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Enhancement the Performance of Compression Refrigeration Cycle by Cooling Condenser Air in Hot Climate

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ABSTRACT: The present work, an experimental study has been carried out to investigate the effect of cooling condenser air to the performance of vapor compression refrigeration cycle, which decreases in coefficient of performance because of the increase in ambient air temperature. The experiment rig was constructed by using aluminum box contain the outdoor of spilt unit and evaporative cooling pad that pour water on it from the water tank by small water pump and rubber tube, to evaporative cooling for air which cooling the condenser cycle. The experimental thermal results proved that this method is successful to decrease air temperature that lead to cooling the condenser and decrease the presser and temperature of the refrigerant and lead to improve all the properties of the cycle. The coefficient of performance of the system is enhancing in a rate of 39% as a result of increase the refrigeration effect and decrease the compressor work in a rate of 18% and 34% respectively. The decrease in temperature of exit air from condenser by evaporative cooling compare with dry condenser air and the ambient in a rate of 46% and 29.5% respectively. The consumption of electric power decreased in a rate of (25-32) % compared with dry system.

INTRODUCTION

Refrigeration system conserve the temperature of the heat source under that of its surroundings by refrigerant evaporator, and transferring the extracted heat and any input energy requirement to the heat sink such as ambient air or water by condenser [1]. The construction sector represents a large proportion of energy consumption in most countries. HVAC systems account for up to 60% of energy consumption in local buildings [2]. The condenser cooled by air (fin and tube heat exchangers) are the most widespread class for low and average refrigeration capacities because the air (cooling medium) is a natural and free source [3].Electric power consumption and the coefficient of performance of the refrigeration systems are a main interest. The concern is increased much more if the condenser cooled by air in high temperature climate. The condenser temperature cooled by air is directly depended on the temperature of ambient air, therefore, in the area with very hot ambient temperature in summer; the temperature and pressure of the condenser are increased considerably, which consequently increases the work consumption of the refrigeration system because of the increase the pressure ratio. Increase the pressure so much may lead to pressure control system in the refrigeration system is shut down the compressor [4].

The condenser cooled by evaporation air cooled, increases in the heat rejection process with the refrigeration effect of evaporator and therefore improve coefficient of performance, Sharma et al. [5]. By using evaporative cooling condenser, the power consumption decreased up to 20 % and coefficient of performance increased in a rat of 50%. There are two common devices for cooling air inter to the condensers are mist generators and evaporative coolers, Yu et al [6]. Depending on weather conditions, the evaporative coolers can be enhance the refrigeration effect and coefficient of performance at various degrees. With evaporative air-cooled condenser, the refrigeration effect increased up to 17.5%, and the compressor power consumption decrease below of 15.5%, Torgal et al. [7]. The water mist application for condenser, can be increase the coefficint of performance up to 37%, mostly when the relative humidity of the ambient is low. The experiment result on air-conditioner test rig increase the coefficient of performance for the system in a rat of 39.04%, by spray of water on condenser and decrease the condenser temperature by the evaporative cooling effect. Yadav et al. [8]. Adel et al. [9] presented an experimental study to enhance the performance of a small air-condition rig by direct evaporative cooling method to cool condenser air. The result showed enhancement in the performance of system by increased the refrigeration effect in the range of 5- 7.5% and decrease in electric current by 0.12 - 0.16 for each temperature degree reduction. Can be improved the performance of refrigeration system by provide the evaporative cooling effect by spray the water on condenser. The present work, cooling the air by evaporative cooling without teach the water to condenser fins and pipe to keep it from corrosion and calcification by a simple and economical design.

EXPERIMENTAL SETUP

The experimental setup, shown in Fig. (1), was designed and manufactured in this work. The vapour compression cycle was represented in this test by split unit device, one refrigeration tone, rotary compressor 1500 W, 220 V and R-22 refrigerant fluid. The outdoor unit dimensions are (55×80×25) cm^3. Condenser dimensions are (53×85×2) cm^3, pipe diameter is (0.78 cm). A new technique was employed by mead aluminum case include the split unit and evaporating cooling pad to don the evaporating cooling for the split unit condenser. A cubic water tank made from galvanized plate of (0.9 mm) thickness was used. The tank dimensions are (50×50×100) cm^3, preparation the water to the evaporating cooling pad by water pump.

Figure 1: Experimental setup system with measuring device.

Refrigeration gas pressure gauges were connected with main point of refrigeration cycle section, discharge, after condenser and after expansion valve to determine gas case, as shown in figure (2). Schematic diagram of the experimental rig with measurement devises and thermocouples and pressure location are shown in figure (3).

