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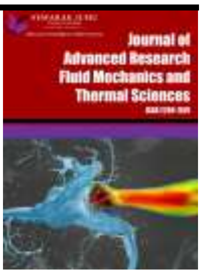

# The Enhancement of Performance Coefficient by Spraying Water on the Condenser of the Compression Cooling Cycle

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**ABSTRACT**

During hot and dry summer months in hot regions or deserts, compression refrigeration cycles that utilize modern, environmentally friendly refrigerants operate at high gas pressures, particularly when the ambient temperature exceeds 40°C. These systems will consume more energy in the summer, leading to a lower coefficient of performance (COP) compared to cooling systems that do not utilize this type of refrigerant gas. In this study, both theoretical and experimental analyses were undertaken to explore an effective solution for enhancing the performance of the cooling system. This involved reducing the air temperature before it enters the compression cooling cycle condenser by passing it through a water spray. The process of water evaporation absorbs the latent heat of evaporation from the air, consequently lowering its temperature. The air temperature drops by about 10 degrees Celsius below the ambient temperature before it enters the compression cooling condenser. This improvement increases the compression cooling capacity of the cycle by up to 19% and boosts the coefficient of performance (COP) by 18%. The proposed method of spraying water on the air inlet of the compression cooling cycle condenser improves its performance and increases its cooling capacity.

## 1. Introduction

Air conditioning systems that utilize environmentally friendly gases are extensively employed in public buildings and residences, especially in hot and arid regions like the area under consideration (Tikrit city). High ambient temperatures make these systems operate at high pressures and consume high electric power, and reducing the ambient temperature contributes to reducing these pressures and reducing electrical power consumption. Hajidavalloo and Eghtedari [1] investigated the efficiency of using a wet pad in an evaporative cooling system to cool a compression cycle condenser. Their study revealed a substantial enhancement in performance, boosting it by up to 50% and reducing power consumption by 20%. They attributed these improvements to lowering ambient air temperatures through evaporative cooling, which significantly raised the Coefficient of Performance (COP) compared to other systems utilizing different cooling methods. Similarly, AlOtaibi *et al.,* [2]

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explored the impact of evaporative cooling on a pressure refrigeration cycle condenser by spraying water mist directly onto the condenser coil. This approach resulted in a 13% increase in the cycle's COP and an 11% decrease in energy consumption [2,3]. Hajidavalloo [4] also conducted an experimental study on a novel evaporative cooling system design for window-type air conditioner condensers. This system circulates water from a tank to a wet pad before the condenser. The ambient air, passing through the moistened pad before reaching the condenser, was humidified and cooled, reducing power usage and a 15% increase in the cycle's COP. An experimental study to cool the compression cycle condenser using a wet pad. It is moistened using water, which circulates and passes through the wet pad was performed by Zaidan *et al.,* [5]. When outside air passes through this wet pad, it is humidified and cooled, thus cooling the compression cycle condenser to increase performance. Power consumption is reduced when the air temperature entering the condenser is less than 35°C. Therefore, cycle factor performance can be improved by up to 15% using a wet pad that pre-cools the air to cool the compression cycle condenser in desert climates. Cooling the compression cycle condenser with an evaporative cooling system has received researchers' attention to reduce energy consumption and improve the cycle performance. It was observed through this research in relatively hot and dry desert areas that using some suitable applications such as spraying water on a steam compression cycle condenser leads to an improvement in the coefficient of performance by up to more than 18% when the ambient temperature rises to more than 40 degrees Celsius.

## 2. Methodology

The utilization of environmentally friendly gases, which operate at high temperatures and pressures, has increased, resulting in elevated electrical power consumption. This increase has made it necessary to explore methods to reduce electrical power consumption, particularly in desert regions where summer temperatures reach 48 degrees Celsius, and relative humidity drops below 18%. Therefore, it is possible to lower the air temperature before entering the condenser cycle by employing evaporative cooling, achieved by spraying water when the temperature exceeds 35 degrees Celsius. Water condensed on the pressure cycle evaporator is collected in a tank daily. An air temperature sensor is placed to signal the pump to draw water from the tank and spray it onto the pressure cycle condenser when the outside air temperature rises to 35°C, as shown in Figure 1. Dry and wet bulb temperatures and pressures are recorded for all system parts. This allows for calculating the coefficient of performance, cooling capacity, and wet bulb effectiveness to evaluate the system's performance after the proposed improvement of spraying water on the condenser.

