# CFD Analysis of Solid Desiccant Dehumidifier Wheel

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*Abstract*— Desiccant cooling and dehumidification systems control both the air humidity as well as the operating cost by reducing the energy requirements of the supply air systems. This study used flow simulation CFD high resolution to better understand the vapor flow through complex porous media. The CFD simulation of the adsorption cooling system showed that the design could have beneficial effects on the performance of the system. The emphasis is on optimizing the process to remove the moisture, and the optimal process inflow velocity for the particular desiccant wheel model is determined to be between 1.5 and 2.5 m/s.

*Keywords*— Adsorption rate, Desiccant wheel, Regeneration rate, Silica gel, Simulation, Solid Desiccant.

## I. INTRODUCTION

The desiccant dehumidifier wheel is the crucial alternative for conventional components used in the HVAC system. The dehumidifier wheel is a vital and pivotal component that may be utilized to make large energy savings in building heating, ventilation, and air conditioning systems and to utilize renewable energy. The optimization of air handling systems based on drying wheels is more sophisticated rather than traditional devices, and appropriate modeling tools are required [1].

In human existence and in the time to come, air condition plays a key part. We may thus claim that high-

quality energy is needed. However, high-quality energy production requires significant prices and pollutes as raw resources through the usage of coal and gas. Conventional climate control is built on a vapor compression mechanism. The usage of CFC and HCFCs is hazardous to our environment. This is why research into alternate air conditioning technologies has been undertaken. The desiccant cooling system is one of the greatest solutions for air conditioning since it is powered by cheap energy and low energy levels, such as solar energy, are widely available. The desiccant wheel is an essential aspect of the desiccant cooling system so that the working parameters of the desiccant wheel are optimized [2], [3].

The actual mass of water vapor in 1 kg of dry air is a specific humidity or humidity content. While relative moisture means the ratio between the actual moisture mass in the air at a certain temperature and the maximum humidity that air can maintain at a certain temperature. There are two criteria used to describe the level of personal comfort with relative humidity and dry-bulb temperature. People often concentrate primarily on temperature but

rarely on moisture, however, the high relative humidity of indoor air can have major health effects on inhabitants. During the suction process around the air with a relative humidity of about 100 percent cannot absorb the human body's latent heat. Under these settings, sustained durations might lead to people feeling thermally uncomfortable due to increased body temperature. This can lead to breathing and skin issues with citrus effects. In addition, a humid atmosphere that promotes bacterial growth can also be created. Therefore, to maintain personal comfort in a limited place, the degree of humidity in the air must be controlled [4].

India is a tropical land with high daytime temperatures of 29–34°C and relative humidity of 70%–90% throughout the year. India is a tropical country. For the interior environment, the temperature and relative humidity of ASHRAE Standard 55 are suggested at between 23–26°C and between 30–60%, respectively. Climate systems in India are frequently utilized to satisfy the ASHRAE standard. The number of climate control systems used rose from 13,000 in the 1970s to more than 250,000 in the year 1991, to over 1.5 million by 2020. The number was predicted to increase in the future. The increased need for air conditioning, however, has resulted in huge electricity usage. Air conditioning also fulfills the crucial role of moisture management, apart from sensitive cooling. The cooling process and air dehumidification normally are powered by a cooling spool in traditional air conditioning machines. India's high humidity leads to a somewhat high dehumidification burden. As a result of the overcooling process, the conventional approach requires a huge quantity of energy to reduce humidity. Recently, modern air conditioning incorporated independent dehumidification load handling and sensible cooling capacities, which lower its power demand. It is generally integrated with the air conditioning system for the comfort of residential buildings and workplaces requiring around 60%–70% humidity and hospital operating rooms, which require around 50–60% humidity[5].

Some sectors are sensitive to moisture, such as textiles, food, pharmaceuticals, and battery manufacture. To preserve the quality of their goods and machinery, these sectors demand a low humidity environment of 20–55 percent. Humid air will produce metal corrosion, worsened hygroscope material features, and raise micro-organisms' hazardous activities in items. The system contains two types of dehumidifiers: compressor-based dehumidifier (CBD) and desiccant-based dehumidifier (DBD). CBD is a traditional technique of eliminating water vapor by condensation that is based on the vapor compression refrigeration system. For condensation to occur, humid air is passed through a cooling coil and cooled below its dew point temperature. The CBD system, on the other hand, consumes a significant amount of electrical energy throughout the cooling process. Meanwhile, the desiccant dehumidification system has recently attracted a lot of attention as an alternative to the CBD type. Air is dehumidified here without the use of condensation, instead of relying on sorption from desiccant material. This can assist to lower the CBD system's electrical energy usage[6].

