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Theoretical Performance of Silica Gel Desiccant Wheel

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Abstract— Silica gel is a substance commonly used in desiccant wheel, which in turn is used in many applications to reduce moisture from the supplied air to a specific space. In this research, the effect of different operational conditions on the performance of silica gel wheel were studied. The desiccant wheel, which has been used, has a diameter of 55 cm and thickness of 20 cm. It contains 34 kg of silica gel and rotate at a speed of 30 rph. The theoretical performance coefficients of the desiccant wheel which have been studied include ,moisture removal capacity(MRC),dehumidification performance(DCOP),latent coefficient of performance (COPlat), and desiccant wheel effectiveness(ϵ_d). The theoretical investigation of these coefficients was done by using Novel Aire Technology software program (Simulation program of desiccant wheel) (2012). While the operational conditions like process air (humid air)inlet temperature between(30 to 43.4)^{0}C, process air inlet humidity ratio between (0.011 to 0.019)kg/kgdry air ,regeneration air inlet temperature between (56.5 to 70)^{0}C,and process air mass flow rate between(0.0814 to 0.199)kg/s. The results shows that the effectiveness and the moisture removal capacity have the same behavior increase with the increasing in mass flow rate from(0.0814 to 0.199) kg/s, humidity ratio from(11 to19)g/kgdry air, and regeneration air temperature from(56 t0 70)^{o}C. But they reduces with increasing of inlet process air temperature from(30 to43.4)^{o}C..

Keywords- Desiccant wheel;silica gel; novel aire technology; humidity ratio; regeneration temperature.

1. INTRODUCTION

Desiccant wheel could decrease about 25% of the total residential electricity demand in humid climate by the dehumidification process and supply more comfortable indoor environment with drier and cleaner air at lower energy consumption. The dehumidification system with desiccant wheel are also being used efficiently in various commercial markets, factories, hotels, and hospitals. E. Chant.[1]. Desiccant wheel which has been used, has a diameter of 55 cm and thickness of 20 cm and divided into two parts 1/3. It contains 34 kg of silica gel and rotate continuously at a speed of 30 rph the desiccant material usually a silica gel or some type of zeolite, is impregnated into a supporting structure. This looks like a honeycomb which is open on both ends. It can absorb moisture from a humid fresh air in a process called adsorption in a dehumidification sector of the wheel. This process of absorbing moisture from the humid air is accompanied by heat releases leads to rise the temperature of humid air at the outlet of the wheel. The desiccant is then regenerated (dried out)in the regeneration sector of the wheel in a process called desorption by using an air heated by low grade thermal energy such as waste heat, natural gas, or solar energy.

Ge et. Al [2] investigated the performance of two stage desiccant cooling system based on thermal coefficient of performance (COP)and moisture removal capacity(MRC). Results showed that the increasing in inlet air humidity ratio caused an increasing in COP and MRC. Ostergaard [3] used solar thermal energy combined with desiccant cooling system and obtained a reduction for cooling and ventilation at 60% when compared with traditional ventilation system. Kisha et.al[4] analyzed the changing of the regeneration temperature and the wheel speed and other factors such as moisture removal and sensible effectiveness used the speeds from 10 to 40 rph they found the optimum rotational speed at 25 rph and showed that the lower speed get better result than the higher one. In Angrisani et.al [5] found that the inlet process air moisture content and regeneration temperature effected on the desiccant wheel performance more than the inlet process air temperature by using micro generator as a heat source to provide thermal energy that regenerated the desiccant wheel. Additionally, Ursla et al[6]found that the regeneration temperature has a positive relationship with efficient dehumidification . However it increases the enthalpy difference of the process air and high moisture content in the fresh outdoor air leads to increase the capacity of the dehumidification but the efficiency of the dehumidification is not affected.

2-AIM OF THE PRESENT WORK

The aims of the current work is to perform a numerical study of the influence of changing some parameters such as(process air temperature, process air moisture content, process air flow rate, regeneration air temperature, regeneration air moisture content , and regeneration air flow rate) on desiccant wheel performance .

