CHAPTER 4

RESULTS AND DISCUSSION

The results of the experiments 1, 3, 4, and 5 (see Appendix A) conducted by A. Abdou [19] are used to enhance and augment the mathematical model, while the results of the second experiment is used for validation purpose. Those experiments are conducted on a stationary desiccant wheel of 10 mm core diameter, on which the corrugated sheet of the desiccant composite is rolled, and outer diameter of 100 mm diameter. The length of the wheel is 200 and has the honey comb structure shown in Figure 1.3. The channel has an isosceles triangular shape of about 2 mm height, about 3.5 mm base, and 0.22 mm thickness (see Figure 1.3). The values of the contact ratio "σ", the incremental time Δτ, the mass transfer augmentation coefficient K_{mCoef} are randomly iterated till the variables estimated by the model converge with those measured in the experiments 1, 3, 4, and 5 (Appendix A). Then the fourth experiment is used to validate the proposed model. The iteration process is a very time consuming process as the form of proposed function to augment the mass transfer function was anonymous. The best value of the incremental time is 0.0033 and the contact ratio is 0.985. The value of the K_{mcoef} varies from an experiment to another and it is discussed in the next section.

4.1 Augmentation of the Mass Transfer Coefficient

The K_{mCoef} is proposed to augment the mass transfer coefficient through considering the processed air mass flow rate $\dot{m}_a$ and its mean velocity inside channel U_{ch} in creating the K_{mcoef} function. The values of K_{mCoef} calculated from programs are recorded along with the air mass flow rates and the air velocities inside channels. Then an optimized curve fitting technique in MatLab is used to get the form of K_{mCoef} function. This function is shown in figure 4.1. The form of the function f (U_{ch}, Ma) is

$$K_{m_{Coef}} = -0.9975\, U_{ch}^{0.997} + 0.041\, M_a^{1.017} + 0.1198 \tag{4.1}$$