Desiccant dehumidifiers are classified into two types: liquid desiccant dehumidifiers (LDD) and solid desiccant dehumidifiers (SDD). The absorber and regenerator are the two primary components of an LDD system. To increase the contact area between the desiccant solution and the process air, both portions are packed with manufactured packing materials. To absorb water vapor from the process air, the absorber is concentrated with a desiccant solution. The process air moves upward within the liquid desiccant, propelled by a fan. The dilute liquid desiccant is then pushed out of the absorber and into the regenerator. Ambient air with a high air temperature moves upward via the diluted liquid desiccant in the regenerator. Because of the difference in vapor pressure between the liquid desiccant and the air, the ambient air absorbs the water vapor from the diluted liquid desiccant. The regenerator restores the liquid desiccant's capacity to absorb moisture for the following process cycle. The liquid desiccant has the benefit of being able to be regenerated at a lower temperature while still having a high moisture removal capacity (MRC). This, however, might cause corrosion of the dehumidifier's components [6].

A process air area and a regenerative air area are included in the wheel. The humid process (atmospheric) air passes through the process air section, while moisture is adsorbed by the desiccant. As the adsorption process releases heat, the air temperature rises little. The process air, therefore, leaves the desiccant wheel with lower humidity and a little higher temperature. The hot regeneration air flows in the opposite direction to process air through the regeneration area of the wheel. In this case, water vapor adsorbed on the desiccant wheel is driven out by hot air, which is called regeneration or reactivation or desorption. This desorbing process also involves heat transfer, which results in greater moisture and lower temperature of regeneration air from the wheel. The desiccant wheel's regeneration part then grows dry, ready to circulate through the process air area. The operations above are ongoing since the draining wheel rotates slowly. Because of the lack of pump and moving parts, this system requires less electrical energy. It is also easier than liquid desiccants as the danger of crystallization and damage caused by high temperatures is less. The solid desiccant substance is also eco-friendly.

The desiccant wheel and the solid desiccating material itself are two of the most crucial components of the SDD system. They are corrugated within the rotary wheel in several channels. A studied on the effect on dehumidifying efficacy of desiccant material qualities shows that thermal conductivity, specific thermal heat, porosity, tortuosity, and thickening of desiccant materials are impacted. Various elements, including the shape of wheels, rotating wheel rating, intake process air property, inlet regeneration temperature, and velocity, have an impact on the performance of the drying wheel. [7].

The temperature of regeneration is established by the qualities of desiccant material, which should be highly adsorbed and suitable for regeneration. Although certain new materials have enhanced the efficiency of SDD systems, the complete demand for energy-efficient, ecologically friendly, and economical materials can be satisfied without currently existing materials. More

investigations are thus necessary to satisfy the needs of industry on the development of desiccant materials. Traditionally, tests on the SDD system have been carried out. However, several tests must be carried out in the trials and this technique is very costly and time-demanding given the necessity to install a range of desiccant wheel types. Numerical modeling should be utilized to increase energy efficiency and cost savings to assure efficiency in carrying out the parametric analysis. There are currently very few investigations on 3D modeling, in which important academics from the past have only generated simple 1D or 2D models. These models diminish the effectiveness of simpler SDD models. This trial is intended, therefore, to explore the impacts on the performance of the solid desiccant material using numerical modeling of air regeneration temperature and drying materials. A 3D model of a single air channel representing the process route and regenerative air via the solid desiccant material has been produced. Flow simulations have been performed under transient conditions to anticipate process air at channel exit average temperature and humidity [8].

## II. DESICCANT WHEEL

A desiccant wheel is a relatively low rotation speed air-to-air heater and mass exchanger. The wheel features a desiccant film frame on the same layer. The channels in the frame come in several forms including sinusoidal, wobble, triangle, etc. In the picture, Two primary streams traverse the wheel axially. The porous drying medium for adsorption and desorption of the matrix is cylindrically operated. During the process, the air is dehumidified and the wheel is humidified in the reactivation section of the air. The wheel revolution causes the adsorption portion to reactivate periodically[9], [10].

