Experimental Investigation of Double Effect Evaporative Cooling Unit

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Abstract

This work presents the experimental investigation of double effect evaporative cooling unit with approximate capacity 7 kW. The unit consisted of two stages, the sensible heat exchanger and the cooling tower composing the external indirect regenerative evaporative cooling stage where a direct evaporative cooler represent the second stage. Testing results showed a maximum capacity and lowest supplied air temperature when the water flow rate in heat exchanger was 0.1 L/s. The experiment recorded the unit daily readings at two airflow rates (0.425 m^3/s, 0.48 m^3/s). The reading shows that unit inlet DBT is effect positively on unit wet bulb effectiveness and unit COP at constant humidity ratio. The air extraction ratio effected positively on the unit wet bulb effectiveness within a certain limit where maximum COP recorded 11.4 when the extraction ratio equal to 40%.

Keywords: Double effect, Evaporative cooling, Dry, Wet bulb temperature, Wet bulb effectiveness.

الخلاصة

يقدم هذه العمل التحقق التجريبي لوحدة تبريد تبخيري ذات التأثير المزدوج بسعة تقريبية 7 كيلوواط. تتكون الوحدة من مرحلتين، المبادل الحراري المحسوس وبرج التبريد يؤلفان مرحلة التبريد التبخيري الخارجي غير المباشر و يمثل المبرد التبخيري المباشر المرحلة الثانية. وأظهرت نتائج الاختبار سعة قصوى وأدنى تجهيز درجة حرارة الهواء عندما معدل تدفق ماء في المبادل الحراري يساوي 0.1 لتر / ثانية. وسجلت التجربة القراءات اليومية للوحدة بمعدلين لتدفق الهواء (0.425 م3 / ثانية، 0.48 م3 /ثانية). القراءة تظهر ان درجة حرارة البصلة الجافة الداخلة الى الوحدة تؤثر إيجابيا على فعالية البصلة الرطبة ومعامل الاداء بثبوت الرطوبة النسبية . وكذلك كانت نسبة استقطاع الهواء تؤثر إيجابيا على كفاءة البصلة الرطبة للوحدة ضمن حد معين حيث سجلت أقصى نسبة معامل اداء 11.4 عند نسبة الاستقطاع التي تساوي 40٪.

الكلمات المفتاحية: – التاثير المزدوج، التبريد التبخيري، درجة حرارة البصلة الجافة والبصلة الرطبة، كفاءة البصلة الرطبة.

Nomenclatures

c	specific heat at constant pressure , (kJ/kg. k)
h	enthalpy,(kJ/kg)
$\dot{m}$	mass flow rate, (kg/s)
Q	cooling capacity of evaporative cooler, (kW)
t	temperature, (°C)
u	air velocity , (m/s)
V	volumetric flow rate, (m^3/s)
w	moisture content ,(g water/kg dry air)
W	measured total power consumption, (kW)
COP	coefficient of performance
ER	air extraction ratio (%)

Greek symbols

ρ	density, (kg/m^3)
ε	saturation effectiveness

Subscripts

w	water
db	dry bulb
wb	wet bulb
in	inlet
out	outlet

1. Introduction

Many countries suffering from the problem of high dry bulb temperatures in summer season, which carries the burdens of high power demand of air condition equipment's. Large percentage of power burdens can be solved by using evaporative cooling technology.The effective of evaporative cooling is depending on the advantage of the large deference between the dry bulb temperature and the wet bulb temperature which can use positively in evaporative cooling system. Iraq is one of these countries that have desert climate and characterized by summer high dry bulb temperature and dryness, also long summer period that could spans for seven months from April to October 2017, the day time often exceed 49 °C with average daily temperature over 37°C in most of summer season, as a results large amount of the power consumption is for air conditioning (A/C).

Many researches investigate the performance of two stages evaporative cooling, (Datta *et.al.,* 1987) studied experimentally an 8.5 ton cooling system consist of indirect-direct evaporative cooling and reported that such a system provides a relief cooling rather than comfort cooling. The room could be kept at 4-5 ºC above the inlet wet-bulb temperature by using such a cooler. (Navon and Arkin, 1994) studies the capability of using indirect-direct evaporative cooling for residential uses in arid regions of Palestine. The system showed the ability of providing higher level of thermal comfort wherever external humidity is around 80%. (El-Dessouky *et.al.,* 2000) developed a membrane air dryer and coupled with conventional direct- indirect evaporative cooler. The membrane drier removes the moisture from the entering air, the air able to be cooled to lower temperature by the subsequent evaporative cooler. By using such a system, a reasonable cooling has been obtained. When a such system combined with mechanical vapor compression system to reach to perfect thermal conditions, almost 50 % electricity savings are obtained. (Gomez *et.al.,* 2005) developed a ceramic evaporative cooling system which worked as a semi-indirect cooler. The water that cooled in a cooling tower is passed from the annulus passage of the ceramic tubes. The outside air is passed through a central region. The Chilled water evaporates by seeping through ceramic pores. Such a system permits indoor air recirculation, which is impossible in the conventional evaporative cooling system. Using of such system is experimentally verified and 5-12 ºC temperatures drop is obtained under various conditions. (Jain, 2007) tested and developed a two-stage evaporative cooler. The researcher tries to improve the efficiency of evaporative cooling for high humidity and low temperature air conditioning; such a cooling system could provide necessary comfort even with high outside humidity. The performance of cooler has been evaluated in terms of temperature drop, efficiency of the evaporative cooling and effectiveness of two stage evaporative cooling over single evaporation, Efficiency of single evaporation was 85–90%. Effectiveness of the two-stage evaporative cooling was found to be 1.1–1.2 over single evaporation. (Riangvilaikul and Kumar, 2010) developed by and tested experimentally a novel dew point evaporative cooling system for sensible cooling of ventilation air. The reported Wet bulb effectiveness was 92%-114% and the reported dew point effectiveness 58-84 %. (Heidarinejad *et.al.,* 2010) studied a ground assisted hybrid evaporative cooling system in Tehran city. The ground coupled circuit delivers necessary pre-cooling effects. The Simulation studies have shown that 100-110 % cooling effectiveness can provide by such a hybrid system. (El-Dessouky *et.al.,* 2004) studied the performance analysis of two stage evaporative coolers. The operated system as a function of the packaging Thickness and the flow rate of water of the direct evaporative cooling unit. The efficiency of indirect and direct evaporative cooling units when operated individually where found to be 20%-40 % and 63%-93 % respectively, whereas the efficiency of two stages IEC/DEC varied over a range of 90%-120%. (Heidarinejad *et.al.*, 2009) studied the cooling performance of two stage indirect / direct evaporative cooling experimentally under various virtual climatic conditions. The cooling effectiveness of indirect evaporative cooling in the range of 55%-61% and that of indirect / direct evaporative cooling of 108%-111 % are reported in varying climatic conditions. Such system founded to be better for the hot and humid climates.

