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"Research Note"

FABRICATION AND EXPERIMENTAL STUDY OF REGENERATION TEMPERATURE, ROTATIONAL SPEED AND INLET AIR HUMIDITY ON THE PERFORMANCE OF A DESICCANT WHEEL*

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Abstract– Due to climate changes in recent years, in order to attain comfort and convenience, demands for heating, ventilating, and air conditioning (HVAC) systems have been increased around the world, which has led to increases in emissions and power. Desiccant cooling systems (DCSs) are designed and built to reduce moisture and power consumption, create comfortable conditions for people in a building, and environmental protection. Evaluation and study of desiccant wheels (DWs) is vital as they are one of the most important components of DCSs and their performances have a direct impact on the total system. So, the primary purpose of this research is to design a DW by focusing on the operational parameters of the wheel. In this regard, an experimental study was conducted to investigate the effect of regeneration temperature, rotation speed and inlet air humidity ratio on the performance of a DW in a hot and humid climate. The experimental results were obtained in the regeneration temperature between 70-100^{o}C, wheel rotation speed 4-12 revolutions per hour (rev/h), 1:2 split between regeneration and process sides and different humidity.

Keywords– Desiccant wheel, silica gel, regeneration temperature, rotational speed, experimental analysis

1. INTRODUCTION

Using conventional vapor compression cooling systems to reduce the moisture content are very expensive and do not have good efficiency in high humidity areas. An effective way to control the humidity level of the space is desiccant cooling systems (DCSs). These systems can supplement the air conditioning systems or replace it. When DCSs are used, cooling and dehumidifier processes are possible in two separate ways. The technology of dehumidification based on desiccant wheels (DWs) has special attention to control of prices, power consumption, and environmental conditions. For more information, please refer to [1].

Esfandiari Nia et al. [2] simulated the combined heat and mass transfer processes that occur in a solid DW with MATLAB Simulink. Using the numerical method, the performance of an adiabatic rotary dehumidifier was parametrically studied, and the optimal rotational speed was determined by examining the outlet adsorption-side humidity profiles. Their model allowed predicting the optimal rotational speed at various regeneration temperatures, comparing the simulation results with experimental work. Chung et al. [3] showed that regardless of the outdoor conditions, as the regeneration temperature becomes higher, the optimum time required per one wheel revolution (the inverse of the rotational speed) decreases and then approaches a constant value. Kodama et al. [4] showed the existence of an optimal value of the

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rotational speed that minimizes the ratio between outlet and inlet process air humidity ratio. Furthermore, the optimal value rose with the regeneration temperature. Panaras et al. [5] attempted to validate a DW model by means of experimental data taken in a test facility. Eicker et al. [6] evaluated the performance of a solar air collector driven DCS experimentally. They focused on two types of dehumidification efficiency. Mandegari et al. [7] assessed the performance parameters such as the moisture removal capacity (MRC) and the sensible energy ratio (SER) experimentally. A theoretical and experimental investigation of the key components for a rotary DW is described by Zamzamian and Pahlavanzadeh [8]. In the paper, an optimum air stream velocity and rotational speed of wheel as 1.86 m s^{-1} and 10 rad h^{-1} were suggested respectively. Pahlavanzadeh and Zamzamian [9] also used a mathematical model to show the dehumidification trend of a desiccant dehumidifier with no rotation.

However, more articles have been dedicated to parameter optimization of manufactured industrial DWs and less devoted to parameter study and design of the wheel as the most important part of the DCS. So, the primary purpose of this research is to design and fabricate a DW and then investigate the effect of some main parameters such as regeneration temperature, rotation speed and inlet air humidity on the performance of the DW in hot and humid climate. The experimental results were obtained in the regeneration temperature range from 70^{o}C to 100^{o}C, wheel rotation speed of 4 to 12 rev/h and 1:2 split between regeneration and process sides at different humidities.

2. DESICCANT WHEEL FABRICATION PROCEDURE

The test facility was located in a hot and humid climate in Bushehr, in the south of Iran. Figure 1 shows the performance of the desiccant wheel.

