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Effect of Regeneration Temperature and Inlet Humidity Ratio on the Performance Evaluation of Air Conditioning System With Direct Evaporative Cooler and Solid Desiccant Wheel: An Experimental Study

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Abstract: The human thermal comfort is the most important demand in all inhabited buildings to have a good indoor air quality (IAQ). In this study a desiccant wheel with evaporative cooler technique which is environment friendly and an energy saving systems was used. An indoor experimental study have been done in Baghdad to investigate the Performances parameter of solid desiccant wheel including (Moisture Removal Capacity, Dehumidification Coefficient of Performance , Sensible Energy Ratio, Efficiency of Desiccant Wheel on Process Side, Efficiency of Desiccant Wheel on Regeneration Side). Affecting factors in this study consisting regeneration air temperatures (40-60)°C, inlet humidity ratio (12-20) g/kg and three mass flow rates (0.33 , 0.41, 0.47) kg/s were studied. The rotational speed of the desiccant wheel was (15 rph) and silica gel was used as solid desiccant material.

Maximum value of $MRC)_p$ was at regeneration temperature of (60)°C and maximum $DCOP)_{lat}$ was at regeneration temperature of (40)°C at a flowrate of (0.47)kg/s; While for the inlet humidity ratio results, maximum value of MRC)p and maximum DCOP)lat was at inlet humidity ratio of (20 g/kg) and flowrate of (0.47) kg/s.

Nomenclature

MRC	Moisture Removal capacity (g/s)
DCOP	Desiccant Wheel Coefficient of Performance
SER	Sensible Energy Ratio
$\dot{m}$	Mass flow rate of Air (kg/s)
w	Humidity ratio (g/kg)
T	Temperature (°C)
hvs	Water Evaporation Enthalpy (kJ/kg)
h	Specific Enthalpy (kJ/kg)

Greek symbols

η	efficiency

Subscript

p	process
r	regeneration
i	in
o	out
lat	latent

1.Introduction: With growing and continuous developing and increasing all aspects life requirements, thermal comfort demands more concentration. All air conditioning system have to provide the necessary comfortable indoor thermal environment and a good inlet air quality (IAQ). Many researches with different environment friendly cycles have been done in order to get high system performance. In addition to lowering energy consumption by using renewable energies like (waste heat or solar energy).

In this paper a solid desiccant-assisted air conditioning system with direct evaporative cooler is presented. This technology can make the latent heat load and the sensible heat load separated , which will successfully increase the system performance and reduce the power consumption.[1].

Desiccant is used when the latent load is considerable in contrast to the sensible load, and when a good controlling of temperature and humidity are needed in which supply air to a space or a ductwork should not be more than (70%) relative humidity.[2]. Temperature of regeneration and inlet humidity ratio is crucial parameter that affected the system performance, so that will be presented in this study.

Sharma and Kaushal. [3] investigated experimentally the performance of a multi-channel flat plate system with liquid desiccant material; the results showed that the maximum alteration of humidity ratio recorded between inlet and outlet was (7.05 g/kg) and the effectiveness of regeneration results were better than dehumidifier because of larger vapor pressure difference between desiccant and adjacent air.

Ahmed.et al.[4] present a numerical and an experimental study to evaluate and optimize the performance of a solar desiccant wheel system. Numerical results showed that there is a greatest value of each design parameter at each operational condition; beyond that no notable changes in the wheel performance are observed; for regeneration temperature this value was between (60-90)°C. Experimental consequences showed that the perforated plate solar air heater that used in the system can give out about (72.8%) of the total regeneration energy needed at (60°C) regeneration temperature and (13.7%) at regeneration temperature (90 °C).

Angrisani.et.al [5]. Presented an experimental study of a desiccant wheel that regenerated by low-temperature energy in Southern Italy. R results showed that the regeneration temperature and inlet air humidity ratio have a greater effect contrasted to the process air temperature on the performance of desiccant wheel. (DCOP) and (SER) were increased with increasing inlet humidity ratio of process air; while it decreased with increasing regeneration temperature.

