**Available online at** www.uofk.edu
Proceedings Vol. 1 pp. 266-271
Annual Conference of Postgraduate Studies and Scientific Research
17-20 February 2012-10-17 Friendship
Hall, Khartoum

# Experimental Investigation of the performance of a Desiccant Wheel

**Wigdan M.H.Kisha[1], Kamal N.Abdalla[2], Ali.A.Rabah[3]**

[1]*Department of Mechanical Engineering, University of Khartoum, Khartoum, Sudan,(wiji84@hotmail.com)*
[2]*Department of Mechanical Engineering, University of Khartoum P.O. Box 321, Khartoum, Sudan,*
[3]*Department of Chemical Engineering, University of Khartoum, P.O. Box 321, Khartoum, Sudan*

**Abstract**: Desiccant cooling systems have the potential to make a major contribution to the reduction of both CFC's emissions and electricity peak load. An experimental investigation on the sensible effectiveness of a desiccant wheel is conducted. Measurements were made for a range of rotational speeds (0-5 rpm), regeneration temperatures (50 to 60oC). A computer based calculation procedure using Excel worksheet was built, and applied to estimate the effect of the desiccant wheel speed on the moisture removal and the sensible effectiveness. The calculations were based on the experimental data obtained during the experiment. The results succeeded in determining the optimum rotational speed for the desiccant wheel, the sensible effectiveness, the moisture removal efficiency and the dehumidification coefficient of performance. It was found that the lower speeds gave better results than the higher ones.

**Keywords:** Desiccants; Dehumidification; Regeneration; Sensible; Effectiveness

## 1. INTRODUCTION

Desiccant systems have been in use as early as 1930's, primarily for industrial applications where there is an economic benefit to close-tolerance humidity control at low levels [1]. Early desiccant applications in comfort control involved semi-process installations such as medical buildings, which profit from the air cleaning and sterilization effects of liquid desiccant systems.

In the last 10 years, evaporative and desiccant cooling technology was considered for air conditioning systems. A typical system combines a dehumidification system that uses a rotary desiccant wheel, with direct and indirect evaporative systems, allowing a filtered and cooled air supply that propitiate environmental thermal comfort, even in equatorial and tropical climates [2].

Interest is now being revived in thermal-driven desiccant dehumidification in non-industrial air-conditioning applications to offset rising electricity prices. Lower cost thermal energy, including natural gas, waste heat, solar energy and other sources is substituted for electric energy to meet the dehumidification load on the air-conditioning system.

Today, desiccant dehumidification technology, supported by ongoing research and development on cost-saving to reduce electric-energy costs and power demand in certain nonindustrial air conditioning sectors [3].

Commonly encountered pre-packaged desiccants are solids, and work through desorption or absorption of water, or a combination of the two. Desiccants for specialized purposes may be in forms other than solids, and may work through other principles, such as chemical bonding of water molecules. All desiccants behave in a similar way in that they attract moisture until they reach equilibrium with the surrounding air. Moisture is usually removed from the desiccant by heating it to temperatures between 120 and 500˚F and exposing it to a scavenger airstream [3].

Air-to-air energy recovery devices exchange energy from one stream of air to another. The air contains sensible (heat) and latent (water vapour) energy. The effectiveness of an energy recovery device reflects the efficiency of the device in recovering available energy. Most devices have a rating for sensible effectiveness; some also have a rating for latent effectiveness and total effectiveness [4].

Enthalpy wheels, or rotary heat exchangers, transfer sensible or latent energy (or both) between the exhaust air and the incoming outside air. The supply and exhaust streams must be located next to each other. Both sensible-only wheels and total energy wheels, sometimes referred to as desiccant wheels, are available. A 50,000 cfm total energy wheel can have a sensible and latent effectiveness as high as 75%, which results in a total effectiveness of 75%. Control of the wheel at part loads is accomplished by varying the speed of the wheel, or using a bypass duct, or both [4].

The useful life of desiccant materials depends largely on the quantity and type of contamination in the airstreams they dry. In commercial equipment, desiccants last between 10,000 and 100,000 hours and longer before they need replacement [5].

In the desiccant wheel, the desiccant material, usually a silica gel or some type of Zeolite, is impregnated into a support structure. This looks like a honeycomb which is open on both ends. Air passes through the honeycomb passages, giving up moisture to the desiccant contained in the walls of the honeycomb cells. The desiccant structure is formed into the shape of a wheel. The wheel constantly rotates through two separate air streams. The first air stream, called the process air, is dried by the desiccant. The second air stream, called reactivation or regeneration air, is heated. It dries the desiccant.

