International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Research Article

CFD Analysis of Solid Desiccant Dehumidifier Wheel

Sarang S. Hole†, **C. Shriramshastri** † **and Vivekanand N.**†

†Department of Mechanical Engineering (Heat Power), SPPU Pune, Maharashtra, India

Accepted 15 June 2016, Available online 20 June 2016, **Special Issue-5 (June 2016)**

Abstract

Desiccant dehumidifier wheel is the crucial alternative for conventional components used in HVAC system. Desiccant dehumidifier wheel is an essential and Pivotal component that can be used in building heating, ventilating, and air conditioning systems in order to reach significant energy savings and to use renewable sources. It is very complicated to optimize the air handling units based on desiccant wheels instead of conventional components and it requires Suitable simulation tools. In the present paper Simulation is carried out with different temperature and different relative humidity. One-dimensional model is considered for developing temperature and velocity profiles along the channels. The model is used to analyze the impact of different working conditions on desiccant wheel performance. Different performance criteria are imported and it is used to check out the optimal desiccant wheel configuration.

Keywords: *Solid Desiccant*, *Desiccant wheel, Adsorption, Performance, Simulation.*

1. Introduction

[1]In conventional air handling units, the air cooling process and air dehumidification process is generally driven by a cooling coil. At present a significance of desiccant wheels is strongly increasing due to the low environmental impact, high energy efficiency of HVAC systems and to use renewable energy. (K. Daou, R.Z. Wang, Z.Z. Xia,2006). The regeneration heat is supplied from low enthalpy sources, such as from heat rejected from engines or solar thermal collectors or from industrial plants or from condensers of chillers. Compared to the Conventional technology based on cooling coil there are following advantages of using desiccant wheels in air handling units reduction of the power required for refrigerating machine. Increase of the refrigerating machine evaporation temperature and COP;

- Decrement in the thermal power consumption
- Minimization of the presence of microorganisms
- Chance to use renewable energies.

While the conventional technology based on cooling coils is relatively easy and accepted from HVAC designers, hydraulic system specialists and customers, the air handling units based on desiccant wheels don't seem to be diffused and are tough to design. Particularly it should be realized that desiccant wheel may be a crucial element because its performance depends on regeneration air temperature and process air temperature, humidity and velocity, on revolution speed and on the process to regeneration area ratio.

A desiccant wheel is a cylindrical rotating wheel obtained from rolling up sheets of a supporting material surrounded with an adsorbent substance in order to obtain a large number of parallel channels with typically a triangular or sinusoidal cross-sectional geometry shown in fig. 1

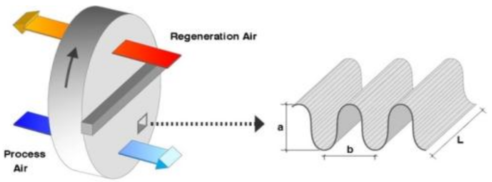

Fig.1 Desiccant Wheel and Channel Schemes

Table 1. Nomenclature

$T_{\mathrm{pro,in}}$	Process air inlet temperature
$\omega_{\mathrm{pro,in}}$	Specific humidity of process air at the inlet
$T_{\mathrm{reg,in}}$	Regenerative air inlet temperature
$\omega_{\mathrm{reg,in}}$	Specific humidity of Regenerative air at the inlet
m_{pro}	Mass flow rate of air
MRC	moisture removal capacity (gv/s)
ε_D	Effectiveness of desiccant wheel

Two air streams pass through the cross sectional area of the desiccant wheel. The process air, which is

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*Corresponding author **Sarang S. Hole** is a PG student; **C. Shriramshastri** is working as Associate Professor and **Vivekanand N.** as Assistant Professor dehumidified and heated, and the regeneration air, which removes water from the adsorbent material. The two streams are always arranged as counter current flows. In order to get extract vapour from the desiccant material, the regeneration air should be heated before passing through the desiccant wheel. Design and operating parameters such as type and amount of adsorbent material, desiccant wheel thickness, humidity and velocity channel geometry, revolution speed, regeneration and process frontal area, and air streams temperature influence the performance of a desiccant wheel.

