al. [14], Ibrahim et al. [16] performed an experimental investigation on a split-type A/C with cooling capacity of 1.5 ton refrigeration. Based on their experiment, the air temperature before entering the condenser reduced by 4°C. The decrease in air temperature resulted in the decrease in discharge pressure. The decrease in discharge pressure caused reduction of power consumption by 6.1%. Consequently, the decrease in power consumption resulted in the increase in coefficient of performance (COP).

The references related to the use of condensate water as a air cooler before entering the condenser. By lowering air temperature before passing through the condenser surface causes decrease in condensation temperature. Furthermore, the decrease in condensation temperature yields increase in system performance due to a decrease in input power. In contrast to the references, the present study focused on compressor discharge cooling using condensate water to pre-cool the refrigerant entering the condenser. The pre-cooling on the refrigerant will generate subcooling on the condenser outlet and will result in improvement the cooling capacity.

2. Methodology
In order to obtain the valid data, a AC test chamber is utilized in the experimental investigation. The chamber can be controlled at constant condition. In this investigation, the indoor and outdoor temperatures are controlled at 20°C and 33°C, respectively, whereas the relative humidity outdoor and indoor are 70% and 50%, respectively. Because the experiments will compare the system performance when without and with condensate water as a compressor discharge cooler, as a result there are two steps in the experiment, which is the first test without condensate water (normal condition) and the second test using a heat exchanger to lower compressor discharge temperature with condensate water to generate subcooling.

A split-type A/C with compressor capacity of 0.8 kW and using R32 as working fluid is utilized in the experiments. There are five parameters will be measured, viz.: temperature, pressure, air velocity, electrical current and voltage. There are six instruments are employed to measure those parameters, that is thermometer, low pressure gauge, high pressure gauge, manometer, ammeter and voltmeter. Table 1 shows the accuracies of those instruments. The data are recorded at every 10 minutes for 60 minutes. Fig. 2 shows the schematic diagram of a split-type A/C employing condensate water to lower the compressor discharge temperature.
Table 1. The accuracies of measuring instruments

| No. | Instrument          | Measurement     | Accuracy       |
|-----|---------------------|-----------------|----------------|
| 1   | K-type thermocouple | Temperature     | ±0.1°C         |
| 2   | Pressure gauge      | Low pressure    | ±0.1 bar       |
| 3   | Pressure gauge      | High pressure   | ±0.5 bar       |
| 4   | Manometer           | Velocity of air | ±0.1 m/s       |
| 5   | Voltmeter           | Electrical potential | ±1 V        |
| 6   | Ammeter             | Electrical current | ±0.1 A    |

Fig. 2. Schematic diagram of a split-type air conditioner without and with condensate water to lower the discharge temperature.

The input power and the power consumption is determined using Eq. (5) and (6), respectively.

\[ P = I \cdot V \quad (5) \]

\[ W_h = P \cdot t \quad (6) \]

where,

- \( P \) = input power, Watt
- \( I \) = electrical current, ampere
- \( V \) = electrical potential, volt
- \( W_h \) = Power consumption, kWh
- \( t \) = time, hour

To determine cooling capacity of A/C, the air velocity before and after the evaporator has to be measured. Using Eq. (7), the mass flow rate passed through the evaporator can be calculated. Furthermore, using psychrometric chart as shown in Fig. 3, the cooling capacity can be calculated using Eq. (8). Point 1 represents the air condition before entering the evaporator, whereas point 2 is air condition after pass through the evaporator.

\[ \dot{m} = \rho \cdot V \cdot A \quad (7) \]
\[ Q = \dot{m} (h_1 - h_2) \]  \( (8) \)

where,
- \( Q \) = cooling capacity, kW
- \( \dot{m} \) = mass flow rate of air, kg/s
- \( h_1 \) = specific enthalpy in point 1, kJ/kg
- \( h_2 \) = specific enthalpy in point 2, kJ/kg
- \( \rho \) = density of air, kg/m\(^3\)
- \( V \) = velocity of air, m/s
- \( A \) = cross section area of ducting, m\(^2\)

Fig. 3. Air process through the evaporator in the psychrometric chart.

Fig. 4 illustrates the ducting utilized in the experiment to determine mass flow rate of the air passed through the evaporator. The ducting was utilized to measure air velocity passed through the evaporator.

Fig. 4. Ducting in the indoor unit to determine the cooling capacity.
Coefficient of performance (COP) of AC is calculated with Eq. (9),

$$COP = \frac{Q}{P}$$ (9)

where Q is cooling capacity (kW) and P is input power (kW).