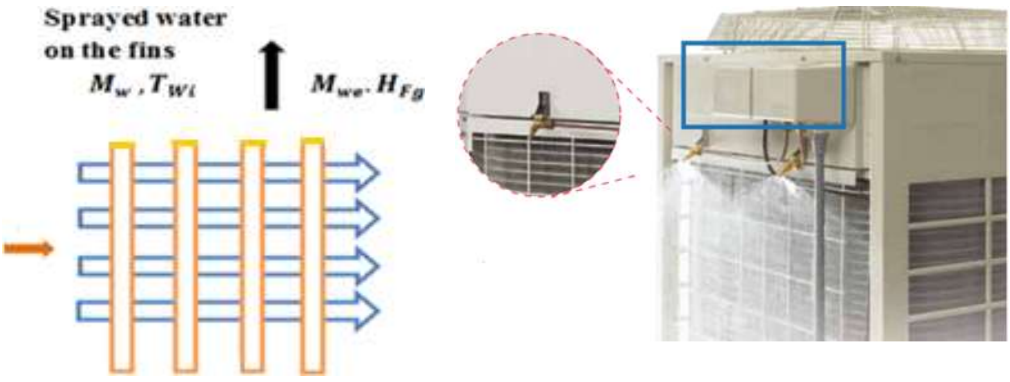

**Fig. 1.** Assemble of spry water location [6]

To perform a thermal and mass balance, as in Figure 2, for the process of heat and mass transfer in the condenser heat exchanger, the following was assumed

i. Neglecting the thermal resistance of the condenser plates, because the thickness of the plates is small (0.12 mm) and their thermal conductivity is high [7-9].
ii. Neglecting the thermal resistance of the water layer covering the surfaces of the condenser plates, as the thickness of the water layer is very small and does not exceed (0.25 mm).
iii. The water temperature difference between the entry and exit is small.
iv. The amount of water is also small compared to the amount of air.

The amount of heat extracted by the water evaporation from the external surface of the condenser becomes as follows [10-13]

$$Q_{wet} = \dot{M}_{we} * H_{fg} \tag{1}$$

Calculating the condenser's evaporation surface area is done by calculating the base area, i.e., the area enclosed between the tube fins, and the surface area of the fins. Then the two regions are combined to obtain the total evaporation area as in the following equations [14,15].

As shown in Figure 2, the number of fins is calculated according to the following relationship

$$Total\ number\ of\ fins = N_t\ =\ N_f\left(\frac{unit}{meter}\right) * L_1(meter)$$

