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Performance Evaluation of Solid Desiccant Wheel Assisted Direct Evaporative Cooler for Space Cooling: An Experimental Study

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Abstract: To have a good indoor air quality, air conditioning system must provide supply air at suitable temperature and humidity to insure human thermal comfort. Desiccant wheel with evaporative cooler is environment friendly and an energy saving systems. An indoor experimental study have been done in Baghdad with (desiccant wheel and evaporative cooler). Performance of solid desiccant wheel is assessed including (moisture removal capacity, sensible energy ratio, latent and thermal dehumidification coefficient of performance, thermal load on evaporative cooler, thermal coefficient of performance, electrical coefficient of performance, efficiencies of desiccant wheel on process and regeneration side, efficiencies of heat exchanger and evaporative cooler of the system).

Influencing factors in this study consisting inlet air process temperatures between (30-38)°C, and three mass flow rates (0.33 , 0.41, 0.47) kg/s, are studied. rotational speed of the wheel is (15 rph) with (55 cm diameter and 20 cm thickness) and silica gel used as solid desiccant material. Across flow flat plate heat exchanger and centrifugal fan were used.

Maximum value of $MRC)_p$ was (1.55 g/s) and maximum $DCOP)_{lat}$ was (0.84) at (0.47 kg/s) mass flow rate. and maximum (SER) was (0.97) at (0.41 kg/s) mass flow rate.

COP)th had its maximum value of (1.5) and maximum (η_p and ηr) were (0.26 and 0.24) respectively at (0.33 kg/s) mass flowrate.

Nomenclature		**Subscript**	
MRC	Moisture Removal capacity (g/s)	wb	wet bulb
DCOP	Dehumidification Coefficient of Performance	p	process
SER	Sensible Energy Ratio	r	regeneration
COP	Coefficient of Performance	th	thermal
ṁ	Mass flow rate of Air (kg/s)	el	electrical
w	Moisture Content (g/kg)	a	air
T	Temperature (°C)	ec	Evaporative cooler
W	Power (kw)	hx	Heat exchanger
Cp	Specific Heat at Constant Pressure (kJ/kg K)	lat	latent
hvs	Water Evaporation Enthalpy (kJ/kg)	sen	sensible
h	Specific Enthalpy (kJ/kg)	tot	total
c	Cooling capacity		
Greek symbols			
η	efficiency		

1. Introduction:

indoor air quality (IAQ) is a basic demand in all inhabited buildings to ensure human's thermal comfortable condition (cool and low- humidity indoor air supplying), as a result of increasing populace and living demands getting higher, The global consumption of the various carbon-based energy resources is rising, Which causing in emission of greenhouse gases and in fragile global energy politics. The conventional air conditioning system utilizing a large amount of the building's energy [1].in this study a desiccant wheel air conditioning system with direct evaporative cooler used. desiccants can catch and not only grasp water vapor, they can eliminate contaminants from the airstreams to enhance (IAQ).[2]

Goodarzia et al.[3] investigated the performance of desiccant wheel based on (COP lat, COP sen, COP total, and MRC). the results showed that all affecting factors have positive correlation with COPs and MRC expect inlet temperature of process air .Also, it is gotten that rising in wheel speed to 25 RPH is upgrade MRC noticeably.

Brumana and Franchini [4] made a Simulations over a one-year duration for two locations (Riyadh and Abu Dhabi) to expect the performance under varying operating conditions; The results verified that all solar cooling techniques are affected by ambient conditions and cooling load characteristic soundly and using of groundwater or seawater as heat sink had a useful influence on the chiller efficiency.

A .E. Kabeel et al. [5] studied the effects of the indirect evaporative cooler with inside baffle on the thermal performance of a hybrid air conditioning system and showed that when rising the inlet temperature from (25-45)°C, the supply temperature rises from (12.7-14.2)°C; while COP rises from (1.5 to 2.3) and supply humidity rises from (76.7% - 77.4%). A. Rachman et al. [6] presented an experimental study which carried out in UKM-Malaysia, The performance of desiccant cooling system with solar energy for regenerating. the results showed that the process air properties and regeneration temperature effected the desiccant wheel performance strongly and effectiveness of heat recovery wheel (more than 0.7) are desired for moral performance.

M. Mujahid Rafique et al.[7] studied the performance of a solid desiccant cooling system for various operating parameters like process and regeneration temperature and air flow rate. The results show that The largest amount of moisture removed from the air at process mode was (17 g/kg) at flow rate of (1.62 kg/s) in July and The optimal value of mass flow rates ratio can be found from the performance curves at a demanded regeneration temperature for better COP of the system.