A detailed review of desiccant wheel models is presented by (Ge *et al*, 2008). The desiccant wheel is a crucial component and its optimization can lead to important energy savings. Anyway only a few studies on performance optimization are available. In many works it has been analyzed how operating conditions, desiccant wheel channel thickness and revolution speed affect desiccant wheel performance. (Chung *et al*, 2009) optimized the desiccant wheel in terms of moisture removal capacity (MRC) through the variation of both the revolution speed and the ratio between process and regeneration area.

Table.2 Simulation Parameters and Constants

Properties of air and water	
Air density	1.1614 kg/m3
Specific heat of air	1007 J/(kg K)
Thermal conductivity of air	0263 W/(m K)
Air velocity	2 m/s
Specific heat of water vapor	1872 J/(kg K)
Specific heat of liquid water	4186 J/(kg K)
Evaporation latent heat of water	2358 kJ/(kg K)
Lewis number	1
Properties of desiccant wheel	
Material	Silica gel Wheel
Channel shape	Sinusoidal
Rotor Diameter, D	0.90 cm
Rotor length, *L*	0.30 cm
Rotational speed, ω	20RPH
Area ratio	1

2. Performance Criteria

The simulation of desiccant wheel is carried out for following different inlet temperature of process air and process inlet relative humidity with constant Regeneration Temperature and relative humidity.

Table 3 Conditions of Inlet Air of process side

Case	$\omega_{\text{pro,in}}$ and $\omega_{\text{reg,in}}$ (g/kg)	$T_{\text{pro,in}}$ ^{0}C	$T_{\text{reg,in}}$ ^{0}C
1	60	32	110
2	62	33	110
3	64	34	110
4	66	35	110
5	68	36	110
6	70	37	110
7	72	38	110

Following are the performance criteria for the desiccant wheel for various operating conditions. the sorption wheel optimization is carried out in terms of moisture removal capacity, defined as:

$$\text{MRC} = m_{\text{pro}}(\omega_{\text{pro,in}} - \omega_{\text{pro,out}})$$

Effectiveness of desiccant, which is defined in this way

$$\varepsilon_{\text{D}} = \frac{\omega_{\text{pro,in}} - \omega_{\text{pro,out}}}{\omega_{\text{pro,in}}}$$

3. Simulation of Desiccant wheel

For a different cases of inlet condition (temperature and relative humidity) of desiccant wheel following are the simulation results. When process air passes through the desiccant wheel, wheel adsorbs the water moisture from air and air gets heated. With the help of ANSYS FLUENT 16.0, the 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 O2, H20 were specified. The inlet specie 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 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 following graph shows the residual plot from one of the simulations.

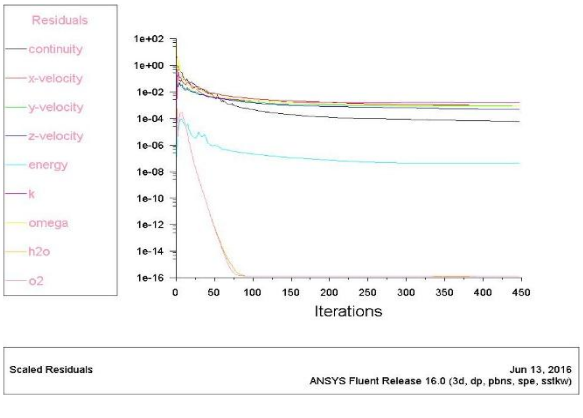


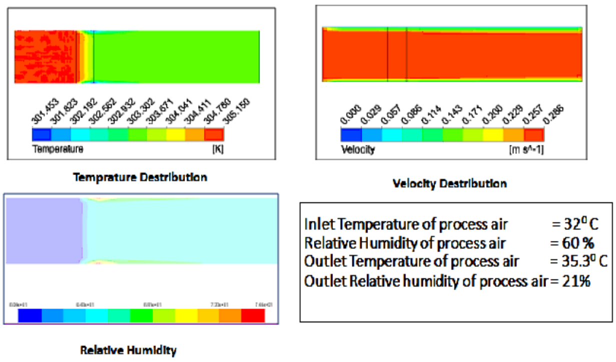
Fig.2 Residual plot

For this project work, the results were obtained after verifying the following criteria