3- ROTATING SOLID DESICCANT WHEEL AND THE INFLUENCE OF THE OPERATION PARAMETERS ON THE PERFORMANCE:MODEL DESCRIPTION AND EXPERIMENTAL WORK

In desiccant wheel Air passes through the honeycomb passages, giving up moisture to the desiccant present in the walls of the honeycomb cells. The wheel constantly rotates through two different air streams. The first stream, namely the process air, is dried by the desiccant. During this process the heat of absorption is released to the air. The second air stream, called reactivation or regeneration air, is heated. It dries the desiccant. The regeneration air can be heated by solar collectors, electric heaters, gas burners, or waste heat sources. Since the wheel is continuously rotating, the desiccant material saturated with moisture during absorption process, should be regenerated in order to remove the absorbed moisture. This process is called desorption process and occurs in the regeneration sector of the wheel using hot air can be obtained from any heat source. Figure (1) shows Working of Desiccant Wheel Dehumidifier Figure (2) illustrate the schematic diagram of the solid desiccant wheel .

The adsorption and desorption process that showed in figure (3) occurs due to the difference in water vapor pressure in the air and on the surface of the desiccant material.

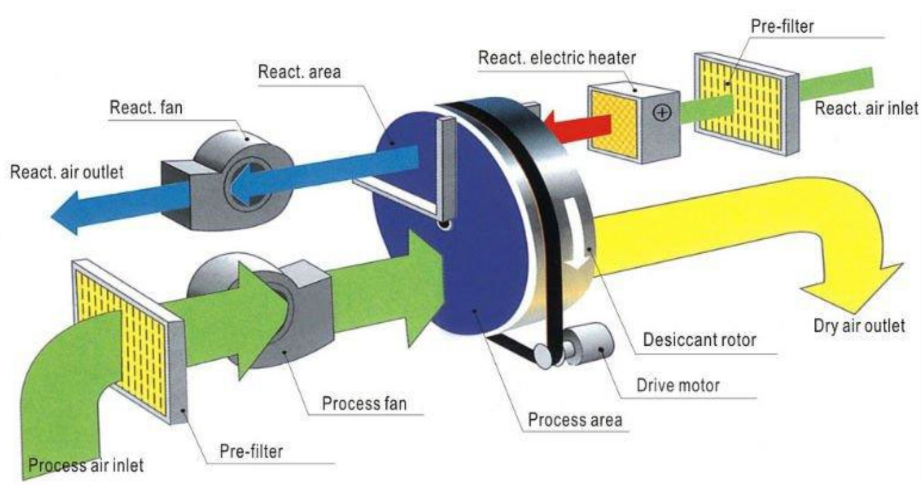

Fig.1. Working of Desiccant Wheel Dehumidifier

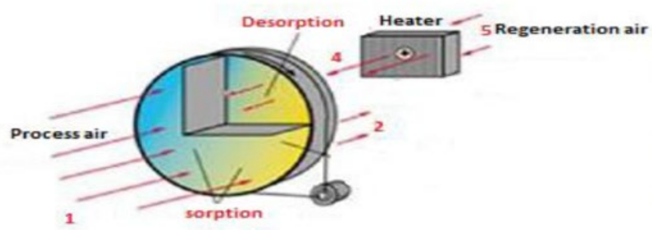

Fig.2. Schematic diagram

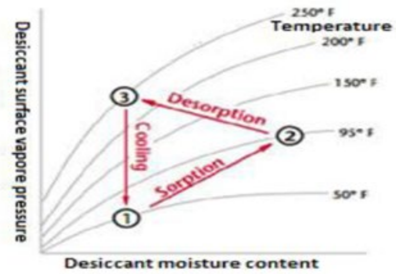

Fig.3. shows sorption &desorption processes

4- THE CHOSEN SILICA GEL

Many types of desiccant are available such as: Alumina, silica gel, Molecular sieves type 4A, but silica gel is the most commonly absorbed material used in the desiccant wheel dehumidifier. It has great affinity for water vapor due to the significant quantity of microscopic pores. Some of the properties of silica gel can be listed in the following table (1) [4].