Goodarzia.et.al [6] investigated the influence of affecting factors like (inlet air humidity ratio and regeneration temperature) on the solid desiccant wheel performance. They studied effectiveness parameters including moisture removal capacity (MRC) and dehumidification coefficient of performance (COP). Results showed that all influencing factors have positive relationship with (MRC) and (COP) excluding inlet process air temperature.

Kabeel.et.ai.[7] studied numerically the influences of indirect evaporative cooler with internal baffle of a hybrid air conditioning system on the performance; The result of this study showed that when regeneration temperature increased from (70) to (110)°C, the supply temperature decreased from (15.9) to (10.9) °C and supply humidity decreased from (82.7%) to (71.8%) while the coefficient of performance dropped from (3.05) to (1.54).

Mujahid Rafique.et.al.[8]presented a numerical model for solid desiccant air conditioning system with evaporative cooler in Dhahran, Saudi Arabia. The authors concluded that when the mass flowrate ratio increased from (1) to (3) kg/s the cooling load increased from (22) to (78) kw and when regeneration temperature increased the sensible energy ratio decreased but it increased when inlet humidity ratio increased.

Bassuoni.[9] presented an experimental study of a (HDBAC) system performance. In this study the (COP) of the system was reduced and (SMR) was raised with regeneration temperature increasing. And the energy saving percentage achieved by using this system was between (33) to (46)%.

Alahmer.et.al.[10] developed a mathematical model to study the influence of vital operating parameters, like (inlet humidity ratio of process, regenerative temperature, regeneration and process air flowrates) on the performance of desiccant wheels, using silica gel and molecular sieve as desiccant materials. The most important notes were that at regeneration temperature of (80) °C, silica gel was more effective than molecular sieve. And when regeneration temperature increased from (70) to (140) °C the (MRC) increased about (2.065 g/kg) for silica gel and about (5.71 g/kg) for molecular sieve.

Connor.et.al.[11] presented an experimental study of a desiccant wheel in a duct with two channel. radial blades coated with Silica gel expanding from the center of the wheel arranged in (32) blade and (20) blade outlines. The regeneration temperature was between (80 and 120)°C. The results showed that the inlet process air was dehumidified at all regeneration temperatures and when the regeneration temperature increased the moisture removal of the air was increased.

Niemann.et.al.[12] investigated experimentally an air conditioning system for one year with a geothermal system used for heating and cooling. This system used LiCl as a desiccant material and getting an average dehumidification COP of (1.15) and moisture recovery COP of (0.75).

2. Experimental Work:

This paper depends on many indoor experimental tests . An apparatus has been assembled for air conditioning system with desiccant wheel and direct evaporative cooler in the city of Baghdad. The aim of this work is to study the effect of regeneration temperature and inlet humidity ratio on a different performance’s parameter of the system with three flow rates values of air.

2.1 System Description:

Figure (1) shows the schematic diagram of the system in which all parts appears sequentially.

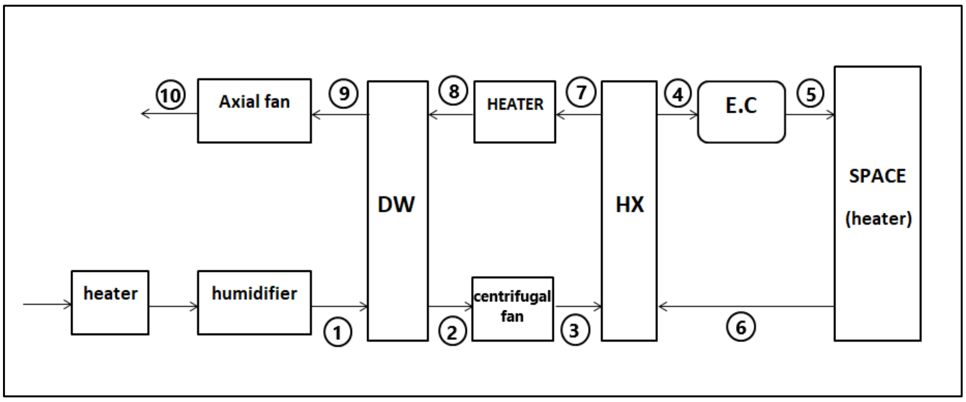


Figure (1) Schematic diagram

The most important part in this system is the desiccant wheel (DW) which is used to remove moisture from the air stream before go forward to the direct evaporative cooler, the solid desiccant material used in this system is Silica gel. Fig (2) shows the rotating desiccant wheel (550mm diameter, 200mm width, 15 rph), with aspect ratio (1:1) for process and regeneration.