A.Speerforck and G. Schmitz [8] presented hybrid system that got an electric energy efficiency ratio of (6.63) during the studying time. Results showed that If borehole heat exchangers were used gathering with a heat pump in winter season, the system presents an fascinating possibility for a full air conditioning system including (cooling, heating, and dehumidification). M. Intini et al. [9] discussed by a numerical model, The influence of inlet velocities. Results shown that obtaining an optimum couple of area ratio and revolution speed is essential to have good dehumidification performance, for both balanced and unbalanced velocities.

Sh. Hussain et al. [10] showed that for the weather conditions of Kuwait seaside regions, the desiccant cooling system with solar heat for regeneration can achieve the humans comfortable conditions in the cooling space. it was noted that When the outdoor air at greater than (45°C) and (60%) RH, the supply air from the evaporative cooling was about (27°C) and (65%) RH.

Sharma &Kaushal. [11] investigated the performance of multi-channel flat plate with ($CaCl_2$) as a liquid desiccant in which the maximum dehumidification efficiency was (0.239) has been achieved on (40%) liquid concentration when air velocity (0.5) m/s; While the efficiency of regeneration was higher by reason of higher vapor pressure difference between the liquid desiccant and process air.

2. Experimental work:

This paper presented an indoor experimental study. A device has been manufactured for a desiccant cooling system with direct evaporative cooler in the city of Baghdad. the objective of this work is to study the effect of process inlet temperature on a different performance's parameter and on thermal load of direct evaporative cooler of the system with three flow rates values of air.

2.1. system description:

The main part in this system is the desiccant wheel to dehumidify the air stream before interring to the evaporative cooler, using (34 kg) of silica gel as a solid desiccant material. This wheel (55cm diameter ,20cm width, 15 rph), separated into two equal part (1:1) for dehumidification and regeneration process. Fig (1) shows wheel device. Three electrical heaters, two fans, evaporative cooler and cross flow heat exchanger were used as shown in fig (2) / section (1&2) below:

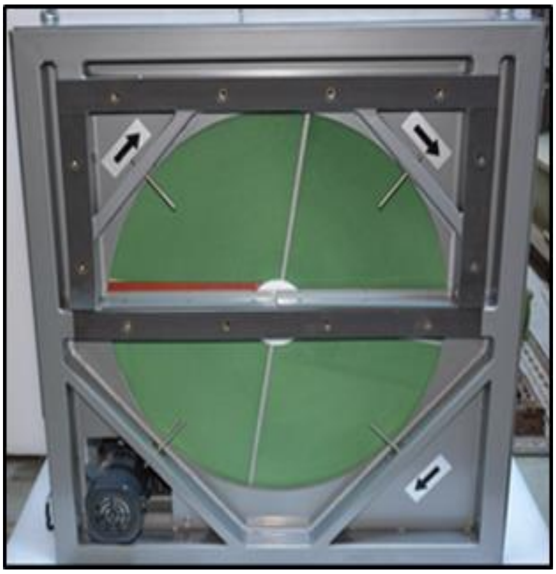

Fig (1) Desiccant Wheel device

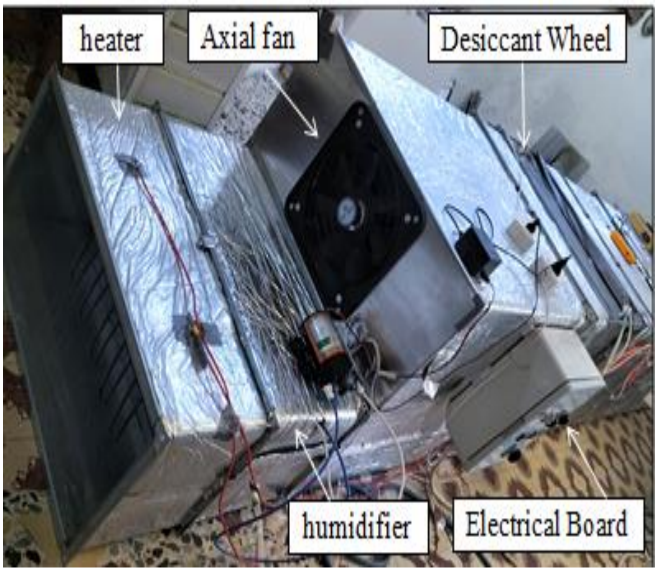

Fig (2) section(1) Air conditioning system

Fig (2) section(2) Air conditioning system

2.2 Methodology: the schematic diagram of the system shown below at fig (3)

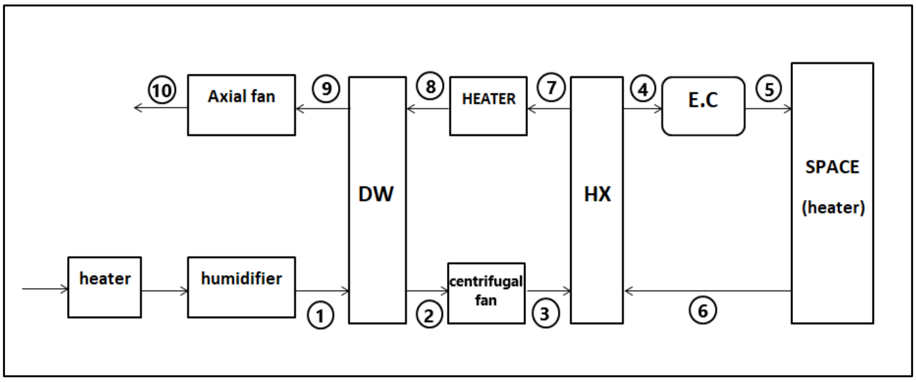

Fig (3) schematic diagram

First heater used for controlling inlet temp[...]ed between (30 -38)°C. Regeneration heat was fixed to (50° C) Three values of mass flow rate [...]3,0.41,0.47) kg/s. Dehumidifiers' performance was evaluated on the following criteria:

* **Moisture Removal Capacity (MRC):** This parameter presented as mass of moisture eliminated from humid air per time (g/s) for process section which calculated by the following equation[6]:

$$MRC)p = \dot{m}p * (w_1 - w_2) \qquad (1)$$

- **The Sensible Energy Ratio (SER):** is also used when evaluating the desiccant dehumidifier . It can estimate additional sensible load to be controlled by some supplementary cooling means like an evaporative cooler. For better dehumidification performance of the desiccant system, the value of SER should be low assesses which means that the desiccant dehumidifier is making a lesser sensible cooling load, which implies better performance of the system. SER calculated by the following equation[7]:

$$SER = \left(\frac{\dot{m}p}{\dot{m}r}\right) * \frac{(T1-T2)}{(T8-T7)} \qquad (2)$$

- **Dehumidification Coefficient of Performance (DCOP):** A higher latent and sensible (DCOP) points out an improved system performance for the reason that the regeneration air input energy is consumed in a better manner or fewer energy is used to heat up the desiccant. Latent DCOP calculated by the following equation[3]:

$$DCOP)lat = \frac{\dot{m}p*(w1-w2)*(hvs)}{\dot{m}r*(h8-h7)} \qquad (3)$$

For sensible DCOP which is the ratio of air sensible heat through the desiccant wheel to the heat difference of regeneration , calculated from the following equation[3] :

$$DCOP)sen = \frac{\dot{m}p*CPa*(T2-T1)}{\dot{m}r*(h8-h7)} \qquad (4)$$

- **Sensible Thermal load on Evaporative cooler:** sensible load related with temperature difference between inlet and outlet of evaporative cooler during cooling process.

Sensible load calculated from the next equation[2]:

$\dot{Q}_S = \dot{m}_p * cp_a * (T4 - T5)$ (5)

- **<u>COP thermal</u>:** is the ratio between the cooling loads ($\dot{Q}c$) consumed by the system to the regeneration load ($\dot{Q}r$) of the regeneration air heater. It calculated from the next equation[8]:

$$COP)_{th} = \frac{\dot{Q}c}{\dot{Q}r} = \frac{\dot{m}p * cpa * (T1 - T5)}{\dot{m}r * cpa * (T8 - T7)} \quad (6)$$

- **<u>COP Electrical:</u>** is the ratio between the cooling loads ($\dot{Q}c$) consumed by the system to the total work input to the system. It calculated from the next equation[8]:

$$COP)_{el} = \frac{\dot{Q}c}{Wtot} \quad (7)$$

- **<u>Efficiencies of Process and Regeneration</u>**: Efficiencies are important parameters to evaluate system operation. Process and Regeneration efficiencies which are represent the ratio between (Δw)p devided by wi)p for process mode and (Δw)r to wo)r for regeneration mode as shown in the equations bellow [7]:

$$\eta p = \frac{(w1 - w2)}{w1} \quad (8)$$

$$\eta r = \frac{(w9 - w8)}{w9} \quad (9)$$

- **<u>Evaporative Cooler and Heat Exchanger efficiencies:</u>** for evaporative cooler the efficiency is the ratio between $(\Delta T)_{ec}$ to the difference between dry and wet bulb temperature at the inlet of evaporative cooler. And for the heat exchanger it is the ratio between (ΔT) of the hot side to the difference between the inlet temperature of hot and cold stream. These two factors calculated by the following equations[7]:

$$\eta ec = \frac{(T4 - T5)}{(T4 - Twb,4)} \quad (10)$$

$$\eta hx = \frac{Cc\,(T3 - T4)}{Cmin\,(T3 - T6)} \quad (11)$$

Where Cc is the capacity rate for cold side air (kw/°C) and (C_{min}) is the minimum capacity rate between cold and hot fluid.