The aim of this research is constructing and testing of double effect evaporative cooling unit used to produce fresh, cooler air with less humidity than normal direct evaporative cooling unit and consequently decrease the energy demand in the hot climate area (Iraq) that facing the problem of high energy demand used for cooling purposes.

2. Test Rig Deletion and Construction

In order to test the proposed of improving of the double effect evaporative cooling the prototype of the system has been designed and constructed in Baghdad. The test set up had to be of a sufficient scale to insure that the experimental results could be extrapolated to larger systems. The system layout is shown in Figure (1) and (2). The components describe as follows.

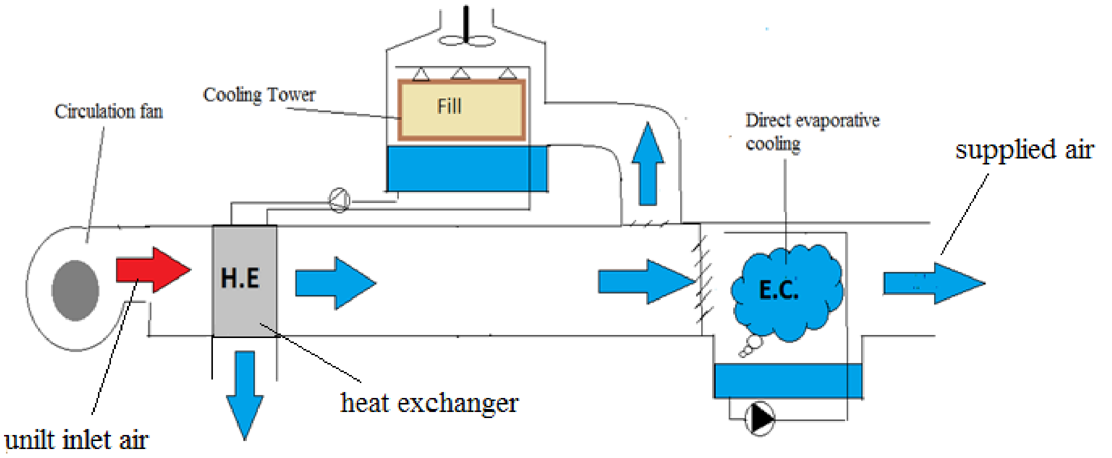

Figure (1) Combined system layout

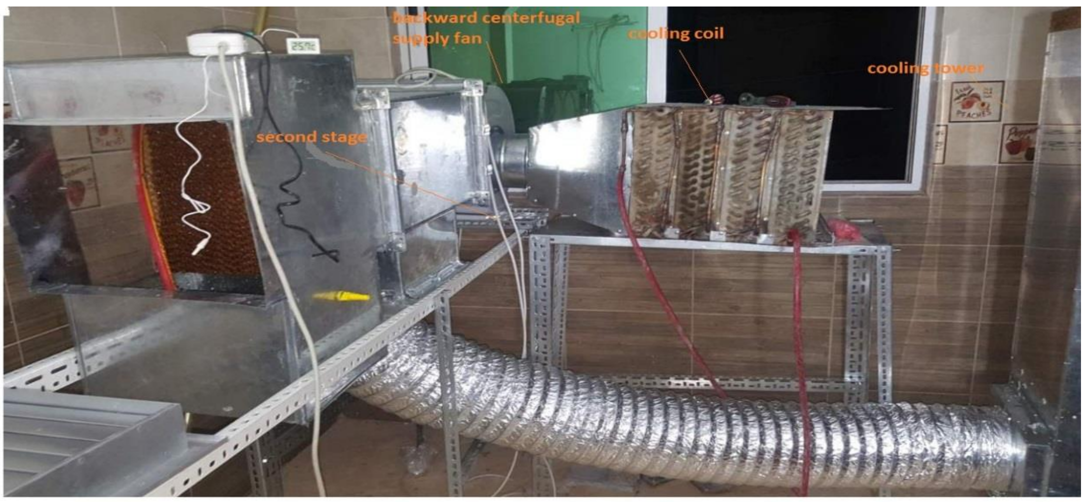

Figure (2) Photographs of the system

3.1 Indirect evaporative regenerative section

The first stage of constructed unit is the indirect regenerative evaporative cooling system; Figure (3) illustrates the external regenerative indirect evaporative cooling. Which depending on producing cold water from cooling tower that used a part of air that has been already cooled by the heat exchanger, the heat exchanger used the supplied cold water that supplied from the cooling tower to cool outside fresh air; Table (1) shows the used heat exchanger parameters.