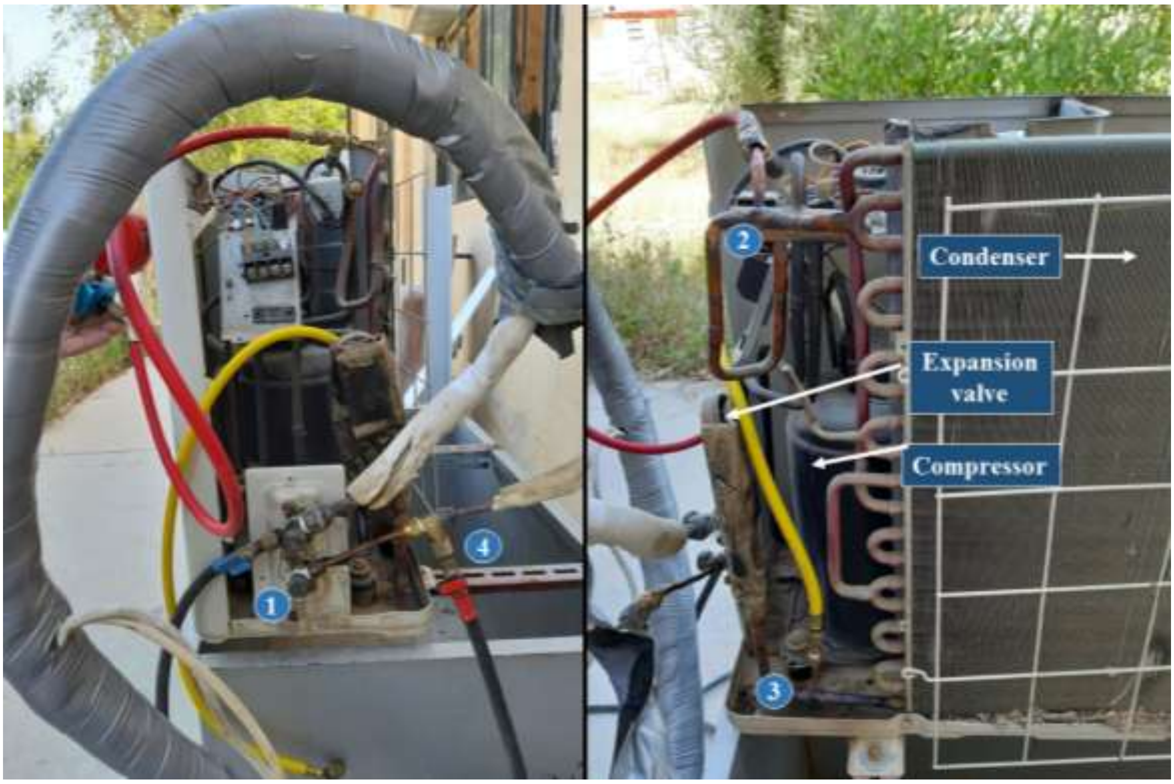

Figure 2: Gas gauge pressure location.

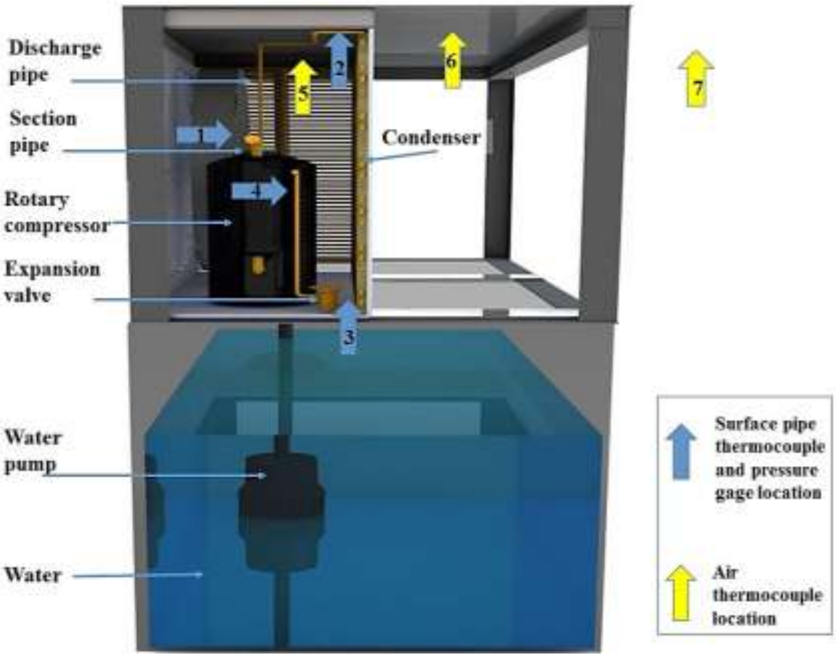

Figure 3: Experimental setup with thermocouples and pressure location.

