Experimental Exploration on Performance Advancement of Solid Desiccant Dehumidifier

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Abstract. The foremost idea of this current effort is to study the performance parameters of silica gel based desiccant dehumidifier and optimize its performance on the basis of Process air inlet velocities and air inlet temperatures. Desiccant dehumidifier considered in this work is coupled with the VCRS system. This Analysis is carried out for hot and humid conditions at four different air velocities (i.e. 2.8, 3.5, 4.5, 5.2 m/s) and different ambient temperatures (i.e. 32, 33, 34, 35℃). Regeneration rate and adsorption rate at different air flow rates and at different ambient temperatures is analysed. Regeneration is occurring through an electric heater fitted in the regeneration sector. Thermal factors, for instance temperature (dry bulb) and relative dampness are measured to enhance performance parameters like Adsorption rate, latent COP, Regeneration rate and Effectiveness of desiccant of wheel. Revamp values of this parameters are obtained at 3.5 m/s entering velocity of process air and 34℃ ambient temperature which results in better performance of desiccant dehumidifier with less energy utilization for the conditioned space.

1. Introduction

Decreasing energy utilization and furthermore to dislodge petroleum derivatives with environmentally friendly power sources fuel, we need advancements energy productive and very much coordinated with environmentally friendly power assets. Dehumidification measure is one of the energy burning-through cycles with which we are managing in an unexpected way, going from drying items to giving wanted air quality to molded spaces. Three different ways to eliminate dampness from air are applied: warming and ventilation, buildup and adsorption. Adsorption dehumidification by strong desiccant wheels is an energy-productive approach to eliminate dampness from air particularly when waste energy is being utilized.

Golubovic et al. (2007) [1] assessed, exhibition of rotational device to be specific based on three extents, cleanse, cycle and recovery, the presentation of a desiccant wheel with a warmed viable cleanse point was contrasted and the exhibition of a similar wheel without a cleanse point, it was discovered that warmed compelling cleanse point had a general beneficial outcome on the exhibition of a rotational dehumidifier. Jeong et al. (2010) [2] improved COP by 94% when contrasted with ordinary vapour pressure fridge created and indicated that an ideal rotational speed existed which amplified the dehumidification execution. Goldsworthy and White (2011) [3] discovered the electrical coefficient of performance (COPr) was more noteworthy than 20 once the temperature of recovery was 70℃ by source/recovery wind stream proportion of 0.67 at encompassing conditions, consequently this framework could accomplish considerable energy saving and decreased ozone harming substance
emanation. Jani et al. (2016) [4] utilized standard of strong desiccant cooling framework and its mechanical applications and progressions was given, also various arrangements of cooling desiccant cycles, ordinary in addition crossover cycles of cooling desiccant, various sorts of numerical replicas of turning desiccant wheel, execution assessment of framework of cooling desiccant, mechanical enhancement and bit of leeway it might proposed as far as cost and energy reserve funds were signified. Vivekh et al. (2020) [5] uncovered that the recovery cycle added to huge entropy age rates and by decreasing 10 °C the boiling water temperature. Also, by choosing to cover the warmth exchanger with a material of polymer composite rather than silica gel, the proficiency of second law of desiccant wheel is upgraded via 2.6. Hussain et al. [6] compare the performance of evaporatively cooled and steel wire mesh condenser and improve the heat rejection rate with less energy utilization.

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℃ to 35℃. The range of Process Air Velocities ranges from 2.8 m/s to 5.2 m/s is chosen for the present work because of the restrictions of the investigational arrangement.

2. Experimental Arrangement
The analyses have been performed to examine the exhibition of desiccant based half breed framework. Different trials at various wind stream rates and at various encompassing temperatures have been performed. The adsorption interaction has been completed following recovery. In this arrangement, measure air is prepared through the blower which further went through the silica based desiccant wheel framework, in the wake of going through the desiccant wheel moistness diminishes and temperature of interaction air expands which further disregards the evaporator loop of the crossover VCRS framework as demonstrated in figure 1.

![Figure 1. Shows Actual Experiment setup involved in this study.](image)

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

2.1. Assessing device and Instruments

Relative humidity and Dry bulb temperature of air are measured with help of thermo hygrometer. Air velocity is measured by anemometer.

| Equipment          | Range          | Accuracy  |
|--------------------|----------------|-----------|
| thermo Hygrometer  | -10 to +60 ℃   | ±0.5℃     |
|                    | 0 to 100 %RH   | ±2.5%     |
2.2. Specification of Desiccant Wheel