### A. Working of the wheel

While the wheel is rotating, it is also traversed by two different airflows in opposite directions: these are the process airflow and the regeneration one, as shown in Figure 1. Process air at ambient temperature, flows through
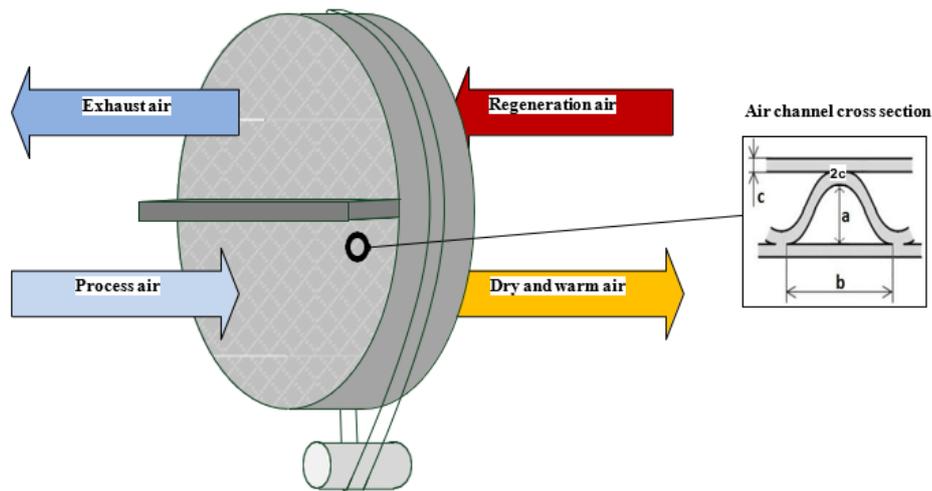
Figure 1: Schematics of a desiccant wheel

the process area, where a part of the water vapor contained in it, is adsorbed by the desiccant material of the wheel [11].

Regeneration air flows through a usually smaller (or at most equal) area, called the regeneration area. Before the regeneration air passes through the wheel, it is heated up. During the regeneration process, water contained in the wheel is extracted from the desiccant by the airflow, and the desiccant is regenerated. The wheel rotation brings the desiccant material alternatively in the process area and the regeneration one. Passing through the regeneration area, the desiccant material is brought back to the condition it had when last entering the process area, and the adsorption/desorption cycle can start again [12], [13].

The adsorption capacity is thus intuitively foreseen to be a function of desiccant material, the angular speed of the wheel, process, and regeneration areas ratio, geometry of the wheel, and of course temperature, humidity, and velocity of the airflows. Therefore, the choice of the desiccant material plays a crucial role in the design of the wheel and significantly affects the performance of the whole air conditioning system.

*B. Desiccant material*

Almost all materials can adsorb and hold water vapor. There are however some, of the so-called desiccant materials, in which said capability is particularly relevant; among these are e.g. activated carbon, activated alumina, silica gel, lithium chloride, and calcium chloride. The most

commonly used adsorbent for desiccant wheels is silica gel, i.e., a porous, amorphous form of silica ($SiO2$). Silica gel has a great affinity for water vapor due to the enormous quantity of microscopic pores: the internal surface area of pores is several orders of magnitude larger than the outer surface area of the adsorbent (Figure 2) [14].
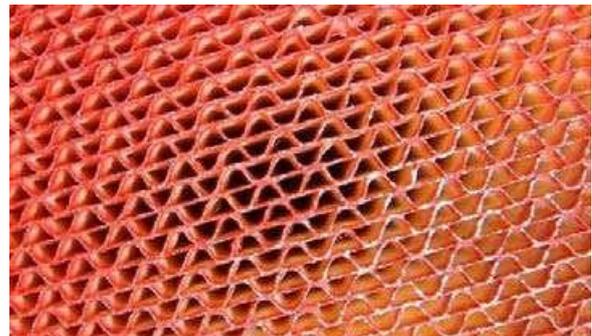


Figure 2: Honeycomb Structure on Desiccant Wheel

Adsorption of water vapor involves two different processes: chemical sorption and physical adsorption. The first process is permanent, and cannot be reverted by regenerating the silica gel, while the physical adsorption is a reversible process, driven by the intermolecular forces of attraction called Van Der Wall forces, that hold water molecules on the surface of the pores. Thus, it is the physical adsorption that plays a crucial role in the dehumidification process involving desiccant wheels.

An important characteristic of a desiccant material is its adsorption isotherm, which determines its water vapor adsorption capacity as a function of temperature and vapor pressure.

## C. Rotating speed

Another element that affects the wheel operation is the rotating speed. At the same process and regeneration air inlet conditions, process air outlet humidity depends on the wheel velocities shown in Figure 3.

