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An Experimental and Psychrometric Analysis of Desiccant Wheel with Comparative Study of Dehumidification using Desiccant Material used in hybrid Air Conditioning

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***Abstract*: Air-conditioning systems combined with rotary dehumidification were widely used in industrial buildings with low humidity requirements. In this paper, a rotary desiccant wheel-based hybrid air conditioning system with natural cold source was presented, which was used in civil buildings. In this system, sensible load was undertaken by the natural cool source, and latent load was undertaken by rotary dehumidification wheel. The performances of rotary desiccant wheel-based hybrid air conditioning system with natural cold source were studied in two typical outdoor meteorological conditions. The results showed that the system under both high temperature high humidity and high temperature low humidity conditions can satisfy the indoor environment demand for civil buildings, while the energy consumption on high temperature high humidity condition is less. While waste heat or solar energy is adopted as regeneration heat source, the energy consumption of rotary desiccant wheel-based hybrid air conditioning system can further reduce. So, Comparative Study of Solid Desiccant and Liquid Desiccant Material is done in this Paper.**

***Keywords*: Rotary Desiccant Wheel, Air Conditioning, Solid and Liquid Desiccant Material.**

1. Introduction

A conventional air conditioner consumes large amount of electrical energy especially in hot and humid climatic conditions due to high latent load which is decide by the outside contents. Desiccant wheel-based hybrid air conditioning system is one of the promising alternative to handle the high latent load efficiently where sensible and latent heat of air are being removed separately. A desiccant wheel is very similar to a thermal wheel, but with a coating applied for the sole purpose of dehumidifying or 'drying' the air stream. The desiccant is normally Silica Gel. As the wheel turns, the desiccant passes alternately through the incoming air where the moisture is adsorbed, and through a "regenerating" zone where the desiccant is dried, and the moisture expelled. The wheel continues to rotate, and the adsorbent process is repeated.

Regeneration is normally carried out by the use of a heating coil, such as a water or steam coil, or a direct-fired gas burner. Thermal wheels and desiccant wheels are often used in series configuration to provide the required dehumidification as well as recovering the heat from the regeneration cycle. A desiccant material can be described as a material that naturally attracts moisture from both gases and liquids. This moisture is then adsorbed or retained within the desiccant and can be released again when heated. There are various types of desiccant available on the market, but all Aggreko dehumidifier's use what is known as Silica Gel as the desiccant within the drying wheels. Strangely silica gel is not a "gel" as the name implies, but in fact a porous granular form of silica which is made from sodium silicate. The internal structure of each silica granule is made up of a network of interconnecting microscopic pores, which by a process called physical adsorption or capillary condensation, attract and holds moisture within each granule. This trapped moisture can then, with the addition of heat, be released from the desiccant. This desiccant can then be used again and again. As low ambient temperatures do not restrict the material, it makes it a more all season drying system.

A. Moisture removal

The moisture removal capacity of a desiccant dehumidifier is related to several parameters. One parameter is the amount of "surface" area of the desiccant that is exposed to the air-stream. Each rotor contains hundreds of square feet of sheet area per cubic foot of rotor volume. This surface area multiplied by the "internal" pore surface area results in thousands of square feet of area of desiccant available for adsorption. This tremendously high ratio of surface area to volume is one of the significant reasons for the excellent performance of the desiccant dehumidifier. The rotor speed is also optimized such that a maximum amount of desiccant is "rotated" through the process air-stream without causing over heating of the desiccant. By selecting the optimum speed of rotation, the adsorption cycle is carefully balanced against the de-sorption cycle. All desiccant dehumidification rotors are bearing supported for long life and dependable mechanical support. Rotors with a diameter larger than 20-inches are shaft mounted and bearing supported. The full weight of the rotor and the adsorbed moisture are supported by the shaft and bearing arrangement.

B. Adsorption

Adsorption occurs when the attractive forces of a desiccant capture water vapour. The vapour is drawn to and adheres to the surface of the desiccant. The vapour is then drawn into the macro-pores and then the micro-pores by capillary action. In the process the moisture converts adiabatically from vapour to a quasi-liquid and is stored within the desiccant. (An adiabatic process occurs without the external addition or removal of heat.) It is important to distinguish between the vapour quasi-phase changes as opposed to a desiccant phase change.