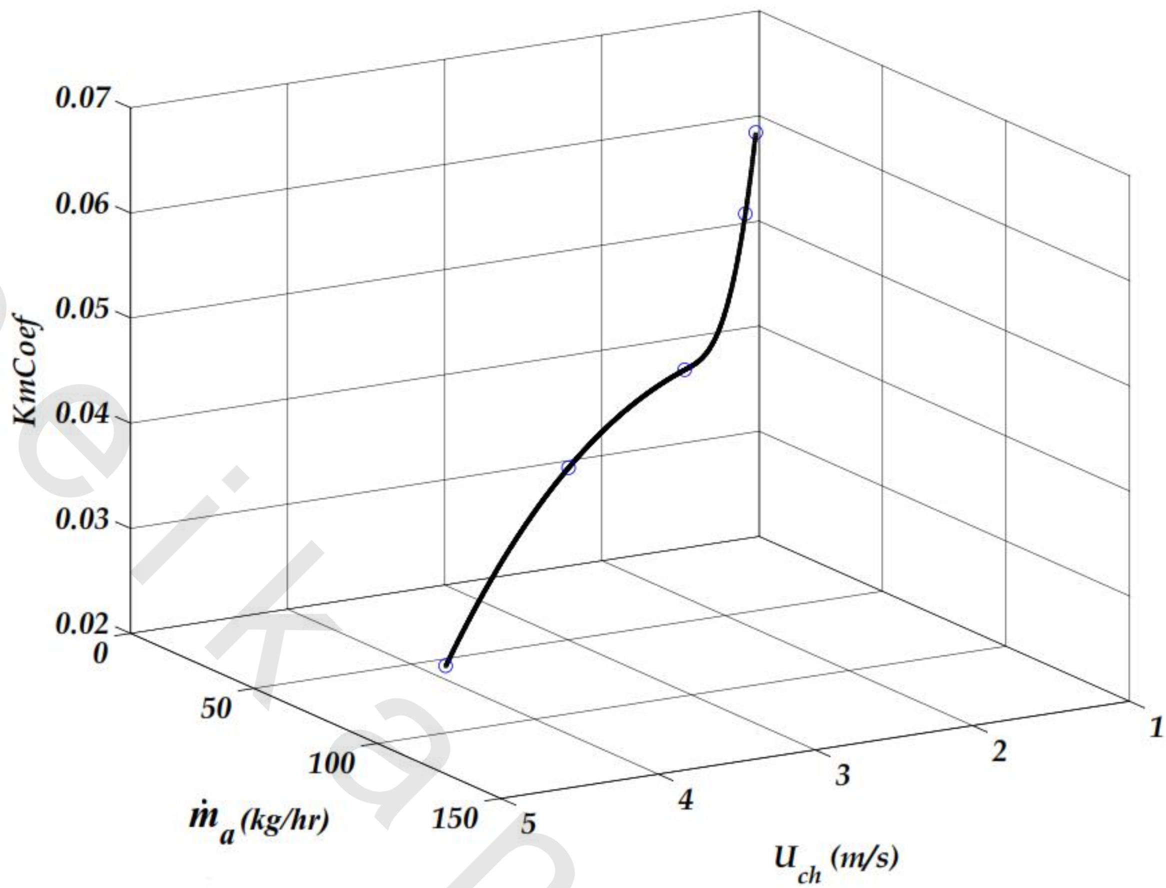

Figure 4.1 Mass Transfer Augmentation Parameter

After creating the above discussed function, we plotted a group figure to show the change the air humidity ratio and the change in desiccant water content along the desiccant. Figures 4.2 to 4.6 show the change in the humidity ratio of the air along the desiccant for 5 different combinations of U_{ch} and $\dot{m}_a$. As shown in the following figures, the humidity ratio of the inlet air is decreasing along the desiccant bed and the rate of change depends dually on the mass flow rate of dehumidified air and its velocity in the desiccant channels. For the sake of readability and comparison the above shown relation between the humidity ratio at different experimental parameters and conditions shown in Figures 4.2 to 4.6 are collected in Figure 4.7. On the other hand, Figures 4.8 to 4.12 shows the changes of water content along the desiccant.