First, it is clear that at low speed the desiccant material remains for a long time in the process area, and its dehumidification capacity is exhausted before the material comes into contact with the regeneration air. Increasing the rotating speed, the adsorption capacity is better exploited, and water content in outlet process air reaches a minimum. If, however, we continue to further increase the speed, desiccant material comes to not use all its adsorption capacity because the time spent in the process area is too short concerning the adsorption time constant. In such a case, the process is dominated by heat transfer and the dehumidification rate decreases.

Figure 3 shows an example of such behavior. Note that there is an optimal rotating speed for dehumidification, corresponding to the minimum water content in the outlet process air. For different operating conditions the optimal wheel velocity can be found and exploited to maximize the wheel efficiency [15].
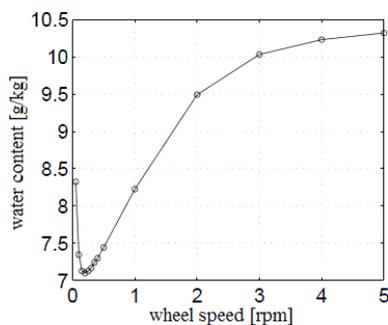


Figure 3: Air outlet water content for different desiccant wheel rotating speeds

## III. CFD SIMULATION OF DESICCANT WHEEL

The desiccant wheel of diameter 0.25 m and a length of 0.2 m is used for CFD simulation. For different cases of inlet conditions (temperature and relative humidity) of desiccant wheel following are the simulation results. When process air passes through the desiccant wheel, the wheel adsorbs the water moisture from the air, and the air gets heated. With the help of ANSYS FLUENT 2021, steady-state CFD simulations were conducted for the Desiccant wheel. The simulation settings are discussed below. The segregated solver approach was utilized for this low-speed internal flow. The gravitational effects were minimal in this scenario and were neglected in the simulations. The SST k-omega turbulence model was applied for providing the closure to the time-averaged Navier-Stokes equations. The flow entry to the domain was modeled using the 'velocity inlet type boundary condition wherein the flow velocity magnitude, inlet temperature, and the mass fraction of $O_2$, $H_2O$ was specified. The inlet species mass fraction was based on the Psychometric chart calculations. 'Pressure-outlet' boundary condition was applied for the flow to leave the computational volume. The wall of the Desiccant wheel refrigeration was modeled using the 'Wall' boundary condition, with an adiabatic condition imposed. This was to re-produce the existing experimental conditions in the CFD simulations. In CFD, the equations are solved iteratively. The residuals for each governing equation are plotted. The resulting graph shows the residual plot from one of the simulations. The simulation results of silica gel and molecular desiccant wheel are analyzed and compared for the counter-flow arrangement for various rotational speeds at various sector angles with various regeneration temperatures and various airflow rates.

TABLE I

PARAMETER AND PARAMETRIC VARIATION OF DESICCANT WHEEL

SIMULATION

| Parameters | Parametric variation |
|---|---|
| Material | Silica gel |
| The rotational speed of the desiccant wheel, (rph) | 10, 20, 30 |
| Airflow rate of process air, Mp (kg/h) | 135, 271, 406 |
| Airflow rate of regeneration air, Mr (kg/h) | 135, 271, 406 |
| Airflow velocity (m/s) | 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 7, 8, 9, 10, 11, 12 |
| Sector angle of process air, θp (°) | 180 |
| Sector angle of regeneration air, θr (°) | 180 |
| Regeneration temperature (°C) | 70, 80, 90 |
| Regeneration to process airflow ratio (R/P) | 1 |
| Flow type | Counterflow |

Table 1 shows parameters and parametric variations of desiccant wheel simulation. For this project work, the results were obtained after verifying the following criteria. Table 2. Shows the parametric values for best performance.

| Parameters | Parametric variation |
|---|---|
| Material | Silica gel |
| The rotational speed of the desiccant wheel, (rph) | 10, 20, 30 |
| Airflow rate of process air, Mp (kg/h) | 406 |
| Airflow rate of regeneration air, Mr (kg/h) | 406 |
| Airflow velocity (m/s) | 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 7, 8, 9, 10, 11, 12 |
| Sector angle of process air, θp (o) | 180 |
| Sector angle of regeneration air, θr (o) | 180 |
| Regeneration temperature (oC) | 70 |
| Regeneration to process airflow ratio (R/P) | 1 |
| Flow type | Counterflow |

*A.  Preliminary assumptions*

As said at the beginning of this chapter, the proposed model deliberately does not take into account some phenomena which would make it too complex for our purposes. Thus, before introducing the governing equations for the single-channel, it is required to underline the preliminary assumptions based on the model construction. These assumptions are listed below.