Table 2. Desiccant Specification

| Factor                                      | Measurement |
|---------------------------------------------|-------------|
| desiccant Volume ratio, (Φ)                 | 0.48        |
| Route of flow pitch, 2b (m)                 | 0.0032      |
| silica gel warmth conductivity, kd (W/mK)   | 0.175       |
| Height of flow passageway, 2a (m)           | 0.0018      |
| Solid desiccant specific heat, cd (J/kgK)   | 921         |
| channel Width of wall, δ (m)                | 0.00034     |
| silica gel density of, ρd(kg/m3)            | 1129        |
| Permeability, ε                             | 0.4         |
| matrix material density of, pm (kg/m3)      | 625         |
| Diameter of DW, D (m)                       | 0.37        |
| matrix materials Specific heat,cm (J/kgK)   | 1030        |
| Extent of Wheel, Lw (m)                     | 0.1         |
| Radius of Pore, r (m)                       | 11 × 10−10  |
| The ratio of stream of air route to entire part of a passage, (Ar) | 0.844 |

3. Methodology

Via the adsorption subdivision humid air flows. On the inlet of desiccant dehumidifier temperature of dry bulb and air relative dampness is measured via digital hygrometer. The wetness from the moist air is removed at adsorption part. On the exit of adsorption subdivision relative dampness and temperature (dry bulb) of air is taken by thermo hygrometer. On desiccant surface this dampness is adsorbed and it is condensed over. The temperature of the incoming air increases from heat released by condensation process.

By using electric heater which is fitted in the regeneration duct sensible heating of air is done. Air forced over the electric heater in the regeneration sector by a centrifugal fan which is connected in the regeneration duct. On recovery inlet relative humidity and dry bulb temperature is considered. Air velocity at regeneration entry is fixed throughout experiment i.e. 2.8 m/s. In the recovery part, to renew the desiccant wheel hot air is used, 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.

3.1. Performance Factors

Various performance factors 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 diverse temperatures ( i.e. 32 °C, 33 °C, 34 °C & 35 °C ) and Recovery Air inlet velocity is 2.8 m/s throughout entire experiment .

Adsorption rate or MRC characterises moisture mass flow rate detached by the desiccant [7].
\[ MRC = \rho_1 \times \dot{V}_p \times (\omega_1 - \omega_2) \]  \hspace{1cm} (1)

Regeneration Rate signifies moisture mass flow rate of regained via dehumidifier at regeneration sector [7].

\[ \text{Regeneration Rate} = \rho_1 \times \dot{V}_{\text{reg}} \times (\omega_3 - \omega_4) \]  \hspace{1cm} (2)

Wheel effectiveness symbolizes the ratio among the actual to perfect dehumidification ability of DW [8].

\[ \text{DW effectiveness} = \frac{\omega_1 - \omega_2}{\omega_1} \]  \hspace{1cm} (3)

Latent COP signifies the ratio amid the power connected to the moisture removal from air and the power provided at recovery section [9].

\[ \text{Latent COP} = \frac{\rho_1 \times \dot{V}_p \times \Delta h_{vs} \times (\omega_1 - \omega_2)}{\rho_1 \times \dot{V}_{\text{reg}} \times C_p \times (T_4 - T_1)} \]  \hspace{1cm} (4)

Water latent heat of vaporization of \( \Delta h_{vs} \), assessed through the subsequent empirical cubic function [10].

\[ \Delta h_{vs} = -0.614342 \times 10^{-4} \times T_1^3 + 0.0158927 \times 10^{-2} \times T_1^2 - 0.236418 \times 10 \times T_1 + 0.250079 \times 10^4 \]  \hspace{1cm} (5)

3.2. Assumptions

- Constant specific heat, ideal gas model assumed.
- Adsorption section and the recovery section is separated into two segments equally.
- Mass diffusion & Heat conduction are ignored in humid air.
- No leakage among Dissimilar areas of desiccant wheel.
- Laterally via air passage Mass transmission and the heat coefficients between the desiccant wall and the air stream is constant.
- Entirely honeycombed passages of rotatory desiccant wheel are same.
- The adsorbent the capacity of hygroscopic of material matrix is insignificant.
- Along the channel air domain, the air inlet situations are uniform.
- Thermo physical properties of the dry air & properties of the dry desiccant material are constant.
4. Results

**Figure 2.** Shows the dissimilarity of regeneration rate with regeneration temperatures at different flow rates of air.

**Figure 3.** Illustrates the variation of regeneration rates and MRC with Ambient temperatures at 2.8, 3.5, 4.5 & 5.2 m/s air inlet velocity respectively.
5. Error Analysis
The error investigation completed in present effort detailed by Kline and McClintock [11], depends on the root sum square strategy, the performance parameters described in this work (Wheel effectiveness, COP (Latent), Regeneration rate and Adsorption rate) are found by measurement from considered variables such as velocity of the air, relative humidity and temperature (DBT) all of these considered parameters is described via identified uncertainty values. Comparative uncertainty values obtained for the considered factors are, 8.2% for Wheel effectiveness, 11.5% for Adsorption rate, 12.9% for COP (Latent) and 12.5% for Regeneration rate.

