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Experimental Analysis and Performance Evaluation of Solid Desiccant Dehumidifier Using Silica Gel

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***Abstract*—Simple and Economical method to produce dehumidification is by solid desiccant wheel with a desiccant material (silica gel) which attract moisture from moist air. Experimental analysis of the working of the dehumidifier desiccant wheel is indicated in this work with actual thought to the performance deviation as a function of airflow rates at the process side and ambient temperature for hot and humid conditions. The silica gel is reactivated by an electric heater which is fixed in the reactivation portion. Flow rates of the air have been varied (that is, 2.8, 3.5, 4.5, & 5.2 m/s) at the process section of the desiccant wheel, while on the reactivation section, airflow rate is constant (i.e., 2.8m/s). At various ambient temperatures (i.e., 32, 33, 34, & 35°C) and various airflow rates, performance parameters also analyzed like Moisture Removal Capacity (MRC), Dehumidification Coefficient of Performance (DCOP), dehumidification effectiveness, and Sensible Energy Ratio (SER). We observed that the optimum values of these performance parameters in this work are obtained at 3.5m/s air velocity at the process section and 34℃ ambient temperature. Optimum values of these parameters show a decrease in energy used and improved air quality in the conditioned space.**

***Keywords*—** desiccant wheel, regeneration, dehumidification, moisture removal capacity, sensible energy ratio

I. Introduction

Arid air has a lively influence for refining the cycle, item or circumstances in numerous ventures, for example, drug creation, food creation, modern synthetic substances creation and so forth It is likewise basic in bundling hardware rooms, distribution center stockpiling, hygroscopic crude materials stockpiling, inorganic items natural and plant drying out. Dai et al. (2001) recommended currently that AC is suitably the elementary requirement in humans' life, earlier AC established on vapour compression system which develops HCFC & HFC that has bad effect to the surroundings [1]. Sheridan et al. (1985) termed dehumidifier cooling system as further striking substitute than regular VCRS because of its benefits of consuming small energy temperature and provides surroundings awake maneuver [2]. Collier et al. (1981) and Worek (1982) depicted sturdy dehumidifier may recovered by utilizing second rate energy at various degrees of temperature and that was discovered to be relied upon the materials of desiccant which are utilized in recovery, silica gel for instance was quite possibly best broadly encouraging and researched strong material of desiccant that mandatory need a temperature of recovery of nearly 65℃ [3]. Jurinak et al. (1984) assessed the exhibition of climate control systems based on open cycle desiccant for private solicitation and contrasted it and

