Development of Rotary Desiccant Wheel Simulator

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Abstract-This paper presents the development and experimental investigation of a rotary desiccant wheel simulator aimed at efficient air dehumidification. The system utilizes silica gel as the desiccant material due to its high adsorption capacity and thermal stability. The primary objective of this project is to enhance indoor air quality and reduce energy consumption in humid climates by replacing conventional vapor-compression dehumidification systems. The prototype consists of a rotating cylindrical wheel embedded with silica gel, a centrifugal blower, and a heating element for desiccant regeneration. Using assumed psychrometric conditions, we analyzed moisture removal and addition using humidity ratios derived from the psychrometric chart. The results demonstrate the system's ability to remove 0.005 kg of moisture per kg of dry air in the process stream and add 0.013 kg/kg in the regeneration stream. This study validates the potential of rotary desiccant systems in low-energy, climate-adaptive HVAC solutions

Keywords – Desiccant, Silica gel, Dehumidification, Psychrometric, Regeneration, Adsorption

I. INTRODUCTION

Indoor air quality (IAQ) has become a significant concern in residential, commercial, and industrial buildings, especially in regions with high humidity. Maintaining thermal comfort not only involves controlling temperature but also humidity, which directly influences occupant comfort, health, and energy consumption. Traditional air conditioning systems are designed to manage both sensible heat (temperature) and latent heat (humidity). However, managing latent loads requires the cooling coil temperature to drop below the dew point, resulting in excessive energy consumption and inefficient operation, particularly during the rainy or monsoon season.

One promising solution to this challenge is desiccant-based dehumidification, a technology that directly targets the latent heat by absorbing moisture from the air using hygroscopic materials. Among the available systems, rotary desiccant wheels are gaining popularity due to their continuous operation, high moisture removal efficiency, and ability to be regenerated using low-grade heat sources. These systems separate the dehumidification and cooling processes, allowing for more efficient climate control.

A rotary desiccant wheel consists of a slowly rotating porous wheel coated with desiccant material (such as silica gel). The wheel is divided into two sectors—process and regeneration. Moist process air passes through the desiccant-coated section, where moisture is adsorbed, drying the air. Meanwhile, a heated regeneration air stream passes through the other section of the wheel, releasing the moisture previously captured by the desiccant. This cyclical operation allows for simultaneous adsorption and desorption, ensuring continuous and efficient dehumidification.

This research focuses on developing a rotary desiccant wheel simulator using silica gel as the desiccant. Silica gel is chosen due to its favorable properties: high surface area, excellent moisture adsorption capacity, low regeneration temperature requirement, and cost-effectiveness. The goal is to create a compact, low-energy system capable of simulating the dehumidification cycle in laboratory conditions and analyze its performance using psychrometric principles.

By constructing and testing a prototype, this study aims to:

- Demonstrate the feasibility of using rotary desiccant wheels for energy-efficient dehumidification.
- Analyse the moisture transfer capability using psychrometric data.
- Identify key parameters that influence system performance such as wheel speed, air velocity, and regeneration temperature.

- Lay the foundation for integrating such systems with renewable energy sources (e.g., solar heat) for sustainable HVAC applications.

With increasing energy demand and climate change concerns, the development of such systems is not only academically valuable but also relevant to real-world applications. The findings of this project are expected to contribute to the field of green building technology and low-energy air conditioning systems, especially in tropical and coastal regions where traditional air conditioning systems often struggle with high humidity levels.

The specific objectives of this research are as follows:

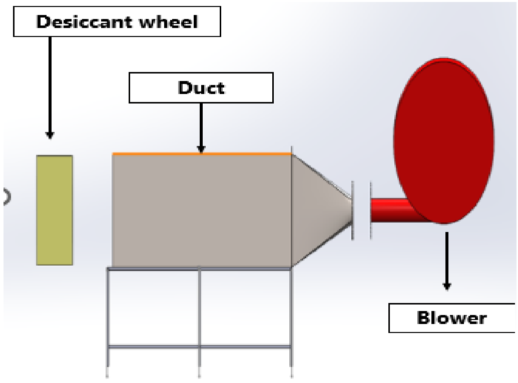
1. To select suitable system components based on the design requirements of a rotary desiccant wheel setup, including air handling, heating, and control instrumentation.
2. To develop a laboratory-scale desiccant wheel simulator using silica gel as the adsorbent material, ensuring continuous adsorption and regeneration cycles.
3. To evaluate the system's performance under various ambient humidity and temperature conditions.
4. To analyze dehumidification and regeneration behavior using psychrometric charts for accurate representation of air properties.
5. To investigate and determine optimum operating parameters, such as airflow velocity, wheel speed, and regeneration temperature, based on experimental analysis.