The system include also (electrical heaters, fans, evaporative cooler and cross flow heat exchanger).Figures (3-1,2) shows the whole device.

First heater used for adjusting inlet air temperature which is fixed to (35)°C when the humidifier used to controlling the inlet humidity ratio between (12 and 20) g/kg. And inlet temperature fixed to (32)°C when regeneration temperature range between (40-60)° C. Three values of inlet mass flow rate were used (0.33,0.41,0.47) kg/s.

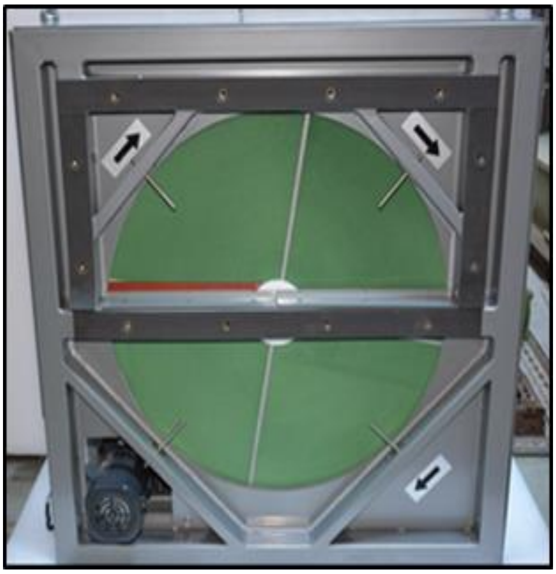


Figure (2) Desiccant Wheel

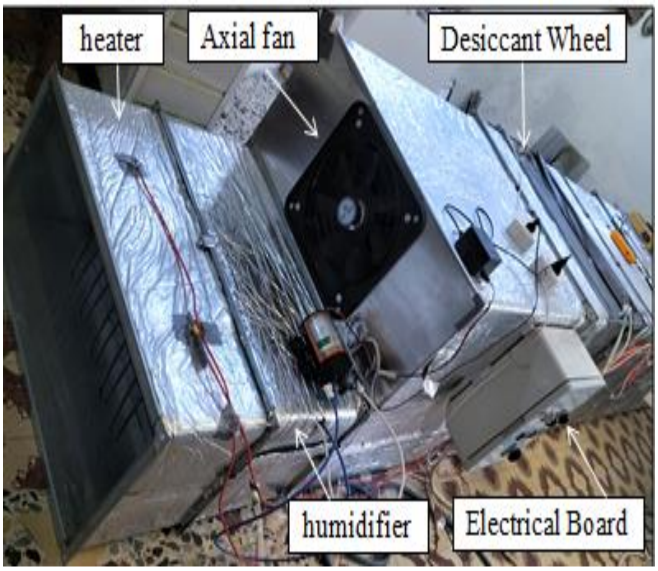


Figure (3-1) Air conditioning system

Figure (3-2) Air conditioning system

2.2 Methodology: System performance evaluated based on the following parameter:

* **Moisture Removal Capacity (MRC):** This factor presented as amount of moisture removed from air per time (g/s) for process sector which calculated by the following equation[6]:

$$MRC)_p = \dot{m}_p * (w_1 - w_2) \quad (1)$$

And moisture reactivation capacity of regeneration by using the following equation[11]:

$$MRC)_r = \dot{m}_r * (w_9 - w_8) \quad (2)$$

- **Dehumidification Coefficient of Performance (DCOP):** A higher latent (DCOP) presented a better system performance because the regeneration input energy is utilized in an enhanced manner or fewer energy is used to heat up the desiccant. Latent DCOP calculated by the following equation[3]:

