Experimental Study to Performance Improvement of Vapor Compression Cooling System Integrated Direct Evaporative Cooler and Condenser

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Abstract. For areas with very hot and humid weather condition increased latent and sensible load are a major problem in cooling systems that will increase compressor work so that electricity consumption will also increase. Combined condenser with direct evaporate cooling will increase the heat removal process by using an evaporative cooler effect that will increase the efficiency of energy use. This paper presents the study of the use of evaporator cooling and condenser. This paper mainly calculated energy consumption in steam compression cooling systems and related problems. From the results of this study, the use of condensers with evaporative cooling, power consumption can be reduced to 46% and performance coefficient (COP) can be increased by about 12%, with 1,2 kW cooling capacity.

1 Introduction

Energy is a very important factor in encouraging strong economic development for growth in any country. With the rising prices of fossil fuels [1]. The savings and reductions in energy consumption, help reduce global warming.

The increase in living standards and demand for human comfort has led to an increase in energy consumption. The amount of energy consumed by air conditioners, refrigerators, and water heaters is increasing rapidly, and occupies about 30% of total power consumption [3]. Electricity consumption for air conditioning systems has been estimated at about 45% for residential and commercial buildings [4]. Due to the rapid growth in world population and economy, total world energy consumption is projected to increase by about 71% from 2003 to 2030 [5]. Therefore, any attempt to reduce the overall cooling system energy consumption will contribute to large-scale energy savings at the international level. Reduced cooling unit energy consumption can be achieved by improving performance. This can be done by lowering the compressor power consumption, increasing the heat dissipation capacity of the condenser, or reducing the difference between condenser and evaporator pressure.

Higher condensation temperatures lead to an increase in pressure ratio across the compressor, thereby increasing the compressor's work and thereby reducing compressor life and coefficient of performance (COP). High outdoor temperatures above 35°C in summer are one of the reasons, leading to a decrease in the coefficient of performance (COP) of most air-cooled units to the range of 2.2 to 2.4 [6]. In addition, if this temperature stays above 45°C for long periods of time, the AC will be over trip due to excessive condenser working pressure. Chow and Cengel [7,8] mentioned that the air conditioning performance coefficient decreased by about 2-4% for every 1°C increase in condenser temperature.

In Middle Eastern countries, atmospheric temperatures during summer are approaching 40-45°C sometimes higher. During this condition, the AC compressor works continuously and consumes more electrical power and COP decreases [9]. Therefore, it is necessary to lower the ambient air temperature before passing through the condenser coil, to lower the temperature and pressure of the condenser. This can be achieved by using evaporative cooling, which lowers the condensation temperature from the dry ball temperature outdoors to near wet ball temperatures [10]. The efficiency of evaporative cooling is essentially unaffected by high environmental temperatures in dry climates. The most significant evaporative coolant benefits during peak periods of utility when the difference between the largest dry and wet ball temperature [11]. This can result in significant overall energy and demand savings because any small reduction in electricity consumption in the housing sector can save significant amounts of energy [12,13].

2 Methodology

2.1 Experimental

The new air conditioning systems with independent condenser and cooling evaporative cooling are shown schematically in Figure 1. It mainly consists of evaporative cooling and steam compression cooling systems, measuring instruments and control devices.

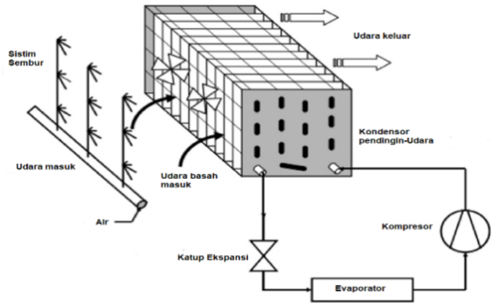

Fig. 1. Combined condenser evaporative cooler

2.2 Measurement

The water flow rate of the shell and tube evaporative coolers is measured using a volume flow meter with an accuracy of ± 0.5%, the total airflow rate of the evaporative fan is controlled by the frequency converter. Anemometer is used to measure air flow rate (maximum 4.8 m/s). Relative humidity was measured using a psychrometer with an accuracy of 1%. Thermo-gun is used to measure various temperatures, and the data collected is analyzed.