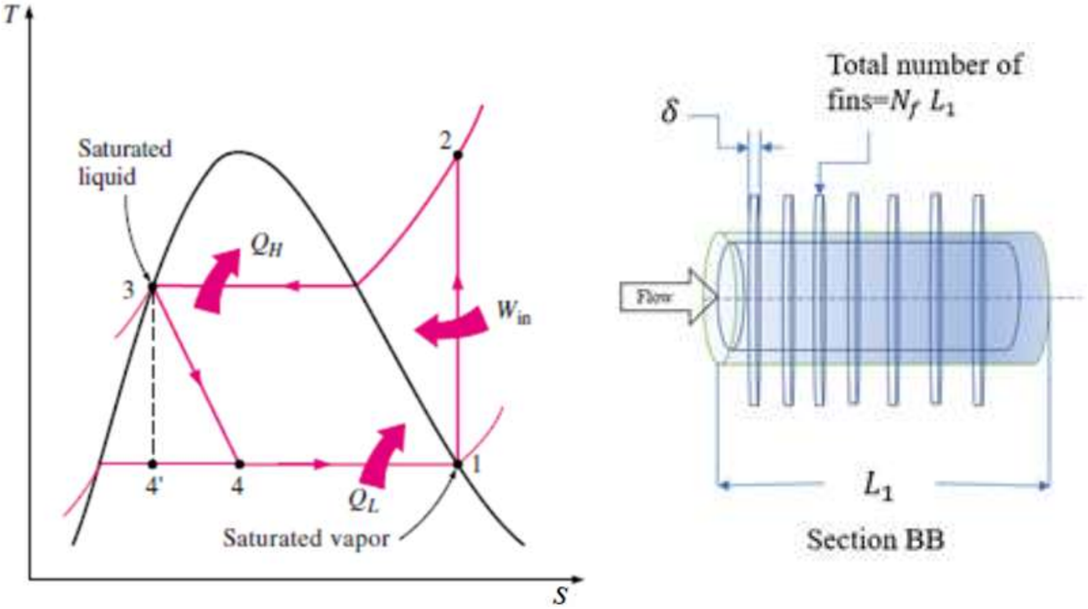

**Fig. 2.** The fins geometry and cycle refrigeration diagram [6]

The surface area between the fins is calculated from the following equation [16]

$$A_b = \pi d_O(\ L_{H1} - \delta_H N_f\ )N_t + 2\left(\ L_{H2}L_{H3} - \frac{\pi d_O^2}{4}N_t\ \right) \tag{2}$$

The surface area of the fins is calculated from the following equation

$$A_f = 2\left[L_{H2}L_{H3} - \left(\frac{\pi d_{O1}^2}{4}\right)N_t\right]N_f + (\ 2L_{H3}\delta_H + 2L_{H2}\ \delta_H)N_f \tag{3}$$

The total evaporation surface area of the condenser is calculated from the following equation [17-21]

$$A_{THE} = A_b + A_f \tag{4}$$

The amount of water that evaporated from the surfaces of the condenser is calculated after knowing the surface area of the condenser and the speed of the air passing through it according to the following equation [6,9,22]

$$\dot{M}_{we} = \forall \times A_{THE} \times (\, g_{Sat} - \, g_{ai}) \,/3600 \tag{5}$$

($\forall$) represents the evaporation coefficient and is calculated from the following experimental equation [23]

$$\forall = (\, 25 + 19 \times V_{wet} \,) \tag{6}$$

The moisture content ($g_{oc}$) of outlet air leaving the condenser was calculated as

$$g_{oc} = g_{ai} + \left(\frac{\dot{M}_{we}}{\dot{m}_a}\right) \tag{7}$$

The dry air pressure at the air entry temperature into the condenser is calculated after obtaining the water vapor pressure from the saturated air characteristics from the following equation

$$P_{doc} = P_B - P_{Soc} \tag{8}$$

The relative humidity ($\emptyset_{of}$) of the outlet air from the condenser is calculated as follows

$$\emptyset_{of} = \left[\frac{P_B * g_{oc}}{(0.622 + g_{oc}) * P_{soc}}\right] \tag{9}$$

From the energy balance of the condenser, evaporator, and compressor as shown in Figure 2 is described as follows [24]

$$Q_H = Q_c = Q_{2-3} = \dot{m}_f(h_2 - h_3) \tag{10}$$

$$Q_L = Q_e = Q_{4-1} = \dot{m}_f(h_1 - h_4) \tag{11}$$

$$W_{in} = W_{1-2} = \dot{m}_f(h_1 - h_2) \tag{12}$$

The performance coefficient is shown in Figure 2 as follows [24,25]

$$COP = \frac{Q_{4-1}}{W_{1-2}} = \frac{\dot{m}_f(h_1 - h_4)}{\dot{m}_f(h_2 - h_1)} = \frac{(h_1 - h_4)}{(h_2 - h_1)} \tag{13}$$

To calculate the temperature leaving the heat exchanger as follows [26-32]

$$T_{doc} = \left(T_{dic} + \frac{Q_c}{Q_{wet} * \rho_a * Cp_a}\right) \quad (14)$$

