Experimental Investigation on Composite Desiccant Wheel for the Dehumidification

Yogesh Deepak Bansod[1] Prof. V. G. Gore[2] P. S. Lakade[3] S. C. Joshi[4]
[2]Assistant Professor
[1,2,3,4]Department of Mechanical Engineering
[1,3]P.R.P.I.P&T, Amravati, India [2]P.R.P.G.E.&M. Amravati, India [4]P.R.P.C.O.E. Amravati, India

Abstract— Any material that attracts and holds water vapor is a desiccant. Commercial desiccants attract and release a large amount of water vapor depending on moisture available in the environment they are exposed to. Composite desiccants can be made into any shape, so a low- pressure drop desiccant wheel with air flow channels can be designed to reduce the power consumption of the system. Moreover encouraging is that the new desiccant wheel can be driven by a lower recovery temperature for securing a low measure of moisture release. The reason is that the composite desiccant materials, which are worked with composite material joining silica gel is a flawless technique, bear on superior to anything silica gel alone in moisture adsorption. This paper presents a combined analytical study on dehumidification, cooling and circulating air through cooling systems using distinctive solid composite desiccant with focus on different air flow rates, dehumidification of moist air and regeneration of solid desiccant wheel. A comparable examination of various solid desiccants has low operating and maintenance cost and its condition friendly.

Keywords: Desiccant Wheel, Silica Gel, Hot Humid Climate, Moisture, Dehumidification

I. Introduction

Humidity is the amount of water vapour present in air. It is expressed in various ways. Normal atmospheric air in most of the cases is humid. Humid air is also called moist air. The capacity of air to hold moisture increases with temperature. Humidity plays an important role for surface life. Presence of humidity in the environment affect the animal and plant life, human comfort, human health, electronic material, building constructions, industry, baking etc. Due to Improper humidity control inside a building can lead to occupant discomfort, people feeling sick, building deterioration, and the development of mold, mildew or odors and it also responsible for greenhouse effect. In presence high humid condition conductivity of porous material increases where as low humid condition causes brittleness of electronic material. Humidity is also responsible for metal corrosion. To resolve the effect of humidity various techniques are employed for dehudification.

II. There are Various Methods Employed for Dehumidification Such As

A. Over Compression

Air compression suggests a method of reducing moisture content in air. With air as compressed, partial pressure of the water vapour in the water gas mixture is raised to the point where moisture can be condensed from the air at a higher temperature.

B. Refrigeration Dehumidification

The template Another method most commonly employed is the reduction of moisture in the air by means of reducing the temperature. By examination of the dew point alone or saturation curve on the psychrometric chart, it can readily be seen that as the temperature of the air is lowered, the amount of moisture it can hold is reduced considerably. Thus by cooling the air below the dew point, the moisture contained in that air can be condensed out and some of the moisture vapour removed in liquid form, but cooling to very low temperature makes the refrigeration process impractical, as it requires a great deal of subsequent re-heating. The reduction in air temperature is also limited by the freezing point of water condensing on the cooling coil, which in some designs is tried to be offset by complicated brine spray and liquid lithium chloride type systems available, using a combination of refrigeration and adsorbent liquid, but these are very bulky and involve complicated control systems for the proper maintenance of solution density.

C. Sorption Dehumidification

Sorbents are solid or liquid materials which have the property of extracting and holding other substances (usually water vapour) brought into contact with them. Sorbents can be classified into two general categories:

1) Absorbents
2) Adsorbents

1) Desiccant dehumidification:

Desiccant dehumidification is one of the mechanical processes of removal of moisture from air. Thought of in another way, dehumidification is the drying of air. The degree of dehumidification varies with the application requirements and greatly influences the type of equipment utilized. Most engineers are familiar with mechanical dehumidification. A process of cooling an air-stream to below its dew point temperature causing moisture to condense from the air. This process frequently requires re-heating of the air to avoid supplying saturated air to a space. Desiccant dehumidification is becoming more familiar. Many engineers are just becoming knowledgeable concerning the use of desiccants for dehumidification. Desiccant dehumidifiers utilize a “sorption” material to attract and hold moisture from air. Once the sorption material, called a desiccant, is “saturated” with moisture, it can be reactivated or regenerated. Reactivation is usually accomplished by thermal means and restores the desiccant’s dehumidification capacity. The mass exchange of the moisture from and to an air. Desiccant dehumidifiers are required for use below the frost point where mechanical refrigeration type dehumidifiers experience freezing on the coil surface or when dehudification is required, but cooling is not, such as for dry goods storage or preservation requirements.