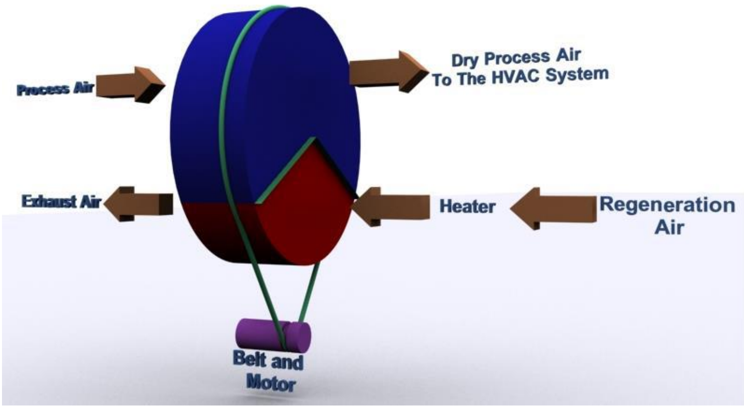

Fig. 1. Schematic of the desiccant wheel

Figure 2 displays the fabricated wheel of DCS. For this study, the wheel was designed with a diameter of 55 cm and a thickness of 18 cm. Absorbent material (silica gel) is in the honeycomb section where air passes over it. On the wheel 250 holes were embedded with a diameter of 2 cm. The plan of the wheel and silica gel places was outlined by using the SOLIDWORK software. Then the holes were created by drilling with a CNC machine. The wheel has the following configuration: 67% of the wheel area is crossed by the process air, while the remaining 33% by the regeneration air. The wheel was placed in a small gap in the middle of a box. A motor with 90 W power has been used to rotate the wheel of containing silica gel as it is shown in Fig. 3. The needed temperature for DW regeneration is 70-100^{o}C, so, an electric air heater was placed to heat the air in the inlet side of the regeneration side. Finally, humidity is measured using a capacitive hygrometer for an air relative humidity range of 0-100% within ±2% uncertainty and temperature is measured using T-type thermocouples which operate in temperature range of -200 to 350^{o}C within ±1%^{o}C uncertainty.