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vapour pressure cooling framework based on expense and energy. To recharge the desiccant wheel, likewise proposed that frameworks of these type are combined using sun-oriented energy, they achieved in a way that is better than the regular climate control systems [4]. Aly et al. (1988) introduced the unit of vapour pressure joined by a revolving strong desiccant wheel or desiccant dehumidifier where was recovered with the leftover warmth of unit of vapour pressure by a Thermal siphon in a warmth recuperation framework and the overseeing condition was tackled mathematically for a common contextual investigation and it was discovered that equal stream decreased by 40% the warmth of recovery than counter stream, 27% energy investment funds contrasted with the VC alone also the general COP was 1.76 [5]. Yadav and Kaushik (1991) dissected a crossover vapour pressure through strong desiccant sun powered cooling framework, desiccant material changed over the inactive warmth load into reasonable warmth load that is then utilized in a regular vapour compression cycle, also Warmth dismissed in VC cycle from condenser was utilized to improve COP of the framework and recover the desiccant material. This framework functioned in a way that is improved than typical vapour pressure framework at elevated dormant warmth load, altogether energy saving [6]. Farooq and Ruthven (1991) distinguished that strong desiccant's primary part framework was the desiccant wheel haggle COP might be essentially enhanced via refining its presentation, along these lines, the investigation of plan and working boundaries of desiccant wheel was essential [7]. Waugaman et al. (1993) portrayed different plans for framework of desiccant cooling and called attention to the framework benefits was then utilized second rate warm energy because of which the working expense was decreased however its underlying expense was high [8]. San and Hsiau (1993) built up transient one-dimensional mass and warmth exchange prototype to examine the impact of pivotal mass and warmth conduction dissemination on the presentation of a rotary wheel that (NTU) number of move unit and Biot number (Bi) were two significant boundaries which influenced the dehumidification capacity [9]. Pesaran and Wipke (1994) utilized an unglazed unfolded sun powered gatherer for recovery of desiccant wheel in strong desiccant cooling framework on the grounds that these authorities were more affordable than customary coated level plate gatherers and originate that recovery of cooling desiccant framework with an unglazed happened sun-oriented gatherer diminished the warm COP of the framework to about half than regular coated level plate authority [10]. Zheng and Worek (1995) examined the impacts of mass exchange attributes, warmth and desiccant sorption properties, and dehumidification execution on wheel size, the isotherm state additionally examined and it was discovered that to get most extreme dehumidification, 0.07 factor of detachment is necessary [11]. Gao et al. (2005) depicted a numerical model (one dimensional) taking mass exchange and the warmth inside clammy air just as material of desiccant to foresee the consistent state and transient conveyance in rotary wheel and the impact of thickness of desiccant (believed thickness) and shape of section on the exhibition of a rotary dehumidifier likewise researched [12]. Xuan and Radermacher (2005) built up model (1-D) based on momentary mass and warmth exchange to examine the presentation of the wheel dehumidifier and their reproduction outcomes uncovered a huge impact of various recovery temperature, wheel speeds and wind stream rates on the exhibition of wheel [13]. Nia et al. (2006) built up a transient mass and warmth exchange model (one dimensional) and they decided the ideal rotating speed through inspecting source side where adsorption takes place [14]. Jani et al. (2016) Developed Artificial neural network to approximate the performance on rotary desiccant dehumidifier for different process air inlet conditions. They were found the moisture removal rate and effectiveness of the dehumidifiers, which indicate the performance of rotary dehumidifiers [15]. Abbassi et al. (2017) compared the transient performance of different solar desiccant cooling system on the basis of finite time thermodynamics. They investigated solar desiccant system in three different stages and performance of the desiccant system was approximated in single and double stage configurations. The Uckan and Dunckle configurations utilizes 50% lower electrical energy compared to conventional air conditioning system [16]. Lee et al. (2021) developed one dimensional steady state model using MATLAB-Simulink. They simulated three types of models (i.e. direct evaporative cooling, indirect evaporative cooling and hybrid desiccant cooling) under various temperature ranges (25-50\degc) and humidity conditions (4%-98%). They Concluded that desiccant cooling system can be effective when outside temperature is lower than 35\degc [17]. Hussain et al. (2021) improved the precooling of spherical food product by making the improvement in heat transfer behavior of spherical food product. They suggested that cooling is improved up to critical speed i.e., 2 m/s for the spherical food product orange [18]. Hussain et al. (2020) improves the COP of the VCRS system by using cellulose and steel wire mesh condensers. They suggested that COP in case of cellulose condensers is more than the steel wire mesh condensers due to evaporative cooling [19]. Alam and Hussain (2022) optimized the performance of desiccant based dehumidifier on the basis of process air flow rates and ambient temperature of the process air on the basis of regeneration rate and other performance parameters [20].

The objective of this work is to find out the optimum values of these parameters for hot and humid conditions at Refrigeration and Air conditioning Laboratory, Mechanical Engineering department, Aligarh Muslim University, Aligarh, India. The present work only focused on the hot and humid conditions that is why temperature range is taken into consideration is from 32\degc to 35\degc. The range of Process Air Velocities ranges from 2.8 m/s to 5.2 m/s is chosen for the present work due to the limitations of the experimental setup. Optimized values of these parameters ultimately lead to reduction in energy consumption and improved air quality of the conditioned space for the given Range of process air velocities and process inlet temperatures.