The indirect evaporative regenerative cooling part consists of:

a) The quasi – counter flow heat exchanger to cool the fresh air.
b) Counter flow induced Water cooling tower.
c) Water circulation system (pump, piping).

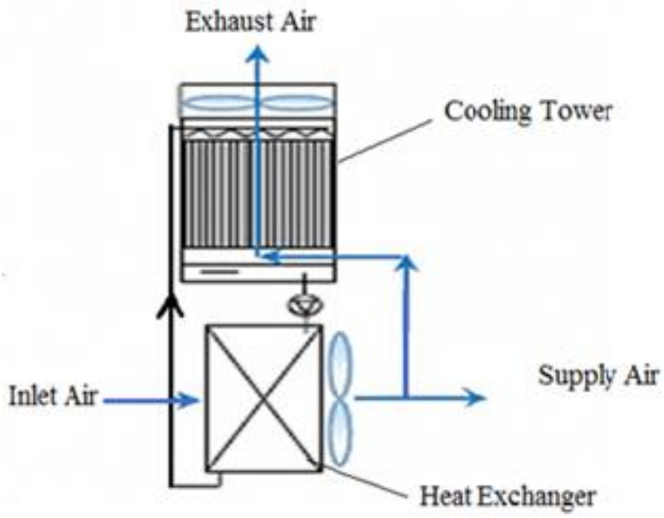

Figure (3) external regenerative indirect evaporative cooling

Table (1) heat exchanger parameters

Parameter	Value
Outside tube diameter,	do = 12.7 mm
Inside tube diameter,	di = 12 mm
Longitudinal tube spacing,	SL = 26.16 mm
Transverse tube spacing,	ST = 31.75 mm
No. of fins	Nf = 352
Aluminum fin thickness,	Tf = 0.2 mm
Number of tube Rows	Nr = 16
Number of tubes passes per row	Np= 16

3.2: Direct evaporative cooling section

The direct evaporative part shown in figure (4) is consists of three main parts:

a) Water collection basin

The direct evaporative cooling water basin is collecting the cold water that fill down from the cooling pad, the basin is sized by 0.4 m × 0.3 m and has a total height of 20cm , equipped with fresh water feeder via float valve to controlling the amount of feeding water.

b) Evaporative cooling pad

The CELdek Cellulose evaporative cooling pad is selected, the size of Cellulose evaporative cooling pad is sized by 40cm × 40cm and 5 cm thickness, and can be increase to 10 cm.

c) Water pump and water distribution

The water pump with maximum water flow rate (Q max =1400 L/h) and maximum head (H=3 m) were used to circulate the water from the basin to sprayers by connected plastic water hose, water sprayers is made from plastic tube has a length of 40 cm and with 13mm diameter closed from one end and connected to water pump via plastic water hose, a holes of 1 mm diameters spacing of 2mm made along the plastic tube.

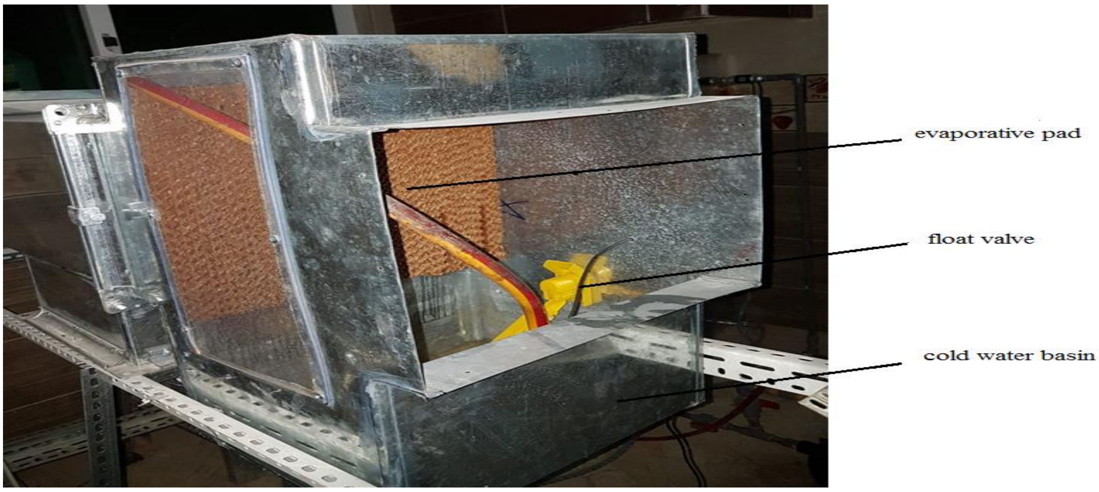

Figure (4) direct evaporative section

4.1 Measuring Instruments

A collection of calibrated measures instrument were used to measure temperature, humidity, water flow and air flow rate.

a) Digital Hygrometer & Thermometer instrument

This instrument used to measure the air dry bulb temperature and relative humidity at different locations, figure (5) shows the digital air Hygrometer & Thermometer instrument.