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

- **The Sensible Energy Ratio (SER):** another parameter used to evaluating the desiccant dehumidifier . Values of SER should be at low rates for improved dehumidification performance of the desiccant system, that means the desiccant wheel is making less sensible cooling load, which indicates better performance of the system. SER calculated by the following equation[7]:

$$SER = \left(\frac{\dot{m}p}{\dot{m}r}\right) * \frac{(T2 - T1)}{(T8 - T7)} \quad (4)$$

- **Efficiencies of Process and Regeneration**: the system operation evaluated by a pair of parameter related with process and regeneration operation which is process and regeneration efficiencies. Process efficiency denote the ratio of $(\Delta w)_p$ to $w_i)_p$. while the ratio of $(\Delta w)_r$ to $wo)_r$ regeneration represented the regeneration efficiency, as shown in the equations bellow [7]:

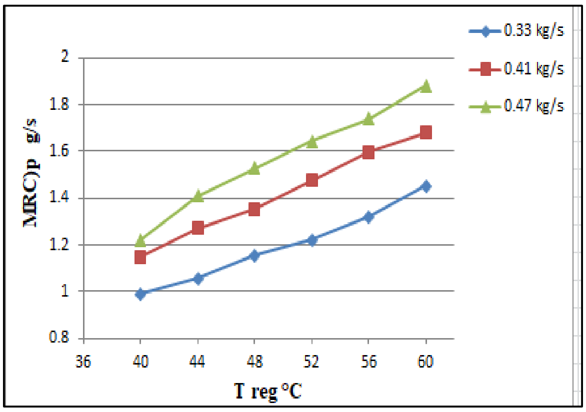
$$\eta p = \frac{(w1 - w\,2)}{w\,1} \quad (5)$$

$$\eta r = \frac{(w\,9 - w\,8\,)}{w\,9} \quad (6)$$

3. Result and Discussion:

3.1 Effect of Regeneration Temperature and Inlet Humidity Ratio on (MRC) for Process and Regeneration:

Fig (4) shows the relation between the $(MRC)_p$ and regeneration temperature which increase with increasing regeneration temperature for the three mass flow rates. For (0.33) kg/s the $(MRC)_p$ increases from (0.99 g/s) at T_{reg}=40°C to (1.45 g/s) at T_{reg}=60°C. At (0.41) kg/s mass flowrate the (MRC)p increases from (1.14 g/s) at T_{reg} =40°C to (1.68 g/s) at T_{reg} =60°C. And at (0.47) kg/s mass flow rate the $(MRC)_p$ increases from (1.22 g/s) at $T_{reg=}$40°C to (1.88 g/s) at T_{reg}=60°C.



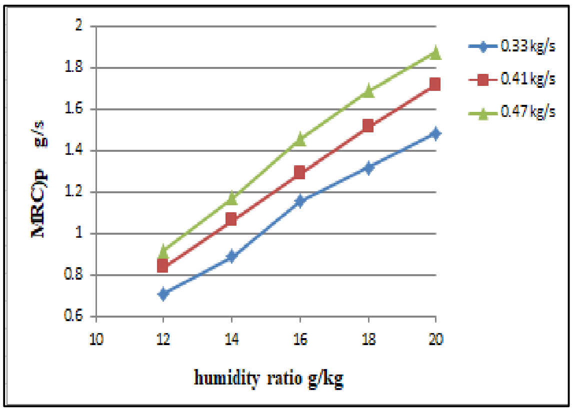


Figure (4) Effect of (T_{reg}) on MRC)$_p$

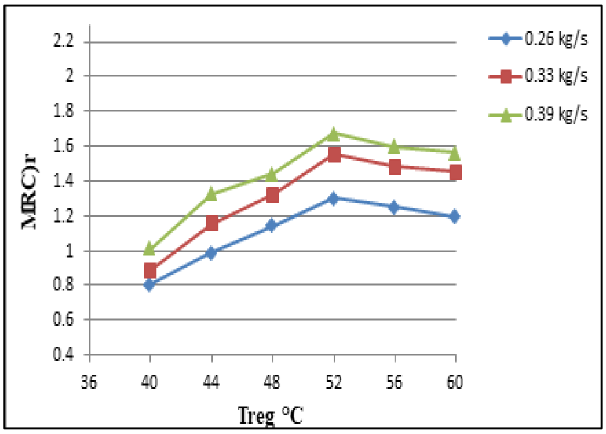
Figure (5) Effect of (w_{in}) on MRC)$_p$