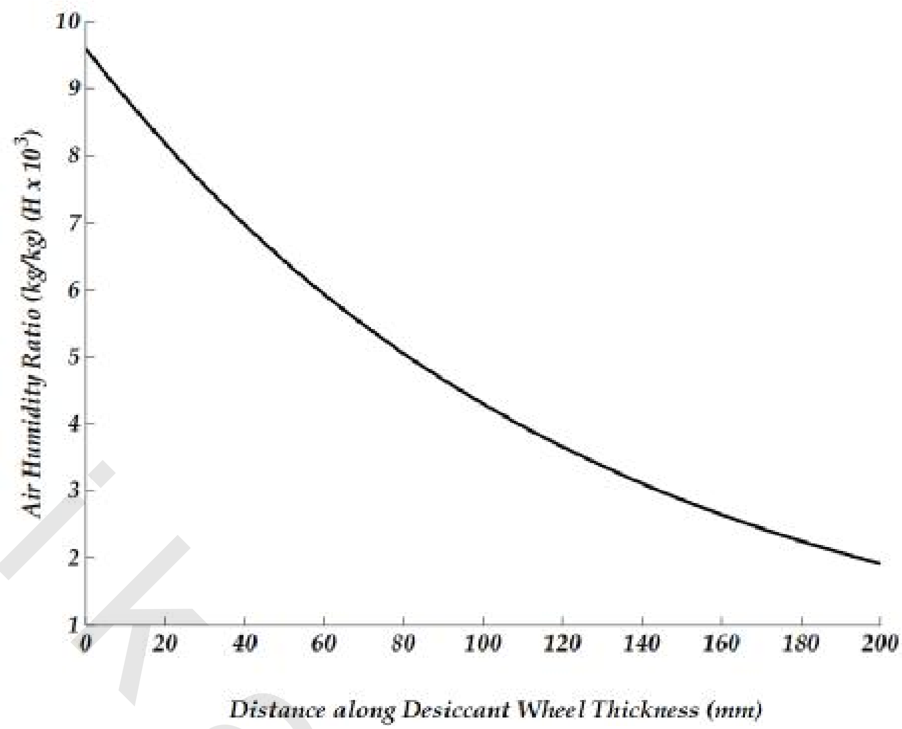

Figure 4.2 Air Humidity Ratio along the Desiccant Thickness for Air mass flow rate of 34.3 kg/hr and Air Velocity of 1.56 m/s

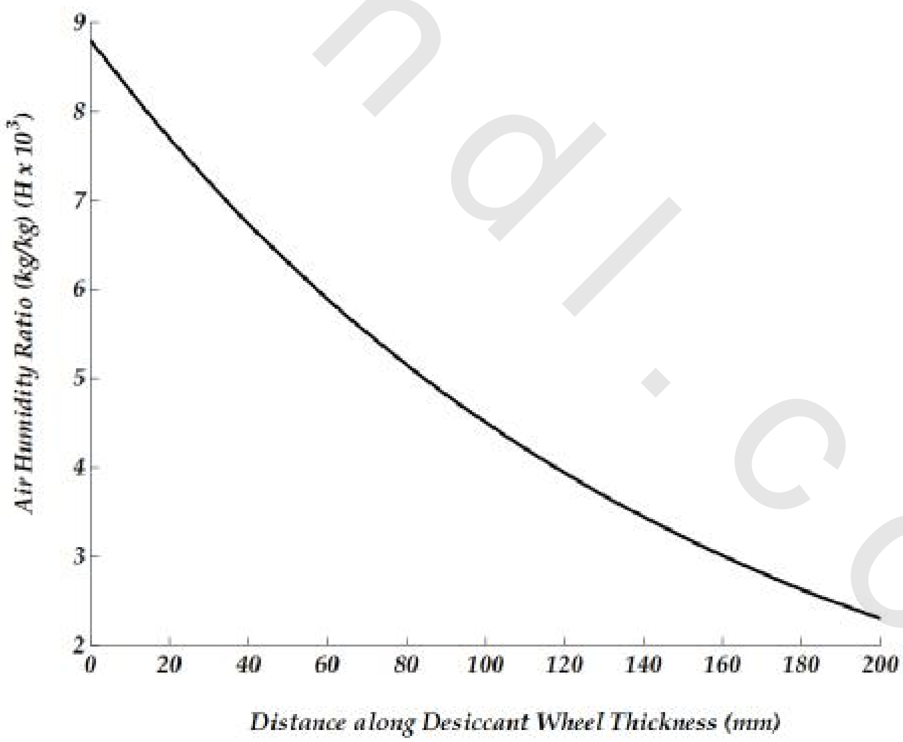

Figure 4.3 Air Humidity Ratio along the Desiccant Thickness for Air mass flow rate of 36.4 kg/hr and Air Velocity of 1.66 m/s