A desiccant wheel rotates slowly, and contains more desiccant than enthalpy wheel. By heating the reactivation air, it can remove much more water vapour than an enthalpy wheel [6].

The objective of this study is to determine the sensible effectiveness of the desiccant wheel by addressing the effect of the desiccant wheel speed for several temperatures. Also, to determine the moisture removed by the desiccant wheel and the desiccant wheel coefficient of performance.

## 2. EXPERIMENTAL SETUP

The desiccant wheel Figure (1) consists of a circular wheel driven by a small motor where the matrix has porous channels. The channels are made of metal coated with desiccant material. Several desiccant coatings, such as molecular sieve, silica gel, activated alumina and activated carbon have been in use. The channels of the matrix are made of different configurations (parallel surfaces, equilateral triangle, square, hexagonal, circular or corrugated geometry). The matrix usually has a large heat/mass transfer area per unit volume, e.g. $4000 m^2/m^3$, and large number of channels per surface area of the face, e.g. 40,000 channels/$m^2$.

The wheel diameter varies between 0.2 to 5 meter and depth is between 0.1- 0.5 meter. Thin (0.07-1.2 mm) aluminium foil is generally corrugated to make minute, mostly sine-wave, channels. The height of the sine-wave varies from 1.6 to 2.5 mm. The aluminium foil is coated with thin (0.3nm-0.05mm) desiccant layer.

For heating, ventilation and air conditioning (HVAC) applications, the desiccant wheel generally rotates with low speed (8 - 25 rpm). The sensible and latent heat is transferred by convection from the moist air stream and adsorbed in the desiccant. As the wheel rotates the adsorbed mass in the desiccant is released to the dry-air stream. Desiccant wheels do not reduce the air energetic load; they only change latent heat (humidity) by sensitive heat (temperature).

The wheel is driven by 90 W motor with variable frequency of 0-120Hz, equivalent to wheel rotational speed of 0-10 rpm. The electric heater Figure (3) manufactured by VOLTA, has a variable power of 0-7.2 kW. Two air fans Figure (4) were used for each air stream. Each air fan has a power of 100 W and delivers air volume of up to 200 $m^3$/hr. The wheel is operated in a counter current arrangement. For hot section, ambient air is blown using the air fans. Prior to the inlet of the wheel, the air is passed through the electric heater. This is made to bring the air to desired temperature range of 40 to 70$^o$C. At the exit of the electric heater a distribution plate is installed to create uniform velocity and temperature at the inlet of the wheel. For the cold air stream, the temperature at the inlet of the wheel is measured at the center of the duct. For the hot air stream, the inlet temperature is measured at the center, top and bottom of the duct. This is made to check the condition of uniform temperature at the inlet of the wheel. At the exit of the hot and cold streams, the air temperatures are measured at different locations. The regenerator Figure (2) is very similar to the desiccant wheel; however, its matrix is not coated with desiccant material. It is a rotary counter flow air-to-air exchanger used to transfer both sensible and latent heat between supply and exhaust air streams.

There were twenty four temperature sensors fixed at specific locations in the system to measure the temperature of the air in each position. Also, there were two pressure sensors and four differential pressure sensors to measure the pressure and pressure drop through the desiccant wheel and the regenerator wheel. The humidity was measured in two positions for the cold air and in other two positions for the hot one. All the sensors were calibrated before being used in the experiment.

A digital multimeter was used to measure all the previous parameters. The LabVIEW program was used in gathering the data which is used in an excel sheet to make the calculations. Two groups of experiments were done by adjusting the heater temperature first to 50°C and then for 60°C for desiccant and regenerator wheels frequencies 1, 3, 5,10,15,20,25,30,40 & 50 Hz respectively. Figure 5 shows the desiccant cooling system.