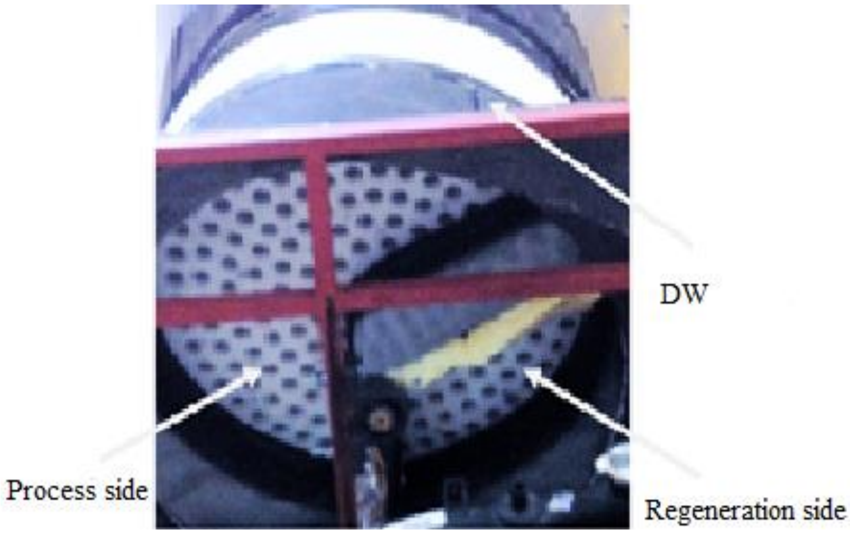

Fig. 2. The fabricated wheel

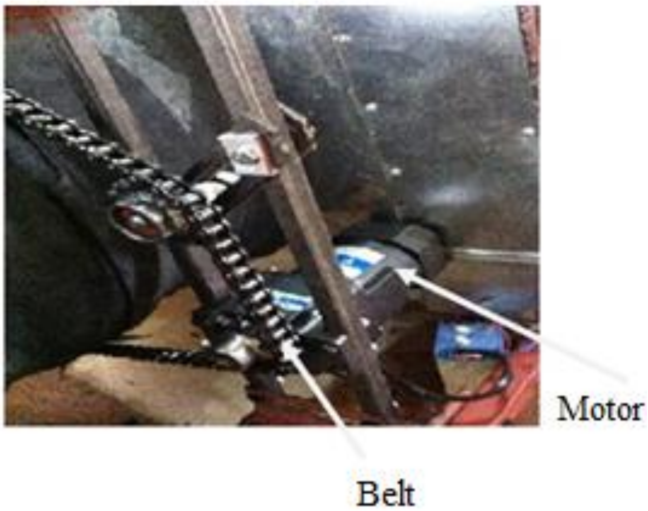

Fig. 3. Illustration of the driving mechanism of the DW

3. RESULTS AND DISCUSSION

a) The impact of process inlet air humidity ratio and regeneration temperature

Regeneration temperature leads to changes in the amount of process outlet humidity and temperature. Also, the amount of inlet air humidity ratio has a direct impact on the amount of outlet air humidity ratio. In Fig. 4 the outlet humidity ratio of process air is reported as a function of the inlet humidity ratio of process air at different regeneration temperatures at a constant speed 5 rev/h. As seen in this figure, the higher the inlet air moisture, the higher the outlet air moisture. For example, if the inlet air humidity ratio is 12.49 g/kg at 80^{o}C, the outlet air humidity ratio is 9.26 g/kg, while for the air inlet humidity ratio of 14.95g/kg, the amount of outlet moisture increases to 10.96 g/kg. This shows that the desiccant material has a certain capacity to absorb moisture that is confirmed by [10-12]. When regeneration temperature increases, the process outlet humidity ratio is lower. For example, for air inlet humidity of 12.49 g/kg at 80^{o}C, the output humidity is 9.26 g/kg, while for air inlet humidity of 12.49 g/kg at 100^{o}C, the amount of outlet humidity ratio reaches 7.16 g/kg. Therefore, it can be concluded that increasing the regeneration temperature leads to more moisture attraction from the air that is in accordance with [11, 13 and 14].

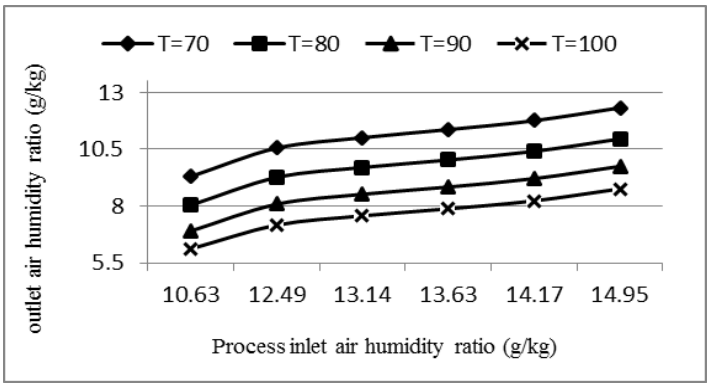

Fig. 4. Outlet humidity ratio of process air as a function of inlet humidity ratio of process air at different regeneration temperatures

In Fig. 5 the reactivation outlet humidity ratio is reported as a function of the process inlet humidity ratio at the different regeneration temperatures at a constant speed of 5 rev/h. As can be seen, the reactivation outlet humidity ratio increases with increasing the process inlet humidity ratio as well as the regeneration temperature. For example, for the air inlet humidity of 12.49 g/kg at the regeneration temperature 80^{o}C, the outlet humidity is 56.46g/kg, while for the humidity of 14.95g/kg, the amount of output moisture increases to 57.99 g/kg.