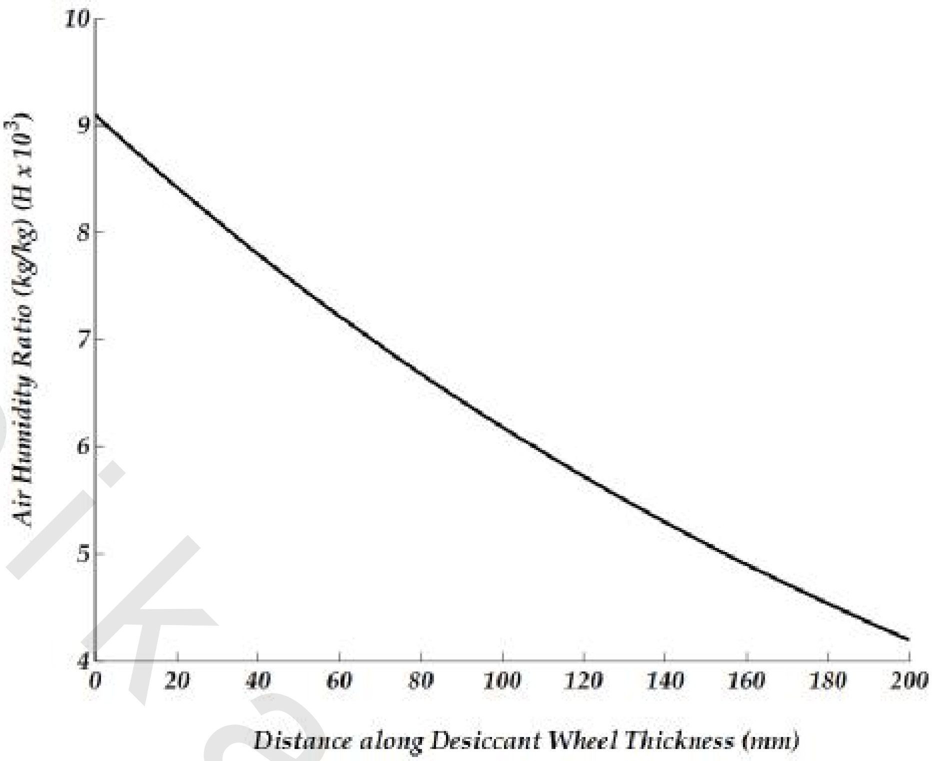

Figure 4.4 Air Humidity Ratio along the Desiccant Thickness for Air mass flow rate of 49.4 kg/hr and Air Velocity of 2.25 m/s

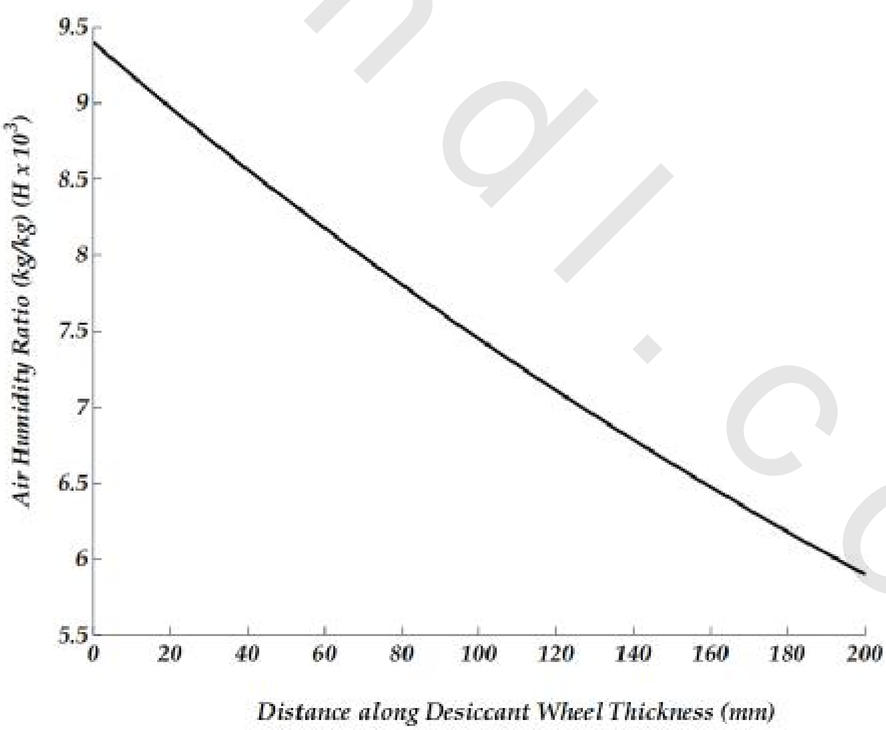

Figure 4.5 Air Humidity Ratio along the Desiccant Thickness for Air mass flow rate of 74.3 kg/hr and Air Velocity of 3.38 m/s