2) Desiccant Wheel:

The Solid desiccants are used in different technological arrangements. One of the typical arrangements consists of a slowly rotating wheel impregnated with a desiccant like a silica gel or a molecular sieve, in which a part of the wheel is intercepting the incoming air stream while the rest of it is being regenerated. For continuous operations, adsorption and regeneration must be performed periodically. Fig. 1 shows the schematic diagram of the desiccant wheel and its air streams. Solid desiccants are compact, less subject to corrosion and carryover, hence in comparison with the other methods, desiccant wheels are more common. Furthermore convenient adjustment of the operating parameters is another advantage of it. Because of desiccant wheel importance in solid desiccant cooling systems, many investigations have been performed on its design, modeling and optimization. Jia et al. improved desiccant wheel adsorption efficiency about 50% by preparation of a new kind of hybrid desiccant (silica gel and lithium chloride). Moreover new desiccants have a lower regeneration temperature which leads to a lower energy consumption [1]. In their recent paper, they investigated on the effect of a new adsorbent on desiccant cooling system and achieved 35% efficiency increase to the silica gel [2]. Also Cui [3] and Golubovic et al. [4] conducted independently two different studies on the improvement of the adsorbent. Wheel modeling is often used as a strong tool for analyzing different parameters and predicting the wheel behavior. One of the first desiccant wheel modeling was done by solving simultaneous mass and heat transfer equations in one rotary desiccant wheel in 1993 (Worek and Zhen [5]). Another modeling was performed by Zhang and Niu with finite element method [6]. They used modeling for predication and optimization of it. Pahlavanzadeh and Zamzamian have presented new modeling by considering Ackerman coefficient in simultaneous mass and heat transfer [7]. Mathematical modeling of desiccant wheel and utilization of Matlab Simulink software for solving mass and heat transfer equations is a recent study done by Esfandiarinia et al. They derived simple correlations based on a simulation in which by entering inlet air condition and physical parameters of the wheel, the outlet conditions are predicted with a 2% error [8]. Nobrega and Brum have developed a desiccant-wheel behavioral model. An Effectiveness number of transfer units (NTU) analysis was carried out, the results show that heat wheels can be far less efficient than enthalpy recovery wheels, depending on the atmospheric conditions [9].

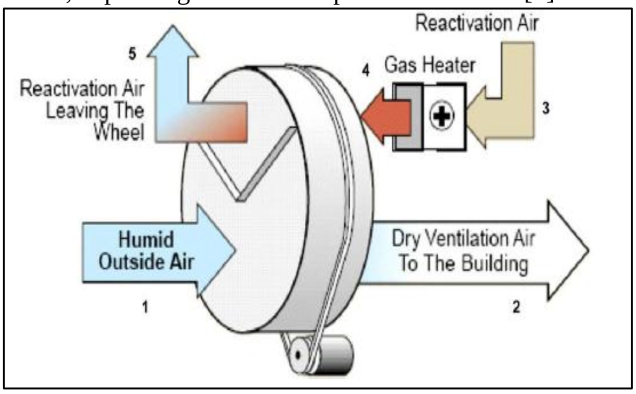


Fig. 1:

D. *Hygroscopic Material*

Hygroscopic is the capacity of a substance to draw in and hold water particles from the encompassing condition. This is accomplished through either ingestion or adsorption with the engrossing or adsorbing material winding up physically "changed" fairly, by an expansion in volume, stickiness, or other physical normal for the material, as water atoms progress toward becoming "suspended" between the material's particles all the while. While some comparable powers are grinding away here, it is not the same as narrow fascination, a procedure where glass or other "strong" substances draw in water, yet are not changed all the while (for instance, water atoms getting to be suspended between the glass particles). Hygroscopic substances incorporate Zinc and calcium-chloride, and in addition potassium hydroxide and sodium hydroxide (and a wide range of salts), are hygroscopic to the point that they promptly break down in the water they assimilate: this property is called deliquescence. Desiccants are hygroscopic materials, e.g. silica gel, sub-atomic strainer, lithium chloride or calcium chloride. Some different illustrations are dry powders as utilized as a part of pharmaceuticals, heated merchandise, and ice cream parlor fixings.

1) Silica Gel

Silica gel has high moisture adsorption limit and low regenerative temperature of 120°C. It is additionally settled that adsorption limit of silica gel by and large reductions with the rise in temperature. It is proposed that consolidating both by blending them chemically or physically will conquer the individual deficiencies of each sort. For example, blend of silica gels with lithium chloride will diminish the impact of danger and to lessen the recovery temperature accomplishing the halfway trademark. Many research works have been completed in this field where these desiccants are referred to as composite desiccants.

2) Molecular Sieve

a) 3A Molecular Sieves

A 3A Molecular sieve has a pore size of 3å or 3angstrom.it is striking to assimilate any particle bigger than3å.molecular sieve is an antacid metal alumino-silicate, the potassium for sort a precious stone structure. 3A molecular sieve is utilized fundamentally to remove moisture from liquefied and gaseous materials. It has turned out to be a standout amongst the most dependable desiccants for different applications.

b) 4A Molecular Sieves

A 4A molecular sieve has a pore size of 4å or 4 angstrom. It doesn't adsorb any particle bigger than 4 angstroms are the sodium types of the sort a crystal structure. 4A atomic strainer is principally utilized for expelling moisture from liquefied and gaseous materials.

3) Scope of Present Project Work

- Dehumidification of desiccant wheel is built up for effectively utilization in institutions and mechanical applications for long time.
- The composite desiccant has a similar inclination at high regenerative temperature, high relative humidity and low inlet temperature which give the superior dehumidification performance.
- The emended plan can make this a straight household cooling framework.

- No unique refrigerants, for example, alkali, sulfur or CFCs, are utilized that could be harmful, costly to supplant, add to ozone exhaustion as well as be liable to stringent authorizing and ecological controls.

4) Purpose of Study

- To create a desiccant dehumidifier that is suitable for all household application.
- To reduce dehumidification of air in summer season using the approach of Desiccant Wheel Dehumidifier in buildings to achieve comfort condition.
- To create combination of composite desiccant in such a way that the dehumidification can be done quickly.
- To enhance the cooling capacity as well as effectiveness of desiccant wheel.
- To design the wheel in such way that no extra financial burden in collection and transportation of waste.
- To develop an arrangement for supplying dehumidified air to room.

III. Experimental Setup and Working

A. Experimental Steps

A desiccant wheel with a grid of small air passages, similar to a large bundle of coffee straws, is impregnated with silica gel. Make an electrical connection and start the motor for using the rotating of wheel. The desiccant wheel rotates slowly through the different air flow zones (v) of the desiccant, as it works to remove moisture. The size of this rotor and the speed at which it rotates varies depending on the unit's specifications for target humidity and air volume. Most of the cost of desiccant dehumidifiers is in the desiccant wheel. The experimental fan inside the duct moves the air through the desiccant wheel. Measure the process air temperature (Tpi) along with the humidity (Øi). Normally, 75 percent of the air is dried and sent through the wheel, exiting the unit as warm, dry process air. Measure the temperature of outlet process air (Tpii) and humidity (Ø2).to. The remaining 25 percent of the air is used to remove moisture from the wheel, exiting the unit as warm, wet reactivation air. A heater boosts the temperature of this reactivation air (Tri), so that it can drive out the moisture that has collected on the desiccant rotor. Hot air removes moisture from the silica by adding enough energy to the water molecules to overcome the chemical attraction they have to the desiccant media (e.g., silica gel). This function of a desiccant dehumidifier requires a high level of power consumption. Repeat the same procedure for further reading in a span of 10 min including silica gel alone and composite desiccant.