2.3 Theoretical Analysis

The cooling system components comprising one compressor, evaporative cooling water pump, and a single phase power fan are measured separately. The cooling capacity can be calculated by applying the equilibrium energy equations as follow:

$$Q_c = \dot{m}_w C_{pw} (\dot{T_{in}} - T_{out}) \tag{1}$$

The cooling capacity can be calculated by the equation

$$Q_c = \dot{m}_r (h_1 - h_3) \tag{2}$$

Furthermore, the compressor input power and heating capacity are also calculated in Equation 3 and Equation (4):

$$W_C = \dot{m}_r (h_2 - h_1) \tag{3}$$

$$Q_h = \dot{m}_r (h_2 - h_3) \tag{4}$$

The overall performance of the air conditioning system is evaluated by the performance coefficient (COP), which can be obtained by the equation

$$COP_c = \frac{Q_c}{W_C + W_{pump,e} + W_{pump,c} + W_{fan,c}} \tag{5}$$

As for the condensing coil on the condenser, the heat exchange from the condenser is affected by the heat transfer coefficient (K_o), which can be calculated as follows:

$$K_o = \frac{1}{\frac{1}{\alpha_k}\frac{F_o}{F_i} + \frac{1}{\alpha_{wa}}} \tag{6}$$

According to the Cooling Principles and Tools (Zhang 1987), the heat transfer coefficient (k) of the refrigerant in the condensation coil is calculated in Eq. (7).

$$\alpha_k = 0.683 {r_s}^{1/4} C_m (t_k - t_w)^{-1/4} {d_i}^{-1/4} \tag{7}$$

The values of ${r_s}^{1/4}$ and C_m with the temperature difference can be seen in table 1 (Zhang, 1987).

Table 1. Value of ${r_s}^{1/4}$ dan C_m

T (°C)	0	10	20	30	40	50
${r_s}^{1/4}$	21.26	21.039	20.792	20.513	20.192	19.811
C_m	86.68	83.30	79.65	75.81	71.65	66.84

The coefficient of heat transfer for water (α_w) out of the condenser coil can be calculated in equation (8) by reference (Parker and Treybal, 1962).

$$\alpha_w = [982 + 15.58 t_w] (\frac{\Gamma}{d_o})^{\frac{1}{3}} \tag{8}$$

The coefficient of heat transfer for air (α_{wa}) out of the condenser coil is calculated in equation (9) according to the reference (Zhang, 1987).

$$\alpha_{wa} = 0.88 \frac{C \lambda_{wa} Re_{wa}^{m} Pr_{wa}^{0.36}}{d_o} \tag{9}$$

The values of the parameters *C* and *m* in the temperature difference are shown in table 2.

Table 2. Values of parameters *C* and *m*

Re	Array of inline tubes		Arrangement of multilevel tubes		S1/S2
	C	*m*	*C*	*m*	
<200~10^3	0.52	0.50	0.6	0.5	-
=10^3~2x10^5	0.27	0.63	0.35 $(S_1/S_2)^{0.2}$	0.6	<2
>2x10^5	0.02	0.84	0.021	0.84	-

3 Results and Discussion

3.1 Effect of dry air inlet temperature

To improve the cooling performance of air conditioning systems with evaporative cooling, many factors influence it. Meanwhile, to limit the number of tests, only four key parameters have been tested: the water temperature in the evaporative cooler, the dry air ball temperature, the air velocity and the rate of water spray. Therefore, experimental testing is conducted under different conditions. Based on the experimental results, the thermodynamic properties of the refrigerant at different points of the cooling cycle are obtained (figure1) and parameters such as mass flow rate, cooling capacity, compressor input power and COP of the system are also calculated.

For dry temperature conditions 30ºC to 32ºC, with relative humidity of 80%, evaporative cooler with variation of 0.03kg/ms to 0.05 kg/ms, air velocity 4m/s to 4.8m/s, and under the 50Hz compressor frequency condition the variation of the cooling capacity with the inlet water temperature of the evaporator is plotted in fig. 2 and 3.