II. Experimental Setup

This research has implemented to inspect the desiccant based hybrid system's performance as shown in figure 1. Various experiments at unlike flow rates of air and at different ambient temperatures have been performed. The regeneration and adsorption process has been conceded out continuously. In this setup, process air is processed through the blower which further passed through the silica based desiccant wheel system, subsequently passing via the desiccant wheel humidity decreases and process air temperature increases which further passes over the evaporator coil of the hybrid VCRS system. Figure 2 shows the line diagram of set-up.

Figure. 1 Actual Experiment setup

1) Blower	4) Desiccant Wheel
2) Compressor	5) Capillary tube
3) Condenser	6) Evaporator Coil

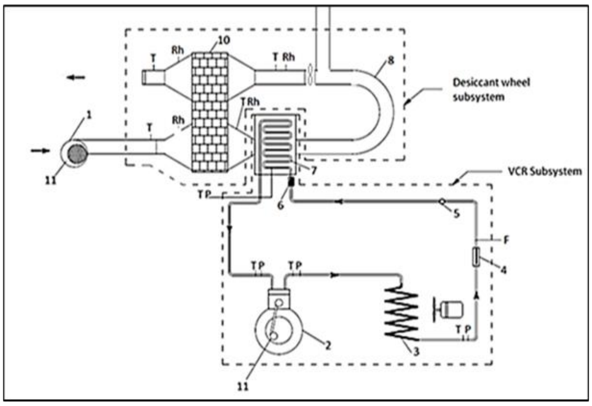

Figure. 2 Line diagram of Experiment setup

A. Assessing device and Instruments

Dry bulb temperature and Relative humidity of air is measured using the thermo hygrometer. Air velocity is measured by anemometer. Table.1 shows the assessing device and table 2 show the specification of desiccant wheel.

TABLE 1
ASSESSING DEVICES

Equipment	Range	Accuracy
Humidity Sensor	0 to 100 %RH	±2.5%
Temp. Sensor	RTD PT-100/3W / -50 to 400 Celsius	±0.1Celsius

TABLE 2
SPECIFICATION OF DESICCANT WHEEL

Factor	Measurement
desiccant Volume ratio, (Φ)	0.48
Silica gel specific heat, c_d (J/kgK)	921
silica gel thermal conductivity of, k_d (W/mK)	0.175
Altitude of flow route, 2a (m)	0.0018
Pitch of flow route, 2b (m)	0.0032
channel wall Width, δ (m)	0.00034
silica gel density of, ρ_d(kg/m^3)	1129
Permeability, ε	0.4
matrix material density of, ρ_m (kg/m^3)	625
Diameter of wheel, D (m)	0.37
matrix materials Specific heat,c_m (J/kgK)	1030
Wheel Length, L_w (m)	0.1
Radius of Pore, r (m)	11×10^{-10}
Air stream route to the total area of one passage (Ratio), (A_r)	0.844

III. METHODOLOGY

Main processes happening in this work are as follows as shown in Fig.3:

(a) Adsorption process (1-2): At the inlet of the desiccant wheel relative humidity and dry bulb temperature of the air is measured by digital hygrometer. The process region adsorbs the dampness from the moist air. At the outlet of adsorption sector relative humidity dry and bulb temperature of the air is measured by thermo hygrometer. The temperature of the process air increases by the heat released from the condensation process. On the surface of material of desiccant humidity is being adsorbed and condensed over it continuously.

(b) Sensible heating (5-4): Air is sensibly heated by electric heater which is fitted in the regeneration duct. Air forced over the electric heater in the regeneration sector by a centrifugal fan which is connected in the regeneration duct. At the inlet of the recovery region relative humidity and dry bulb temperature of the air is found. Air velocity at the inlet of the regeneration is fixed throughout the experiment i.e. 2.8 m/s.