The effectiveness of the wet bulb ($\eta_{wb}$) was calculated as follows [33]

$$\eta_{wb} = \left(\frac{T_{doc} - T_{dic}}{T_{doc} - T_{wi}}\right) \times 100 \quad (15)$$

The experimental part of this work is to study available compression refrigeration systems by adding water spray nozzles in front of the compression system condenser. These water spray nozzles consist of a circular tube with a diameter of (2.54 cm) and a length of 1.4 meters, perforated with a distance of 10 cm between each hole, and water sprinklers are installed on each hole. An electric pump was used to supply the water from the condensing container on the compressed refrigeration cycle evaporator to a water distributor mounted on the top of the compressive cycle condenser. The main parameters of the experiment are the temperatures and the amount of water accumulated on the cycle evaporator, as well as the amount of water evaporated on the cycle condenser. For this purpose, ten thermocouples linked to a data logger were installed to measure air dry and wet bulb temperatures before and after the water spray nozzles, condenser, and evaporator of the compression cycle. The amount of accumulated water resulting from water condensation on the compression cycle evaporator is also measured, as shown in Figure 3.

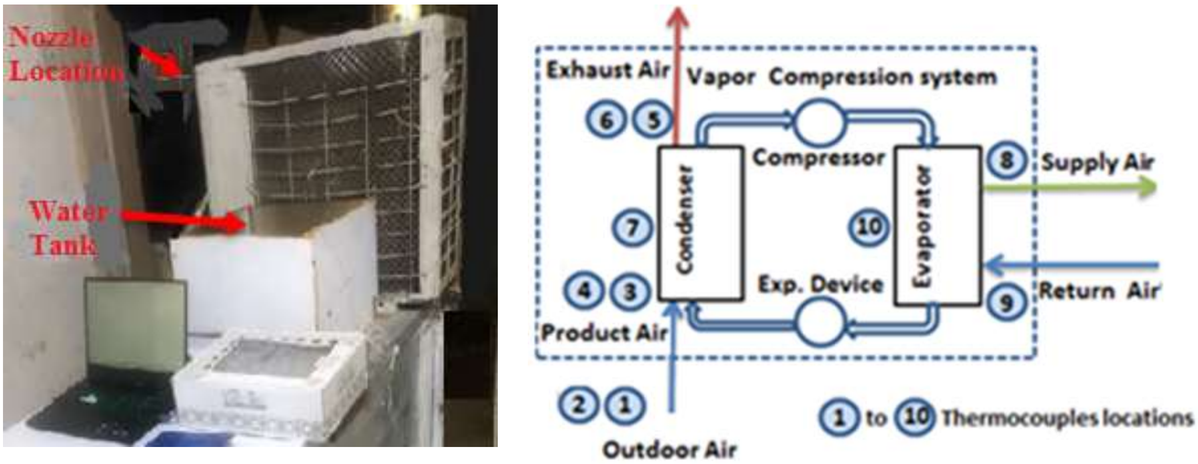

**Fig. 3.** Compression cooling cycle thermostat locations [6]

## 3. Results and Discussion

The values of temperatures, pressures, and the rate of water condensed and evaporated in the evaporator and pressure cycle condenser were measured and recorded. The performance of the compression cooling cycle was studied over the entire day after calculations were made. The hourly results for the peak hot days during July were analyzed and are shown in the following figures.

Figure 4 illustrates the diurnal variation of dry ambient air temperatures and relative humidity for the study area in central Iraq (Tikrit city) on July 10, 2023, during the summer season. It is observed that there is a significant fluctuation in the dry bulb temperature from sunrise to sunset, with the most notable difference occurring between nine in the morning and four in the afternoon. The dry bulb temperature reaches its peak during this period. Additionally, Figure 4 displays the hourly variation in relative humidity throughout July 10, 2023. The lowest values of relative humidity occur at sunrise when the dry bulb temperature is typically at its minimum. The relative humidity increases after sunrise due to the evaporation of condensed water at night. Subsequently, the relative humidity begins to decrease, reaching its minimum value after midday. It then increases again during the end of the day and the beginning of the night. It appears that the climatic conditions in the study area are relatively dry. Therefore, activating the evaporative cooling system through direct water spraying is effective during daylight hours.