Figure (5) Digital Air Hygrometer & Thermometer

b) Digital Thermometer

This digital thermometer with mini LCD used to read the inlet and outlet water temperature of the cooling tower also water temperature in the water basin in direct evaporative cooling section.

c) Digital Air flow meter

This kit used to measuring airflow rate in unit inlet and outlet and existing air from the cooling tower. Figure (7) show the used digital air anemometer.

Figure (7) digital air anemometer.

d) Digital water flow meter

Digital water flow meter used to measure the water flow rate between cooling tower and heat exchanger, Figure (8) shows the water flow meter.

Figure (8) the used water flow meter.

4.2 Performance Parameters

IEC/DEC standards indicated that the performance of an IEC/DEC system could be represented by several characteristic parameters including (1) wet-bulb effectiveness; (2) cooling capacity; (3) power consumption; (4) energy efficiency (COP) (5) air extraction ratio; and (6) air flow rate. These are detailed as follows:

1- Wet-bulb effectiveness

Wet bulb effectiveness is defined as a parameter describing the extent approach of the outlet product air temperature against the wet-bulb temperature of the unit inlet air, and can be written as:

$$\varepsilon_{wb} = \frac{t_{db,in} - t_{db,out}}{t_{db.in} - t_{wb,in}} \quad \text{.... (1)}$$

2- Cooling capacity

The cooling capacity refers to the change in enthalpy during air processing, and is expressed as follows:

$$Q_{total} = \rho_{air} V_{out} (h_{db,in} - h_{db,out}) \quad \text{.... (2)}$$

Since the air is cooled at the constant moisture content at first stage IEC throw dry heat exchanger, the enthalpy change at first stage could be represented by the temperature reduction of the air throw heat exchanger. For this reason, the above equation for first stage could be rewritten as:

$$Q = C_{air} \rho_{air} V_{out} (t_{db,in} - t_{db,out}) \quad \text{.... (3)}$$

3- Power consumption

An evaporative cooling system consumes much less electrical power than conventional refrigeration mechanical compression air conditioning systems. Unlike the conventional air conditioning systems that use electricity to drive energy intensive compressor, and fan/ pump, an evaporative cooling system uses electrical power to drive only a fan and pump. In this system, the electrical power is measured by W or kW.

4- Energy efficiency or (COP)

Energy efficiency or coefficient of performance (COP), is the ratio of the cooling capacity to the power consumption of the system. This term can be expressed as:

$$\text{Energy efficiency} = \frac{Q}{W} = \frac{C_{air} \rho_{air} V_{out} (t_{db,in} - t_{db,out})}{W} \quad \text{....(4)}$$

If COP is multiplied by a unit conversion factor of 3.413, then the COP is converted into the energy efficiency ratio (EER).

5. Results and Discussions

5.1 The effect of water flow rate between heat exchanger and cooling tower

Figure (9) shows the effect of water flow rate on the heat exchanger cooling capacity and ability to remove the heat, it can be seen that increasing in flow rate case to increases heat exchanger cooling capacity with limited range and then decline when the water flow rate exceed 0.1 L/s, this drop in heat exchanger capacity occurred due to the increasing of tower outlet water temperature is shown in figure 10 which it’s Aggravated with a higher air temperature entering to cooling tower as cleared in figure 11.

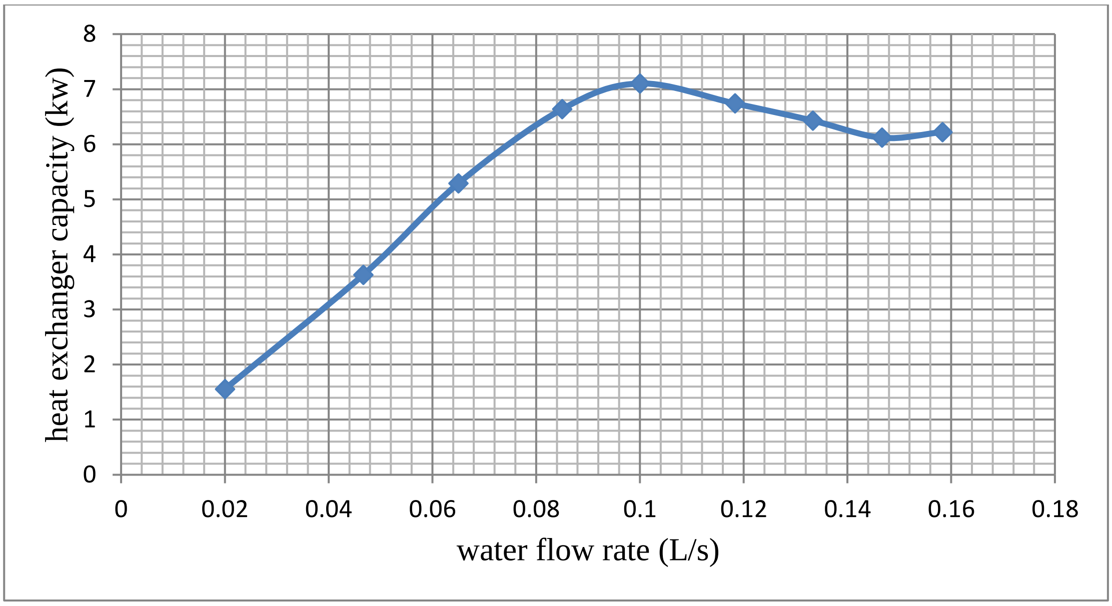

Figure (9) the heat removed from the heat exchanger with various water flow rates , (Unit Inlet DBT= 40°C , inlet WBT = 20°C , inlet volumetric air flow rate = 0.425 m^3/s ,extraction rate = 35%).

