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Inclusion of Purge Sector in Rotary Desiccant Wheel: A Review

Amarjeet Kumar Prasad [1]
Department of Mechanical Engineering
Madan Mohan Malaviya Institute of Technology
Gorakhpur, India

Ravi Pratap [2]
Department of Mechanical Engineering
Madan Mohan Malaviya Institute of Technology
Gorakhpur, India

***Abstract*— Purge sector is introduced by modifying two sector into three sector or by introducing purge in four sector to make it six sector. Few researchers have found that by adding purge in desiccant wheel increases the moisture removal capacity (MRC) and effectiveness of the wheel compared to two and four sector desiccant wheel. The direction of rotation of wheel i.e. clockwise or anticlockwise rotation has a significant effect on the MRC, temperature difference of process velocity and effectiveness of the wheel. In this paper, a minor review is done to justify the why the introduction of purge is important in the desiccant wheel.**

Keywords*— *Desiccant wheel, purge moisture removal capacity, effectiveness.

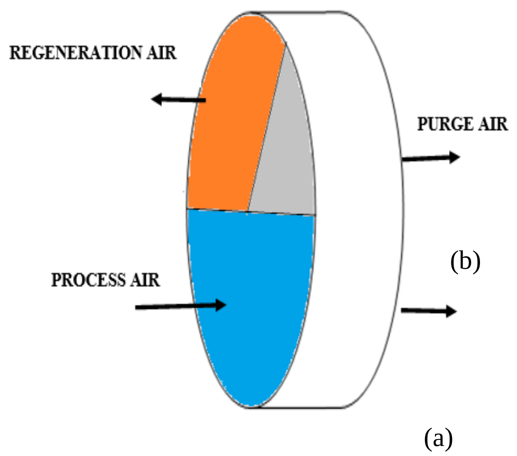
I. INTRODUCTION

A traditional air conditioning is primarily based on vapour compression system in which water vapour is eliminated by means of cooling the air beneath dew point temperature. This method consumes more energy and additionally impacts the surroundings through liberating hydrocarbons. Desiccant based cooling system are green and eco- friendly. According to one estimate desiccant dehumidification could lessen overall residential or commercial electricity demand by 25% or greater in hot and humid climatic region, providing drier, purifier and greater comfortable indoor surrounding with a decrease energy invoice. Desiccant cooling system displaces chlorofluro carbon based cooling system, the emission from which it contributes to the depletion of earth ozone layer.

Munters [1] investigated that by adding an extra sector on the process inlet and outlet side, an external duct is used to recirculate air into the regeneration cycle after the heater. Depending on airflows application etc. the savings on energy needed for regeneration reaches up to 25%. Y. M. Harshe et al. (2005) [2] developed 2-dimension study state model of a rotary desiccant wheel. This model developed was capable of predicating steady-state behaviour of desiccant wheel having at the most three section (process, purge and regeneration). The temperature and humidity profile in the wheel during both the dehumidification and the regeneration process curve analysed M.Golubovic, M.Hettiorocchi, M.Worek (2007) [3] evaluated the rotary dehumidifier with and without heated purge sector. The performance parameter of both were compared and it was found that the heated purge angle had an overall positive effect on the performance of a rotary dehumidifier.. J.Jeonget et al. (2009) [4] carried out evaluation by means of doing 4 partition of desiccant wheel and hybrid dehumidification air conditioning device. It was determined that the exist an optimum rotational velocity to maximize the dehumidification overall performance and that the hybrid air conditioning device improves COP by 94% in comparison to traditional V-C system refrigerator. R.Narayan et al (2011) [5] advanced 1-D heat and mass transfer model for desiccant wheel one considering simplest the gas aspect resistance and different considering most effective the both solid and gas side resistance. The model is used to examine the overall performance of various wheel layout. The examine must be that the advent of an axial cooling segment on enhance the overall performance of desiccant wheel substantially. W.Ruan et al. (2012) [6] advanced one dimensional transient heat and mass transfer model to examine the overall performance of enthalpy restoration wheel each with and with out purge air. It was concluded that the an enthalpy restoration wheel with purge air are offered and indicated that there is an most efficient wheel depth and rotation velocity to obtain most overall performance for enthalpy restoration wheel with purge air. A.Yadav (2014) evolved a mathematical model for predicting the overall performance of a desiccant wheel with purge zone, which has been used for both heat, and mass transfer of wet air and desiccant material. It was observed that for all of the cases on this model like rotation of wheel, regeneration temperature velocity and atmospheric moisture, result is higher in an anticlockwise in comparison to clockwise course of the rotation direction of desiccant wheel. A Yadav and L. Yadav (2014) [8] evaluated a comparative overall performance of desiccant wheel with effective and regular regeneration area. furthermore, it was determined that for all of the instances like velocity and ambient moisture, the desiccant wheel with affective regeneration zone offers higher end result in comparison to regular regeneration sector. Yadav and Yadav (2015) [9] developed a mathematical model to investigate the purge sector angle of the desiccant wheel for different operating condition and found that the anti-clockwise rotation gives purge angle at any operating condition, the performance increase in lower purge sector angle as compared to higher purge angle. Yadav and Yadav (2017) [10] divided desiccant wheel in to three parts process regeneration and third small sector(TSS). This wheel is numerically investigated by installing TSS in wheel in four different arrangement. A comparative study amongst those arrangement reveals that the for low exit humidity TSS need to be established inside the regeneration side of the desiccant wheel, and DCOP should be excessive and the growth in temperature of system air.