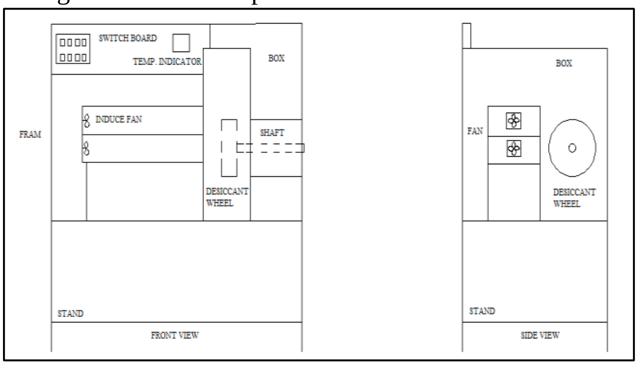


Fig. 2: Experimental setup

IV. Observations and Calculations Observations

The experiments were conducted on the composite desiccant with fixed air flow rate and the different temperature characteristics were calculated. Several trails were conducted on desiccant wheel using any silica gel alone and composite material silica gel and molecular sieve and composite material silica gel and calcium chloride.

Sr.No.	V	Tpi	ϕi	Tpo	ϕo	Tri	Wi	Wii
	m/s	ºC	%	ºC	%	ºC	g/kg	g/kg
1	4	27.6	45	32.6	43	40	10.2	12.5
2	4	28.4	45	34.8	43	40.8	10.5	14
3	4	29.5	44	35.8	42	41.2	11	14.4
4	4	29.8	46	36	44	42.6	12.1	15.8
5	4	30.5	46	37.1	43	44.8	12.8	16.9
6	4	31.8	43	38	42	45.6	12.2	16.6

Table 1: Observation Table for silica gel at air flow velocity (4m/s)

Sr.No.	V	Tpi	ϕi	Tpo	ϕo	Tri	Wi	Wii
	m/s	ºC	%	ºC	%	ºC	g/kg	g/kg
1	4	28.1	68	35	65	46.4	15	21.8
2	4	28.6	66	35.5	65	47.6	16	23.1
3	4	29.6	68	36.6	66	48.3	17.8	23.8
4	4	30.3	60	37.2	59	48.3	16.9	23.4
5	4	31.5	64	38.4	62	49.4	19	24.8
6	4	32.3	62	38	60	50.2	19.1	24

Table 2: Observation Table for silica gel and molecular sieve at air flow velocity 4m/s

Sr.No.	V	Tpi	ϕi	Tpo	ϕo	Tri	Wi	Wii
	m/s	ºC	%	ºC	%	ºC	g/kg	g/kg
1	4	29	58	35	55	45	14.9	19
2	4	32	55	37.2	52	47	16.4	20.1
3	4	32.8	56	38	51	46	17	21
4	4	34.1	51	39.1	48	45	16.8	20.9
5	4	34.8	52	40	46	47	17.4	20.6
6	4	35.3	48	39	45	47	17.5	19.8

Table 3: Observation Table for silica gel and calcium chloride at air flow velocity 4m/s Sample calculation for Silica gel from Table No.01

At 27.60C, ρ = 1.174 kg/m3

Mass of Process air = ρ A V

= 1.174 × (0.508 × 0.254) × 4

= 0.606 kg/s

At 400C, ρ = 1.127 kg/m3

Mass of regenerative air = ρ A V

= 1.127 × (0.508 × 0.254) × 4

= 0.582 kg/s

Ambient Condition : Ta = 29 , RH=47, ha= 57

Process air at inlet : TPi = 27.6, RH=45, hs= 54.5

Process air at outlet : TPo = 32.6, RH=43, h6=68

Regenerative air : TRi = 40, RH=22, h5 =65

$$COP = \frac{mpa\ (ha-hs)}{mra\ (h6-h5)} = \frac{0.606\ (57-54.5)}{0.582\ (68-65)} = 0.87$$

$$\text{Thermal effectiveness} \quad \varepsilon = \frac{Tpo-Tpi}{Tri-Tpi} = \frac{32.6-27.6}{40.0-27.6} = 0.403$$

Moisture removal rate (MRR) = Mpa (Wii – Wi)

= 0.606 (12.5 – 10.2)

= 1.394gm/kg of dry air.