3. <u>Result and Discussion:</u>

3.1 <u>The Effect of Inlet Parameter on Moisture Removal Capacity (MRC) for Process and Regeneration Sides:</u>

Figure (4) shows The relation between inlet temperature and (MRC)p values which decreases with increasing process inlet temperature for the three flow rates. For the first flow rate (0.33 kg/s) the (MRC)p decreases from (1.25 g/s) at (30°C) to (0.69 g/s) at (38°C). At (0.41 kg/s) mass flow rate the (MRC)p decreases from (1.35 g/s) at (30°C) to (0.77 g/s) at (38°C). At (0.47 kg/s) mass flowrate, the (MRC)p decreases from (1.55 g/s) at (30°C) to (0.98 g/s) at (38°C). This is because of that the difference of vapor surface pressure decreasing between the silica gel and adjacent air layer.

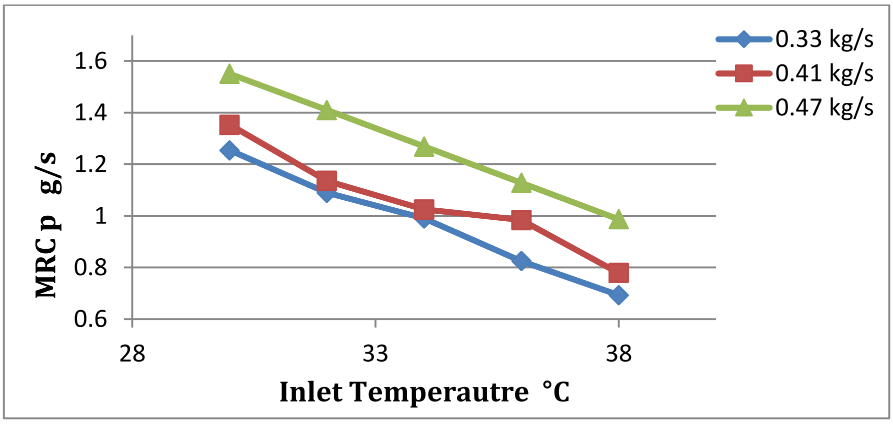

Figure (4) Effect of inlet temperature on MRC)p

The reason of lessening in values is because the deference between inlet and outlet moisture content is getting less due to decreasing the difference of surface vapor pressure between the silica gel and adjacent air layer with increasing in inlet temperature to the wheel while noticed that it is increased with flow rate rising.

3.2. Effect of Inlet Parameter on Sensible Energy Ratio (SER):

In studying the effect of inlet temperature on (SER). It was found that the (SER) decreases with increasing inlet temperature as shown in figure (5). At (0.33 kg/s) mass flowrate, (SER) deceased from (0.73) at (30°C) to (0.58) at (38°C). For the (0.41 kg/s)mass flowrate it decreased from (0.79) at (30°c) to (0.65) at (38°C); at (0.47 kg/s) mass flowrate it decreased from (0.75) at (30°C) to (0.63) at (38°C). This values ruled by the temperature difference before and after the desiccant wheel which is getting lesser and for the regeneration heater which is getting lesser to.