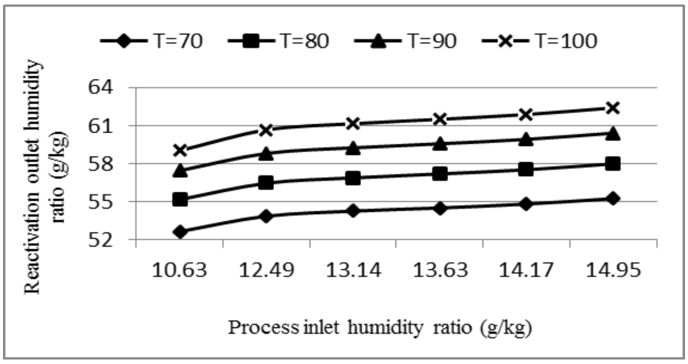

Fig. 5. Reactivation outlet humidity ratio as a function of process inlet humidity ratio at different regeneration temperatures

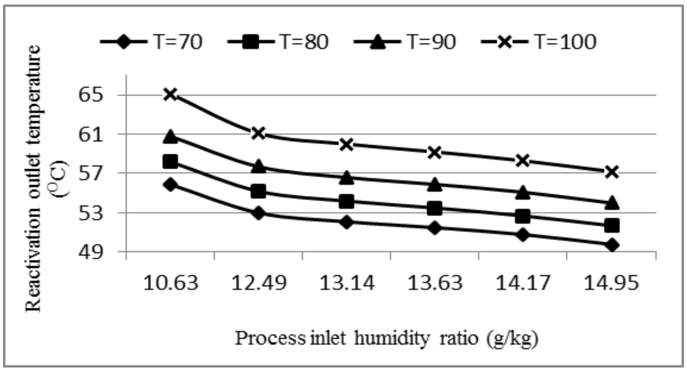

Fig. 6. Reactivation outlet temperature as a function of process inlet humidity ratio at different regeneration temperatures

Figure 6 illustrates the reactivation outlet temperature as a function of the process inlet humidity ratio at different regeneration temperatures at a constant speed of 5 rev/h. It was found that the reactivation outlet temperature decreases with increasing the process inlet air humidity ratio. For example, the outlet temperature for inlet air humidity of 12.49 g/kg at temperature of 90^{o}C is 57.7^{o}C, while for the air inlet humidity of 14.95 g/kg, the amount of outlet temperature decreases to 54^{o}C. Moreover, the augmentation of the regeneration temperature causes an increase in reactivation outlet air temperature. For example, for the air inlet humidity of 12.49 g/kg in temperature 80°C, the outlet temperature is 55.2°C while for 12.49 g/kg air inlet humidity at temperature of 100°C, the amount of outlet temperature increases to 61.1°C.

b) The impact of regeneration temperature and rotational speed

The process outlet humidity ratio is reported as a function of DW rotation speed at the different regeneration temperatures in Fig. 7. In terms of the effect of the rotation speed, the rise in rotation speed causes an increase in the process outlet humidity ratio. Also, it is clear that a drier DW is more able to absorb more moisture from the air at a higher regeneration temperature. From Fig. 7, when the wheel rotates with 8 rev/h at regeneration temperature of 80°C, the outlet humidity is 8.57 g/kg, while by increasing the regeneration temperature to 100°C the outlet humidity is reduced to 6.36 g/kg.

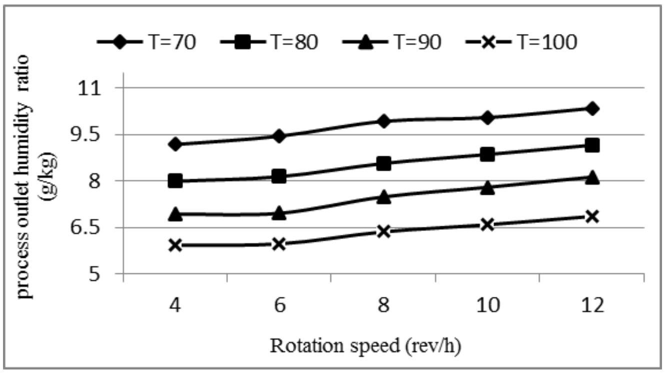

Fig. 7. Process outlet humidity ratio as a function of rotation speed at different regeneration temperatures