II. MATHEMATICAL MODEL

The desiccant wheel is divided into more than two section, which includes process sector, regeneration sector, and Purge sector. Where process section is kept at 180°, purge section varies from 10° to 40°, and remaining portion is given to the regeneration section. Purge in to come in to effect when wasteful heat is used to regenerate the absorbent material or purge sector comes into effect because as the wheel is continuously rotating at very low speed. When this heated region entered in to process air section, it absorbs very less moisture. This decreases the absorbing capacity of the wheel. Thus decreases the efficiency of the wheel. Different purge angle can be analyzed based on process velocity and other parameters to determine the moisture removal capacity and temperature difference effect. The desiccant wheel consists of numerous flow channel from which airflow.



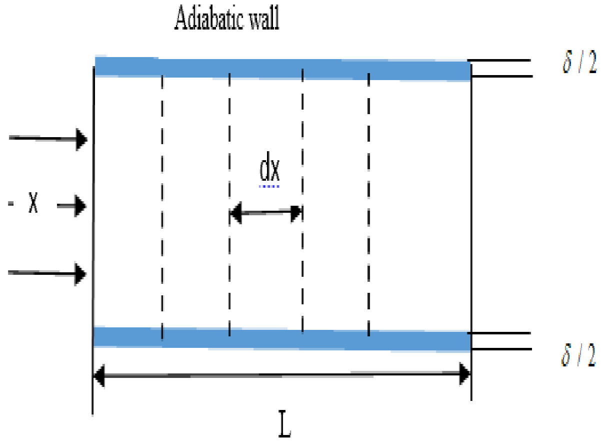


Figure 1: (a) Three sector desiccant wheel, (b) Differential control volume (c) Cross-sectional of matrix channel showing desiccant material with substrate.

Flow channel height $= a$

Flow channel pitch $= b$

Upper boundary of sine curve expressed as,

$$y = \frac{a}{2}\left[1 + \cos\left(\frac{2\pi}{b}x\right)\right]$$

Flow channel Cross-sectional area = $A_f = \frac{ab}{2}$

Channel with the desiccant layer Cross-sectional area: $A_{cst} = \frac{(a+\delta)(b+\delta)}{2}$

Desiccant channel Wall thickness $= \delta$

Flow channel perimeter of given by Zhang et al. (2003)] (11)

$$P_f = b + 2\sqrt{\left(\frac{b}{2}\right)^2 + \left(\frac{\pi a}{2}\right)^2}\;\frac{3 + \left(\frac{ab}{a\pi}\right)^2}{4 + \left(\frac{2b}{a\pi}\right)^2}$$

The flow channel hydraulic diameter given by Narayan et al [2011] (12)

$$D_f = \frac{4A_f}{P_f} = a\left[1.0542 - 0.466\left(\frac{a}{b}\right) - 0.1180\left(\frac{a}{b}\right)^2 + 0.1794\left(\frac{a}{b}\right)^3 - 0.043\left(\frac{a}{b}\right)^4\right]$$