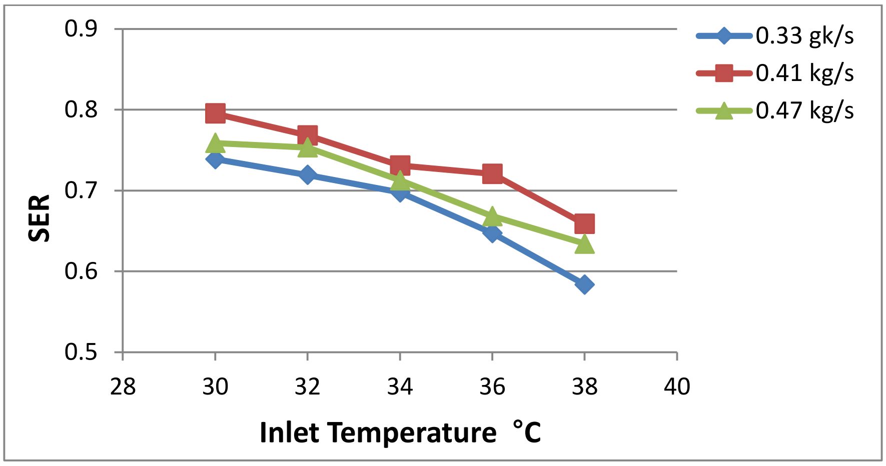

Figure (5) effect of inlet temperature on SER

3.3

3.4 Effect of Inlet Process Inlet Temperature on The Dehumidification Coefficient of Performance (DCOP):

There was a decrease in latent $(DCOP)_{lat}$ with increasing inlet temperature as shown in figure (6). At the (0.33 kg/s) mass flow rate, $DCOP)_{lat}$ decreased from (0.77-0.72); At (0.41 kg/s) mass flow rate, it reduced from (0.8-0.75); while at (0.47 kg/s) mass flow rate it reduced from (0.84-0.81).

This is because of decreasing of (Δ h) of regeneration heater of the system with increasing of inlet temperature

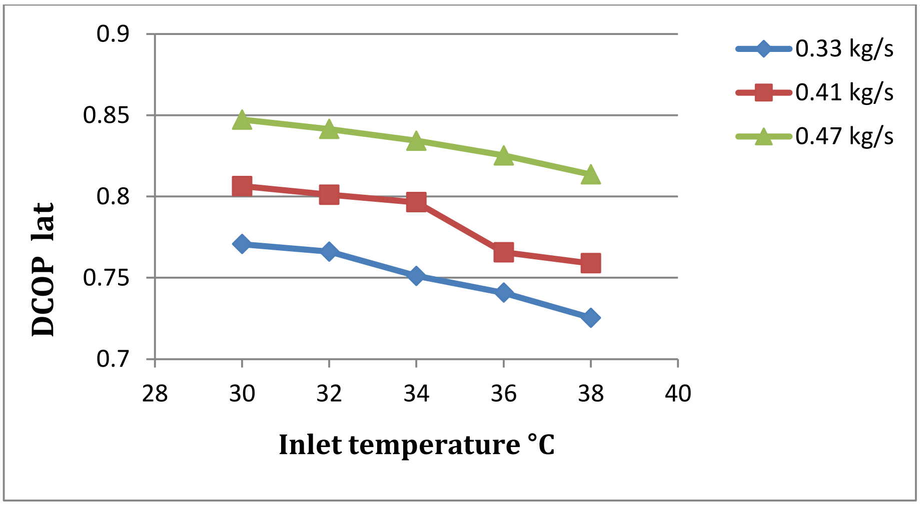

Figure (6) Effect of inlet temperature on DCOP)lat

Figure (7) shows that $(COP)_{sen}$ values also decreased with increasing of inlet temperature as a result of decreasing of the values of (Δ h) of regeneration heater although the (ΔT_p) decreased with increasing inlet temperature.

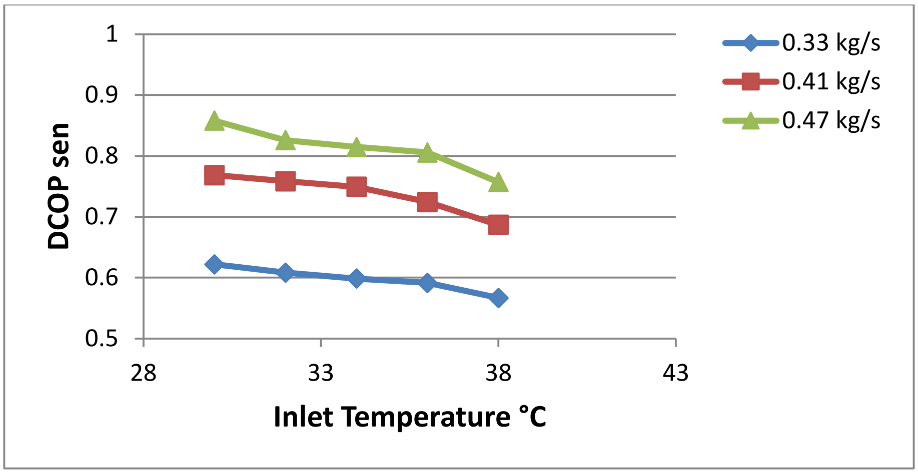

Figure (7) Effect of inlet temperature on DCOP)sen

At (0.33 kg/s) mass flow rate, COP)sen decreased from (0.62-0.56); at (0.41 kg/s)) mass flow rate, it reduced from (0.76-0.68); at (0.47 kg/s) mass flow rate it reduced from (0.85-0.75).