(c) Regeneration process (4-3): In the regeneration zone, the desiccant dehumidifier is regenerated by hot air, forced by another blower connected at the regeneration sector. The hot air loses its temperature by evaporating the water vapour from desiccant layer. At the outlet of regeneration sector measurement of relative humidity and dry bulb temperature have taken with the help thermo hygrometer.

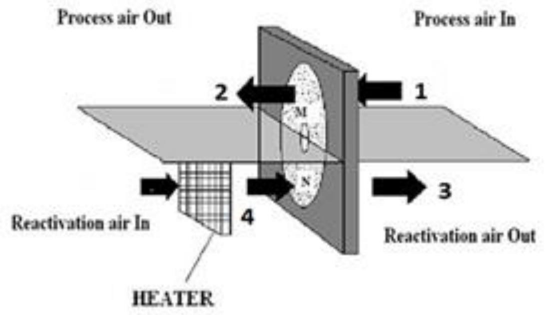

Figure. 3 Sketch of the desiccant wheel involved in this study

A. Performance parameters

After taking all these readings mentioned above various performance parameters have been calculated and analyzed at different Air inlet velocities (i.e. 2.8 m/s, 3.5 m/s, 4.5 m/s & 5.2 m/s) at different ambient temperatures (i.e. 32 ºC, 33 ºC, 34 ºC & 35 ºC) and Regeneration Air inlet velocity is 2.8 m/s throughout the entire experiment.

The dehumidification effectiveness (η_{deh}) symbolizes the relation between the actual and the ideal dehumidification ability of the desiccant wheel [21]:

$$\eta_{deh} = \frac{\omega_1 - \omega_2}{\omega_1} \quad (1)$$

The Moisture Removal Capacity (MRC) shows the amount moisture removed by the desiccant unit [22]:

$$\text{MRC} = \rho_1 \times \dot{V}_P \times (\omega_1 - \omega_2) \quad (2)$$

The Dehumidification Coefficient of Performance (DCOP) characterizes the relationship between the thermal power associated to the air at process region and the thermal power gave for the recovery region [23]:

$$\text{DCOP} = \frac{\rho_1 \times \dot{V}_P \times \Delta h_{vs} \times (\omega_1 - \omega_2)}{\rho_1 \times \dot{V}_{reg} \times C_p \times (T_4 - T_1)} = \frac{\dot{V}_P \times \Delta h_{vs} \times (\omega_1 - \omega_2)}{\dot{V}_{reg} \times (h_4 - h_1)} \quad (3)$$

The water latent heat of vaporization Δh_{vs} has been assessed through the following observed cubic function [24]:

$$\Delta h_{vs} = -0.614342 \times 10^{-4} \times T_1^3 + 0.0158927 \times 10^{-2} \times T_1^2 - 0.236418 \times 10 \times T_1 + 0.250079 \times 10^4 \quad (4)$$

The Sensible Energy Ratio (SER) symbolizes the relationship among the thermal power linked to the air heating by desiccant wheel on the adsorption region and the thermal power provided for the recovery region [25]:

$$\text{SER} = \frac{\rho_1 \times \dot{V}_P \times C_p \times (T_2 - T_1)}{\rho_1 \times \dot{V}_{reg} \times C_p \times (T_4 - T_1)} \quad (5)$$

Readings of temperature and relative humidity have been taken at four places as follows- Desiccant inlet i.e. process inlet (T1, φ1) & Regeneration inlet (T3, φ3) and Desiccant Outlet i.e. Process outlet (T2, φ2) & Regeneration outlet (T4, φ4) as shown in Fig.3.

For the simplification of the examination, the given conventions are made: The ideal gas model by constant specific heat is supposed, Adsorption section and the recovery section is divided into two equal sections, Mass dispersion and Heat transmission in moist air are ignored, No leakage in different regions of desiccant wheel, Along the air channel Mass transfer and the heat coefficients between the desiccant wall and the air stream is fixed, Entirely honeycombed passages of rotatory desiccant dehumidifier are same, Matrix material has negligible hygroscopic capacity. The inlet air conditions along the channel air domain are uniform and the thermo physical properties of the dry air and the properties of the dry desiccant material other than of the matrix are constant.