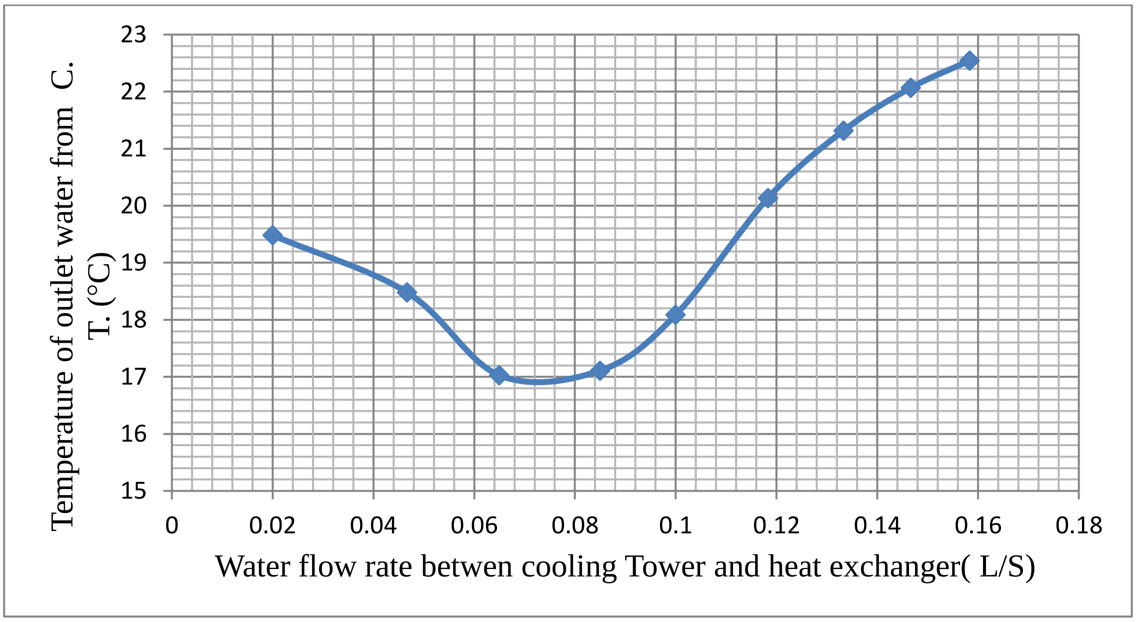

Figure (10) the effect of water flow on cooling tower Water outlet temperature (Unit Inlet DBT= 40°C, inlet WBT = 20°C, inlet volumetric air flow rate = 0.425 m^3/s, air extraction rate =35%).

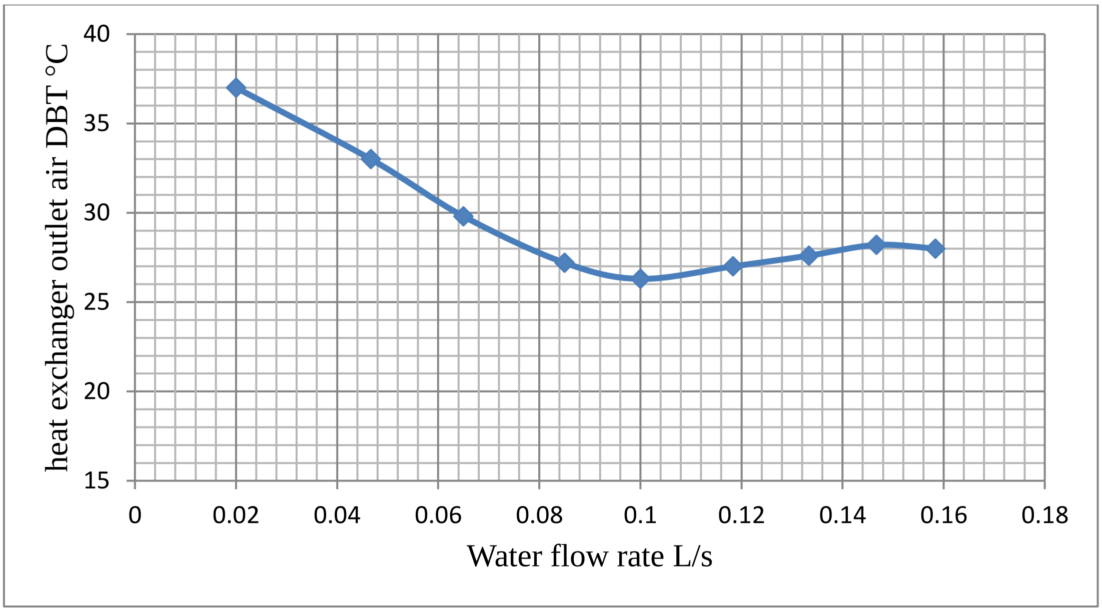

Figure (11) the effect of water flow between the cooling tower and heat exchanger on heat exchanger outlet air DBT (Unit Inlet DBT= 40°C, inlet WBT = 20°C, inlet volumetric air flow rate = 0.425 m^3/s, extraction rate = 35%).

5-2 The effect of Unit inlet air flow rate

In order to test the effect of inlet air flow rate to the system on the double effect evaporative unit, two conditions of flow rates were tested (0.425 m^3/s, 0.48 m^3/s). as shown in Figure (12) and Figure (13) It can be depict that the increasing of inlet air flow rate led to Increasing the first stage outlet air temperature due to two effects, first the effect is the increasing of amount of air which led to decreasing the time of heat exchange with heat exchanger, second effect is the increasing in the temperature of the outlet water of cooling tower water because the in air DBT that entering to cooling tower. Increasing the unit supplied air DBT temperature due to the increasing of second stage inlet air DBT.