6. Conclusion
In this work execution boundaries of desiccant wheel have been determined. At first, dry bulb temperature and relative moistness esteem have been estimated at the inlet and outlet of the interaction segment and recovery segment separately. Wind stream rates have been shifted (for example 2.8, 3.5, 4.5 and 5.2 m/s) at the cycle part of the desiccant wheel while on the recovery or recuperation area it is steady (for example 2.8 m/s). At various surrounding temperatures (for example 32, 33, 34 and 35°C) and at various wind current rates execution boundaries like Adsorption rate, dehumidification effectiveness, Latent COP and Regeneration rate have been broke down and discovered that ideal estimations of these exhibition boundary in this work is gotten at 3.5 m/s Process Air speed and 34°C surrounding temperature. Temperature of Regeneration is direct relating to the Regeneration rate and the adsorption rate equally. Rise in recovery temperature gives higher...
Regeneration (recovery) and adsorption rate. Also, a critical working limit (i.e. Wind stream rate) which impacts the Regeneration and the adsorption speeds of desiccant dehumidifier. As rate of Air stream surges, both the Regeneration rate and the adsorption rate rises and the reverse way around. Also, it is assumed that the ascent in wind stream rate in territory of adsorption is more practical than rise in wind recovery rate for the better working of dehumidifier. To assemble the reasonability of wheel in mutual zones (Regeneration and adsorption), high recovery temperature and low flow rates of air in both the respective sections are required.

Nomenclature

| Symbol | Description |
|--------|-------------|
| MRC    | Adsorption rate (kg/h) |
| h      | specific enthalpy (kJ/kg) |
| cp     | specific heat of air (kJ/kg K) |
| COP    | coefficient of performance (dimensionless) |
| V̇      | flow rate (volumetric) (m³/h) |
| T      | temperature (°C) |
| DW     | wheel of desiccant |

Greek signs:

| Symbol | Description |
|--------|-------------|
| ρ      | air density (kg/m³) |
| ω      | air humidity ratio (kg/kg) |
| Δhv    | water heat of vaporization (latent) (kJ/kg) |

Subscripts:

| Subscript | Description |
|-----------|-------------|
| P         | process |
| reg       | regeneration |

References

[1] Golubovic, M.N., Hettiarachchi, H.D.M. and Worek, W.M., 2007, “Evaluation of rotary dehumidifier performance with and without heated purge”, International Communication in Heat and Mass Transfer, Vol. 34, pp. 785-795.

[2] Jeong, J., Yamaguchi, S., Saito, K. and Kawai, S., 2010, “Performance analysis of four – partition desiccant wheel and hybrid dehumidification air conditioning system”, International Journal of Refrigeration, Vol. 33, pp. 496-509.

[3] Goldsworthy, M. and White, S., 2011, “Optimisation of a desiccant cooling system design with indirect evaporative cooler”, International Journal of Refrigeration, Vol. 34, pp. 148-158.

[4] Jani, D. B., Mishra, M., & Sahoo, P. K. (2016). Solid desiccant air conditioning—A state of the art review. Renewable and Sustainable Energy Reviews, 60, 1451-1469.

[5] Vivekh, P., Bui, D. T., Islam, M. R., Zaw, K., & Chua, K. J. (2020). Experimental performance evaluation of desiccant coated heat exchangers from a combined first and second law of thermodynamics perspective. Energy Conversion and Management, 207, 112518.

[6] Hussain, T., Singh, A. K., Mittal, A., Verma, A., & Alam, Z. (2020). Performance Evaluation of Vapor Compression Refrigeration System by Varying Air Flow Rates in Air-Cooled and Evaporatively Cooled Condensers. International Journal of Energy for a Clean Environment, 21(1).

[7] Slayzak, S. J., & Ryan, J. P. (2000). Desiccant Dehumidification Wheel Test Guide. National Renewable Energy Laboratory. NERL/TP-550-26131.

[8] Mandegari, M. A., & Pahlanvazadeh, H. (2009). Introduction of a new definition for effectiveness of desiccant wheels. Energy, 34(6), 797-803.

[9] Ge, T. S., Ziegler, F., & Wang, R. Z. (2010). A mathematical model for predicting the
performance of a compound desiccant wheel (A model of compound desiccant wheel). Applied Thermal Engineering, 30(8-9), 1005-1015.

[10] Angrisani, G., Minichiello, F., Roselli, C., & Sasso, M. (2011). Experimental investigation to optimise a desiccant HVAC system coupled to a small size cogenerator. Applied Thermal Engineering, 31(4), 506-512.

[11] Kline, S. J. (1953). Describing uncertainty in single sample experiments. Mech. Engineering, 75, 3-8.