Fig (5) shows the relation between (MRC)$_p$ and inlet humidity ratio which increase with increasing inlet humidity ratio for the three flow rates. For (0.33 kg/s) mass flowrate the (MRC)$_p$ increases from (0.7 g/s) at (12 g/kg) to (1.48 g/s) at (20 g/kg). At (0.41 kg/s) mass flow rate the (MRC)$_p$ increases from (0.84 g/s) at (12 g/kg) to (1.72 g/s) at (20 g/kg) and At (0.47 kg/s) flow rate the (MRC)$_p$ increases from (0.91 g/s) at (12 g/kg) to (1.88 g/s) at (20 g/kg).

Fig (6) shows the relation between the (MRC)$_r$ and regeneration temperature. For the first regeneration air mass flow rate of (0.26 kg/s) the (MRC)$_r$ increase from (0.8 g/s) at T_{reg} =40°C to (1.3 g/s) at T_{reg} =52°C , then it decrease to (1.19 g/s) at T_{reg} =60°C . At (0.33 kg/s) regeneration air mass flow rate,(MRC)$_r$ increase from (0.89 g/s) at T_{reg}=40°C to (1.55 g/s) at T_{reg} = 52°C, then it decrease to (1.45 g/s) at T_{reg} =60°C. At (0.39 kg/s) regeneration air mass flow rate ,(MRC)$_r$ increases from (1.01 g/s) at T_{reg} =40°C to (1.67 g/s) at T_{reg} = 52°C then it decrease to (1.56 g/s) at T_{reg} =60°C.

Fig (7) shows the relation between (MRC)$_r$ and inlet humidity ratio. For the (0.26 kg/s) mass flow rate, the (MRC)$_r$ increases from (0.67 g/s) at (12 g/kg) to (1.27 g/s) at (20 g/kg). At (0.33 kg/s) mass flow rate the (MRC)r increases from (0.82 g/s) at (12 g/kg) to (1.41 g/s) at (20 g/kg). At (0.39 kg/s kg/s) mass flow rate the (MRC)$_r$ increases from (0.93 g/s) at (12 g/kg) to (1.63 g/s) at (20 g/kg).

In fact for MRC)$_P$ and MRC)$_r$, the purpose of rising in values is because the deference between inlet and outlet moisture content is getting higher . This is due to increasing the difference of surface vapor pressure between the silica gel and adjacent air layer with increasing in regeneration temperature except for the values beyond T_{reg} =52°C in which it began to decrease again which mean that the surface vapor pressure difference between silica gel and nearby air layer is reduced.



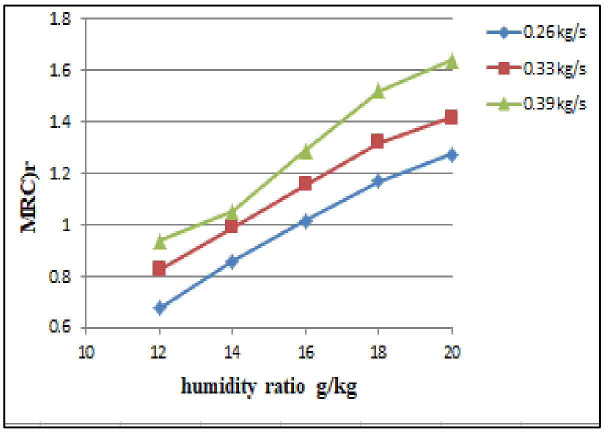
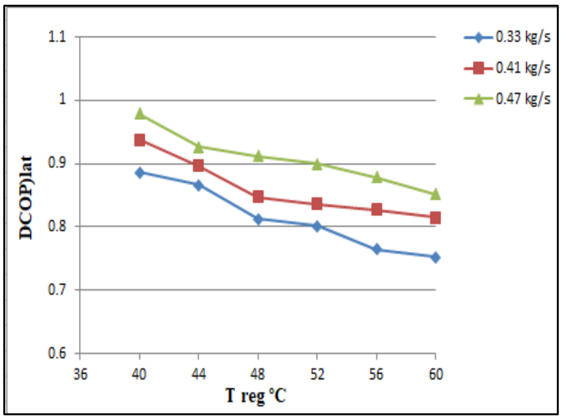