Porosity in desiccant, $\varepsilon = \frac{\text{Volume of pores } (V_{pores})}{\text{Total volume of layer } (V_{total})}$

Volume ratio, $\varphi = \frac{\text{Volume of desiccant } (V_{desiccant})}{\text{Total volume of layer } (V_{total})}$

Cross sectional area of desiccant layer of a channel,

$A_{csdl} = A_{cst} - A_f$

Mathematical model of desiccant wheel has been derived through making use of fundamental mass and energy conservation equations within the control volume of air and desiccant.

A. Mass conservation in control volume of air

Applying mass conservation in control volume of air as shown in Figure 2

Rate of change of mass in control volume = inflow – outflow

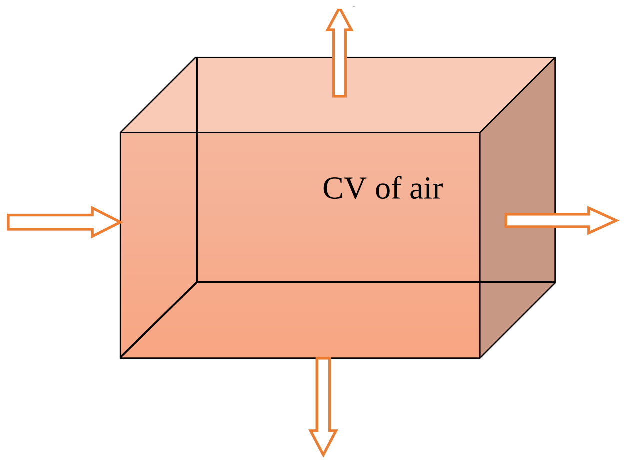


Figure 2: Control volume of air for mass conservation

The mass conservation in air can be expressed as:

Convective mass

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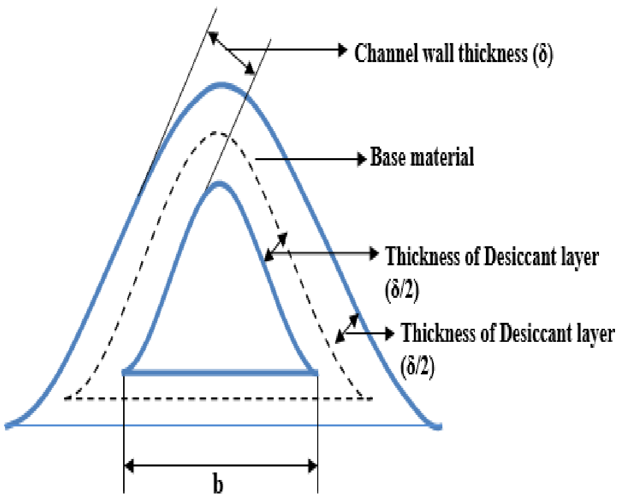

$$\left(\frac{\partial Y_a}{\partial t}+u\frac{\partial Y_a}{\partial x}\right)=\frac{h_m P_f (Y_d - Y_a)}{\rho_{da} A_f} \qquad (1)$$

B. Mass conservation in control volume of desiccant

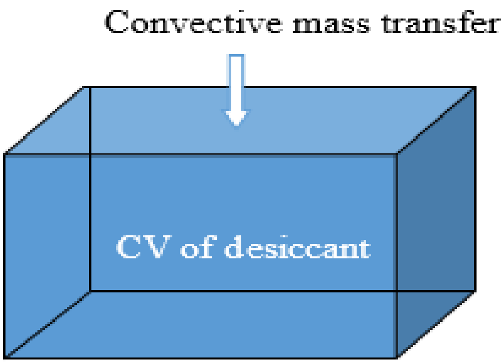

Figure 3: Control volume of desiccant for mass conservation

Applying mass conservation in control volume of desiccant as shown in Figure 3

Rate of change of mass in control volume = inflow – outflow

$$\left(\frac{\partial Y_d}{\partial t}+\frac{\partial W}{\partial t}\right)=\frac{\emptyset \rho_d A_{csdl} D_s \frac{\partial^2 w}{\partial Z^2}+hP_f(Y_a - Y_d)}{\emptyset A_{csdl} \rho_{ad}} \qquad (2)$$