II. METHODOLOGY

Literature Review: Studied various types of desiccant dehumidification technologies, focusing on rotary desiccant wheels and suitable desiccant materials (like silica gel and zeolites).

Design & Component Selection:

- Desiccant Wheel: Diameter 370 mm, width 200 mm, embedded with silica gel.
- Blower: Centrifugal, 90 m^3/hr capacity, 2200 RPM.
- Heater: 100 W nichrome wire heating element for regeneration air.
- Sensors: Temperature and RH sensors to monitor inlet/outlet air.
- CAD Modeling: A 3D model of the system was designed using SolidWorks to ensure component alignment, effective air routing, and minimal leakage.
- Prototype Fabrication: The setup was built using sheet metal ducts, a mounted desiccant wheel, insulation, and an electrical heating system for regeneration.



Exploded View

Airflow Velocity Control-To investigate the effect of airflow velocity on the system's performance, the suction side of the blower was partially blocked to simulate varying flow conditions. Three levels of obstruction were introduced: 50%, 75%, and 100% blockage of the blower's suction inlet. This method provided a simple yet effective way to control and reduce the airflow rate without modifying the blower's speed or system layout. The airflow velocity was measured using an anemometer at each blockage level to ensure consistent data collection. This controlled reduction in velocity allowed for analysis of the desiccant wheel's moisture adsorption and regeneration performance under different airflow conditions.

Humidification Setup-To simulate high humidity conditions on the process air side, a vaporizer was integrated into the system to act as a humidifier. The vaporizer introduced controlled amounts of water vapor into the incoming air stream before it entered the desiccant wheel. This setup allowed for precise regulation of inlet air humidity, which was essential for evaluating the moisture adsorption capacity of the desiccant wheel under varying environmental conditions. Relative Humidity (RH) sensors placed before and after the wheel monitored the change in humidity levels, while the data logger recorded the readings for performance analysis.

III. EXPERIMENTAL SETUP

The simulator consists of two air ducts intersecting at the desiccant wheel – one for process air and one for regeneration air. The process air enters the wheel, loses moisture, and exits dehumidified. Simultaneously, regeneration air is heated and used to remove moisture from the other side of the wheel.

Component	Specification	Function
Desiccant Wheel	Type: Cylindrical rotary wheel Diameter: 370 mm Width: 200 mm Material: Silica gel on ceramic matrix Rotation Speed: 20 RPH	Core component for moisture adsorption (process air) and desorption (regeneration air). Centrally mounted.
Blower	Type: Centrifugal Capacity: 90 m³/h Motor Power: 8 HP Fan Speed: 2200 RPM	Maintains consistent airflow through process and regeneration ducts. Placed at the inlet of process side.
Heating Element	Type: Nichrome wire or ceramic Power: 100 W Voltage: 110 V Temp. Range: Up to 150°C (adjustable	Heats regeneration air to release moisture from desiccant. Includes temperature control features.
Ducting System	Material: Insulated sheet metal Design: Tapered to reduce pressure loss	Channels air through desiccant wheel, maintains laminar flow, separates process/regeneration sides.

IV. PSYCHROMETRIC ANALYSIS

To evaluate performance, we used assumed standard air conditions and determined humidity ratios from a psychrometric chart.
Assumed Conditions:

- Process Air Inlet: 30°C, 60% RH → Humidity Ratio ≈ 0.016 kg/kg dry air
- Process Air Outlet: 40°C, 30% RH → Humidity Ratio ≈ 0.011 kg/kg dry air
- Regeneration Air Inlet: 70°C, 10% RH → Humidity Ratio ≈ 0.010 kg/kg dry air
  - Regeneration Air Outlet: 45°C, 70% RH → Humidity Ratio ≈ 0.023 kg/kg dry air

  Calculations:
  - Moisture Removed (Process side) = 0.016 – 0.011 = 0.005 kg/kg dry air
  - Moisture Added (Regeneration side) = 0.023 – 0.010 = 0.013 kg/kg dry air

  These values indicate that the system is capable of substantial moisture transfer under designed conditions.