THEORETICAL MODEL

The ideal vapour compression refrigeration cycle, schematic diagram and *p-h* diagram as shows in figure (4).

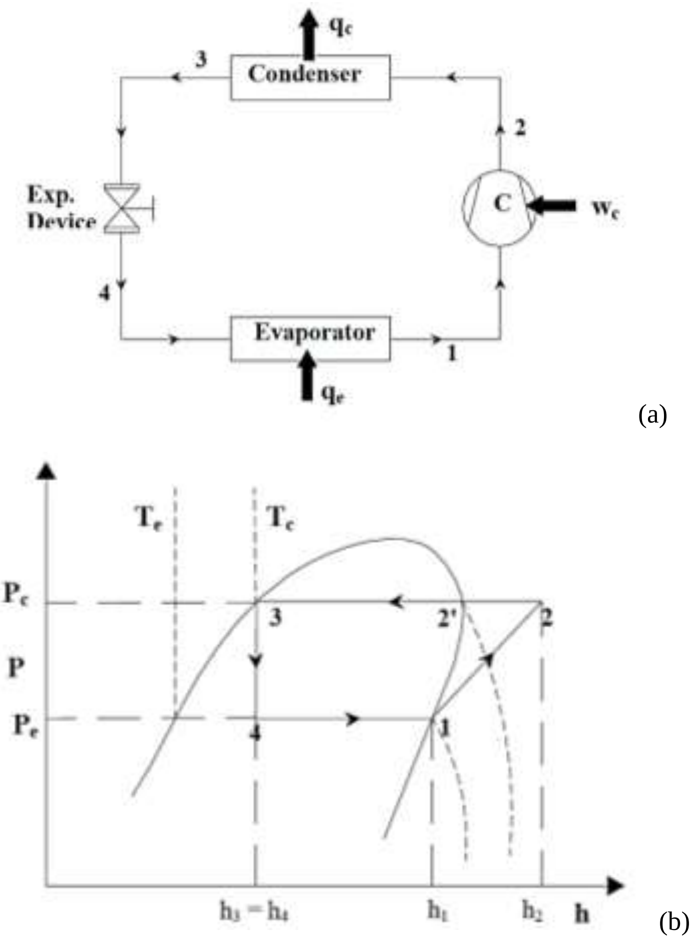

Figure 4: Ideal vapour compression refrigeration cycle: (*a*) schematic diagram, (*b*) *p*-*h* diagram.

The process between points 4 and 1, there is no work done during evaporation and very small change of kinetic energy and it is usually neglected. The refrigeration effect can be determined as:

$$q_{ref} = q_{4-1} = h_1 - h_4 \quad \text{(kJ/kg)} \tag{1}$$

h_1, h_4 = refrigerant enthalpy at points 1 and 4, respectively, kJ/kg

q_{ref} = heat supplied of working substance during evaporation process, kJ/kg

For points 1 and 2 the isentropic compression process, work input to the compressor W_{in} is determined as:

$$W_{in} = h_2 - h_1 \quad \text{(kJ/kg)} \tag{2}$$

The heat rejected for condensation process between points 2 and 3 q_{rej} is calculated as:

$$q_{rej} = -q_{2-3} = h_2 - h_3 \quad \text{(kJ/kg)} \tag{3}$$

The throttling process done between points 3 and 4 and assuming that no heat loss during the process.

$$h_3 = h_4 \tag{4}$$

Accordingly, the coefficient of performance (COP) of the ideal vapour compression refrigeration cycle is:

$$COP = \frac{\text{Refrigeration Effect}}{\text{Work Input}} = \frac{q_{ref}}{W_{in}} = \frac{h_1 - h_4}{h_2 - h_1} \tag{5}$$

Actual vapour compressor cycle take the same equation to calculate the refrigeration capacity, heat reject by condenser, work conception and C.O.P of the cycle with the below deferent [10].

$$W_T = W_C + W_F + W_P = V(I_C + I_F + I_P)COS\varphi \tag{6}$$

$$\text{C.O.P} = \frac{Q_r}{W_T} \tag{7}$$

Electric power consumption can be calculated by [11]:

$$P = I\ V\ COS\ \theta \tag{8}$$

P= electric power (Watt).