**Figure (1).** the desiccant wheel

**Figure (2).** the regenerator wheel

**Figure (3).** the electric heater

**Figure (4).** the air fan

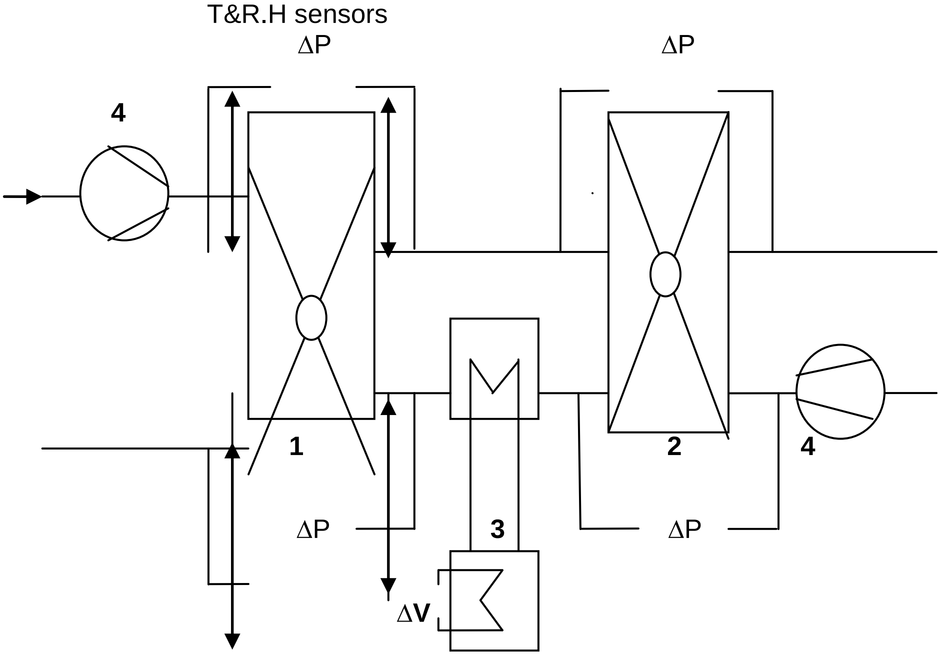


**Figure (5).** Desiccant Cooling System

**Key: 1**≡ Desiccant wheel, **2**≡ Regenerative wheel, **3**≡ Electric heater, **4**≡ Air fan

**ΔP**≡ Pressure drop

## 3. RESULTS

To determine the effect of the wheel on the heat transfer rate and the wheel effectiveness, the following equations were used:

$$q = C_h(T_{h,i} - T_{h,o}) = C_c(T_{c,o} - T_{c,i})$$

$$C_h = \dot{m}_h Cp_h \,,\; C_c = \dot{m}_c Cp_c$$

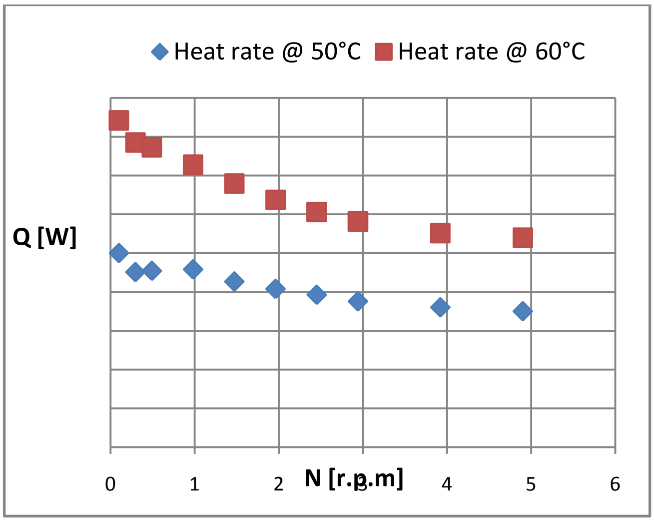


**Figure (6).** the effect of desiccant wheel speed on the heat transfer rate at different temperatures

The following equation was used to determine the effectiveness of the desiccant wheel:

$$\varepsilon = q / q_{max.}$$

Where:

$$q_{max.} = C_{min}(T_{h,i} - T_{c,i})$$

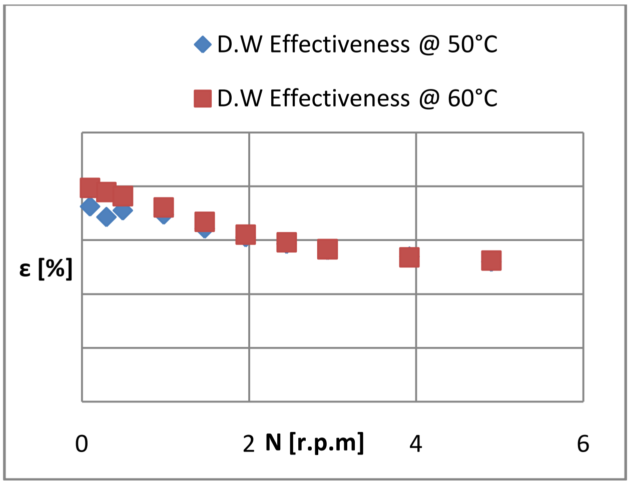


**Figure (7).** the effect of the desiccant wheel speed on the effectiveness

The main function of the desiccant wheel is to remove the water vapour from the process air. Moisture removal D is adopted as an index to represent the absolute dehumidification capacity of the desiccant wheel:

$$D = w_{C,in} - w_{C,out}$$

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

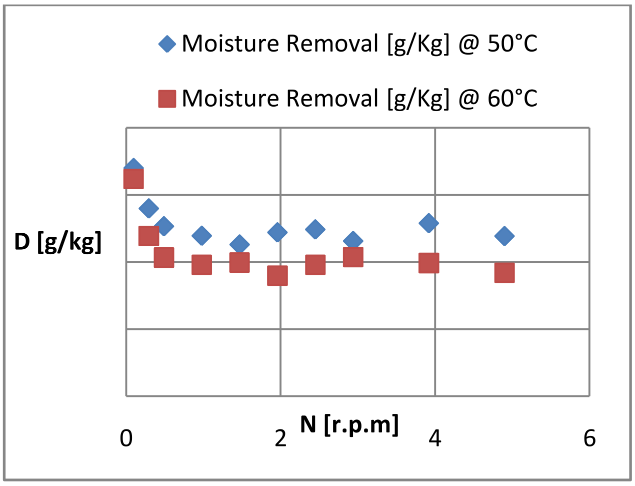


**Figure (8).** the effect of the desiccant wheel speed on the moisture removal

Relative moisture removal efficiency ζ is adopted as:

$$\zeta = D / w_{C,in}$$

ζ shows the ratio of moisture removal to inlet humidity ratio of process air. Its value is between 0 and 1. For constant inlet humidity ratio of process air, ζ increases with increasing the moisture removal D.

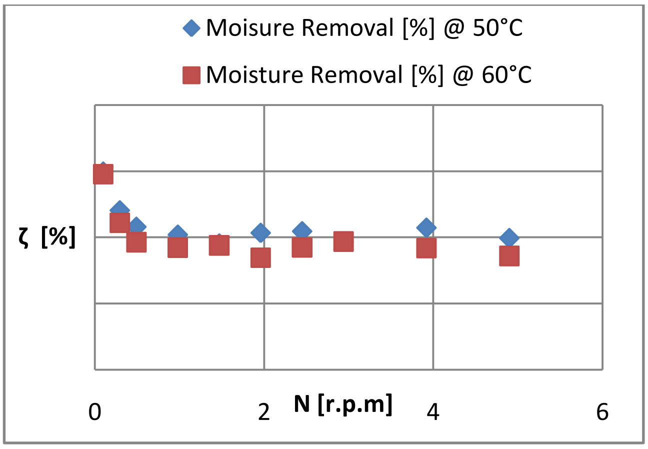


**Figure (9).** the effect of the wheel speed on the moisture removal efficiency

Moreover, another index, the dehumidification coefficient of performance (DCOP), which reflects the dehumidification capacity and energy utilization performance at the same time, is also adopted. It is the ratio of the latent heat which is contained in the adsorbed moisture and the effort to produce the high inlet temperature in the regeneration air:

$$DCOP = \frac{(\dot{m}_c * D * h_v)}{(\dot{m}_h * (T_{h,in} - T_{ambient}))}$$

A higher DCOP indicates a better system performance because the energy input to the regeneration air utilized in a better way or less heat is being used to heat up the desiccant wheel [7].