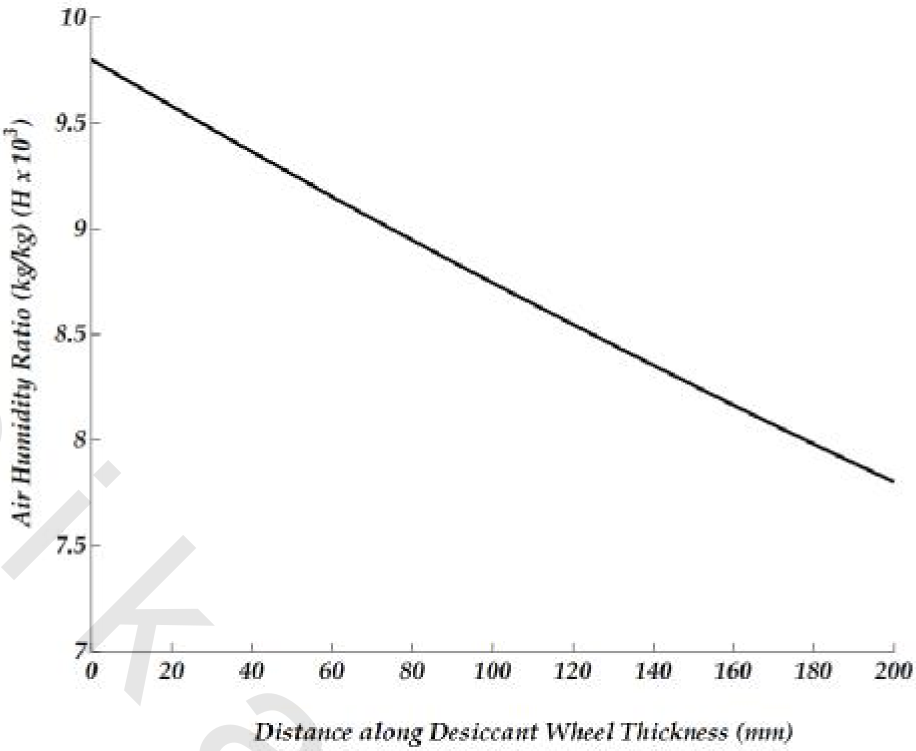

Figure 4.6 Air Humidity Ratio along the Desiccant Thickness for Air mass flow rate of 100.3 kg/hr and Air Velocity of 4.57 m/s