Figure (6) Effect of (T_{reg}) on MRC)$_r$

Figure (7) Effect of (w_{in}) on MRC)$_r$

3.2 Effect of Regeneration Temperature and Inlet Humidity Ratio on (DCOP)$_{lat}$:

Fig (8) shows the relation between (DCOP)$_{lat}$ and regeneration temperature which decrease with increasing regeneration temperature although that (MRC)$_p$ increased, This is because of increasing of (Δ h)$_r$ of the system with increasing of regeneration temperature. At (0.33 kg/s) mass flow rate, DCOP)$_{lat}$ decreased from (0.88) to (0.75); At (0.41 kg/s) mass flow rate it reduced from (0.93) to (0.81) and at (0.47 kg/s) mass flow rate it reduced from (0.97) to (0.85).



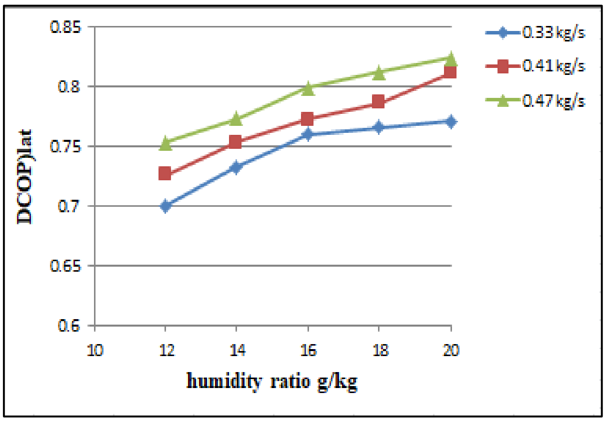


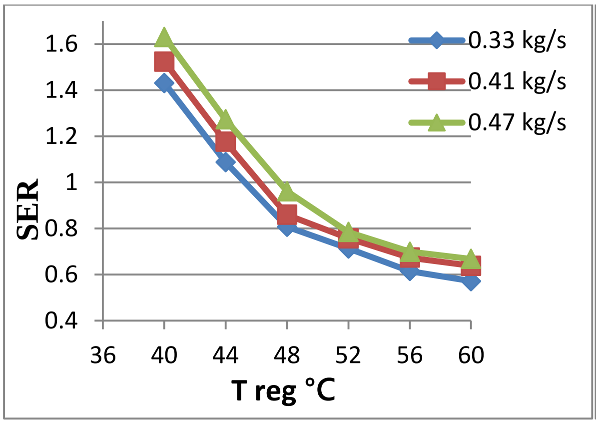
Figure (8) Effect of T_{reg} on DCOP)$_{lat}$ Figure (9) Effect of w_{in} on DCOP)$_{lat}$

Figure (9) shows the relation between DCOP)$_{lat}$ and inlet humidity ratio which increase with increasing inlet humidity ratio due to increasing in $(MRC)_p$, At (0.33 kg/s) mass flowrate, DCOP)$_{lat}$ increased from (0.7) to(0.77). At (0.41 kg/s) mass flow rate it increased from (0.72) to (0.81); while at (0.47 kg/s) mass flow rate it increased from (0.75) to (0.82).

3.3. Effect of Regeneration Temperature and Inlet Humidity Ratio on(SER):

Figure (10) shows the relation between (SER) and inlet humidity ratio which decrease with increasing regeneration temperature because that the difference of $(\Delta T)_{rh}$ is increased with increasing regeneration temperature, At (0.33 kg/s) mass flowrate, (SER) decreased from (1.43) to (0.57); At (0.41 kg/s) flow rate it reduced from (1.52) to(0.63); while at (0.47 kg/s) mass flow rate it reduced from (1.63) to (0.66).