C. Absorption

absorption, collecting moisture changes the desiccant physically or chemically. Most absorbents, such as solutions of lithium chloride or triethylene glycol in water, are liquids.

D. Sensible heat

The amount of Heat required to chang the temperature of a system without changing its state or phase is known as sensible Heat.

E. Latent heat

The amount of Heat required to chang the state or phase of a system without changing its temperture is known as Latent Heat.

F. Process Inlet

Air to be dried. May be outside air, inside air or, more commonly, a mixture of air with high humidity content.

G. Process Outlet

Air is dried by desiccant wheel. May be cooled, filtered or otherwise hanoled. Relative humidity is substantially lower and temperature slightly raised.

H. Reactivation inlet

Air flow, usually outside air, that drives moisture off wheel. Reactivation air is heated by direct-fired gas burner or indirect-fired water or steam.

I. Reactivation Outlet

Hot, wet air from wheel is exhausted outside or passed through an air-to-air heat-exchanger. Using a heat exchanger to preheat incoming process air offers substantial savings in northern climates.

J. Dehumidification

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2. Literature review

Experimental performance study of a proposed desiccant based air conditioning system, M.M. Bassuoni, An experimental investigation on the performance of a proposed hybrid desiccant based air conditioning system referred as HDBAC is introduced in this paper. HDBAC is mainly consisted of a liquid desiccant dehumidification unit integrated with a vapor compression system (VCS). The VCS unit has a cooling capacity of 5.27 kW and uses 134a as refrigerant. Calcium chloride($CaCl_2$) solution is used as the working desiccant material. HDBAC system is used to serve low sensible heat factor applications. The effect of different parameters such as, process air flow rate, desiccant solution flow rate, evaporator box and condenser box solution temperatures, strong solution concentration and regeneration temperature on the performance of the system is studied. The performance of the system is evaluated using some parameters such as: the coefficient of performance (COPa), specific moisture removal and energy saving percentage. A remarkable increase of about 54% in the coefficient of performance of the proposed system over VCS with reheat is achieved. A maximum overall energy saving of about 46% is observed which emphasizes the use of the proposed system as an energy efficient air conditioning system [1].

An experimental study on the dehumidification performance of a low-flow falling-film liquid desiccant air-conditioner, S. Bouzenadaa, C. McNevinb, S. Harrison c, A. N. Kaabid, the dehumidifier is one of the main components in open-cycle liquid desiccant air-conditioning systems. An experimental study was carried out to evaluate the performance of a solar thermally driven, low-flow, falling-film, internally-cooled parallel plate liquid desiccant air-conditioner in Kingston, Ontario at Queen’s University. A solution of LiCl and water was used as the desiccant. Unlike high-flow devices, the low-flow of desiccant solution flowing across the unit’s dehumidifier and regenerator sections produces large variations in solution concentration. In this study, a series of tests were undertaken to evaluate the performance of the dehumidifier section of the unit. Results presented are based on mass flow and energy transport measurements that allowed the moisture transport rate between the air and liquid desiccant solution to be determined. Based on these results, a relationship between the desiccant concentration and the rate of dehumidification rate was found and the effect of inlet-air humidity on the dehumidification effectiveness identified. The moisture removal rate of the system was found to range from 1.1 g/s to 3.5 g/s under the conditions evaluated. These result corresponded to an average dehumidification effectiveness of 0.55 [2].