Sample calculation for Silica gel and molecular sieves from Table No.02

At 28.10C, ρ = 1.178 kg/m3

Mass of Process air = ρ A V
= 1.178 × (0.508 × 0.254) × 4
= 0.608 kg/s
At 46.40C, ρ = 1.104 kg/m3
Mass of regenerative air = ρ A V
= 1.104 × (0.508 × 0.254) × 4
= 0.569 kg/s
Ambient Condition: Ta = 33 , RH=48, ha= 73
Process air at inlet: TPi = 28.1, RH=68, hs= 68
Process air at outlet: TPo = 35, RH=65, h6=92
Regenerative air: TRi = 46.4, RH=18, h5 =77

$$COP = \frac{mpa\,(ha-hs)}{mra\,(h6-h5)} = \frac{0.608\,(73-68)}{0.569\,(92-77)} = 0.356$$

Thermal effectiveness $\varepsilon = \frac{Tpo-Tpi}{Tri-Tpi} = \frac{35-28.1}{46.4-28.1} = 0.377$

Moisture removal rate (MRR) = Mpa (Wii – Wi)
= 0.608 (23 – 16.2)
= 4.134gm/kg of dry air

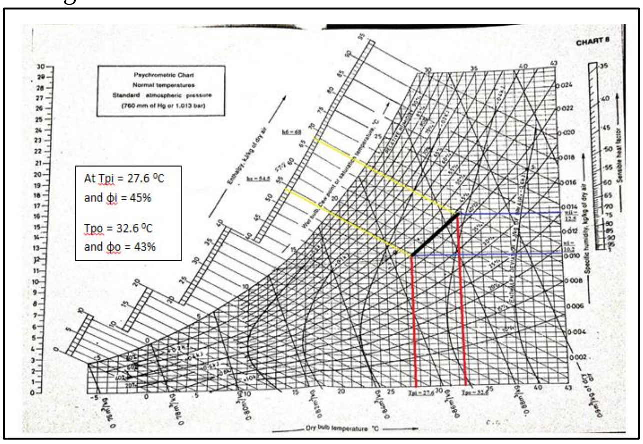
Sample calculation for Silica gel and CaCl2 from Table No.03
At 290C, ρ = 1.161 kg/m3
Mass of Process air = ρ A V
= 1.161 × (0.508 × 0.254) × 4
= 0.599 kg/s
At 450C, ρ = 1.109 kg/m3
Mass of regenerative air = ρ A V
= 1.109 × (0.508 × 0.254) × 4
= 0.572 kg/s
Ambient Condition: Ta = 33, RH=48, ha= 73
Process air at inlet: TPi = 29, RH=58, hs= 66
Process air at outlet: TPo = 35, RH=55, h6=84.9
Regenerative air: TRi = 45, RH=20, h5 =76

$$COP = \frac{mpa\,(ha-hs)}{mra\,(h6-h5)} = \frac{0.599\,(73-66)}{0.572\,(84.9-76)} = 0.82$$

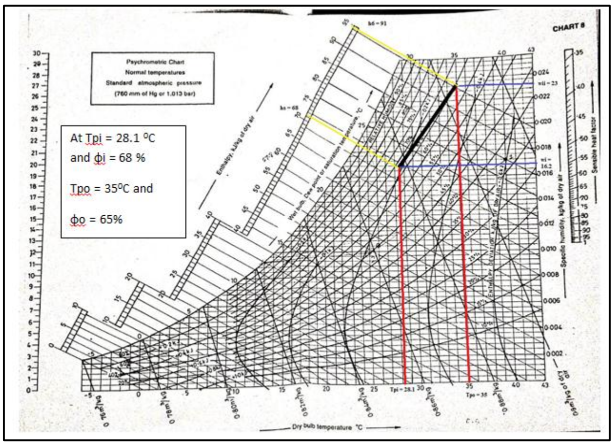
Thermal effectiveness $\varepsilon = \frac{Tpo-Tpi}{Tri-Tpi} = \frac{35-29}{45-29} = 0.375$