C. Energy conservation in control volume of air

Applying energy conservation in control volume of air as shown in Figure

Rate of change of stored energy in control volume = inflow – outflow

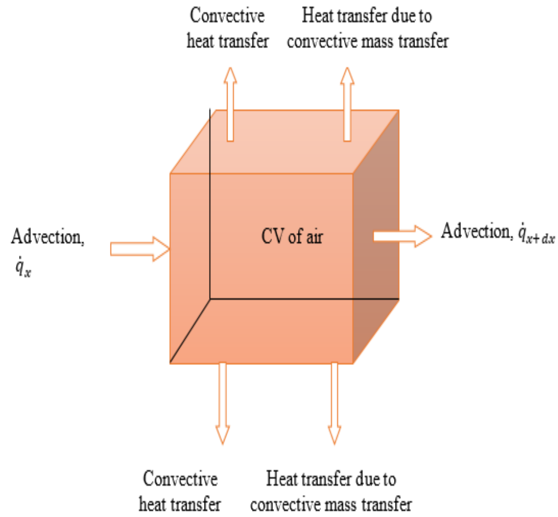

Figure 4: Control volume of air for energy conservation

$$\left(\frac{\partial T_a}{\partial t}+u\frac{\partial T_a}{\partial x}\right)=\frac{hP_f(T_d - T_a) - h_m P_f (Y_d - Y_a) c_{pv} (T_d - T_a)}{\rho_{da}\left(c_{pda}+Y_a c_{pv}\right)(A_f)} \qquad (3)$$

D. Energy conservation in control volume of desiccant

Applying energy conservation in control volume of desiccant as shown in figure

The rate of change of stored energy in control volume = inflow-outflow

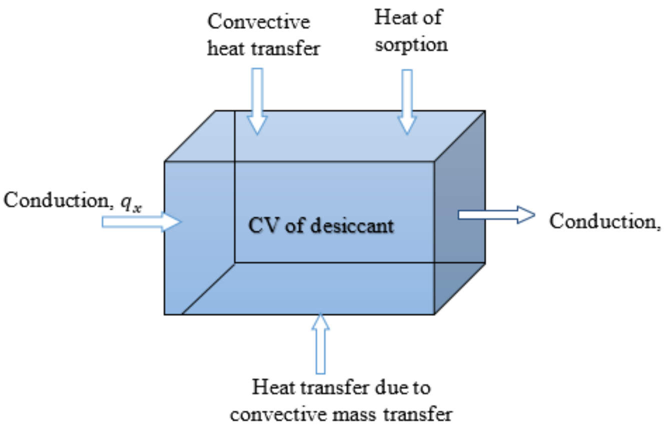

Figure 5: Control volume of desiccant for energy conservation

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The energy conservation in the desiccant is given by:

$$(\rho_d c_{pd} + \varphi \rho_{ad} c_{pw} W) A_{csdl} \frac{\partial T_d}{\partial t} + \varphi \rho_{ad} A_{csdl} c_{pw} T_d \frac{\partial W}{\partial t} - k_d A_{csdl} \frac{\partial^2 T_d}{\partial x^2} = hP_f(T_a - T_d) + h_m P_f (Y_a - Y_d)\, c_{pv}(T_a - T_d) + h_m P_f (Y_a - Y_d) h_{ads} \quad (4)$$

The governing equations (1) to (4) have five unknown variables T_a, T_d, Y_a, Y_d, and W in order to solve this set of equations; boundary conditions and some auxiliary equations are required.

E. Auxiliary equations

Humidity ratio and relative humidity are given as

$$Y_d = \frac{0.62188 P_v}{P_a - P_v} = \frac{0.62188 RH_d}{\frac{P_a}{P_{vs}} - RH_d}$$

Where P_{vs} is the saturation pressure of water vapour, which can be related as [Zhang et al. (2003)] (11):

$$P_{vs} = e^{\left(23.196 - \frac{3816.44}{T_d - 46.13}\right)}$$

Relative humidity and Water content in the desiccant is related by a general sorption isotherm as:

$$RH_d = \frac{R \times \frac{W}{W_{max}}}{1 + (R-1) \times \frac{W}{W_{max}}}$$

Where W_{max} is the maximum water content, R is the separation factor that determines the shape of isotherm, RH is the relative humidity.