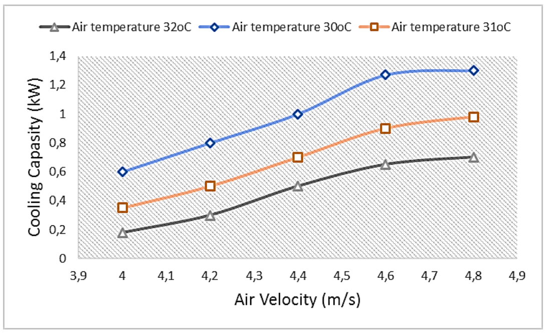

Fig.2. Variation of cooling capacity with dry ball temperature and air velocity

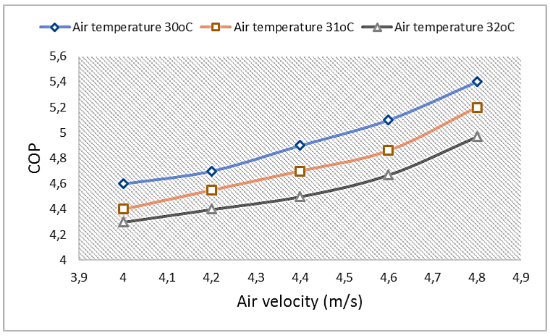

Fig. 3. COP variation with dry air temperature and air velocity

It can be seen that the cooling capacity and COP of air cooling system with evaporative cooler will increase as air speed increases from 4 m/s up to 4.8 m/s, but the cooling capacity and COP of the evaporative cooling system decreases when the dry-ball temperature increases from 30ºC to 32°C This is due to the fact that the temperature and condensation pressure increase with increasing dry ball temperature, so the specific cooling capacity decreases and the specific compressor power increases.

3.2 Effect of air velocity and spray water rate

Under the 70Hz compressor frequency condition, 80% relative humidity, temperature of dry air 32ºC and water inlet temperature evaporative 27ºC. Variations of cooling capacity and COP with water spray rate and air velocity are plotted in Figures 4 and 5.

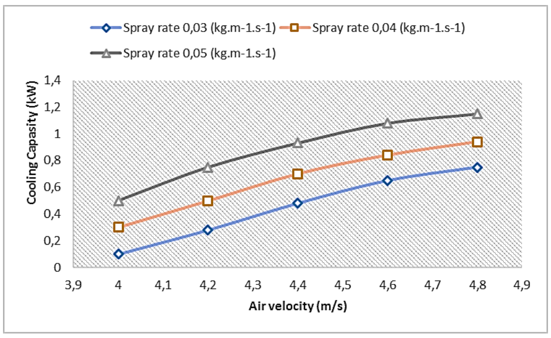

Fig. 4. Variation of cooling capacity with spray water rate and air velocity

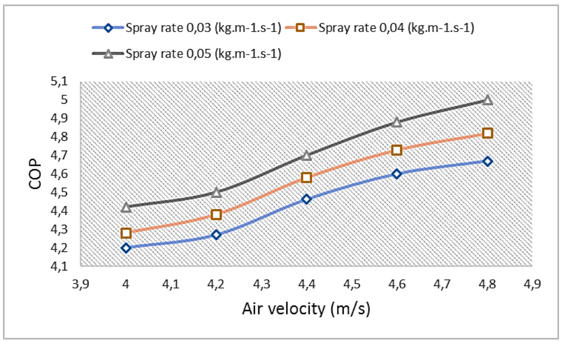

Fig. 5. Variation of cooling capacity with spray water rate and air velocity

As shown in Fig. 4 and 5, when air velocity of 4.0 m / s and spray water rate increased from 0.03 to 0.05 kg/m-s, cooling capacity and COP increased from 0.4 to 1.2 kW and 4.4 to 4.9, respectively. The main reason is that the cooling water soaks the condensation roll better as the spray water rate increases from 0.03 to 0.05 kg/m-s, and the moisture vapor also increases. Therefore, the higher heat transfer coefficient and mass transfer will increase due to higher rate of bursts. Furthermore, the temperature difference between cooling water and refrigerant decreases with increasing spray water rate, and condensation temperature also decreases. Thus, cooling capacity and COP increase with increasing water spray.
On the other hand, the cooling capacity and COP of the air conditioning system with the evaporative cooler condenser increases with the air velocity rising from 4 m/s to 4.8 m/s. With a water spray condition of 0.04kg/m-s, the cooling capacity and COP increased from 0.23 to 0.8 kW and 4.2 to 4.8 respectively. This is mainly because the higher air velocity increases the heat exchanger coefficient, and the condensation temperature and lowers the pressure.

4 Conclusions

From the research has been done, the improvement of air conditioning system performance with evaporative cooling condenser combined, and the variation between influenced factors, such as evaporator air temperature, dry temperature, air velocity and water spray rate, cooling capacity, COP has been analyzed. The main conclusions are as follows.

1) The experimental tests show that the cooling capacity and COP of the air conditioning system with the combined evaporative cooling-condenser increased significantly with increasing inlet temperature of evaporator, air velocity and water spray rate. COP increased by 12% with air velocity increasing from 4.0 to 4.8 m / s and with spray rate increasing from 0.03 to 0.05 kg / m-s.

2) It was also found that an increase in dry air ball temperature would decrease COP.

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