The Experiment and Simulation of Solid Desiccant Dehumidification for Air-Conditioning System in a Tropical Humid Climate, Juntakan Taweekun, Visit Akvanich, the aim of this research was to study and design a solid desiccant dehumidification system suitable for tropical climate to reduce the latent load of air-conditioning system and improve the thermal comfort. Different dehumidifiers such as desiccant column and desiccant wheel were investigated. The ANSYS and TRASYS software were used to predict the results of dehumidifiers and the desiccant cooling systems, respectively. The desiccant bed contained approximately 15 kg of silica-gel, with 3 mm average diameter. Results indicated that the pressure drop and the adsorption rate of desiccant column are usually higher than those of the desiccant wheel. The feasible and practical adsorption rate of desiccant wheel was 0.102 kgw/h at air flow rate 1.0 kg/min, regenerated air temperature of 55°C and at a wheel speed of 2.5 rpm. The humidity ratio of conditioning space and cooling load of split-type air conditioner was decreased to 0.002 kgw/kgda (14%) and 0.71 kWth (19.26%), respectively. Consequently, the thermal comfort was improved from 0.5 PMV (10.12% PPD) to 0.3 PMV (7.04% PPD). [3]

Performance Characteristics of Solid-Desiccant Evaporative Cooling Systems, Ramadas Narayanan, Edward Halawa and Sanjeev Jain , Air conditioning accounts for up to 50% of energy use in buildings. Increased air-conditioning-system installations not only increase total energy consumption but also raise peak load demand. Desiccant evaporative cooling systems use low-grade thermal energy, such as solar energy and waste heat, instead of electricity to provide thermal comfort. This system can potentially lead to significant energy saving, reduction in carbon emissions, and it has a low dew-point operation and large capacity range. Their light weight, simplicity of design, and close-to-atmospheric operation make them easy to maintain. This paper evaluates the applicability of this technology to the climatic conditions of Brisbane, Queensland, Australia, specifically for the residential sector. Given the subtropical climate of Brisbane, where humidity levels are not excessively high during cooling periods, the numerical study shows that such a system can be a potential alternative to conventional compression-based air-conditioning systems. Nevertheless, the installation of such a system in Brisbane's climate zone requires careful design, proper selection of components, and a cheap heat source for regeneration. The paper also discusses the economy-cycle options for this system in such a climate and compares its effectiveness to natural ventilation [4].

Solar Air Conditioning System Using Desiccant Wheel Technology, Arfidian Rachman, Sohif Mat, Taib Iskandar, M. Yahya, AzamiZaharim and Kamaruzzaman Sopian, the electrical energy consumption in Malaysia has increased sharply in the past few years. Modern energy efficient technologies are desperately needed for the national energy policy. In this paper, a new design of desiccant cooling is being developed at the Solar Energy Research Institute, National University of Malaysia, Malaysia. The new conception of desiccant cooling can be an energy saving and permits to produce heat or cool by using solar energy without polluting the environment. Desiccant cooling systems have been used successfully in northern Europe and a number of studies have demonstrated that solar energy can be used to drive the system in this region. However, to date, desiccant cooling has not been used in Malaysia. This paper presents the results of a study, in which a solar desiccant cooling model will used to evaluate the potential for using solar power to drive a single-stage desiccant cooling system in Malaysia. The study demonstrates that solar desiccant cooling is feasible in Malaysia, provided that the latent heat gains experienced are not excessive. However, if the relative humidities experienced are too high then desiccant cooling becomes impracticable simply because the regeneration temperatures required are excessive [5].

3. Solid desiccant system

Desiccant based air-conditioning systems offers a promising alternative to vapour compression refrigeration air-conditioning systems especially, under conditions involving high latent loads. This technique allows the use of low-temperature industrial waste heat or solar power to drive the cooling cycle. Therefore, it attracted increased research attention during the last two decades. Desiccants are chemicals with great affinity to moisture. They absorb/release moisture because of the variation in vapour pressure between the surface of the desiccant and the surrounding air. Dehumidification will occur when the vapour pressure of the surface of the desiccant is less than that of the environmental air. Dehumidification continues till the desiccant material reaches equilibrium with the surrounding air. Regeneration of this desiccant will occur when the vapour pressure of the desiccant is larger than that of the surrounding air, which is usually accomplished by heating the desiccant to its regeneration temperature and exposing it to an air stream. Desiccants can be classified as adsorbents which absorb moisture without considering physical and chemical changes or absorbents which absorb moisture by considering physical or chemical changes. Desiccants can be solids or liquids and can hold moisture through adsorption or absorption. Most absorbents are liquids and most adsorbents are solids. Several