1) The residuals reduces below 10e-4
2) Mass flow and Energy between the inlet and the outlet is conserved

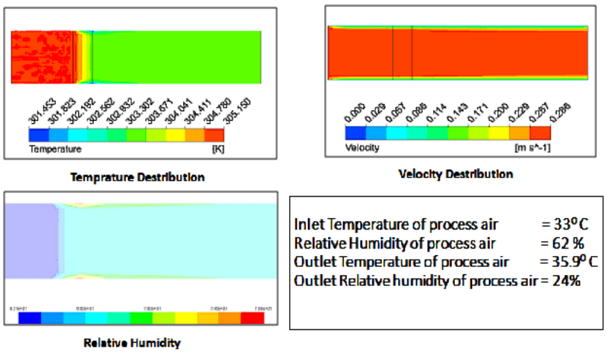
Upon ensuring these criteria, the simulation results were obtained in terms of contour plots and are plotted in the following pages.

Simulation results shows there are decrement in relative humidity of process air at the outlet of desiccant wheel.



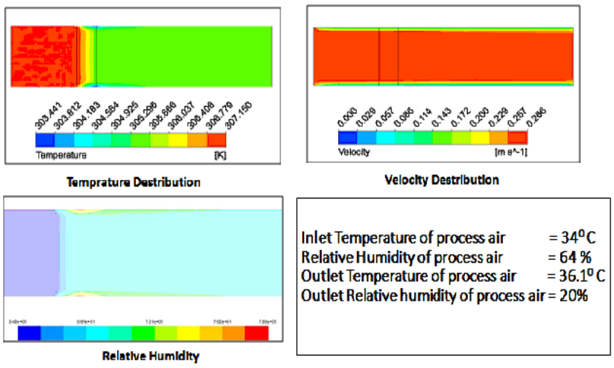
Inlet Temperature of process air = 32^{0}C
Relative Humidity of process air = 60 %
Outlet Temperature of process air = 35.3^{0} C
Outlet Relative humidity of process air = 21%

Fig.3 Representation of temperature, velocity distribution and relative humidity of process air with case-1



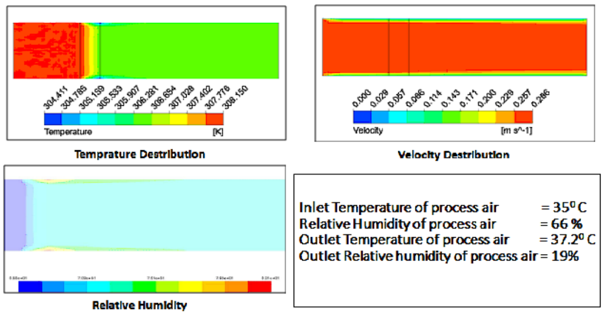
Inlet Temperature of process air = 33^{0}C
Relative Humidity of process air = 62 %
Outlet Temperature of process air = 35.9^{0} C
Outlet Relative humidity of process air = 24%

Fig.4 Representation of temperature, velocity distribution and relative humidity of process air with case-2



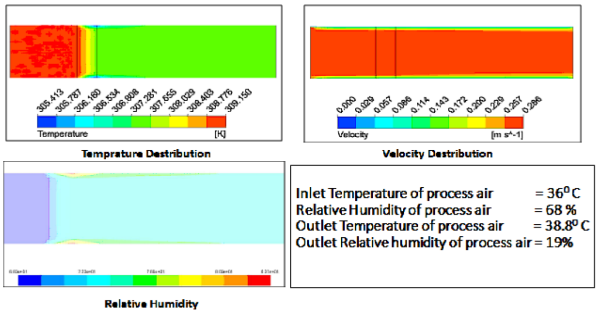
Inlet Temperature of process air = 34^{0}C
Relative Humidity of process air = 64 %
Outlet Temperature of process air = 36.1^{0} C
Outlet Relative humidity of process air = 20%