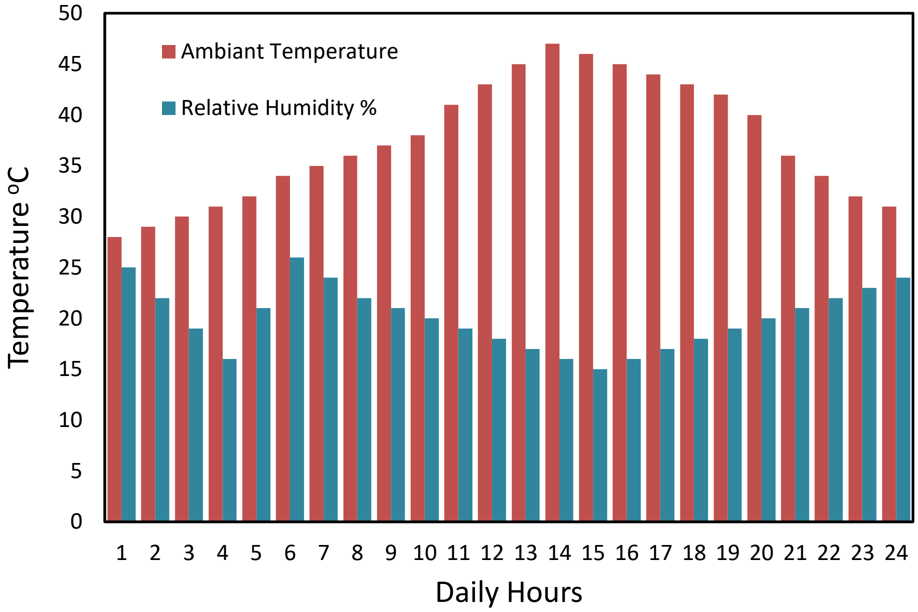

**Fig. 4.** Daily ambient temperature and relative humidity variability in July, 10, 2023

Figure 5 depicts the variation in the evaporation rate of water sprayed on a compression cycle condenser for the ambient air dry bulb temperatures at different inlet air wet bulb temperatures. The curve shapes indicate that as the inlet air wet bulb temperature decreases, corresponding to an increase in relative humidity, the water evaporation rate decreases across different inlet air dry bulb temperatures. With increasing relative humidity, the rate of water evaporation decreases due to the reduced difference between the pressure and the saturation pressure of the air in contact with the condenser fins. This decrease in the pressure gradient leads to a reduced rate of water evaporation on the fins. When the relative humidity of the ambient air increases as the outside air temperature rises, the effect of evaporative cooling decreases. In the process of evaporative cooling through direct water spraying, the rate of water evaporation decreases with an increase in ambient air dry bulb temperature and relative humidity.