IV. Results And Discussion

Moisture deduction Capacity rises with rise in ambient temperature as shown in figure 4. It decreases with relatively high air flow rates as the interaction time between the surface of desiccant and process air is minimized. Moisture removal capacity also decreases after certain ambient temperature as the adsorption process liberated heat, so favored by low temperatures hence, the escalation in the temperature of process air, and causes a reduction in the MRC. MRC is maximum for 3.5 m/s air inlet velocity at 34°C ambient temperature.

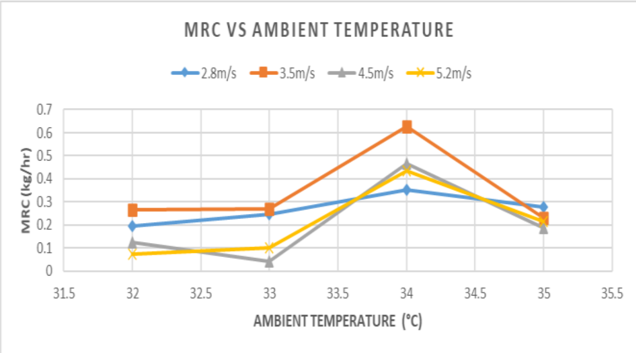

Figure. 4 Variation of MRC with different ambient temperature at different air flow rates

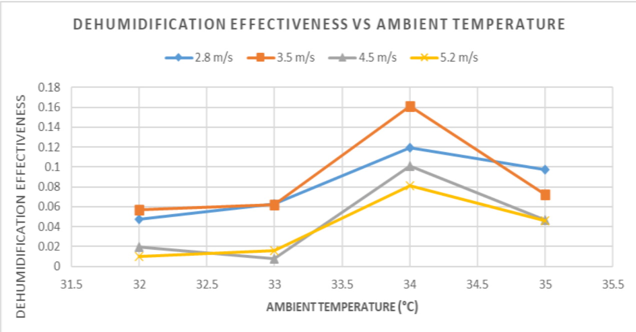

Figure. 5 Variation of Dehumidification effectiveness with different ambient temperature at different air flow rates.

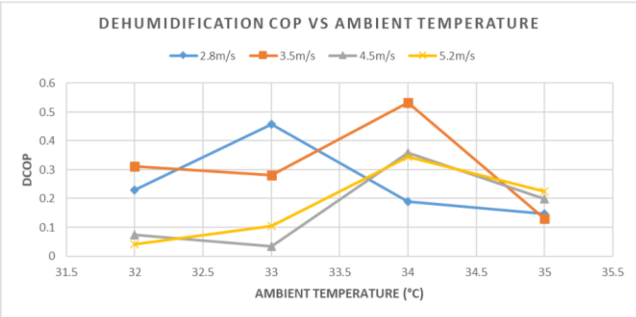

Figure. 6 Variation of Dehumidification COP with different ambient temperature at different air flow rates

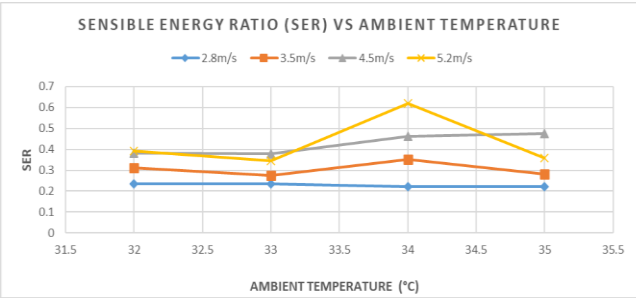

Figure. 7 Variation of SER with different ambient temperature at different air flow rates.