Fig.5 Representation of temperature, velocity distribution and relative humidity of process air with case-3



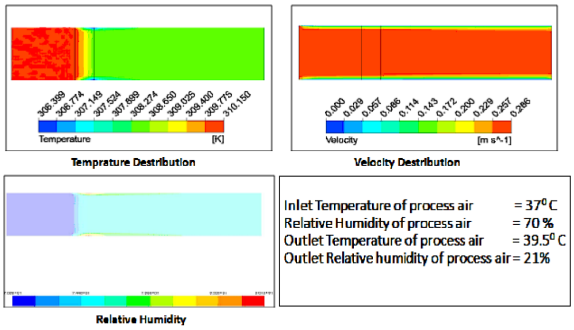
Inlet Temperature of process air = 35^{0} C
Relative Humidity of process air = 66 %
Outlet Temperature of process air = 37.2^{0} C
Outlet Relative humidity of process air = 19%

Fig.6 Representation of temperature, velocity distribution and relative humidity of process air with case-4



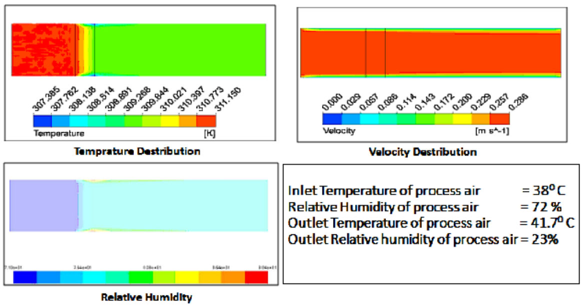
Inlet Temperature of process air = 36^{0} C
Relative Humidity of process air = 68 %
Outlet Temperature of process air = 38.8^{0} C
Outlet Relative humidity of process air = 19%

Fig.7 Representation of temperature, velocity distribution and relative humidity of process air with case-5



Inlet Temperature of process air = 37^{0} C
Relative Humidity of process air = 70 %
Outlet Temperature of process air = 39.5^{0} C
Outlet Relative humidity of process air = 21%

Fig.7 Representation of temperature, velocity distribution and relative humidity of process air with case-6



Inlet Temperature of process air = 38^{0} C
Relative Humidity of process air = 72 %
Outlet Temperature of process air = 41.7^{0} C
Outlet Relative humidity of process air = 23%

Fig.8 Representation of temperature, velocity distribution and relative humidity of process air with case-7

Result and Conclusions

Following are the parametric analysis of desiccant wheel for different cases.

Table 4. Effectiveness of Desiccant Wheel

Case	Effectiveness of Desiccant ε_D
1	0.58
2	0.55
3	0.64
4	0.66
5	0.69
6	0.64
7	0.61

The simulations of one-dimensional desiccant wheel model carried out for a wide range of working conditions. The analysis is in terms of moisture removal capacity and Effectiveness of desiccant wheel. The simulations are carried out in order to investigate the effect of the variation of inlet conditions on the temperature distribution and velocity distribution of solid desiccant wheel. Different desiccant wheel performance criteria are introduced and it is shown how they lead to different optimal configurations.

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Author Profile

Mr. Sarang Holeis completed Bachelor of Engineering in Mechanical from Dr. Daulatrao Aher college of Engineering Karad Now he is doing Master of Engineering in Heat Power Engineering at Dhole Patil College of Engineering Pune.

Prof.C.Shriramshastri is allied with Dhole Patil College of Engineering Pune, department of mechanical engineering as Associate Professor. He had completed his M.E. (Heat Power Engg.).The author is associated with teaching from 19 years. He has published 6 international & 2 National journal Papers & attended 2 international & 2 national conferences. Also he has published book on thermodynamics. His area of Interest is Thermal Engg.

Prof.Vivekanand Navadagi is allied withDhole Patil College Of Engineering Pune, department of mechanical engineering as Assistant Professor. He had completed his M. Tech (Thermal Engg.) from PDA College of Engg. Gulbarga. The author is associated with teaching from 3 years. He has published 12 journal Papers & attended 2 international conferences. His area of Interest is Fluid Mechanics, CFD, AFM.