• Axial heat conduction and water vapor diffusion in the air are neglected;

• all channels are identical, with constant heat and mass transfer surface areas, adiabatic, and impermeable;

• the matrix thermal and moisture properties are constant, as are the mass and heat transfer coefficients, and the adsorption heat per unit mass of adsorbed water;

• mixing between the process and the regeneration airflows is neglected.

## IV. RESULTS AND DISCUSSION

For process input velocities 1.5, 2.5, 3, 3.5, 4, 4.5, 5, 5, 5.5, 6, 7, 8, 9, 10, 11, 12 m/s in connection with following rotational speed 10, 20 and 30 rph, the impact of process input moisture removing has been explored. Increased intake air velocity leads to less moisture removal by lower contact with inlet air at the surface of the desiccant. The desiccant wheel with low processes provides a greater removal of moisture at low speeds. An increase in air speed beyond 2.5 does not affect the removal rate of process air humidity, with changes in desiccant wheel rotations per hour. For the following process intake rate 1.5, 2, 2.5, 3, 3.5, 4, 4, 5, 5, 5, 5, 5, 6, 7, 8, 9, 10, 11, 12 m/s about after rotational rate 10, 20, 30 rph, the impact of the modification on the process outlet air temperature was investigated (shown in Figure 4-7).

The output temperature decreases owing to a lower moisture removal in the process region, with an increase in air intake speed. At varying rotational speeds, the difference between the process output temperature is lower at low velocity than the high velocity. In comparison to the method that eliminated moisture, however, the difference remains considerable. As lower wheel speed is almost the same humidity, but at a lower exit temperature, lower wheel speed is preferable. In connection with the following rotational speed 10, 20 and 30 rph, the influence of the change of humidity in outlet reactivation was tested in 1.5, 2, 2.5, 3, 3.5, 4, 4, 5.5, 6, 7, 8, 9, 10, 11, 12 m/s.

The reactivation outflow moisture rises when the process velocity rises. This is because the increase in speed creates a higher airflow rate which enhances the humidity removal in the regeneration portion from the desiccant further. For different rotations of wheels, however, the difference between moisture taken from reactivation air is less, but the wheel speed is 20 rph so that the best moisture is removed from reactivation air. For the following process input velocities of 1.5, 2, 2, 2, 3, 3, 3.5 and 4, 4, 4, 4, 5, 5, 5, 6, 7, 8, 9, 10, 11, 12, 12 m/s about following rotary speed 10, 20 and 30, rph, the influence of the reactivation exit air temperature was explored.

The air temperature of the exit decreases as the air velocity of the input is increased. The difference in the air stream temperature at different rotating speeds is quite small, and the 20 rph rotation of the wheel is favorable.
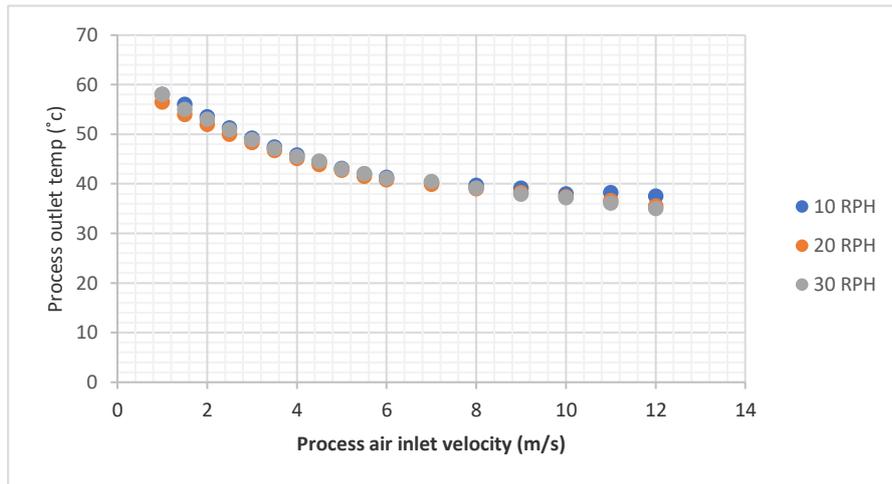
Figure 5. Changes Process Outlet Temperature with Process Inlet Air Velocity for Different Rotational Speed.
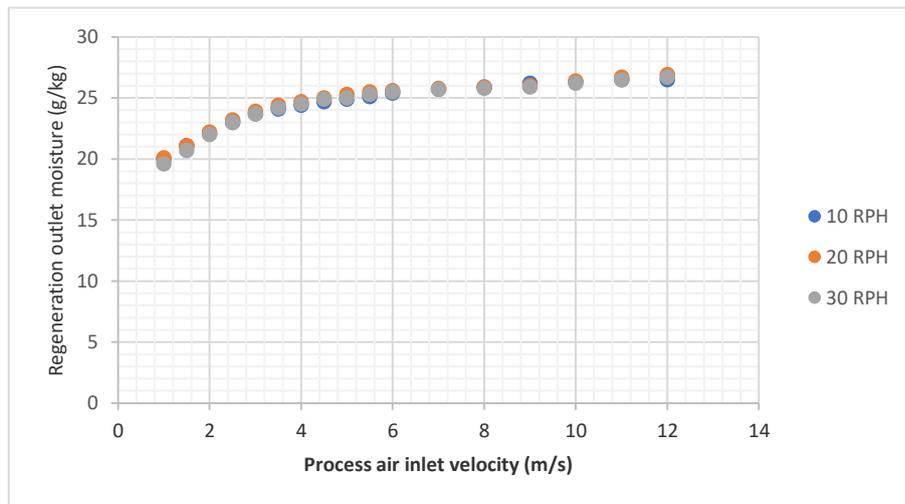