I= electric current (Ampere).

V= electric voltage (Volt).

$COS\ \theta$= power factor

When a water pump operates to pour water, the ambient air dry bulb temperature Tdb1, follows the cooling adiabatic process and decrease to Tdb2. The humidity ratio of air is increased from Wdb1 to Wdb**2**, this is dependent on air mass flow rate and pour water flow rate as given by [12]:

$$mmist = \rho a Vcd\ \Delta W \tag{9}$$

Where: ρa is the air density (kg/m^3) and Vcd is volumetric flow rate of the condenser fan (m^3/s).

And ΔW is the difference between humidity ratio (ΔW= Wdb**2** – Wdb1), water vapor to air mass ratio (kg_v/kg_a)

RESULTS AND DISCUSSION

Temperature

The main factor affecting to the performance of the system is the temperature of the air that cooled the system condenser. Therefore, the air condenser was cooled by evaporative cooling and the air exit from the condenser and surface pipe temperature was measured, for the cooled and dry condenser and compared between them in the same conditions.

Air Condenser Temperature

Figure (5) shows the significant drop in temperature for the exit air temperature (T5) by evaporative cooling compare with dry condenser air and the ambient in a rate of 46% and 29.5% respectively. The decrease is evident in the temperature of the air leaving the condenser, although it absorbs the heat of the condenser, indicating that the cooling method is sufficient for this system, it can be used at high ambient temperatures.

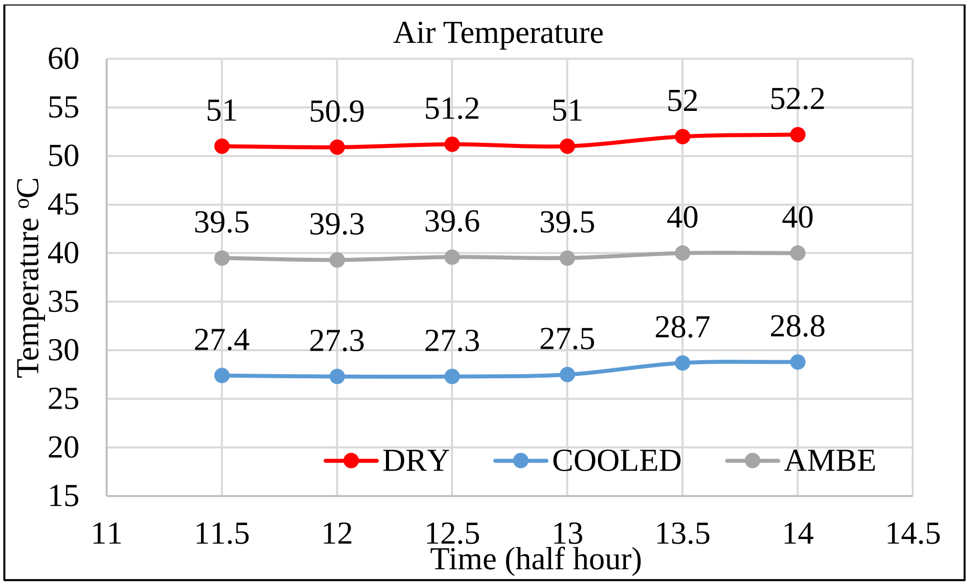

Figure 5: Exit air (T5) and ambient temperature.

Pipe Surface Temperature

The pipe surface temperature was measured at the main point of refrigeration cycle, which represent refrigerant temperature and compared between the dry condenser and cooling condenser. T2 and T3 represent entry and exit point for condenser respectively, the cooling air effect to the condenser temperature and lead to decrease the cooled point temperature compared with dry in a rate of 13.5% for T2 and 44% for T3, as shown in figures (6) and (7).