TABLE 1. SOME PHYSICAL PROPERTIES OF SILICA GEL[4]

Parameter	Value
Thermal conductivity K(Wm^{-1} K^{-1})	0.174
Density ρ (kg m^{-3})	720
Specific heat Cp_d (Jkg^{-1} K^{-1})	921

5- METHODOLOGY

In present study different conditions are taken to measure desiccant wheel (550*200 mm) outlet parameters, also to calculate the performance of the desiccant wheel.

• MRC: Moisture removal capacity presented as mass of moisture removed from humid air per hour(kg/hr),it can be written as shown in equation :

$$MRC = \dot{m}_a\left(w_{ip} - w_{op}\right) \quad (1)$$

• Dcop : the dehumidification coefficient of performance represent the ratio of the reduction of latent heat in the dehumidification process and the energy consumption during the regeneration process,it can be represented in equation:

$$DCOP = \frac{\dot{m}_{ip}(w_{ip}-w_{op})(2501+1.86T_{ip})}{\dot{m}_{ir}(\Delta h_{regeneration})} \quad (2)$$

• COPlatent : latent Coefficients of performance is defined as the ratio between the latent cooling capacity of process air pass through the wheel and the thermal energy supplied by the heat source to the air of regeneration process, it can be written in the form of equation.

$$COP_{Lat} = \left[\dot{m}_{ip}\, h_{fg}(w_{ip} - w_{op})/(Q_{supply})\right] \quad (3)$$

• ε_d: dehumidification effectiveness of desiccant wheel:

$$\varepsilon_d = \frac{w_{ip}-w_{op}}{w_{ip}} \quad (4)$$

Conditions of humid air (process air)and regeneration air entering the wheel which were used to calculate the performance coefficient of the wheel are listed in table(2).

TABLE 2. PARAMETERS CONDITIONS OF AIR

Process inlet air mass flow rate Kg/s	Process inlet air temperature °C	Process inlet air humidity ratio g/Kg $_{dry\ air}$	regeneration inlet air temperature °C
0.081	30	11.8	56.5
0.088	33.2	12.6	60
0.131	37.2	15.1	65
0.175	40	19	70
0.199	43.4	20	

4- GOVERNING EQUATIONS:

In general mass balance between the air and the solid desiccant can be described by the following four governing equations [7]:

- The moisture balance equation in the air flow.

$$\rho_a\left(\frac{\partial w_a}{\partial t}+u\frac{\partial w_a}{\partial x}\right)=K_yP\left(w_{eq}-w_a\right)+\frac{\alpha P(T_{de}-T)}{h_{fg}} \quad (5)$$

- The moisture balance equation in the desiccant material

$$\left(\frac{\partial w_{de}}{\partial t}-D_e\frac{\partial^2 w_{de}}{\partial x^2}\right)=\frac{2k_yP}{f_{de}}\left(w_a-w_{eq}\right)+\frac{2\alpha P(T_a-T_{de})}{f_{de}h_{fg}} \quad (6)$$

7-RESULTS AND DISCUSSION

The result of investigation were obtained from desiccant wheel Novel aire technology software for different air conditions and plotted to calculate desiccant wheel performance.

7.1 Effect of air mass flow rate process on DW performance :

Figure (4) shows an increasing in effectiveness and latent coefficient of performance at constant inlet regeneration temperature(56.5^{0}C) and inlet process [temperature(33.2^{0}C) and humidity(12.7g/Kgdry air)] due to the increasing the difference of moisture content (wip-wop)in the process section.

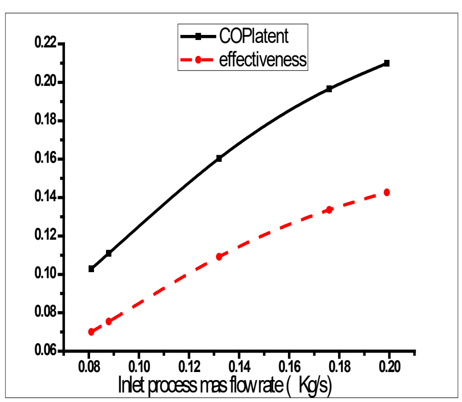

Fig.4. .effect of variation of mass flow rate on COPlatent and effectiveness

Figure 5 shows that both (DCOP) and (MRC) increases almostly (25%) with increasing the mass flow rate of process air pass through the desiccant wheel. The increase in the value of these parameters because of surface vapor pressure of the desiccant will be decreased due to the increase in air moisture content difference of both sides of desiccant wheel.