Types of solid desiccants are mostly used in desiccant cooling systems; silica gels, lithium chloride and molecular sieves. Different methods of dehumidification- In Air bypass control method a portion of the return air is bypassed from the cooling coil. This gives less reheat requirement. In Heat pipe

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system method, precooling of mixed air and reheating of conditioned air can be achieved by introducing a heat pipe between the above air streams. This is also an energy saving device. In Air reheat system method, by selecting the dew point temperature of the coil and reheating the conditioned air to achieve the desired temperature and humidity. This method was widely adopted earlier. It is an energy inefficient method and many countries have banned this method. In Desiccant cooling systems moisture in air is removed by a desiccant that absorbs the moisture when air passes through it.

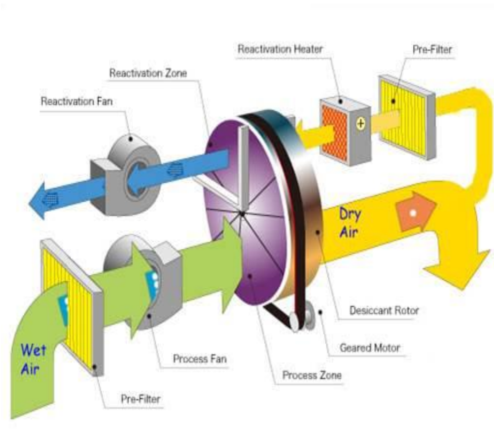

Fig. 1. Desiccant wheel dehumidification

In desiccant wheel dehumidifier, the desiccant material usually a silica gel or some type of zeolite, is impregnated into a supporting structure. This looks like a honeycomb which is open on both ends. Air passes through the honeycomb passages, giving up moisture to the desiccant present in the walls of the honeycomb cells. The wheel constantly rotates through two different air streams.

4. Results and outcomes

Experimental Values and Calculations

Conditions of air at inlet to Wheel: DBT = 29 0C
WBT = 25 0C
RH = 72 %

Specific Humidity = 18.2 g/kg of dry air

At Rotor Speed of 10 rph:

1. Air Inlet Velocity = 1.5 m/s
- Conditions of air at Outlet of Wheel: DBT = 45 ^{0}C

2. Air Inlet Velocity = 2 m/s
- Conditions of air at Outlet of Wheel: DBT = 43.5 ^{0}C

3. Air Inlet Velocity = 2.5 m/s
- Conditions of air at Outlet of Wheel: DBT = 42 ^{0}C

4. Air Inlet Velocity = 3 m/s
- Conditions of air at Outlet of Wheel: DBT = 41 ^{0}C

5. Air Inlet Velocity = 3.5 m/s
- Conditions of air at Outlet of Wheel: DBT = 40 ^{0}C

Table 1
Desiccant Wheel Rotate at a Speed of 10 rph

Speed = 10 rph					
S. No.	Inlet Velocity of Process Air m/s	Processed Removed Moisture Kg/kg of da	Process Outlet Temp. ^{0}C	Reactivation Outlet Moisture Kg/kg of da	Reactivation Outlet Temp. ^{0}C
1	1.5	7.1	22.22	21	28.88
2	2	6.7	21.66	22.2	28.33
3	2.5	6.2	21.38	23	28.05
4	3	5.8	21.11	23.7	27.77
5	3.5	5.3	20.55	24	26.66
6	4	4.8	20	24.5	26.38
7	4.5	4.5	18.88	24.8	25.55
8	5	4.1	18.33	25	24.44
9	5.5	3.8	18.61	25.2	23.33
10	6	3.6	17.77	25.4	23.88

Table 2
Desiccant Wheel Rotate at a Speed of 20 rph

Speed = 20 rph					
S. No.	Inlet Velocity of Process Air m/s	Processed Removed Moisture Kg/kg of da	Process Outlet Temp. ^{0}C	Reactivation Outlet Moisture Kg/kg of da	Reactivation Outlet Temp. ^{0}C
1	1.5	6.7	23.88	21	30
2	2	6.6	23.33	22.2	29.44
3	2.5	6.2	23.05	23.2	29.72
4	3	5.7	22.77	23.7	28.88
5	3.5	5.3	22.22	23.9	28.33
6	4	4.8	21.66	24.7	27.77
7	4.5	4.5	20.55	25	27.22
8	5	4.1	20	25.2	26.66
9	5.5	3.8	20.27	25.2	25.55
10	6	3.5	19.44	25.3	25