For both latent and sensible DCOP, it was noticed that the maximum values have been gotten at the third flow rate.

3.5 The Effect of Inlet Process Temperature on Thermal Load of Evaporative Cooler:

The relation between sensible thermal load and inlet process temperature shown in figure (8), sensible load increased with increasing inlet temperature.

At (0.33 kg/s) mass flow rate it raises from (3.15-3.98) kw, at (0.41 kg/s) mass flow rate it raised from (3.5-4.95) kw, and finally, at (0.47 kg/s) mass flowrate it raised from (4.87-5.86) kw.

The reason of increasing thermal load values is because increasing the temperature difference between inlet and outlet of evaporative cooler with increasing inlet temperature. It noticed that the highest flow rate gave the highest sensible load**.**

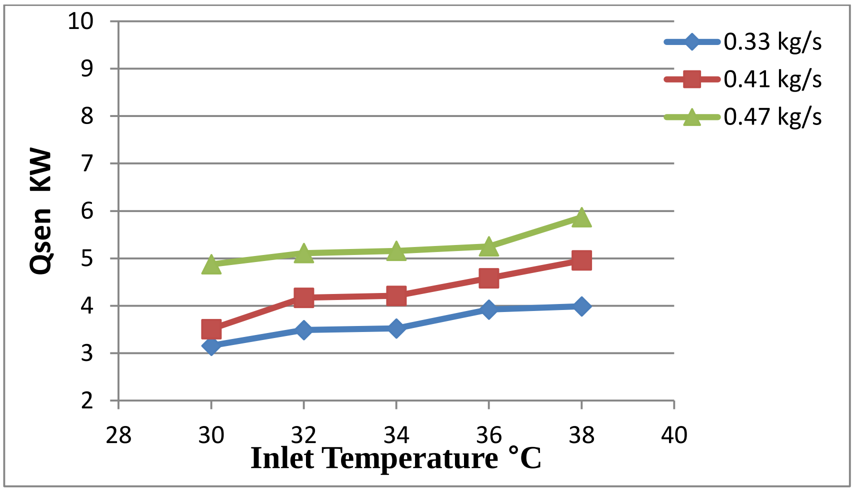

Figure (8) Effect of inlet temperature on Q_{sen}

3.6 Effect of Inlet Parameter on Thermal Performance (COPth):

Figure (9) presented the relation of $(COP)_{th}$ with inlet temperature, which is increased with increasing of inlet temperature
At (0.33kg/s) mass flow rate it raises from (0.52-1.5), at (0.41 kg/s) mass flow rate it raised from (0.44-1.42), at (0.47 kg/s) mass flow rate it raised from (0.34-1.16).

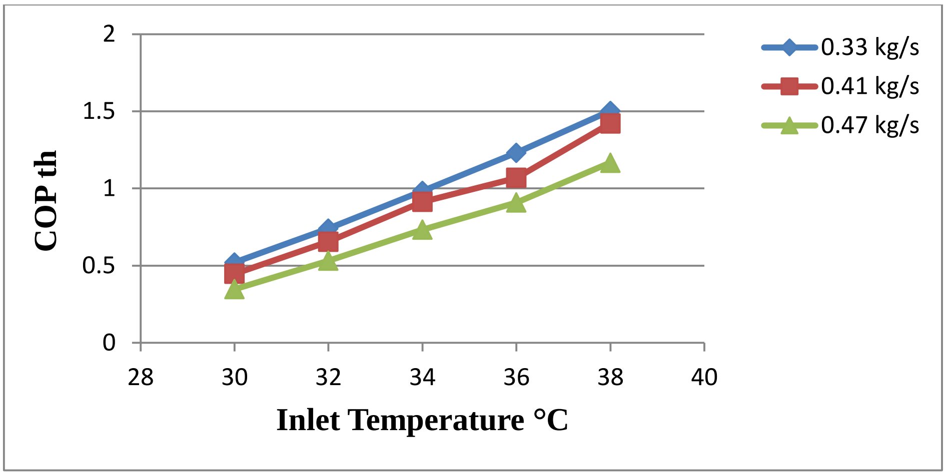

Figure (9) Effect of inlet temperature on COP)th

This is the result of increasing of (Qc) and decreasing of regeneration load with increasing of inlet temperature and flow rate.

3.7 The Effect of Inlet Parameter on Electrical Performance

Figure (10) showed the relation between $COP)_{ele}$ and inlet process temperature.