III. Different Researchers Work on Inclusion of Purge Sector in Desiccant Wheel

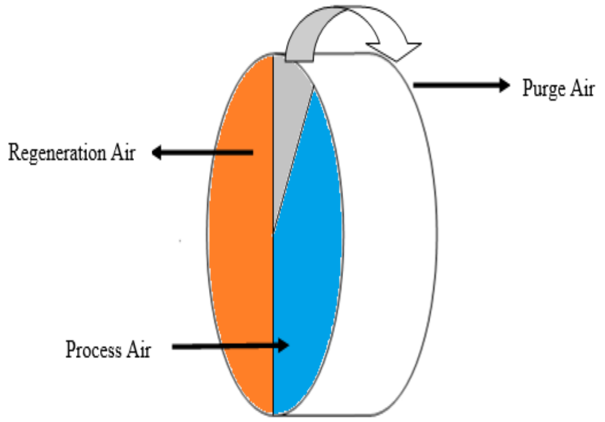

Figure 6: Desiccant wheel with purge sector (3)

M.N. Golubovic et al. (3) suggested a new purge sector by dividing the process section and named it as effective purge angle. Effective purge angle is defined as the ratio of an amount of moisture removed from the inlet air per unit time to the amount of heat required to regenerate the desiccant wheel in per unit time. Effective purge angle is hot and humid in comparison to the process section. Process section will have less temperature and less humidity than the effective purge angle. M.N. Golubovic et al. concluded that introducing purge in the process air section decreases the area of the process section. Effective purge angle for the rotary desiccant wheel when hot regeneration is considered, the temperature range should be between 140° to 170°C with effective purge angle to be around 29.4°. Introduction of the purge in the process section decreases the humidity ratio and temperature of the process section, if purge section air is mixed with outside air in the regeneration section it also saves the energy.

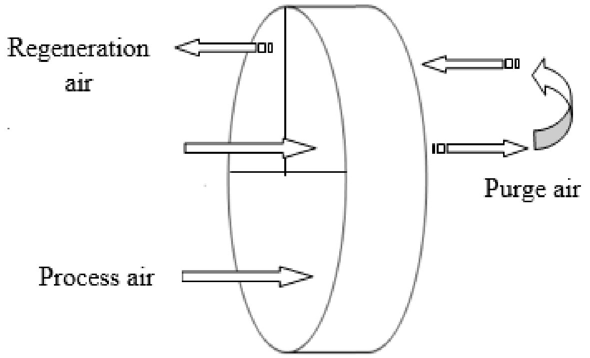

Figure 7: Desiccant wheel with purge sector for clockwise direction (13)

A.Yadav et. al. (13) investigated that at any rotational speed moisture removal capacity of the desiccant wheel is higher for the anticlockwise rotation of the wheel than the clockwise rotation. In the second case, it was found that at any regeneration temperature moisture removal capacity in the anticlockwise rotational of the wheel was better than that of clockwise rotation. In third case process velocity ranging from 1 m/s to 5 m/sec, it was found that the moisture removal capacity was better in an anticlockwise rotation than the clockwise rotation of the desiccant wheel. In the fourth case with ambient moisture,, the desiccant wheel with anticlockwise rotation shows higher moisture removal than the clockwise rotation.