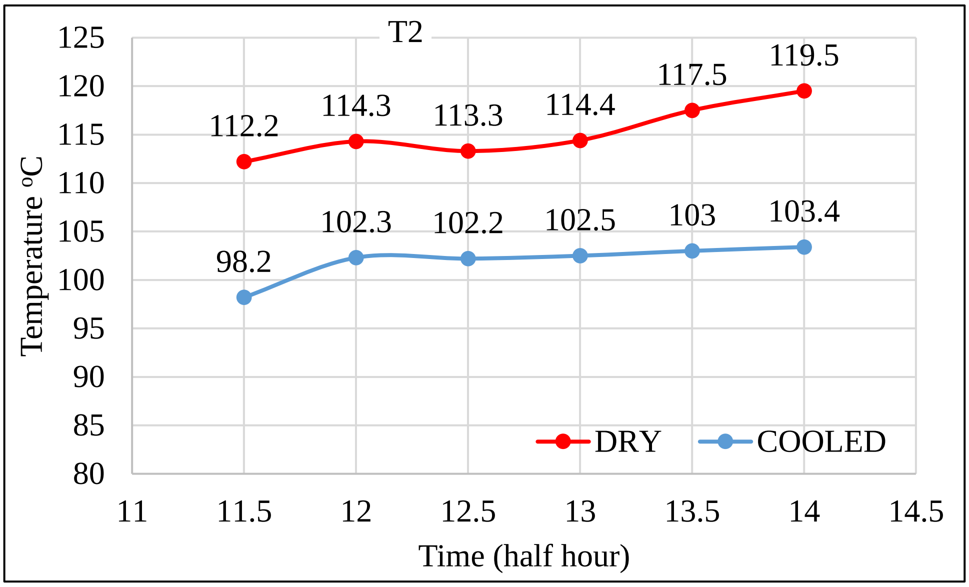

Figure 6: Entry condenser temperature (T2).

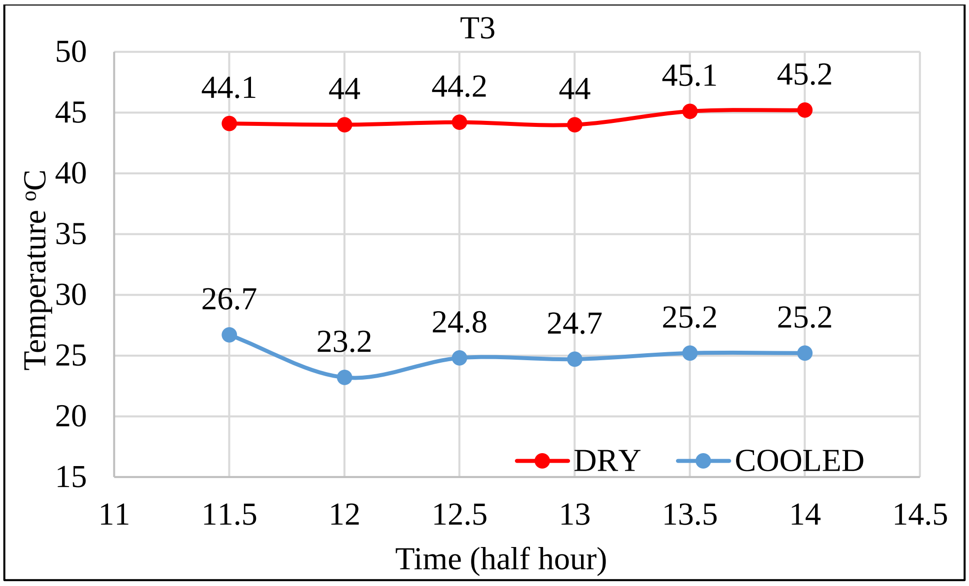

Figure 7: Exit condenser temperature (T3).

T4 represent the expansion valve outlet, it is effect by decrease the condenser outlet temperature and if it saturated or subcooled. In cooled cycle get decrease this temperature compare with dry cycle in a rate of 34%, because subcooled condition is done that lead to decrease the temperature and presser for refrigerant, as shown in figure (8).

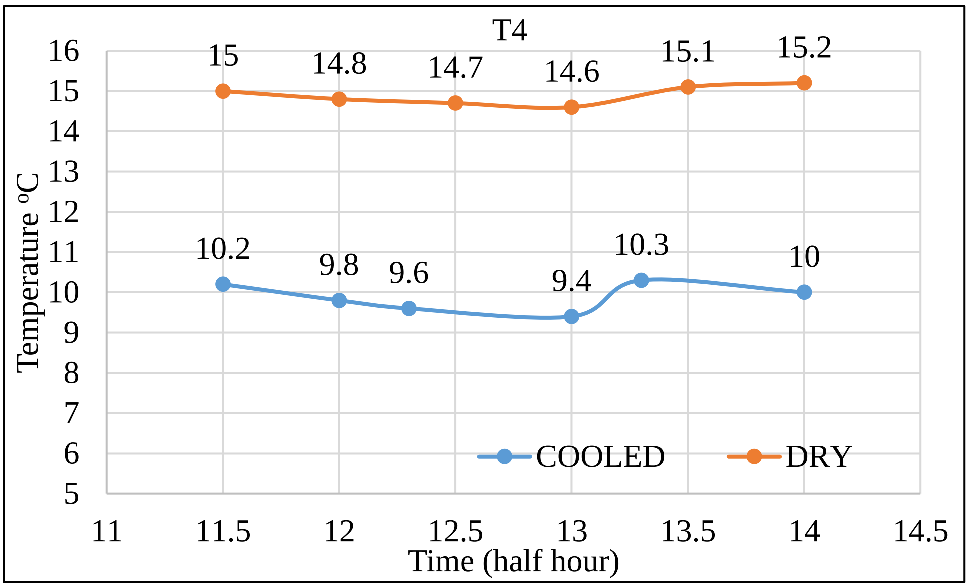

Figure 8: Exit expansion valve temperature (T4).