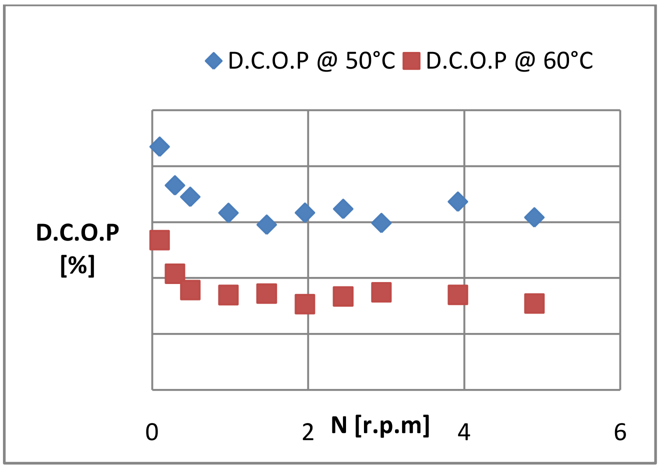


**Figure (10).** the effect of the desiccant wheel rotational speed on the dehumidification coefficient of performance

From Figure (10), it is clear that the DCOP depends strongly on the regeneration temperatures and it decreases as regeneration temperature increases. On the contrary, this is not expected. Apparently, a high regeneration temperature speeds up moisture removal D. However, high regeneration temperatures will dry up the wheel before it completes the regeneration period. Hence part of the energy added will not be utilized in moisture removal [8].

## 4. CONCLUSIONS

Evaluations made from the experiment draw general conclusions on the performance of the system; Desiccant units in humid areas perform better than in less humid areas, Desiccants are especially efficient when drying air to create low relative humidities. For sensible heat exchangers, it is expected that the effectiveness of the desiccant wheel is not dependant on the regeneration temperatures. Visual inspection of Figure (7) confirms this expectation. The variation occuring at the first five points is due to the variation in the mass flow rate for the hot and cold air. The maximum sensible effectiveness of the desiccant wheel can be obtained at a lower rotational speed of 0.098 rpm, it has a value of 79.4% at a heater temperature of 60°C which is higher than its value at a heater temperature of 50°C at the same speed.

The biggest moisture removal (D) and dehumidification coefficient of performance (DCOP) is obtained at an optimum rotational speed of 5.88 r.p.h. This optimum value increases with increasing the humidity ratio of process air at inlet. The desorption capacity decreases with increasing the regeneration temperature, therefore a lower rotational speed is needed to force the desiccant material and regeneration air to have enough contact time to complete the desorption process. The moisture removal has a value 3.39 g/kg at a heater temperature of 50°C which is higher than that at 60°C. This value increases with decreasing the wheel speed till it reaches a lower value of 2.38 at the high speed 4.9 r.p.m of the desiccant wheel.
A lower rotational speed reflects a lower power consumption of the wheel motor. If the power consumption is lowered to a level that can be afforded by a solar panel, a solar desiccant air conditioning system may be realized. Also, Low regeneration temperatures enhance the potential of using solar energy in heating desiccant wheels.

## REFERENCES

[1] V.C.Mei & F.C.Chen (Energy Division), Z.Lavan (Illinois institute of technology), R.K.Collier, (Jr. Engineering services), G.Meckler (Gershon Meckler Associates), P.C. ”An Assessment of Desiccant cooling and Dehumidification Technology”, (Oak Ridge National Laboratory), ORNL/CON-309, July 1992.

[2] J.R.Camargo, E.Godoy Jr.,C.D.Ebinuma, ”An Evaporative and Desiccant Cooling System for Air Conditioning in Humid Climates”, Journal of the Brazilian Society of Mechanical Sciences and Engineering, June 2005.

[3] Kamal A.Abou-Khamis, (Youngstown state university), “Analysis and Design of Desiccant Cooling System, A thesis for M.Sc in Mechanical Engineering, June 2000.

[4] Phil Wirdzek, Will Lintner, Otto Van Geet, Sue Reilly, (Energy Efficiency and Renewable Energy Laboratory), U.S Department of Energy, “Energy Recovery for Ventilation Air in Laboratories, DOE/GO-102003-1774, October 2003.

[5] The American Society of Heating, Refrigeration and Air Conditioning Engineers, “ASHRAE Handbook of Fundamentals”, Inc.NewYork: ASHRAE, 1989

[6] http://masongrant.com/pdf_2008/chapter_2_Fundamentals.pdf, last visit 15/1/2011.

[7] T.S.Ge & R.Z.Wang (Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University), F.Ziegler (Institute of Energy Engineering, Technical University Berlin), ”A mathematical model for predicting the performance of a compound desiccant wheel (A model of compound desiccant wheel)”, 10 Jan 2010.

[8] A.A.Rabah (Department of Chemical Engineering, University of Khartoum-Sudan), A. Feketeb & S. Kabelac (Institute of Thermodynamic, Helmut-Schmidt University, University of Bundeswehr-

Hamburg), " Experimental Investigation on the Performance of a LiCl Wheel", December 2009.