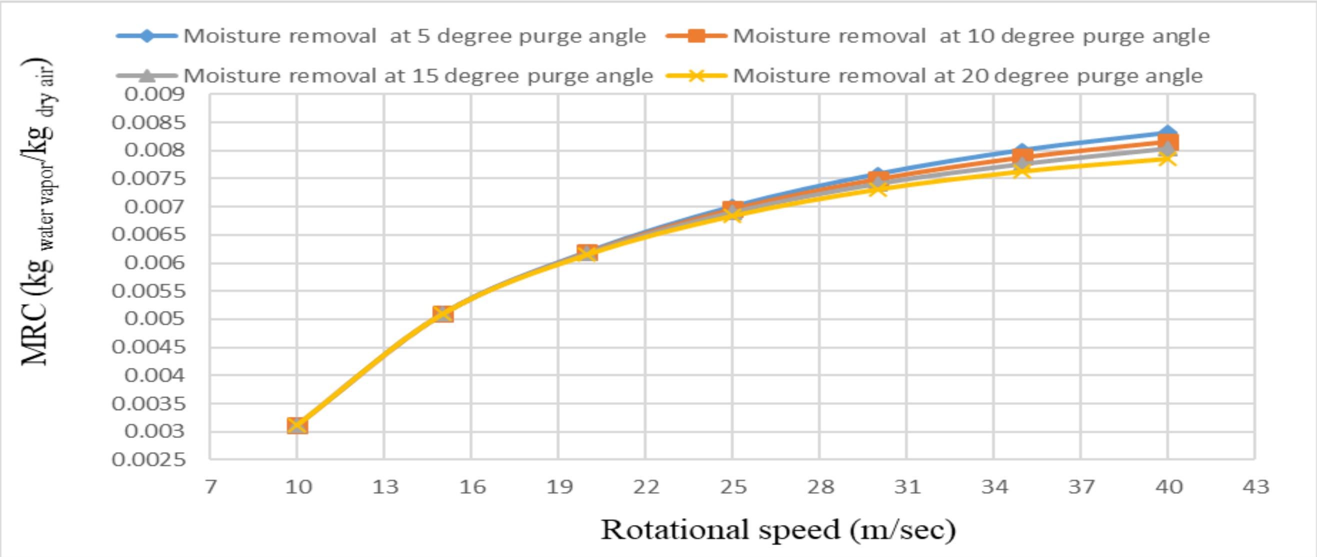

Figure 8. Variation of moisture elimination with rotation of desiccant wheel for distinctive layout

The above graph indicates that the MRC increases with increase in the rotational speed. However, at low rotational speed there is no significant effect on the MRC at any given purge angle but with an increase in rotational speed purge angle at 5° shows higher moisture removal than the other purge angle. Greater the purge angle will affect the regeneration section because there will be the decrease in regeneration area so moisture removal would be less. So in high rotational speed, MRC is high for low purge angle because residence area of hot air is more, whereas for purge angle 10,15,20 there is less MRC due to the decrease in residence area of the regeneration air.

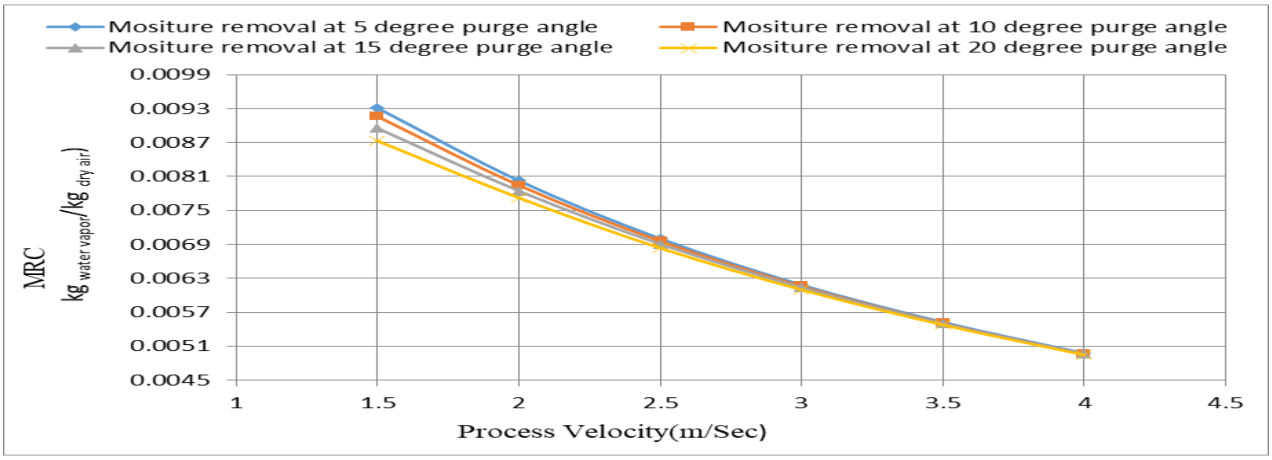

Figure 9. Graph for moisture removal with process velocity of desiccant wheel for different design