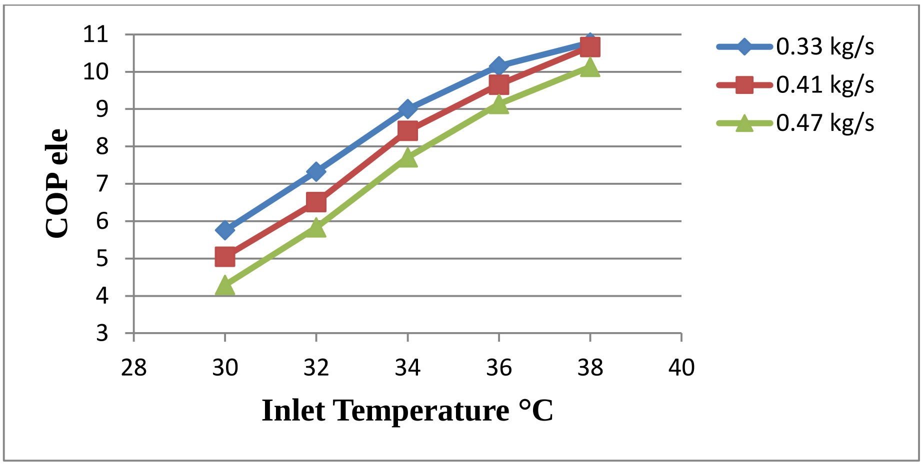

Figure (10) Effect of inlet temperature on COP)ele

At (0.33 kg/s) mass flow rate it raises from (5.76-10.8), at (0.41 kg/s) mass flow rate it raised from (5.06-10.68), at (0.47 kg/s) mass flow rate it raised from (4.3-10.1).

$(COP)_{ele}$ increased with increasing of inlet temperature because of increasing of ($\dot{Q}c$) with increasing of inlet temperature and flow rate.

3.8 The Effect of Inlet Process temperature on Process and Regeneration Efficiencies :

Relation between the process and regeneration efficiencies with inlet process temperature is shown in Figure (11- a,b). The process efficiency at (0.33 kg/s) mass flow rate reduced from (26%-13%), at (0.41 kg/s) mass flow rate it reduced from (23%-12%), at (0.47 kg/s) mass flow rate it reduced from (0.23-0.14).

The regeneration efficiency reduced from (24%-14%) at (0.26 kg/s) mass flow rate , at (0.33 kg/s) mass flow rate it reduced from (21%-13%), at (0.39 kg/s) mass flow rate it reduced from (20%-12%).

The values of (ηp) and (ηr)decreased with increasing of inlet temperature due to decreasing on deference between inlet and outlet moisture content is getting less with increasing in inlet temperature.

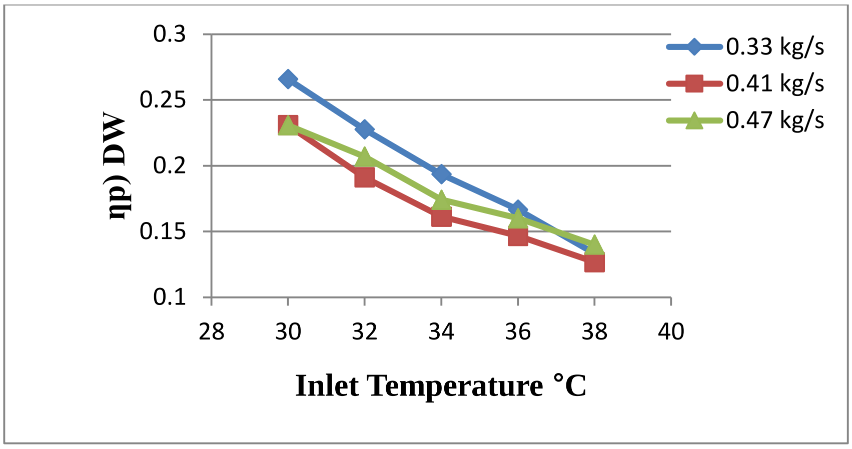

Figure (11-a) Effect of inlet temperature on (η_p)