At Rotor Speed of 20 rph:

1. Air Inlet Velocity = 1.5 m/s
- Conditions of air at Outlet of Wheel: DBT = 46.5 ^{0}C

2. Air Inlet Velocity = 2 m/s
- Conditions of air at Outlet of Wheel: DBT = 44.5 ^{0}C

3. Air Inlet Velocity = 2.5 m/s
- Conditions of air at Outlet of Wheel: DBT = 43 ^{0}C

4. Air Inlet Velocity = 3 m/s
- Conditions of air at Outlet of Wheel: DBT = 42 ^{0}C

5. Air Inlet Velocity = 3.5 m/s
- Conditions of air at Outlet of Wheel: DBT = 41 ^{0}C

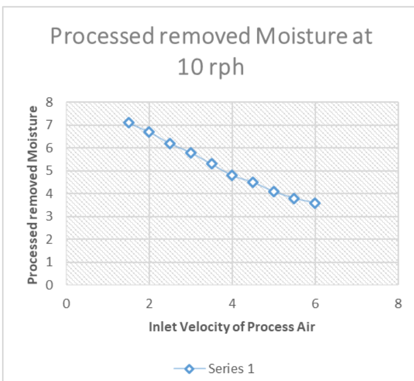

Fig. 2. Processed Removed Moisture at a Speed of 10 rph (kg/kg of dry air)

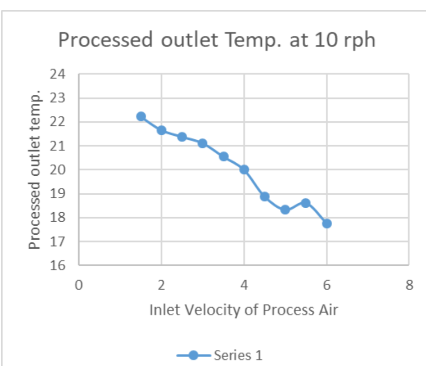

Fig. 3. Processed Outlet Temperature at a Speed of 10 rph

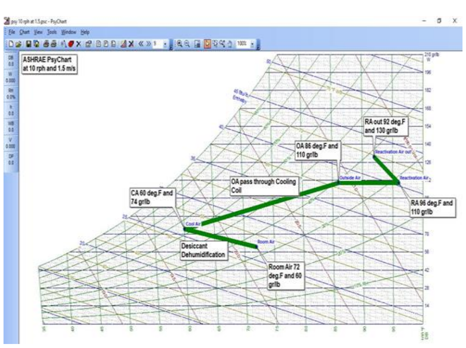

Fig. 4. Psychrometric results at a Speed of 10 rph and Velocity of 1.5 m/s

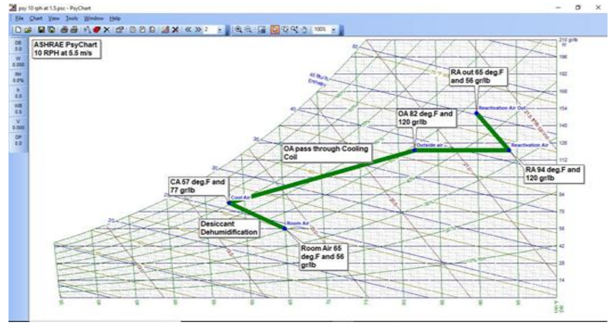

Fig. 5. Psychrometric results at a Speed of 10 rph and Velocity of 5.5 m/s

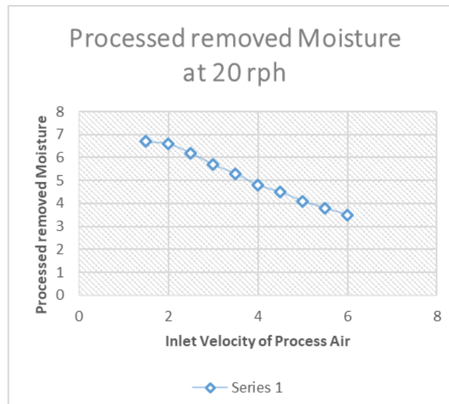

Fig. 6. Processed Removed Moisture at a Speed of 20 rph (kg/kg of dry air)