The MRC of all the purge angle decreases with increase in process air velocity because the increase in inlet velocity of air decreases the residence time of air that with the channel matrix or the desiccant surface. Although at process velocity of 1.5 m /s purge angle of 5°, shows the higher MRC compared to the other purge angle. Whereas at higher process velocity does not affect the any purge angle due to reduce in the residence time of inlet air.

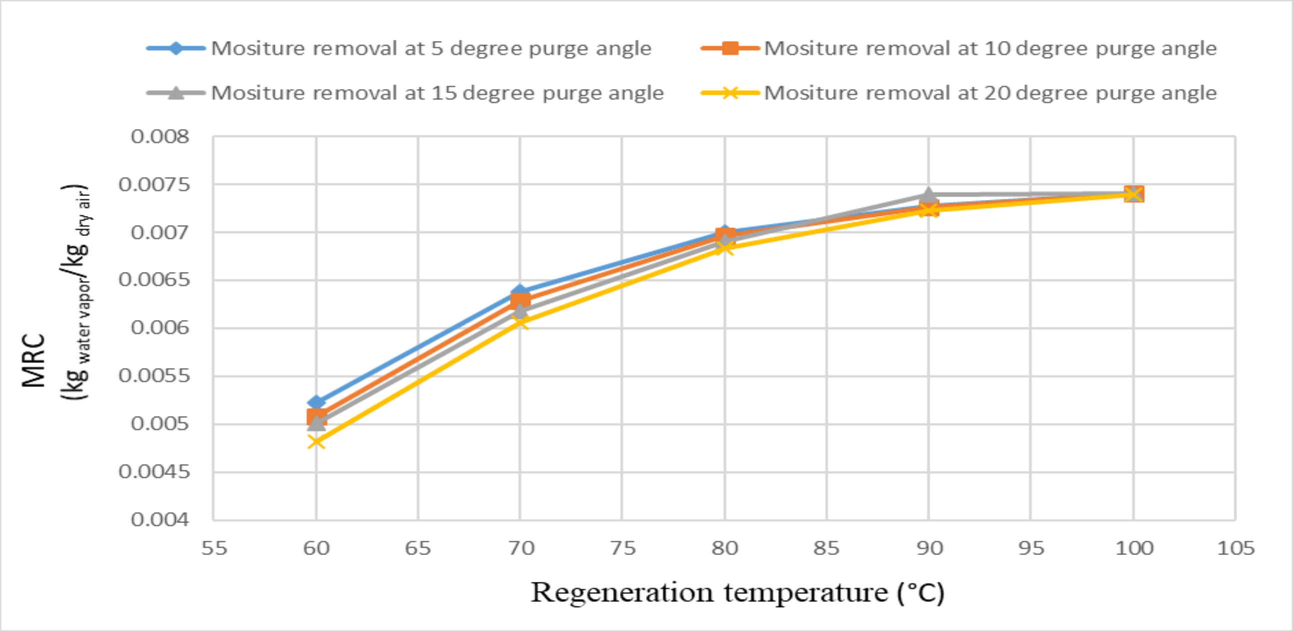

Figure 10. Graph for moisture elimination with regeneration temperature of desiccant wheel for distinct layout

The above graph indicates that the MRC increases with an increase of the regeneration temperature for every purge angle. At the temperature range of 60°- 73°c MRC of purge with 5° is always high than the other purge angle whereas for 20° purge sector MRC is found to be lowest. The reason behind the drop of MRC with the increase in purge sector is purge sector reduces the area of the regeneration air. Therefore, reduction in the area of regeneration decreases the MRC when we compared with four different purge angle.