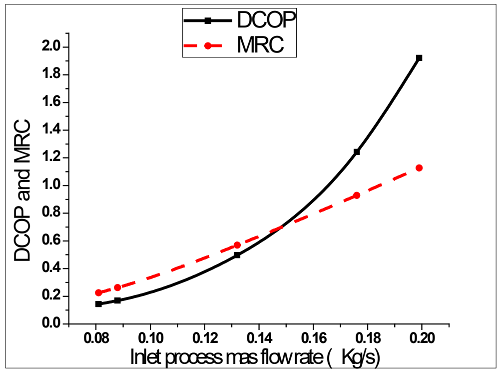

Fig. 5. effect of variation of mass flow rate on DCOP and MRC

7.2 Effect of inlet process air temperature on desiccant wheel performance:

Effectiveness and latent coefficient of performance are decreased with increasing the inlet process air temperature to the wheel at constant inlet regeneration temperature and inlet process (mass flow rate& humidity ratio). This is because of the increasing in temperature of humid air which entering the wheel leads to a reduction in both temperature difference(T_{dip}-T_{dop}) and the moisture content difference(w_{ip}-w_{op}) of the air a cross the wheel as shown in figure 6.

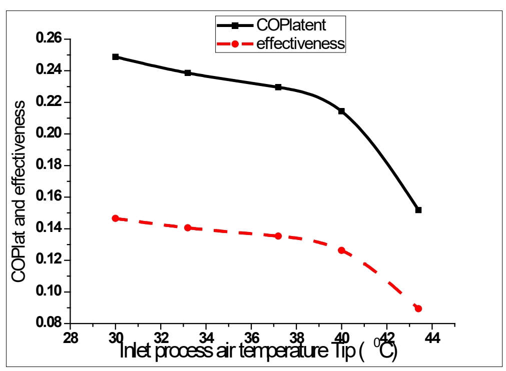

Fig. 6. effect of variation of inlet process temperature on COP_{lat} and effectiveness

Figure (7) shows that MRC decrease with increasing air temperature. This is due to the decreasing in the values of moisture content difference of the air a cross the wheel. But it is shown in this figure, that there are an increase in values of DCOP because increases the enthalpy of water vapor removed from the air in the wheel, which in turn leads to an increase in the value of DCOP

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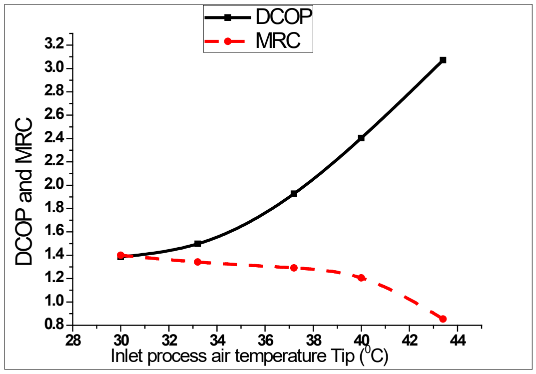

Fig. 7 effect of variation of inlet process temperature on DCOP and MRC

7.3 Effect of Inlet process air humidity ratio on DW performance:

Figure (8) shows an increases in the values of ∈d and COPlat due to the increase in the moisture content values of humid air leads to increases in the absorbing process in the process air by the desiccant material also lead to increase in the pressure difference between the desiccant material and water vapor in process air.