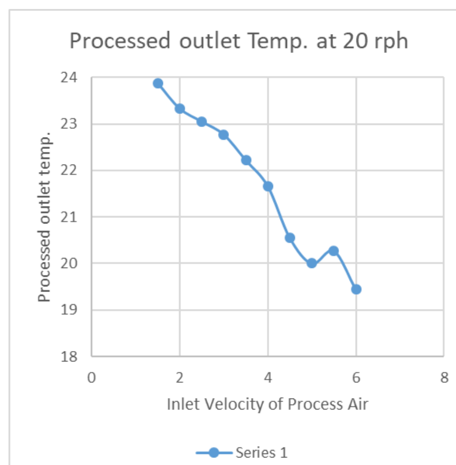

Fig. 7. Processed Outlet Temperature at a Speed of 20 rph

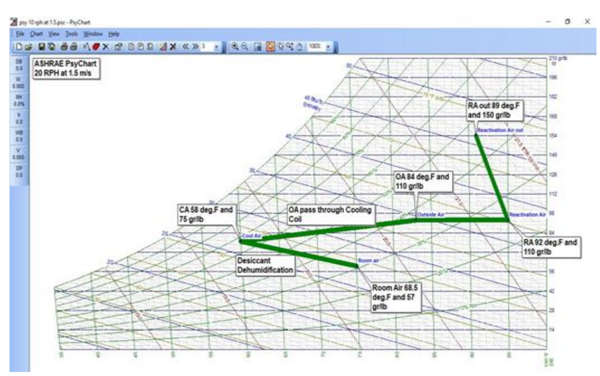

Fig. 8. Psychrometric results at a Speed of 20 rph and Velocity of 1.5 m/s

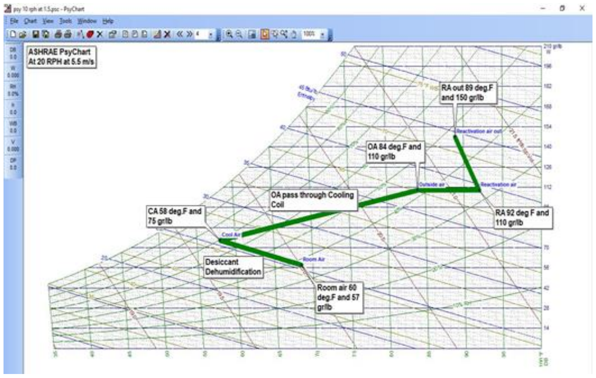

Fig. 9. Psychrometric results at a Speed of 20 rph and Velocity of 5.5 m/s

5. Conclusion

Performance of the desiccant wheel-based hybrid air conditioning system is evaluated conclusion can be made. For a chosen regeneration temperature, hybrid air conditioning system is economically up to certain humidity level compared to window air condition alone. If the regeneration temperature increases the load get completely separated there by performance of cooling coil improve a lot 70% to 80% performance of cooling coil is significantly governed by latent load. Hybrid air conditioning can be good option when the humidity level is high.

6. Future scope of the project

1. This desiccant wheel dehumidifier reduces the moisture level from the cooling air in more effective way compare than other system.
2. This system is less costly compare than other system such as Air- Conditioner.
3. This system has a good future because of its effectiveness and easier to use.
4. This system is eco-friendly and because of this, the cooler covering the market at great level.
5. This system is very useful in industries and party places.
6. The improved design can make this a good domestic cooling system.
7. The mechanism of desiccant wheel can be applied to coolers which have been made before.
8. The whole mechanism can be adopted in one system and the body can be rotated around one axis at 180 degree.

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