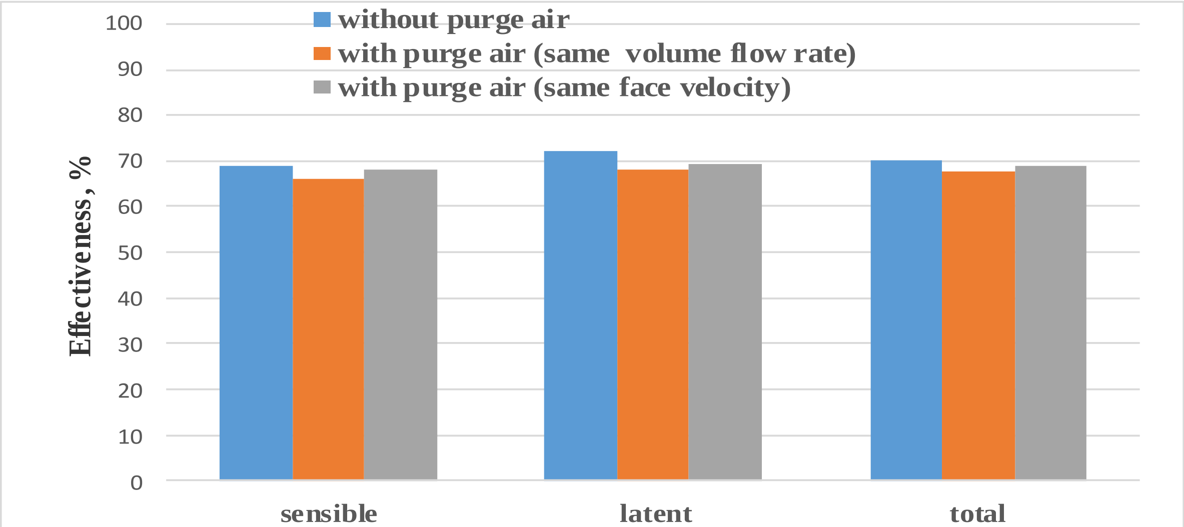

Figure 11: variation of effectiveness of purge and without purge in desiccant wheel

IV. COCLUSION

For the rotational speed of the 39 m/sec, it is found that the purge sector with 5° has the highest MRC compared to the other sector.

At the process velocity of 1.5 m/sec, purge sector with 5° angle produces higher MRC

At regeneration temperature of 60 - 73°c again purge sector with 5° angle shows better MRC compared to other sector discussed above.

Purge section with same face velocity shows higher effectiveness

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NOMENCLATURE

SYMBOLS USED

- A_{cst} $[m^2]$ Total cross sectional area of a channel
- A_{csdl} $[m^2]$ Cross sectional area of desiccant layer
- A_f $[m^2]$ Cross sectional area of flow passage of one channel
- c_p (J/kg K) Specific heat at constant pressure
- c_{pw} (J/kg K) Specific heat of liquid water
- c_{pv} (J/kg K) Specific heat of water vapour
- c_{pda} (J/kg K) Specific heat of dry air
- c_{pm} (J/kg K) Specific heat of substrate (matrix material)
- D [m] Diameter of desiccant wheel
- D_f [m] Hydraulic diameter of flow passage of one channel
- D_s $[m^2 s]$ Surface diffusion coefficient
- h_{fg} [J/kg] Latent heat of vaporization
- h_m $[kg/m^2 s]$ Mass transfer coefficient
- h $[W/m^2 K]$ Convective heat transfer coefficient
- k [W/m K] Thermal conductivity
- L [m] Wheel Length
- N [rph] Rotational speed
- p [Pa] Pressure
- P_f [m] Perimeter of flow passage of one channel
- ΔT [°C] Temperature difference of process air
- h_{ad} [J/kg] Heat of adsorption
- T [Sec] Time
- T [°C] Temperature
- u [m/s] Velocity
- W $[kg\ kg_{adsorbent}^{-1}]$ Water content in desiccant
- Y $[kg\ kg^{-1}]$ Humidity ratio of the air

Greek symbols

- ρ $[kg/m^3]$ Density
- α Thermal diffusivity
- ε Porosity
- θ Fraction Angle
- δ [m] Channel Wall Thickness
- Φ Volume Ratio

Subscripts

- a Air
- ad Adsorbent
- d Desiccant
- da Dry Air
- f Flow Passage
- m Matrix Material
- p Process Air
- r Regeneration Air
- v Vapour