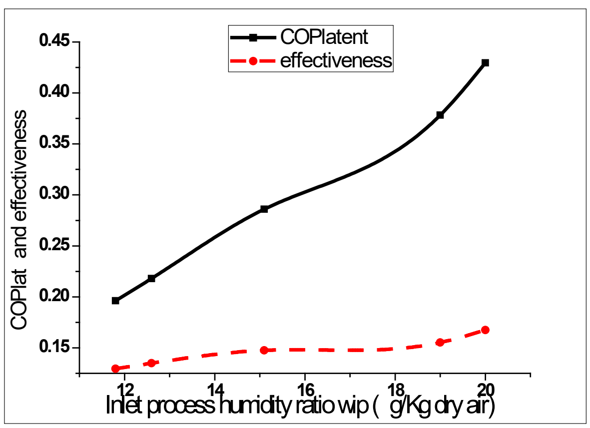

Fig. 8. effect of variation of inlet process humidity ratio on COP_{lat} and effectiveness

Figure (9) indicates that the values of MRC increase with increased the moisture content of inlet process air. This increase is due to the fact that increased moisture content lead to increase in dehumidification rate due to increasing in moisture content difference (w_{ip}-w_{op}) and thus increase in values of this parameter.

As for DCOP values, increase and then decrease due to the fact that increasing the moisture absorbed during the dehumidification process requires the consumption of a different amount of heat to release this moisture during the regenerating process. Therefore a higher point at 15 g/kg $_{dry\ air}$ was due to the smallest consumption of different amount of heat at this point.

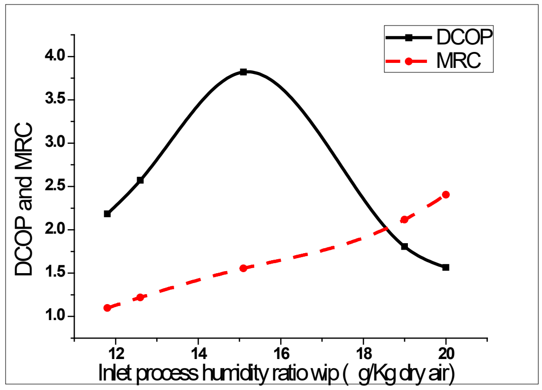

Fig. 9. Effect of variation of inlet process humidity ratio on DCOP and MRC

7.4 Effect of Regeneration Air Temperature on Desiccant Wheel Performance:

Figure (10) the increase in the regenerating air temperature will increase the moisture content difference of the process humid air (w_{ip}-w_{op}) inside the wheel. Thus, this will lead to an increase in the values of (∈) and COP_{latent}. So,the temperature 65°C is the suitable degree to the stability of the desiccant wheel .But the degree after 65°C that was obtained by using a halogen heater (6000W/230V) in practical study the temperature is to high that leads to decrease the efficiency of the DW.

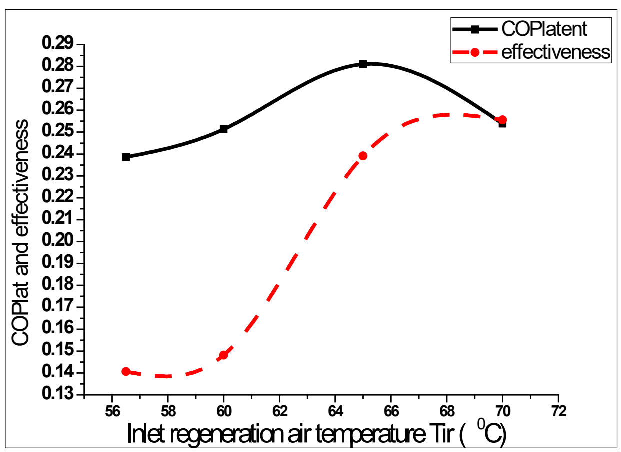

Fig .10. Effect of variation of inlet regeneration temperature on COP_{lat} and ∈

Figure(11) shows that the moisture removal capacity increases with the increasing of regeneration temperature because of the decreasing in the partial pressure of water vapor on the surface of the moisture absorbent. The reason for a decrease in values of DCOP is due to an increase in the amount of heat the air conveys to the absorbent moisture in the wheel during the regeneration process.