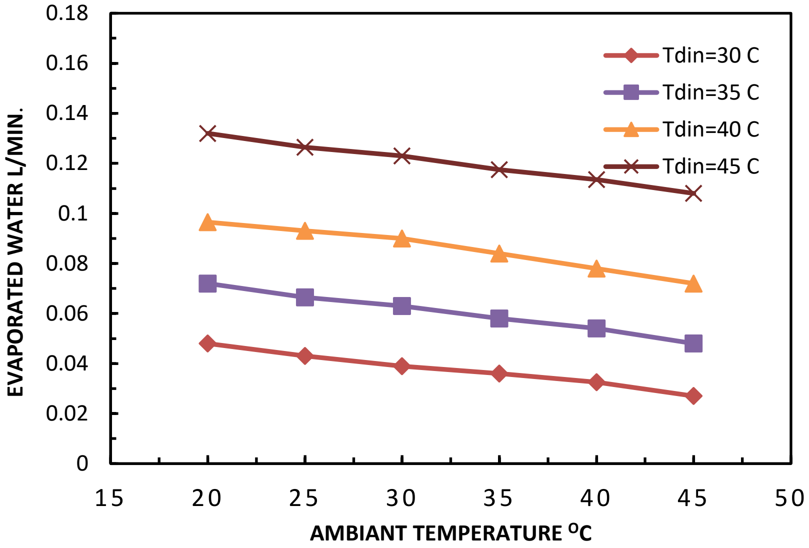

**Fig. 5.** The variation of relative humidity with the evaporation rate of spray water

The variation of the cooling capacity resulting from water evaporation with the air relative humidity entering the compression cooling cycle condenser at different dry bulb temperatures is shown in Figure 6. It is clear from the curves that the cooling capacity decreases with increasing air relative humidity, and the change is linear for all dry-bulb temperatures. Evaporative cooling capacity is based on the evaporation of water from the total wetted surface area of the compression cycle condenser, which is equivalent to the latent heat required to evaporate the sprayed water. This drawn heat cools the air entering the condenser and lowers its temperature. This amount of heat is the same as the amount of latent heat dissipated from the outer surface area of the condenser.

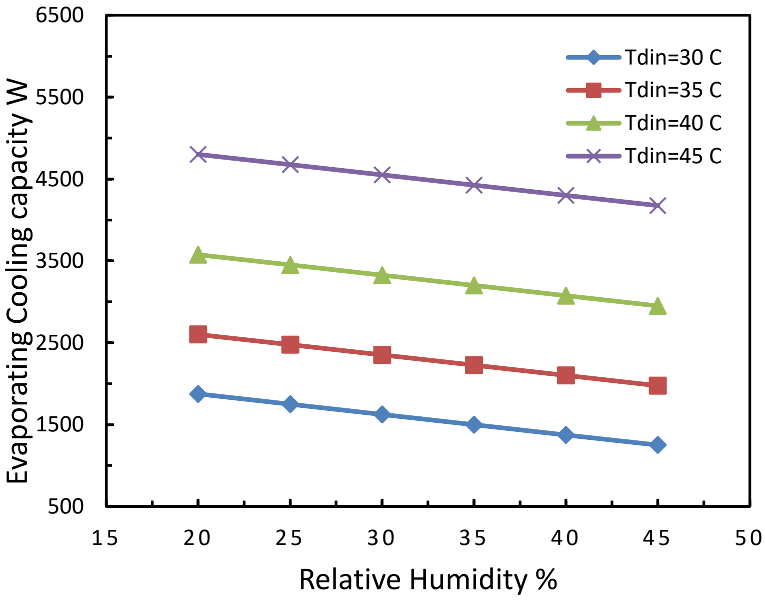

**Fig. 6.** Variation of relative humidity with cooling capacity of spray water

Figure 7 shows the variation in wet bulb effectiveness with the relative humidity of the air entering the compression cycle condenser when the dry bulb temperatures of the ambient air change during daylight hours. Wet bulb effectiveness increases with increasing relative air humidity, and this increase is linear with the changes in dry bulb ambient air temperatures. This is caused by the large difference between the wet bulb temperature and the saturation temperature of the air on the surface of the pressure cycle condenser, which results in an increase in the effectiveness of the wet bulb, which affects the rate of water evaporation from the surface of the condenser. This gives a clear impression that when the relative humidity increases, the effectiveness of the wet bulb also increases, and therefore in evaporative cooling the wet bulb effectiveness of the wet condenser surface increases due to the increase in relative humidity for all dry bulb temperatures.