P-H Diagram

To study the refrigeration cycle should be draw the cycle on the p-h diagram. In this study, tow cycle was drawn to compare between them. Figure (9) shows the dry cycle is high condenser pressure lead to done high work noted the distance between points (1 and 2) compare with cooled cycle. Refrigeration effect that represented by the distance between points (1 and 4), dry cycle lees refrigerant effect than cooled cycle because subcooled effect in cooled cycle that done by cooling condenser. The diagram shows a significant improvement in all characteristics of cooled cycle.

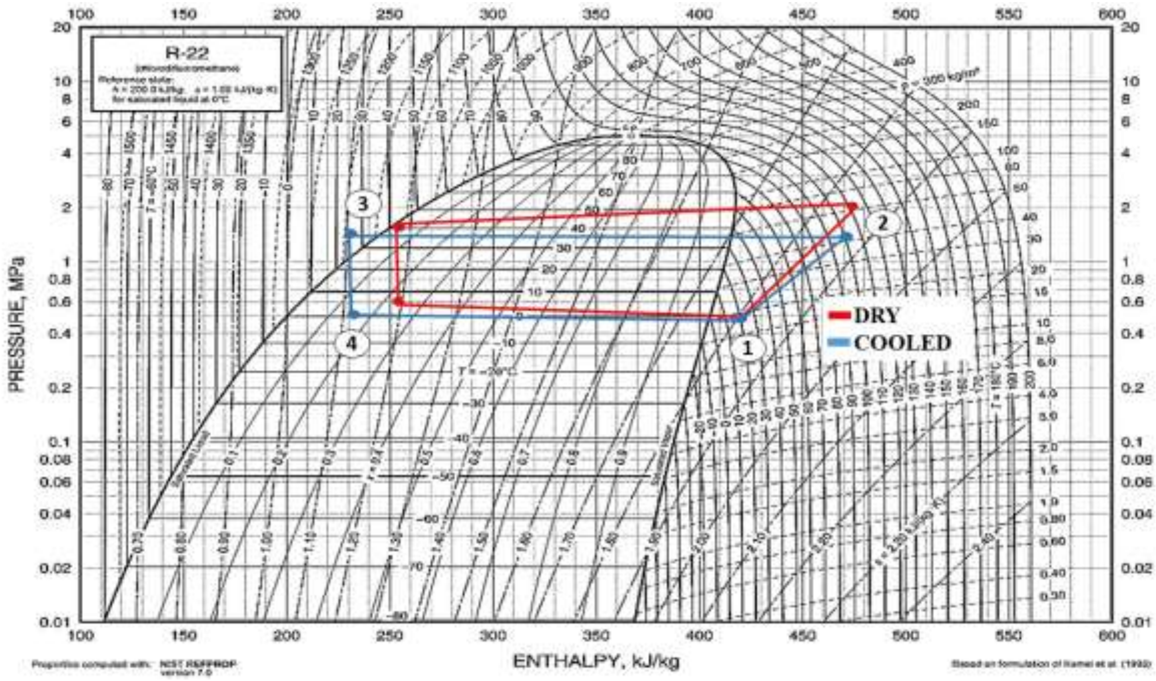

Figure 9: P-h diagram of two cycles.

Refrigeration Effect

After calculate the refrigeration effect for two cycles, the results show that increase in cooled cycle compare with dry cycle in a rate of 18% as a result of decrease pressure and temperature in points (1 and 4) on p-h diagram. That lead to decrease the enthalpy especially at point 4, the refrigerant starts to evaporate (due to the occurrence of subcooled), and when the enthalpy is low, the greater the refrigeration capacity, as shown in figure (10). The variation in the refrigeration effect graph is due to the different heat load because the test was not made in an isolated laboratory room.