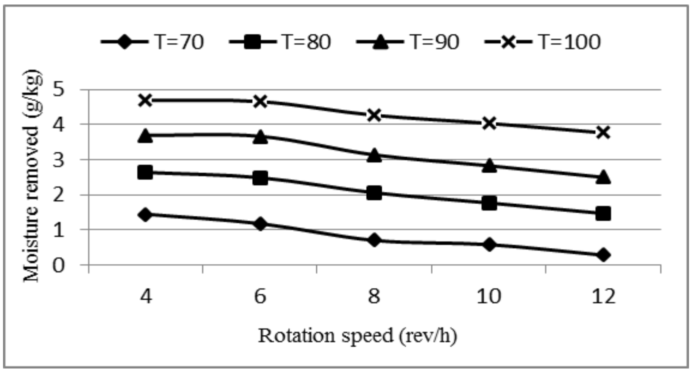

Fig. 8. The process moisture removed as a function of the rotation speed at different regeneration temperatures

One of the most important parameters of a DW is the amount of moisture taken from the inlet air that is defined as follows [14].

$$D = w_{p,in} - w_{p,out} \tag{1}$$

where $w_{p,in}$ and $w_{p,out}$ are the humidity ratio of process air at inlet and at outlet, respectively.

The process moisture removed is reported as a function of the DW rotation speed at different regeneration temperatures in Fig. 8. It is shown that an increase in the regeneration temperature helps to remove more moisture, which is approved by [2, 12, 15 and 16]. It should be noted that if the regeneration temperature is too high, the wheel will be dried before the process period which increases the cost and waste. It was found that at lower speeds of DW, the removal of moisture is better [2, 10, 14 and 17]. This is because of the contact time reduction between the inlet air and the DW at the higher speeds. For instance, when the wheel rotates at 4 rev/h and regeneration temperature of 80^{o}C, the removed moisture is 0.264 g/kg, while with the speed of 12 rev/h this value is reduced to 1.47 g/kg.

Figure 9 shows the process outlet temperature as a function of rotation speed at different regeneration temperatures. The process air outlet temperature is higher than that of the inlet air temperature. Some heat is transferred to the process air because the DW is warm when coming to the process air from the reactivation side. Generally, 80 to 90% of the temperature rise of the process air is from the heat carried over from reactivation [12]. Moreover, Fig. 9 shows that the outlet temperature increases with increasing rotation speed. For example, when the wheel rotates at a speed of 4 rev/h at regeneration temperature of 80^{o}C, the outlet temperature is equal to 35.2^{o}C, while the outlet temperature increases to 37^{o}C for the rotation speed 12 rev/h. Besides, the higher the regeneration temperature is, the higher the outlet air process temperature [2, 13].

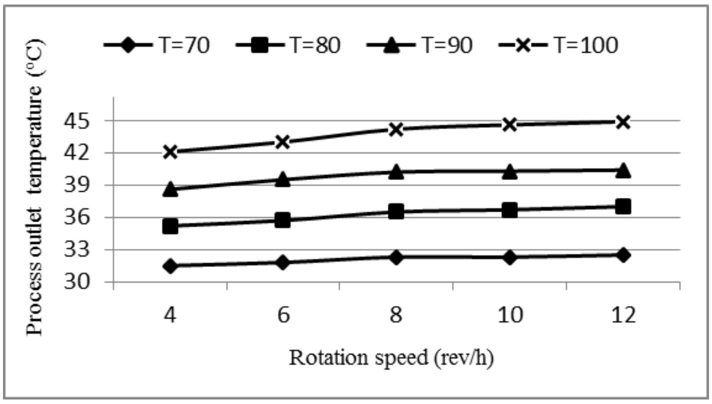

Fig. 9. The process air outlet temperature as a function of rotation speed at different regeneration temperatures

The reactivation outlet humidity ratio is reported as a function of rotation speed at different regeneration temperatures in Fig. 10. It is clear that the reactivation outlet humidity decreases with increasing rotation speed. When the regeneration temperature is 80^{o}C and the wheel rotates at 4 rev/h, for instance, the amount of reactivation outlet humidity is 55.28 g/kg, while the amount of outlet humidity is 52.93 g/kg for the rotation speed 12 rev/h. on the other hand, by increasing the regeneration temperature the reactivation outlet humidity ratio increases.