The use of condensate will increase the cooling capacity. The increase in cooling capacity leads to increase the COP. The cooling capacity and COP improvements are determined using Eq. (10) and (11), respectively.

$$Q_{imp} = \frac{Q_{with} - Q_{without}}{Q_{with}}$$ (10)

$$COP_{imp} = \frac{COP_{with} - COP_{without}}{COP_{with}}$$ (11)

3. Results and Discussion
The main purpose of the use of condensate water as compressor discharge cooler (subcooler) is to generate subcooling on the outlet condenser. The decrease in subcooling leads to increase in cooling capacity. Fig. 5 shows the outlet condenser temperature of a split type A/C when standard condition (without) subcooler and with subcooler. The figure depicts that the outlet condenser temperature of standard condition is always higher than that of using a compressor discharge cooler. It means that the use of subcooler using condensate water results in the decrease in temperature of the outlet condenser. According to Fig. 5, during 60 minutes of operation, the average temperature difference between using subcooler and without subcooler is 4.5°C. The difference in the condenser outlet temperature between without and with subcoolers represents the subcooling occurs in the system. Based on P-h diagram in Fig. 1, decrease in temperature of 4.5°C on the outlet condenser will increases the cooling capacity. The higher the temperature decrement in the condenser outlet, the greater the increase in cooling capacity. In order to attain maximum temperature increment in the condenser outlet, the size and construction of the heat exchanger have to be designed well.

Fig. 5. Comparison of outlet condenser temperature between without and with subcooler.
Fig. 6 illustrates the cooling capacity of A/C without subcooler and with subcooler. It shows that the cooling capacities of A/C with subcooler are always higher than that of without subcooler. The increase in the cooling capacity is due to decrease in refrigerant specific enthalpy entering the expansion device, as shown in P-h diagram in Fig. 1. The data in Fig. 6 show that the experimental results are in accordance with the Eq. (3) and (4). Based on Fig 6 and using Eq. (10), the average cooling capacity increment when employing subcooler is 12.1%. With increasing the cooling capacity, the power consumption of the A/C decreases, because the compressor operation is shorter. It leads the life expectancy of the compressor will enhance.

![Comparison of cooling capacity of AC without and with subcooler.](image)

Besides increasing cooling capacity, the use of subcooler using condensate water also decreases the input power due to decrease in temperature of refrigerant on the compressor discharge. Fig. 7 depicts comparison of input powers of A/C without and with subcooler for 60 minutes operation. The figure shows that the input powers of A/C using subcooler are always lower than that of without subcooler during 60 minutes operation. The decrease in the input power is caused by decreasing temperature and pressure on the compressor discharge. The average input power difference between without and with condensate water as subcooler is 10.9%. Compared to other results, the increase in input power in this study is higher than that of Sawan et al. [14] and Ibrahim et al. [16], but lower than that of Delfani et al. [11]. It indicates that the use of condensate water as a compressor discharge cooler is promising. The use of this subcooler in A/C is not only simple and inexpensive, but also resulted in significant improvements to the system.
According to Eq. (9), the decrease in input power and the increase in cooling capacity lead to increase in the COP. Based on the Eq. (9), the percentage increase in the COP will be higher than percentage increase in the cooling capacity. Fig. 8 depicts the COPs of A/C without and with condensate water as a subcooler. The figure shows that the COPs using subcooler are always higher than that of without subcooler. Using Eq. (11), the percentage increase in the COP is 21.7%. This results is higher than that of Britto and Vasanthanathan [13] experimental result, that is 14.3%. But, if compared to investigation by Ibrahim et al. [16], this experimental result is only slightly higher, that is 21.4%. It indicates that the use of subcooler using condensate water for cooling compressor discharge will generate a higher COP than that of subcooler using condensate water as an evaporative cooling.

Fig. 7. Comparison of input power of A/C without and with subcooler.

Fig. 8. Comparison of coefficient of performance of A/C without and with subcooler.

Conclusions
Performance evaluation of a split-type AC utilizing condensate water as a compressor discharge cooler has been presented in this paper. Based on the the experimental investigation, it is found that the temperature of condenser outlet is decreased by 4.5°C. The decrease in this temperature indicates that the subcooling occurs on the system. The decrease in temperature of condenser outlet results in
increase in cooling capacity by 12.1%. Besides increasing cooling capacity, the use of subcooler results in decrease in temperature and pressure of compressor discharge. The advantage of decrease in discharge pressure leads to decrease in input power. The increase in cooling capacity and decrease in input power cause increase in the COP by 21.7%.

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