Formula used in analysis-

1. Mass flow rate (kg/s)

$$\dot{m}=\rho \cdot A \cdot V$$

Were,

- ρ – Density of air (kg/m^3)
- A – Cross sectional area (m^2)
- V – Velocity of air (m/s^2)

2. Heat supplied in system

$$Q_h = M \,.\, C_p \,.\, (T_1\text{-}T_a)$$

Were,

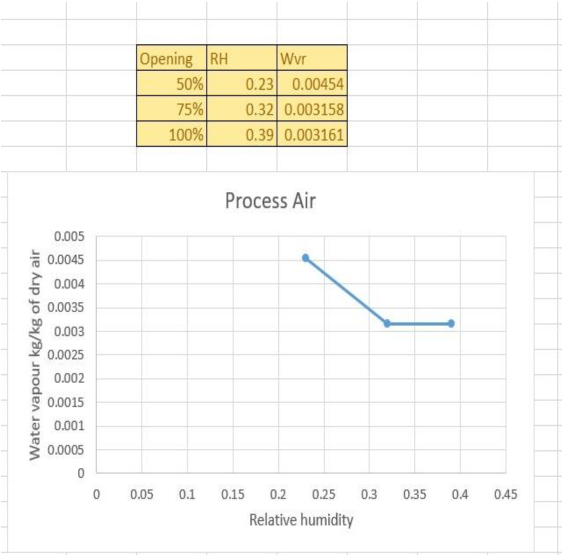
- m – mass flow rate
- C_p- Specific heat at constant pressure
- T_1 – DBT Temperature at inlet
- T_A – Atmospheric Temperature

3. Water Vapour Extracted From desiccant.

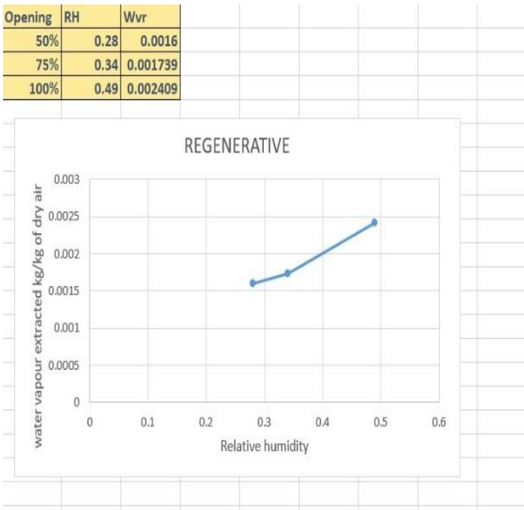
$$W_v = m_a.\ (W_2 - W_1)$$

From psychrometric chart

1. Process Air



3.Regenerative section



V. RESULTS AND DISCUSSION

The simulator successfully demonstrated continuous dehumidification through adsorption and regeneration cycles. Key observations:

- Effective moisture removal from process air without refrigeration.
- Efficient regeneration using low-grade heat (100 W heater).
- Compact design with a low RPM motor helped maintain system simplicity.

Silica gel's effectiveness was verified through psychrometric data, confirming its suitability for small- to medium-scale desiccant systems. Data logging also showed steady-state performance over multiple cycles, highlighting system stability.

- Processing air result-

Opening Of Suction	Relative Humidity (%)	Water Vapour Kg/Kg of dry air
50%	0.23	0.00454
75%	0.32	0.003158
100%	0.39	0.003161

- Regenerative result-

Opening Of Suction	Relative Humidity (%)	Water Vapour Kg/Kg of dry air
50%	0.28	0.0016
75%	0.34	0.001739
100%	0.49	0.002409

VI. CONCLUSION

The development of the desiccant wheel-based air conditioner has demonstrated significant advancements in energy-efficient cooling solutions. By utilizing a silica gel desiccant wheel, the system effectively dehumidifies air through an adsorption-desorption cycle, leading to improved indoor air quality and reduced energy consumption compared to traditional air conditioning systems.

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