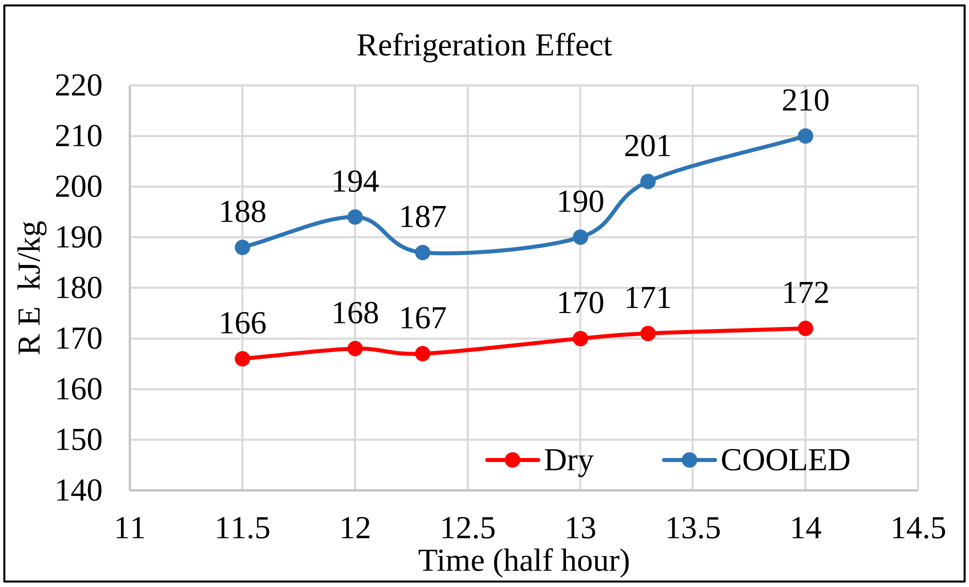

Figure 10: Refrigeration effect.

Work Consumption

The system work consumption for cooled cycle was improved as result of decrease discharge pressure and temperature by cooling condenser that lead to reduce pressure ratio and the deferent between enthalpy at point 2 and 1 on p-h diagram, then reduce work consumption in a rate of (34-26) %, as shown in figure (11).

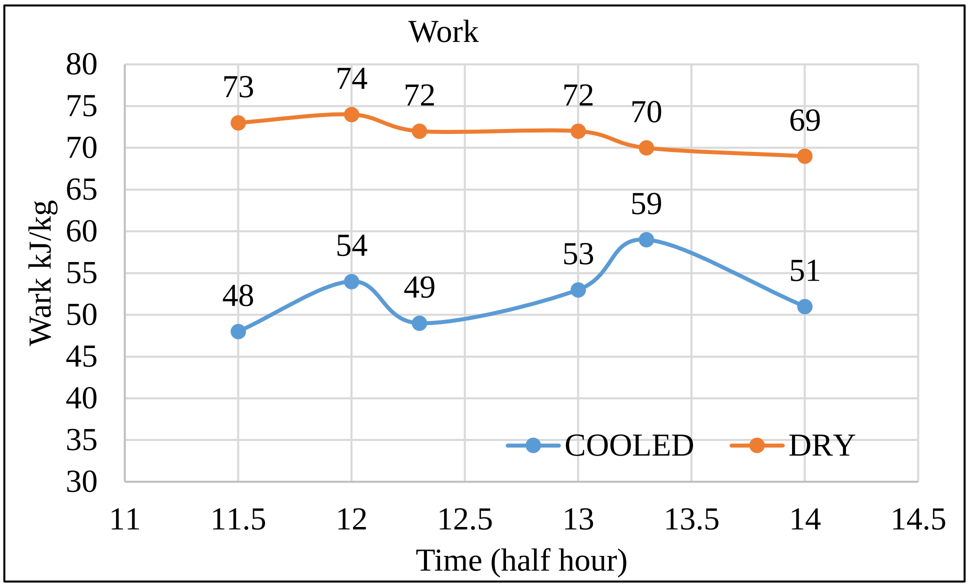

Figure 11: Work consumption.

C.O.P

From the previous work fiend, increase in the coefficient of performance of the cooled cycle more than dry cycle in a rate of 39%, as a result of increase refrigeration effect and decrease work consumption, as shown in figure (12). The apparent increase in the coefficient of performance showed the success of the method in improving the system's operation in very hot climates. The variation in the graph is due to the different in refrigeration effect because different heat load due to the fact that the test was not made in an isolated laboratory room.