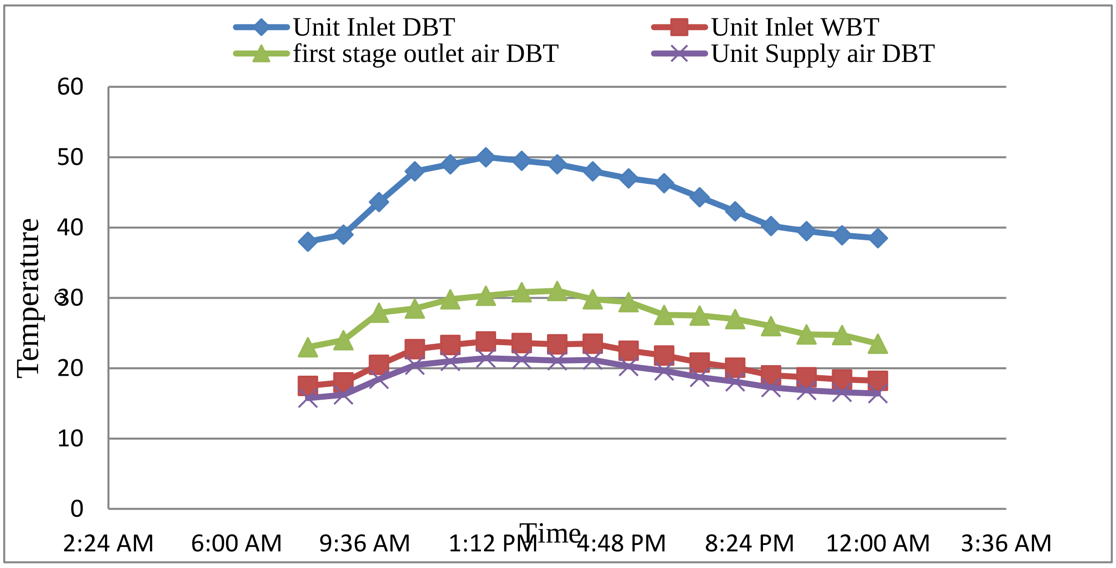

Figure (12) Daily unit temperature readings with volumetric inlet air flow rate = 0.425 m^3/s, H.E. Water flow rate = 0.1 L/s, E.R. = 0.35 %.

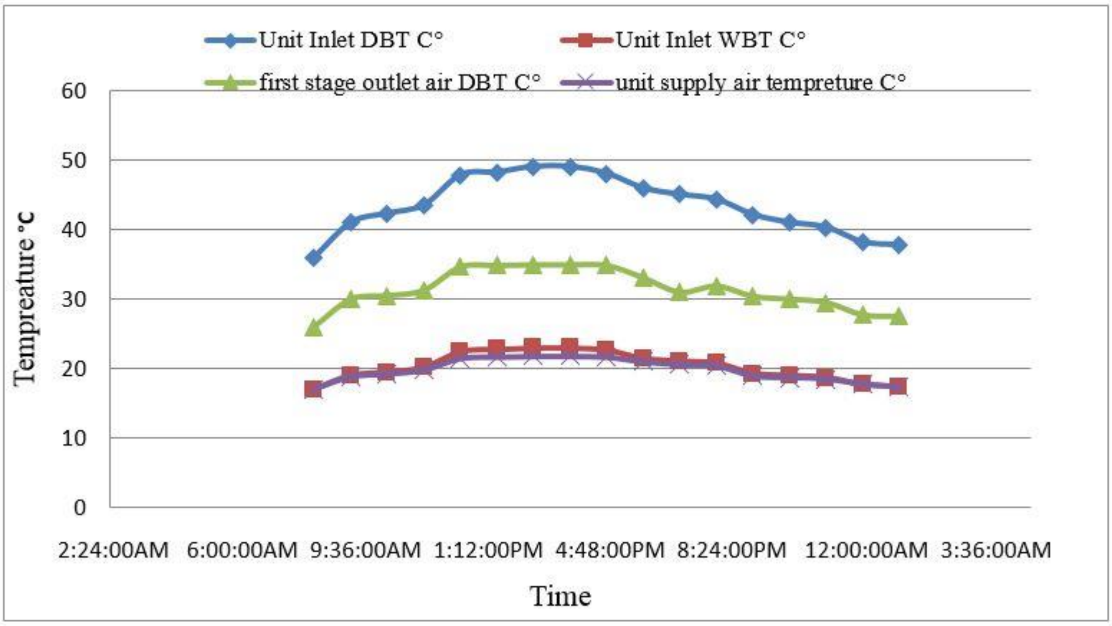

Figure (13) Daily temperature readings when volumetric inlet air flow rate = 0.48 m^3/s, H.E. Water flow rate = 0.1 L/s, ER = 0.35 %.

5-3 the effect of inlet dry bulb temperature

The inlet air DBT effect on the unit wet bulb effectiveness, when inlet air volumetric flow rate is 0.425 m^3/s, figure (14) clear that the wet bulb effectiveness is slightly increased with the increasing of inlet air DBT, this increasing because there is a higher ability of heat and mass transfer between air and water when the DBT increases with constant humidity ratio. At inlet dry bulb temperature 45°C the unit could reach a wet bulb effectiveness equal to 1.06 at constant humidity ratio.