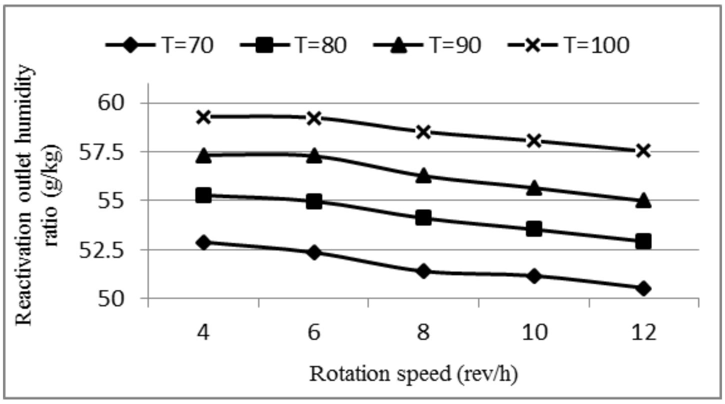

Fig. 10. The reactivation outlet humidity ratio as a function of rotation speed at different regeneration temperatures

Figure 11 illustrates the reactivation outlet temperature as a function of rotation speed at different regeneration temperatures. It can be seen that increase in rotation speed leads to a decrease in reactivation outlet air temperature. The variation of regeneration temperature is higher at lower speeds. It was found that the reactivation outlet temperature increases with increasing regeneration temperature. For example, when the wheel rotates in the state of 80°C and 6 rev/h the reactivation outlet temperature is 57.8°C while at 100°C and the same rotational speed the reactivation outlet temperature is increased to 63.2°C.

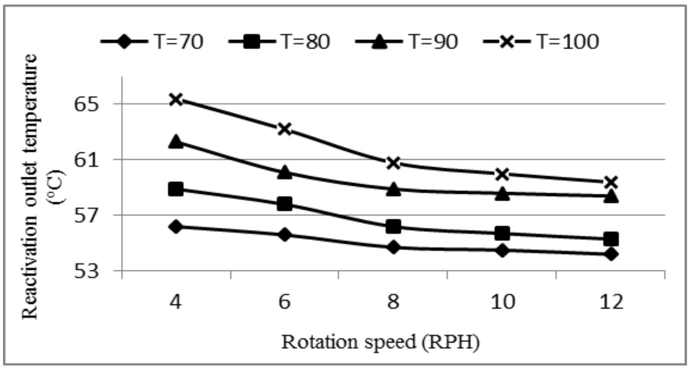

Fig. 11. The reactivation outlet temperature as a function of rotation speed at different regeneration temperatures

4. CONCLUSION

A silica gel DW was manufactured and tested in a hot and humid climate in Bushehr, the south of Iran. The performance of the wheel in the range of 70-100°C regeneration temperatures, 4-12 rev/h wheel rotations and variable humidity was investigated experimentally. There was good agreement between the results obtained in the present work by data of other researchers.

- The process outlet humidity increases with increasing the process inlet humidity ratio. Also, by increasing the regeneration temperature, the process outlet humidity ratio is reduced.
- The reactivation outlet humidity increases with increasing the process inlet humidity ratio. When the regeneration temperature increases, the reactivation outlet humidity ratio is more, but the reactivation outlet humidity decreases with increasing the rotation speed.
- The rise of the wheel rotation speed causes an increase in the process outlet humidity ratio. Moreover, it was concluded that an increase in the regeneration temperature helps to remove more moisture.
- At lower speeds of the rotating DW, the moisture removed is better. Therefore, by increasing rotational speed of the wheel, the moisture removal efficiency of the wheel is decreased.
- The process outlet temperature increases with increasing the rotation speed of the wheel.