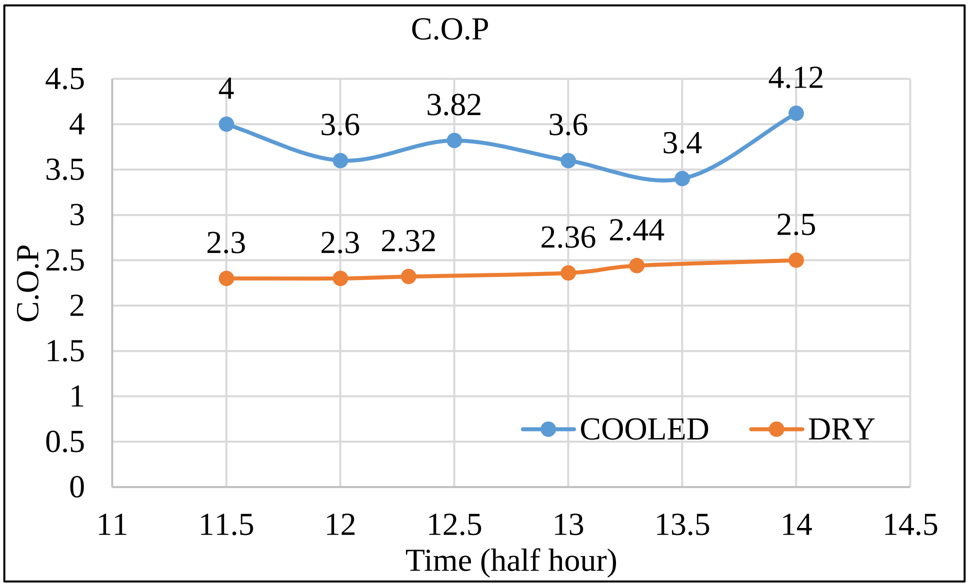

Figure 12: Coefficient of performance.

Electric Power

The consumption of electric power has been a clear change, where it decreased in a rate of (25-32) % compared with dry system, as a result of decreased in work consumption that lead to decreased the electric current, although additional electrical energy was added to the system by the water pump, as shown in figure (13).

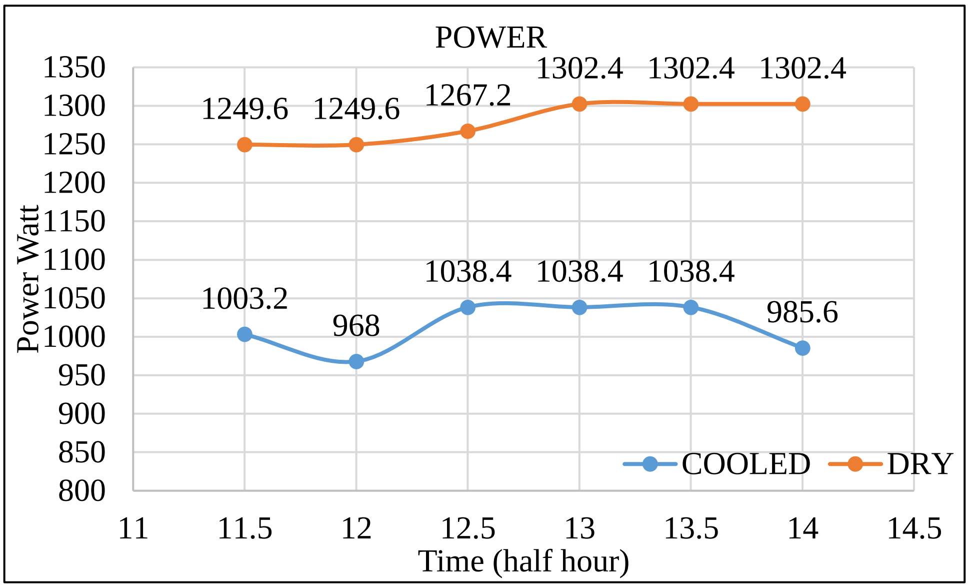

Figure 13: Electric power.

CONCLUSION

According to the previous discussion of the obtained results, the following points can be concluded:

1- The results of cooling condenser air by evaporating cooling are acceptable in all experiments compared with the dry cycle, the cooled condenser is colder than the dry condenser in a rate of 46%.
2- Refrigeration effect for cooled condenser cycle improves by 18% compared with dry condenser cycle.
3- Work consumption for cooled condenser cycle less than work for dry condenser cycle by (34-26) %.
4- Coefficient of performance for cooled condenser cycle improves by 39% more than dry condenser cycle.
5- Power consumption for cooled condenser cycle less than dry condenser cycle by (25-32) %.
6- The experiments tests were success to improve that the cooling condenser led to enhancing the performance of vapour compression refrigeration cycle and energy saving.

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