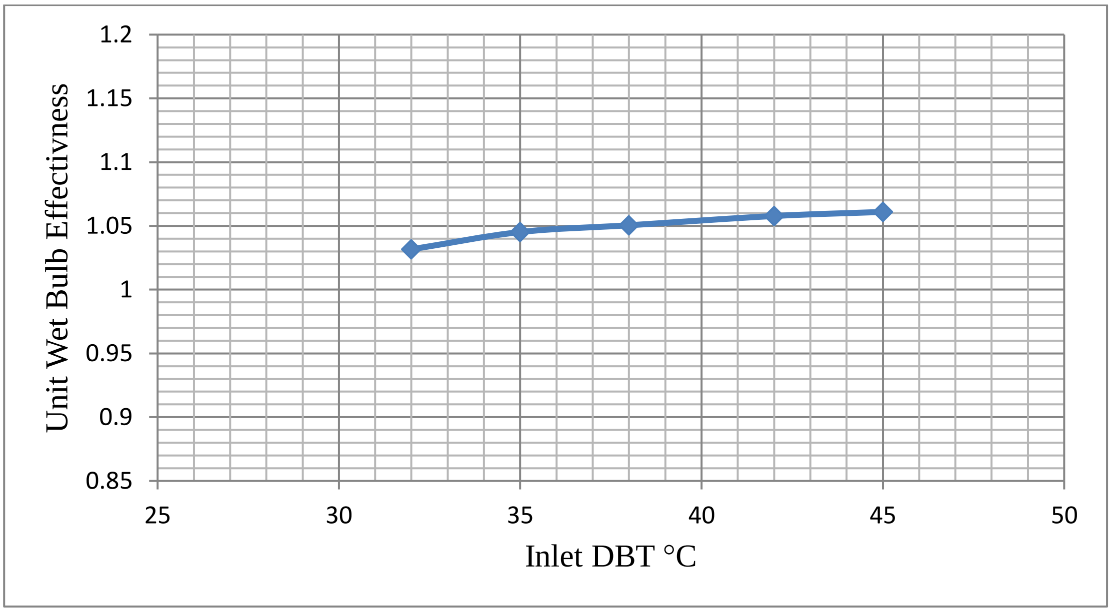

Figure (14) Wet bulb effectiveness versus inlet air temperature (Inlet air volume flow rate = 0.425 m^3/s, Inlet air humidity ratio = 5 g water/kg dry air, E.R. = 35%, water flow rate = 0.1 L/s)

5-4 the effect of extraction ratio (ER) on unit wet bulb effectiveness and unit COP

Four extracted air flow rates (30%, 40%, 50% and 60%) has been tested as shown in figure (15) to explore the effect of it on the cooling tower wet bulb effectiveness, the figure show that the tower wet bulb effectiveness is proportional positively with increasing the air extraction rate because the increase of extraction ratio led to increase evaporation rate of water and then tower wet bulb effectiveness will be high. On The other hand the increasing in extracted air is improve the unit COP with maximum COP at 40% extraction rate and begin declines after this ratio,this declines happened due to the reduction in unit supplied air flow rate which effected on unit capacity, figure (16) illustrates the relation between extraction ratio and unit COP .

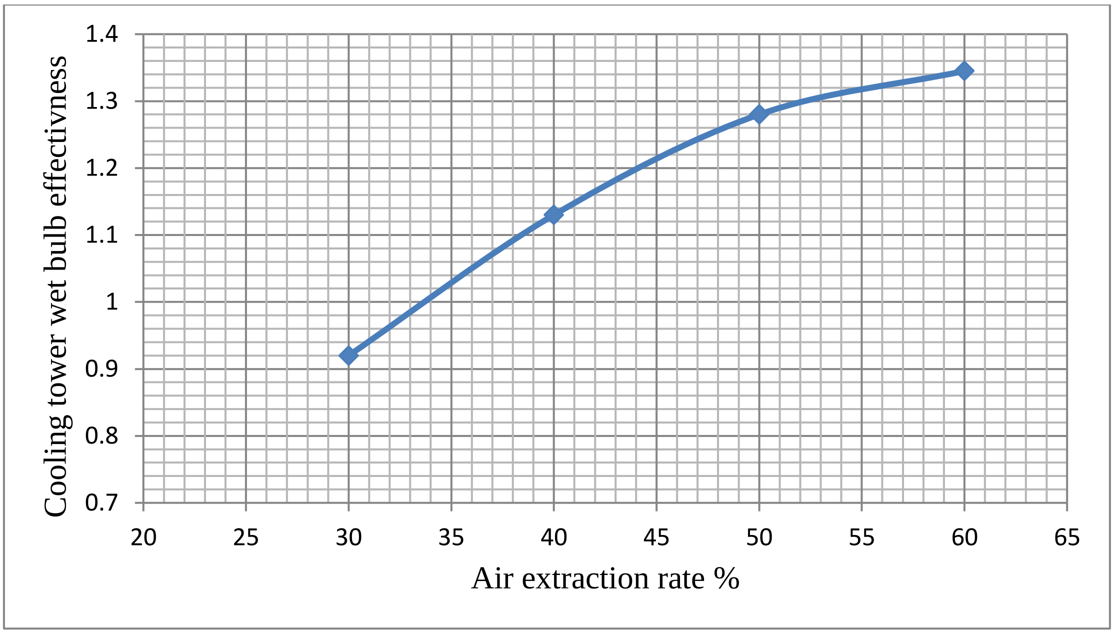

Figure (15) Wet bulb effectiveness versus extraction rate %(Inlet air DBT=38°C, Inlet air volume flow rate = 0.425 m3/s, Inlet air humidity ratio = 5g water/kg dry air).