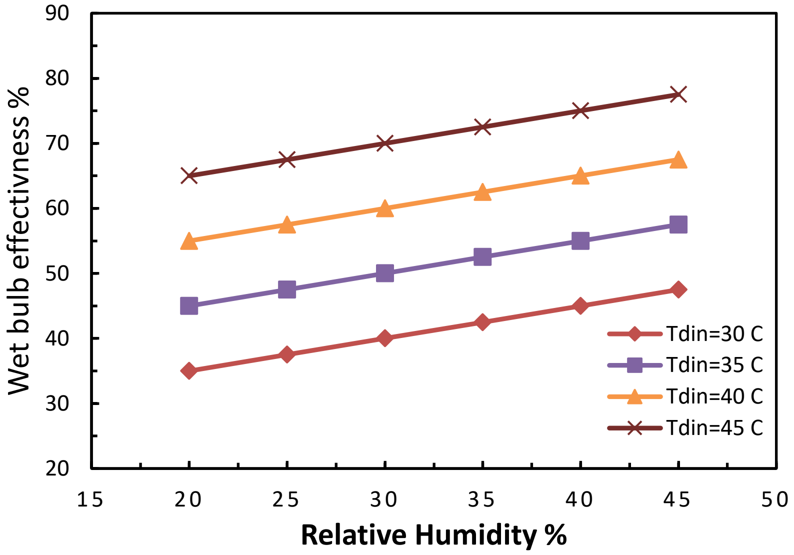

**Fig. 7.** The relative humidity variation with wet bulb effectiveness

Figure 8 illustrates the variation of the Coefficient of Performance (COP) with ambient air dry bulb temperature passing through the compression cooling condenser under normal conditions, as well as with evaporative cooling methods employing a wet pad and water spray. In general, it can be observed that the Coefficient of Performance (COP) decreases as the external ambient temperature increases. The COP increases by reducing the external ambient temperature using evaporative cooling, whether through a wet pad or water spraying [5]. However, the improvement in its value is greater with water spraying than with the wet pad because evaporation occurs more efficiently with a large flow of air in contact with the surface of the water droplets on the condenser fins. Direct spraying of cold water onto the compression cycle condenser assistances to reduce the temperature. It thus contributes to improving the Coefficient of Performance (COP) by up to 18% compared to normal conditions. It is also possible to expand the study to include an investigation into the extent of the effect of evaporative cooling in tropical and humid regions, demonstrating its impact on improving the coefficient of performance of the compression cooling cycle.

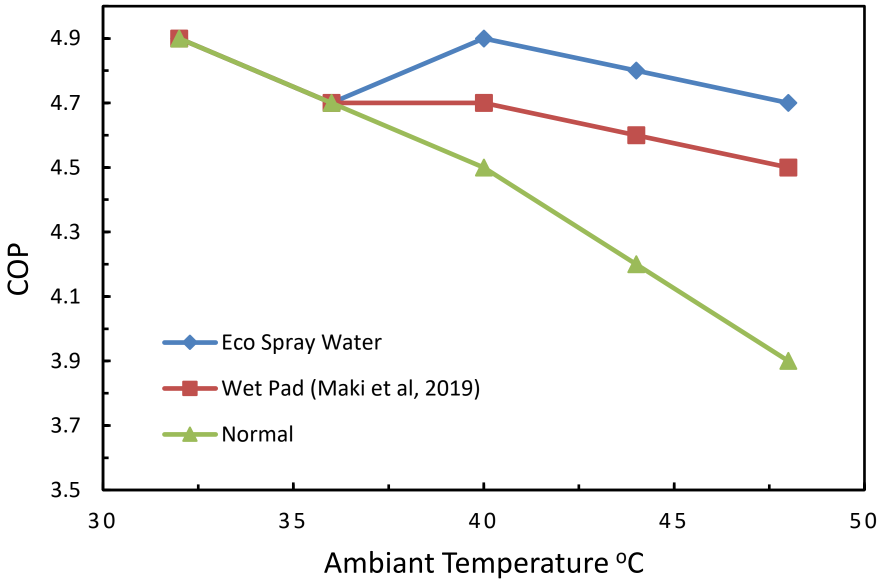

**Fig. 8.** Effect of ambient temperature on coefficient of performance

## 4. Conclusion

The performance of the compression refrigeration cycle was evaluated under realistic operating conditions to enhance the coefficient of performance and reduce energy consumption. This was achieved by incorporating a water spray as an additional cooling unit for the condenser of the compression refrigeration cycle in a desert climate. The results indicated that it is possible to reduce energy consumption and increase the coefficient of performance by more than 18% when the ambient air temperature exceeds 35°C.

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