Figure (11) shows the relation between (SER) and inlet humidity ratio, which increase with increasing inlet humidity ratio because that the difference of $(\Delta T)_{rh}$ decreased with increasing inlet humidity ratio, At (0.33 kg/s) mass flow rate the (SER) increased from (0.43) to(1.43); At (0.41 kg/s) mass flow rate it raised from (0.44) to (1.49); while at (0.47 kg/s) mass flow rate it raised from (0.48) to (1.52).



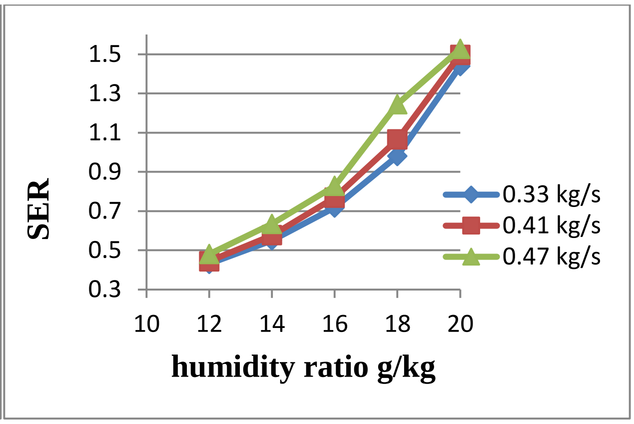
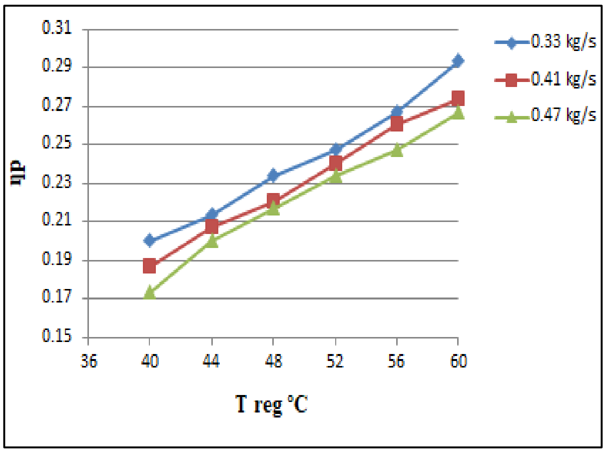


Figure (10) Effect of (T_{reg}) on SER Figure (11) Effect of (w_{in}) on SER

3.4 Effect of Regeneration Temperature and Inlet Humidity Ratio on(η_p and η_r):

Figure (12) and Figure (13) showed the relation between process and regeneration efficiencies respectively with increasing of regeneration temperature. that the values of (η_p) and (η_r) increased with increasing of regeneration temperature due to increasing on deference between inlet and outlet moisture content through the desiccant wheel on process and regeneration sides. For the three flowrate (η_p& η_r) increased about (10%).



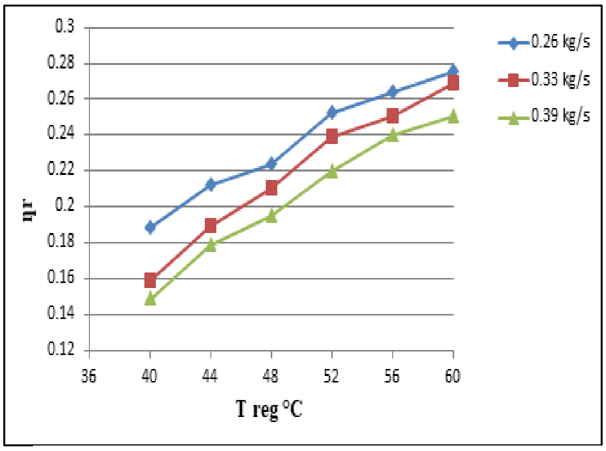
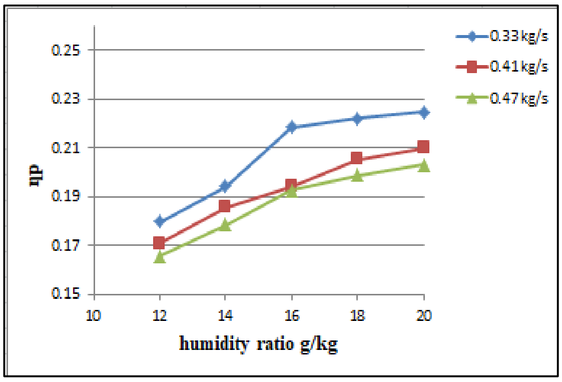