Figure 6. Changes in Reactivation Outlet Moisture with Process Inlet Air Velocity for Different Rotational Speed
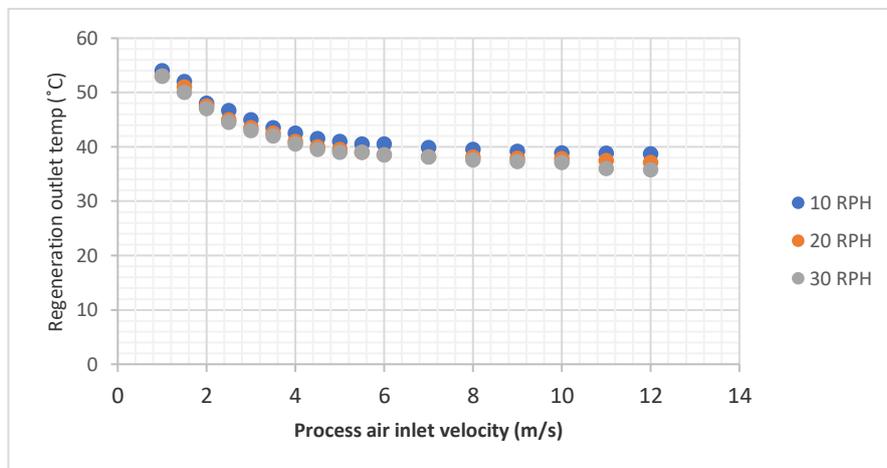


Figure 7. Changes in Reactivation Outlet Temperature with Process Inlet Air Velocity for Different Rotational Speed

## V. Conclusion

Desiccant wheel model simulations are performed for a wide range of situations. The analysis concerns the capability of the desiccant wheel to remove humidity and the effectiveness. The seminars are conducted to analyze the influence on the distribution of heat and speed of solid desiccant wheels of the changes in intake circumstances.

Increased input air velocity results in reduced humidity removal; the outlet air temperature and the outlet temperature of the process are reduced and reactivation moisture outlet further increases. The focus is on optimizing the humidity removal and the optimal intake velocity is discovered to be between 1.5 and 2.5 m/s for the chosen desiccant wheel model.

With the increased input velocity of regeneration the humidity eliminated, the temperature of the intake, the regeneration energy, and the output temperature are only slightly increasing. The increase in process moisture removed is just initial and, beyond 2.5m/s, the moisture removed remains almost the same for all rotational speeds.

Based on the data gathered, the following suggestions were made: It was determined that 10 rph and 20 rph were ideally suited for operating at low process airspeeds (1.5 m/s to 2.5 m/s). The low wheel speed impact is noticed in the event of high speed (>2.5), but the best wheel speed is 10 and 20 rph for both high and low regeneration inlet speeds. The best results may be seen through with a regeneration speed of 3.5 m/s to 4.5 m/s. The CFD simulation models should be supported with experimental studies of the prototypes. The modeled cycles should be constructed and analyzed to further verify the results of CFD simulation models.

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