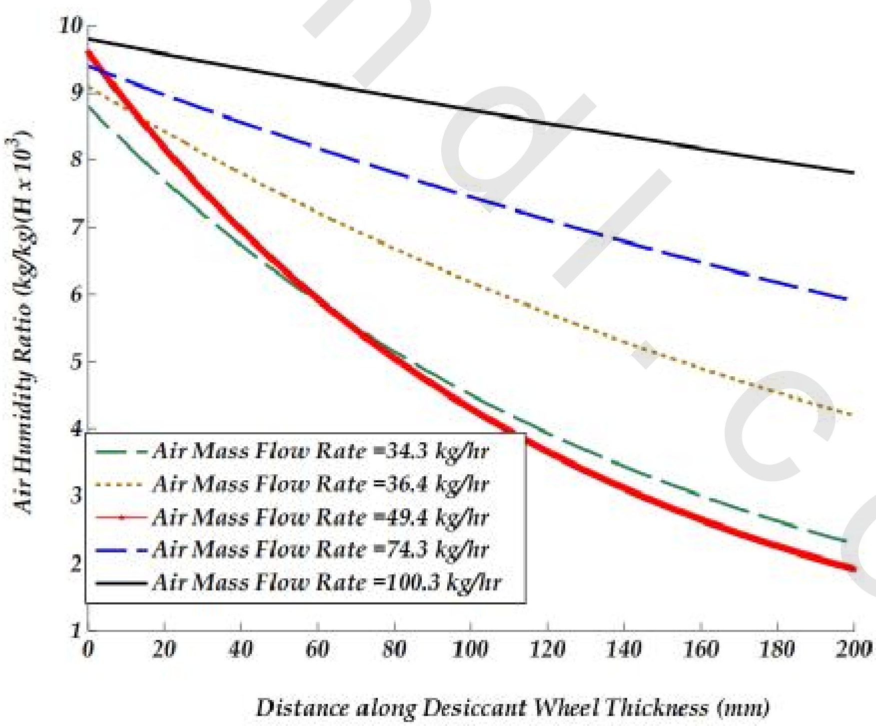

Figure 4.7 Air Humidity Ratio along the Desiccant Thickness for Different Values of Air mass flow rates and Air Velocities

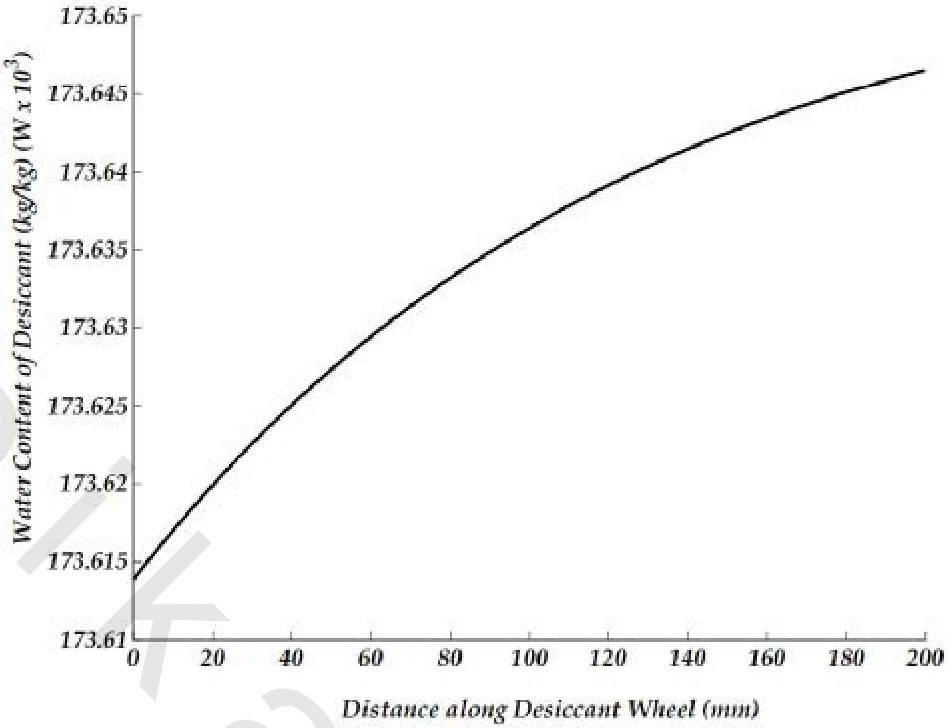

Figure 4.8 Water Desiccant Content along the Desiccant Thickness for Air mass flow rate of 34.3 kg/hr and Air Velocity of 1.56 m/s