REFERENCES

1. Zendehboudi, A. R., Zendehboudi, A. & Hashemi, R. (2014). A Study on the Performance of a Solar Desiccant Cooling System by TRNSYS in Warm and Humid Climatic Zone of IRAN. *International Journal of Advanced Science and Technology*, Vol. 69, pp. 13-18.
2. Esfandiari Nia, F., Paassen, D. van & Saidi, M. H. (2006). Modeling and simulation of desiccant wheel for air conditioning. *Energy and Buildings,* Vol. 38, pp. 1230–1239.
3. Chung, J. D., Lee, D. Y. & Yoon, S. M. (2009). Optimization of desiccant wheel speed and area ratio of regeneration to dehumidification as a function of regeneration temperature. *Solar Energy*, Vol. 83, pp. 625–635.
4. Kodama A., Hirayama T., Goto M., Hirose T. & Critoph R. E. (2001). The use of psychrometric charts for the optimisation of a thermal swing desiccant wheel. *Applied Thermal Engineering*, Vol. 21, pp. 1657–1674.
5. Panaras G., Mathioulakis E., Belessiotis V. & Kyriakis N. (2010). Experimental validation of a simplified approach for a desiccant wheel model. *Energy and Buildings*, Vol. 42, pp. 1719–25.

6. Eicker U., Schneider D., Schumacher J., Ge T. & Dai Y. (2010). Operational experiences with solar air collector driven desiccant cooling systems. *Applied Energy*, Vol. 87, pp. 3735–3747.
7. Mandegari M. A. & Pahlavanzadeh H. (2009). Introduction of a new definition for effectiveness of desiccant wheels. *Energy*, Vol. 34, pp. 797–803.
8. Zamzamian, S. A. H. & Pahlavanzadeh, H. (2011). Theoretical and Experimental Investigation of the Key Components for a Rotary Desiccant Wheel. *Iranian Journal of Chemistry & chemical Engineering*, Vol. 30, No. 3, pp. 25-30.
9. Pahlavanzadeh, H. & Zamzamian, A. (2006). *A Mathematical model for a fixed desiccant bed dehumidifier concerning Ackermann correction factor. Iranian Journal of Science & Technology, Transaction B, Engineering*, Vol. 30, No. B3, pp. 353-362.
10. Angrisani, G, Roselli, C. & Sasso. M. (2013). Effect of rotational speed on the performances of a desiccant wheel. *Applied Energy*, Vol. 104, pp. 268–275.
11. Antonellis, S. D., Joppolo, C. M. & Molinaroli, L. (2010). Simulation, performance analysis and optimization of desiccant wheels. *Energy and Buildings*, Vol. 42, pp. 1386–1393.
12. Sajith, A & Dilip, D. (2009). Experimental analysis of solid desiccant wheel dehumidifier. *10th National Conference on Technological Trends*, pp. 145-150.
13. Yamaguchi, S. & Saito, K. (2013). Numerical and experimental performance analysis of rotary desiccant wheels. *International Journal of Heat and Mass Transfer*, Vol. 60, pp. 51–60.
14. Kisha, W. M. H., Abdalla, K. N. & Rabah, A. A. (2012). Experimental Investigation of the performance of a Desiccant Wheel. *Annual Conference of Postgraduate Studies and Scientific Research*, Vol. 1, pp. 266-271.
15. Camargo, J. R., Junior, E. G. & Slva, N. P. (2007). Performance analysis of a rotary wheel dehumidifier applied to air conditioning. *Journal of engineering and applied sciences*, pp. 186-190.
16. Vineyard, E. A., Sand, J. R. & Durfee, D. J. (2000). Parametric analysis of variables that affect the performance of a desiccant dehumidification system. *ASHRAE Transactions*, Vol. 106, pp. 87 – 94.
17. Yadav, A. & Bajpai, V.K. (2011). Optimization of Operating Parameters of Desiccant Wheel for Rotation Speed. *International Journal of Advanced Science and Technology*, Vol. 32, pp. 109-116.