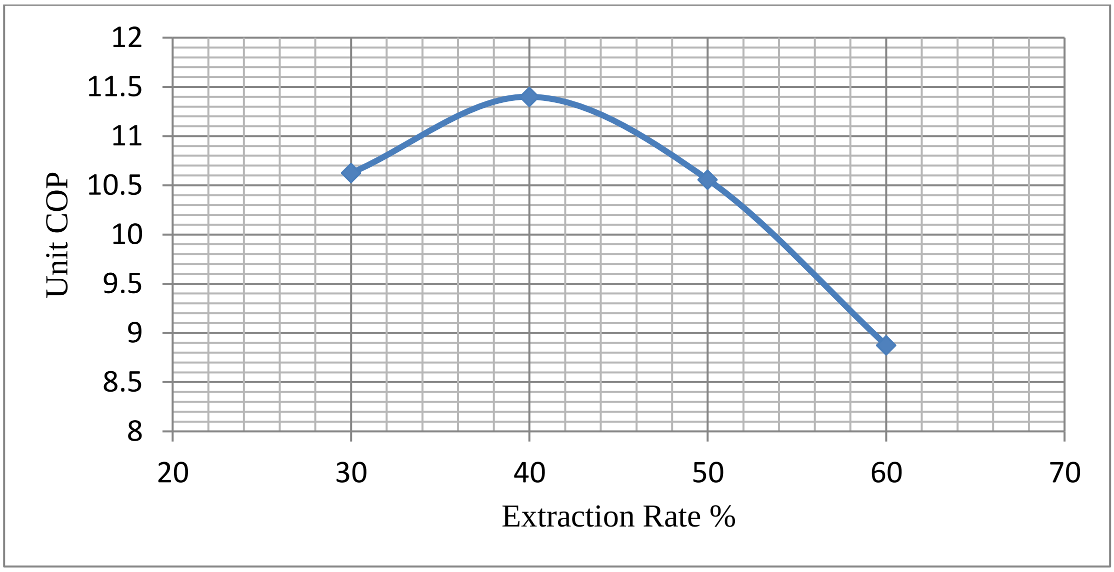

Figure (16) Unit COP versus extraction rate %(Inlet air DBT=38°C, Inlet air volume flow rate = 0.425 m3/s, Inlet air humidity ratio = 5)

5-5 The effect of inlet air DBT on unit COP

Figure (17) shows the effect of the inlet DBT on unit COP when volumetric flow rate is 0.425 m^3/s, the figure shows that the COP Increasing with the increasing of inlet air DBT with constant inlet humidity ratio. The increasing of Unit COP is happening due to increasing the temperature reduction of air throw the evaporative unit and thus increasing the unit cooling at almost constant power consumption.

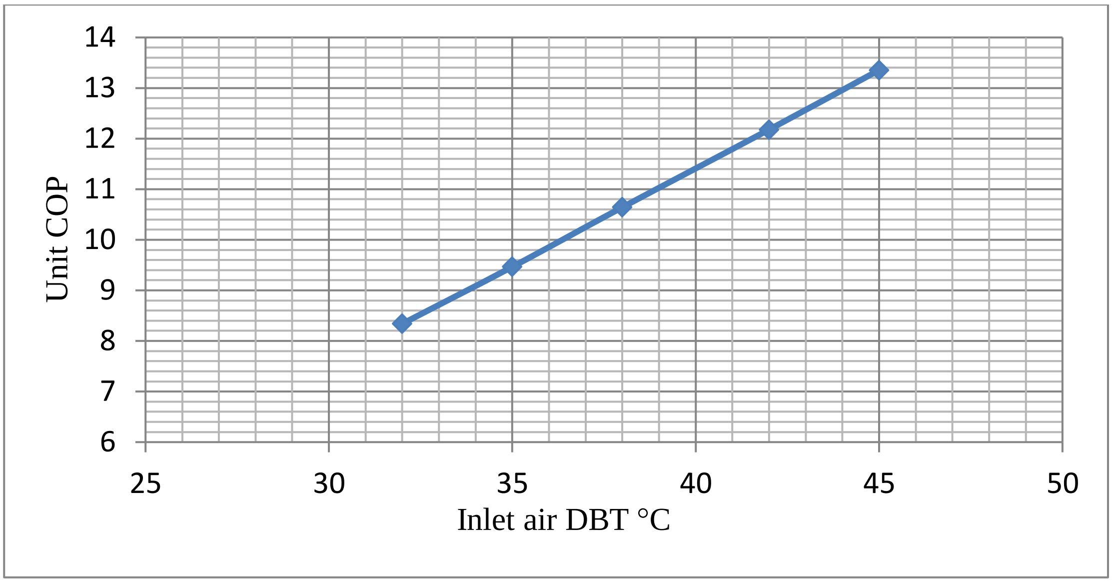

Figure (17) Unit COP versus inlet air temperature (Inlet air volume flow rate = 0.425 m^3/s, Inlet air humidity ratio=5 g water/kg dry air and extraction ratio =35%)

6. Conclusions

The performance of experimental double effect evaporative cooling unit is tested in climate conditions of Iraq. Results showed that the unit has good potential to provide comfort conditions in hot and dry regions with good energy saving potential, and there is a possibility to manufacturing this unit in large capacities as a central cooling system.

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