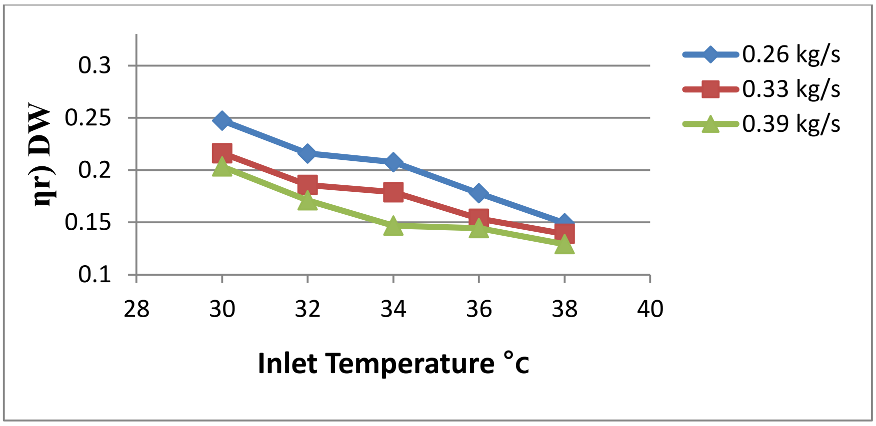

Figure (11-b) Effect of inlet temperature on (η_r)

3.8 The Effect of Inlet Parameter on Evaporative Cooler and Heat Exchanger Efficiency:

Figure (12-a,b) below shows the maximum and minimum values with increasing inlet temperature. For both evaporative cooler and heat exchanger the best values recorded were at (0.33 kg/s) mass flowrate which were (76%) and (51%) respectively. This is because at the lowest flow rate there is more time for heat transfer between cold water and air stream for evaporative cooler and between hot and cold water for the heat exchanger.

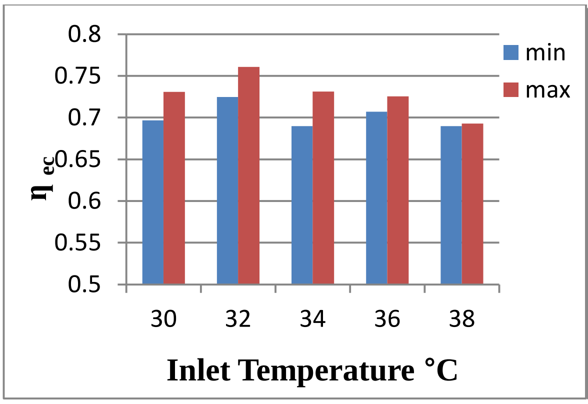

Figure (12-a) Effect of inlet temperature on (η_{ec})

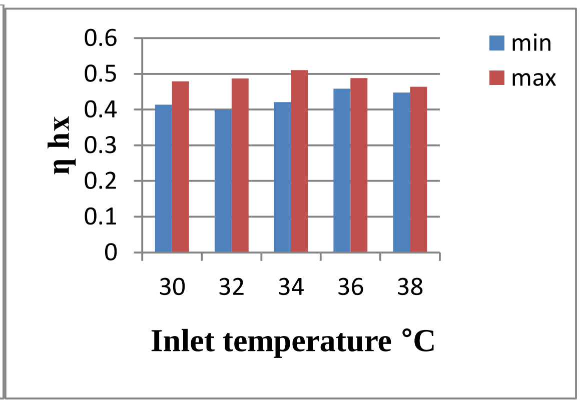

Figure (12-b) Effect of inlet temperature on (η_{hx})

In the present study, the effects of the inlet temperature and flow rate on the performance of an air conditioning system are investigated. The main conclusions that presented in this paper with increasing the inlet temperature from (30°C) to (38°C) for three values of flow rates (0.33,0.41,0.47) kg/s, are as follows:

1. MRC)p decreased for the three flow rates about (0.56 g/s) with increasing of inlet temperature.
2. SER values decreased for the three flow rates to the lowest ratio of (0.58) at first flow rate. which is a good indicated for the system operation.

3. Highest DCOP) lat was at the third flowrate of (0.84) while the lowest was at the first flowrate of (0.72).
   For DCOP)sen, maximum value recorded at third flowrate was (0.85); while, the lowest value recorded at first flow rate was (0.56).
4. For thermal load on evaporative cooler, the result showed that it increased with increasing inlet temperature about (0.8-1.4) kw at different flow rates.
5. COP)el most significant increase is at third flow rate from (4.3-10.1). while for COP)th the maximum value recorded at the first flow rate which was (1.5).
6. Best efficiencies estimated at the first flow rate for the process and regeneration mode which were (26%) and (24%) respectively. Also for the evaporative cooler and heat exchanger the maximum values were at the first flowrate.

Previous results shows that this system is suitable to use at indoor conditions in the city of Baghdad because outdoor condition include higher inlet temperatures which is may be reached to (55°C) some days with low inlet humidity ratio in the summer period in baghdad.

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