Figure (12) Effect of (T_{reg}) on (η_p)

Figure (13) Effect of (T_{reg}) on (η_r)

Figure (14) and Figure (15) shows the relation between process and regeneration efficiencies respectively with increasing inlet humidity ratio. The values of (η_p) and (η_r) raised with increasing of inlet humidity ratio due to increasing on deference between inlet and outlet moisture content through the desiccant wheel on process and regeneration sides. For the three flowrate (η_p& η_r) increased about (4%) to (6%).



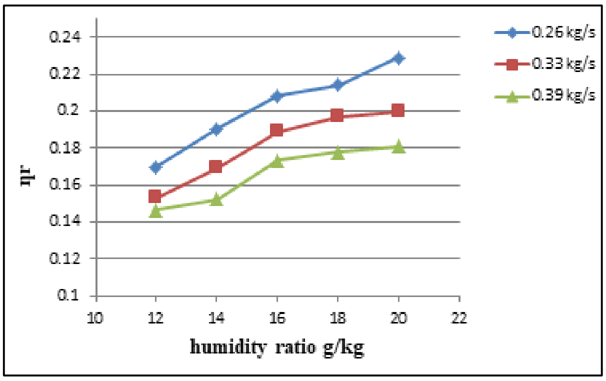


Figure (14) Effect of (w_{in}) on (η_p)

Figure (15) Effect of (w_{in}) on (η_r)

Conclusions:

Effects of the regeneration temperature and inlet humidity ratio on the performance of an air conditioning system with desiccant wheel are studied In this research. The most important conclusions that shown in this paper with increasing the regeneration temperature from (40°C) to (60°C); And increasing inlet humidity ratio from (12 g/kg) to (20 g/kg) for three values of flow rates, are as follows:

1. $MRC)_p$ is increased with increasing regeneration temperature for the three flow rates by about to (0.46,0.54,0.66) g/s respectively; And increased with increasing inlet humidity ratio by about to (0.78,0.88,0.97)g/s

   For $MRC)_r$ it can noticed that best moisture removal capacity was at regeneration temperature of (52°C), while it rising with increasing inlet humidity ratio by about to (0.59-0.7) g/s
2. $DCOP)_{lat}$ is decreased with increasing regeneration temperature and its highest value= 0.97 at (0.47 kg/s) mass flowrate , and lowest value =0.75 at (0.33 kg/s) mass flowrate . While it increased with increasing inlet humidity and its highest value=0.82 at (0.47 kg/s) mass flowrate and lowest value = 0.7 at (0.33 kg/s) mass flowrate.
3. SER values decreases with increasing regeneration temperature by about an average value of (1); while it increases with increasing inlet humidity ratio for an average value of (0.98).
4. Efficiencies are increased with increasing regeneration temperature and inlet humidity ratio. Best efficiencies assessed with respect to regeneration temperature were at (0.33 kg/s) mass flow rate for the process and regeneration sides which were (29%) and (27%) respectively. While best efficiencies assessed according to inlet humidity ratio were also at the first flow rate for the process and regeneration sides which were (22.8%) and (22.5%) respectively.

Previous results shows that apparatus is suitable to use at indoor conditions in the city of Baghdad in which regeneration heater could be controlled and inlet humidity ratio by higher than outdoor condition which include higher temperatures with low humidity ratio in the summer season.

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