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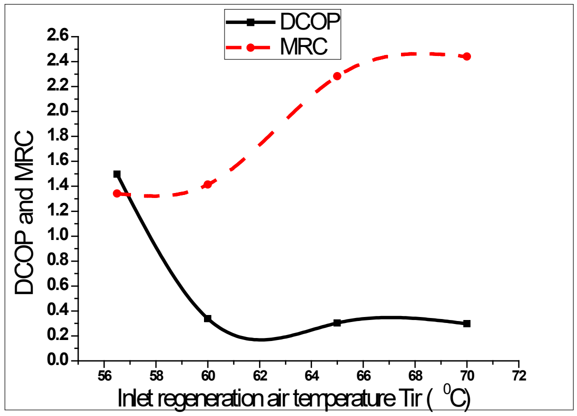

Fig. 11. effect of variation of inlet regeneration temperature on DCOP and MRC

8- CONCLUSION

In this study, the desiccant wheel performance is investigated by using DW software provided by Novel Aire technology based on different parameters consisting of DCOP, COPlat, ∈,and MRC. Affecting factors including air flow rates between (0.0814 to 0.199) kg/s, humidity ratio (11 to 19)g/kg dry air, inlet process air temperatures(30 to 43.4)^{o}C and inlet regeneration temperatures(65 to 70)^{o}C. all influencing factors are discussed . The results showed that the dehumidification effectiveness increases in all previous cases at almost (25%) except that the increasing of inlet process air temperature Tip will decrease due to increasing in temperature of humid air which entering the wheel leads to a reduction in both temperature difference (T_{dip}-T_{dop}) and the moisture content difference(w_{ip}-w_{op}) of the air a cross the wheel.

NOMENCLATURE

$Cp_{d,a}$	Specific heat of dry air(1.007) kJ/kg.K
Cp v	Specific heat of water vapor(1.8772) kJ/kg.K
$Cp=Cp_{d,a}+w*Cp_v$	Specific heat of moist air(1.0308) kJ/kg.K
COP_{latent}	Latent coefficient of performance
Dcop	Dehumidification coefficient of performance
De	Desiccant effective diffusivity(m2/s)
h	enthalpy kJ/kg
h_{fg}	Enthalpy of evaporization (2501) kJ/kg.
ṁ	Mass flow rate kg/s
MRC	Moisture removal capacity kg/hr.
T	Temperature ^{o}C
$\in_d$	Effectiveness of desiccant wheel
w	Humidity ratio g/kg $_{dry\ air.}$
Ky	Mass transfer coefficient Kgm^2/s
Weq	humidity ratio of air in equilibrium with the desiccant kg water /kg dryair
P	pressure Pa

REFERENCES

1 E. Chant, "Transient and Steady State Simulations of an Advanced Desiccant Enhanced Cooling Cycle," Ph.D. Thesis, Georgia Institute of Technology , 1991.

2 T. Ge, Y.Dai, R.Wang, and Y.Li, ″ Experimental analysis on a two-stage rotary desiccant cooling system, "Journal of energy 2008; p.1807-1815.
3 N. Østergaard, ″ Solar thermal cooling office, ″. [Online]. http://www.munters.se/sv/se/nyheter/Division-Avfuktning/E-news/April-2009/4/
4 M. Widgan ,H.Kisha, K. Nasreldin, and A.Rabah, ″ Experimental investigation of the performance of a desiccant wheel, ″. Annual Conference of Postgraduate Studies and Scientific Research, p.266-271, 2012.
5 G. Angrisani, F. Minichiello, C.Rosellia, and M.Sasso, ″ Experimental analysis on the dehumidification and thermal performance of a desiccant wheel ,″ Elsevier, p. 563-572, 2012.
6 Ursla.E. U. Schürger, M. Köhler, and R. Wang ″, Experimental investigations on desiccant wheels ″,Elsevier , p.71-80, 2012.
7 Z. Melikyan, A. A. Elhaleem, A. Fouda." Air Conditioning Systems: Calculating Desiccant Wheels' Design Parameters", Armenia, Encyclopedia of Energy Engineering and Technology, 2010.