Also, the effectiveness of dehumidification of adsorption zone is straightly associated with ambient temperature as shown in figure 5. With increase in ambient temperature, increase in dehumidification effectiveness observed. When the ambient wetness surges the effectiveness drops and when process outlet wetness rises the effectiveness also increases. Dehumidification effectiveness is maximum at 3.5 m/s air inlet velocity and at 34℃ ambient temperature in the adsorption sector.

Figure. 6 signifies the change of Dehumidification COP with different ambient temperatures at different air flow rates, it is clearly observed that first it increases then decreases. DCOP increases with the rise in humidity ratio at the process air inlet. Optimum values of DCOP is obtained at 3.5 m/s and 34℃ ambient temperature.

Figure. 7 signifies the variation of sensible energy ratio with different ambient temperatures at dissimilar flow rates of air. Outlet temperature at the process sector surges considerably with humidity ratio at inlet of the process side, as the wheel eliminates a more amount of water vapor Thus, Temperature difference at outlet and inlet of process air increases because of the rise in the released adsorption heat, on the other hand difference in temperature on the recovery side remains constant which results in increase of SER.

V. Error Analysis And Validations

The error investigation completed in this work depends on the root sum square strategy detailed by Kline and McClintock [26], the performance parameters described in this work (ηdeh, DCOP, MRC, SER) are found via evaluation from calculated parameters like temperature, relative humidity and temperature all these measured parameters is described by identified value of ambiguity.

TABLE.3

VALIDATIONS OF RESULTS OBTAINED IN THIS STUDY

Performance Parameter	*Angrisani et al. (2012) [27]*	*Yadav A (2012) [28]*	Present work	Deviation
DCOP	0.41	-	0.45	12.5 %
SER	0.58	-	0.60	3.44 %
MRC	-	0.57	0.62	8.77 %
ηdeh	-	0.125	0.146	16.8 %

Comparative uncertainty values obtained for the considered factors are, 8.2% for ηdeh, 9.3% for MRC, 7.1% for DCOP and 5.72% for SER. The validations of results are shown in the table.3 below.

VI. Conclusion

Due to vapour pressure difference solid desiccants (silica gel) absorb moisture without changing their chemical and physical configuration. Due to its huge affinity for adsorbing moisture and considerable ability of water absorption the amount of vapor adsorbed is related to the surface area of the desiccant (silica gel). The saturated desiccant gets reactivated by passing hot air using the desiccant again. In this work performance parameters of desiccant wheel have been calculated. Dry bulb and relative humidity measured at the inlet and outlet of the process section and reactivation side. Range of airflow at the process section is considered into examination due to the limitation of experimental setup. This experiment focused on hot and humid conditions; the temperature range considered is from 32℃ to 35℃. We varied airflow rates at the inlet (process section) of the desiccant wheel while airflow rates are constant on the reactivation or regeneration section. We also observed the optimum values of performance parameters like Moisture Removal Capacity (MRC), Dehumidification Coefficient of Performance (DCOP), Dehumidification Effectiveness and Sensible Energy Ratio (SER) at various ambient temperature and different airflow rates. The outcome of the present experimental work (i.e. optimized Process Air inlet Velocity and Ambient Temperature) helps us optimize the performance of desiccant dehumidifier, which led to the lowering in energy and improved air quality, saving funds of capital for the specified Conditions.

Disclosure statement

The authors report there are no competing interests to declare.

Nomenclature

c_p air specific heat (kJ/kg K)
h specific enthalpy (kJ/kg)
MRC moisture removal Rate (kg/h)
$\dot{V}$ volumetric flow rate (m^3/h)
SER sensible energy ratio (dimensionless)
COP coefficient of performance (dimensionless)
DW desiccant wheel
RMSE root mean square error
DCOP dehumidification coefficient of performance (dimensionless)
T temperature (℃)

Greek symbols:

ρ air density (kg/m^3)
Δh_{vs} latent heat of vaporization of water (kJ/kg)
ω air humidity ratio (kg/kg)
η effectiveness (dimensionless)

Subscripts:

P process
deh dehumidification
reg regeneration

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