Moisture removal rate (MRR) = Mpa (Wii – Wi)
= 0.599 (19 – 14.9)
= 2.455gm/kg of dry air

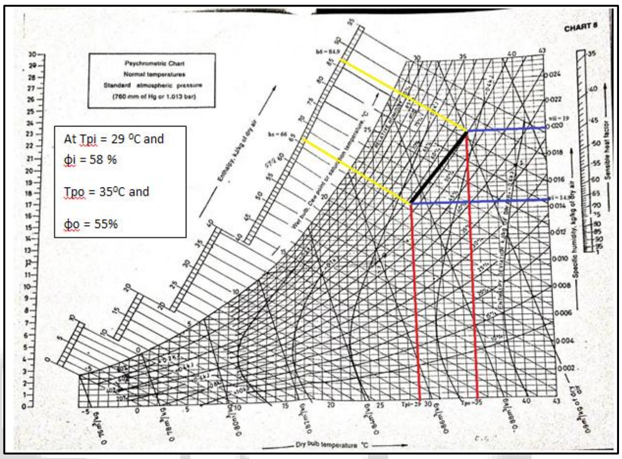
Analysis of psychrometric chart for: Sample calculation of Silica gel.



Analysis of psychrometric chart for: Sample calculation of Silica gel and molecular sieves.



Analysis of psychrometric chart for: Sample calculation Silica gel and CaCl2



V. RESULT AND DISCUSION

Dehumidification under the regenerative temperature and typical climatic condition are shown by desiccant wheel with silica gel and composite material. The experiment were conducted on desiccant wheel with different composite material under constant air flow velocity at different temperature were calculated.

1) Case I: Experimentation on silica gel with air flow velocity 4m/s.
2) Case II: Experimentation on silica gel and molecular sieve with air flow velocity 4m/s.
3) Case III: Experimentation on silica gel and Calcium chloride with air flow velocity 4m/s.

Following parameters are calculated during the performance of experiment.

1) Inlet and outlet humidity ratio
2) Thermal effectiveness
3) Coefficient of performance
4) Moisture removal capacity

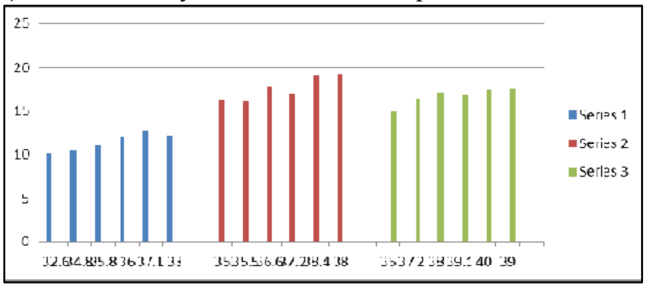
From above calculation following graphs are plotted for interpretation of performance.

1) Inlet humidity ratio vs Outlet temperature
2) Inlet temperature of process air vs Dehumidification amount

Outlet humidity ratio vs regeneration temperature

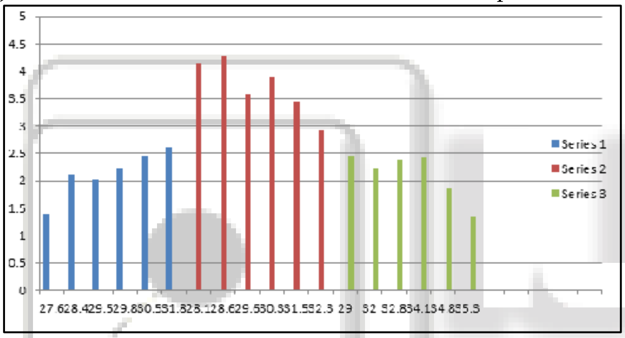
A. Graphs:

1) Inlet Humidity Ratio Vs Outlet Temperature



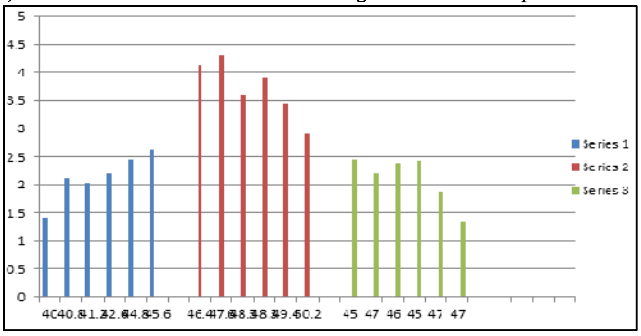
As more moisture is removed (higher inlet humidity), outlet temperature rises. Air entering at inlet humidity ratio, 10.2 g/kg leaves the dehumidifier at 32.6 °9C in first Case I (Only silica gel as a desiccant). So far in Case II observed that if the dehumidifier removes more moisture, such as when the inlet humidity is 19.5 g/kg, outlet temperature rises to 38.4 °C. The increase in temperature rise is roughly proportional to the increase in moisture removal. Where as in Case III the removal of moisture rate is slightly high than the Case I but as compare to Case II the temperature increases and no such raise in moisture removal rate.

2) Moisture Removal Rate Vs Process Air Temperature



Effect of process inlet temperature on desiccant wheel performance: when the temperature of inlet process air increases, moisture removal capacity drop but at Case II inlet temperature is 28.6oC and it give the high rate of moisture removal (4.3 gm/kg of dry air). And moisture removal rate is gradually decreased as the process inlet temperature increases.

3) Moisture Removal Rate Vs Regenerative Temperature



In a rotational dehumidifier, the desiccant is heated by air entering reactivation. The hotter the desiccant, the more easily it vapourises the moisture, so the reactivation air temperature has a strong effect on performance. Essentially, drier the desiccant becomes in reactivation, more the moisture it can absorb when it rotates into the process air stream. The inlet temperature of the reactivation air changes the outlet moisture content of the process air. As more heat is added to the reactivation air, the desiccant dries more completely, which means that it can attract more moisture from the process air.

VI. Conclusion

In the present paper an effort has been made to survey distinctive desiccant material. Desiccant dehumidification is a setup and effective innovation utilized for some years. However, decreasing the cost of desiccant dehumidification frameworks and enhancing the implementation will give more chances to desiccant dehumidification technology. The best in class advances possible to choose right desiccant materials, desiccant wheel geometry and strategy for dehumidification and recovery.

The accompanying conclusions can be expressed:

1) Sorption limit expanded as the proportion of silica gel and molecular sieve in the composite desiccant expanded, yet the composite desiccant wind up plainly softer;
2) A little extent of molecular sieve (70:30) was utilized to accomplish a similar change in the sorption limit of the composite desiccant, which was joined with a vast master segment of silica gel ,enabling the composite desiccant to look after hardness, even with a low proportion of molecular sieve in the get up of adsorbing water;
3) The aggregate mass of water adsorption of every composite desiccant was higher than the silica gel desiccant, yet the most Noteworthy transient dehumidification capacity was lower than the silica gel desiccant.
4) The composite and silica gel desiccants had a similar tendency at regeneration temperatures of 40◦c and 50◦c. the higher there regeneration temperature, the higher the relative humidity, the lower the inlet temperature, and the faster the velocity, which combines to cause a superior dehumidification performance.
5) The composite desiccants with air channels had a much lower pressure drop than the silica gel stuffed and reduce the fans energy consumption
6) Low material expenses, environmentally-friendly posses with low temperatures, a longer extended dehumidifying time of operation, and a low pressure drop are perfect for use in the residential air conditioning framework.

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