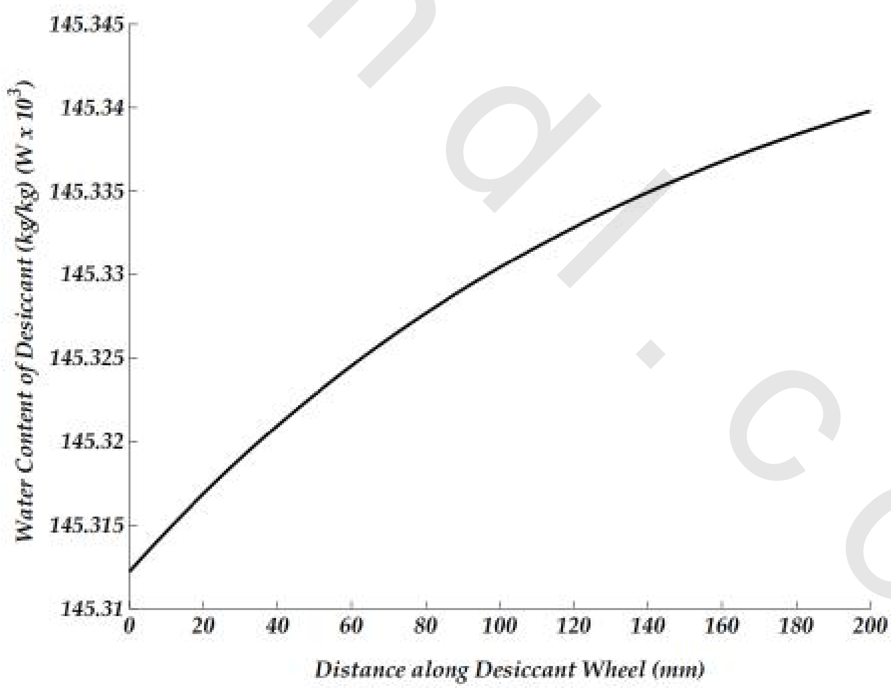

Figure 4.9 Water Desiccant Content along the Desiccant Thickness for Air mass flow rate of 36.4 kg/hr and Air Velocity of 1.66 m/s

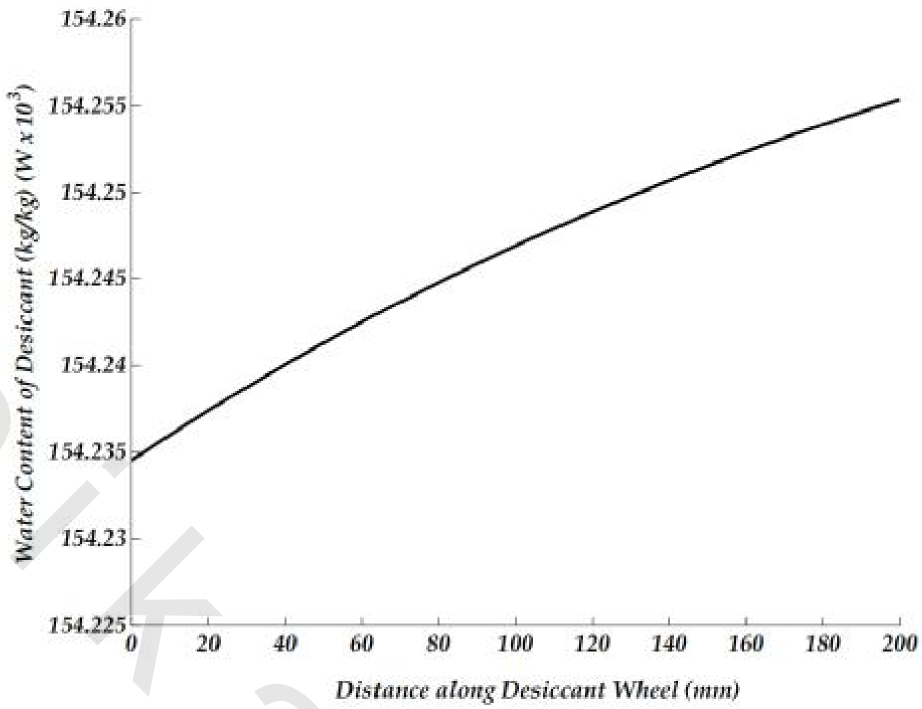

Figure 4.10 Water Desiccant Content along the Desiccant Thickness for Air mass flow rate of 49.4 kg/hr and Air Velocity of 2.56 m/s

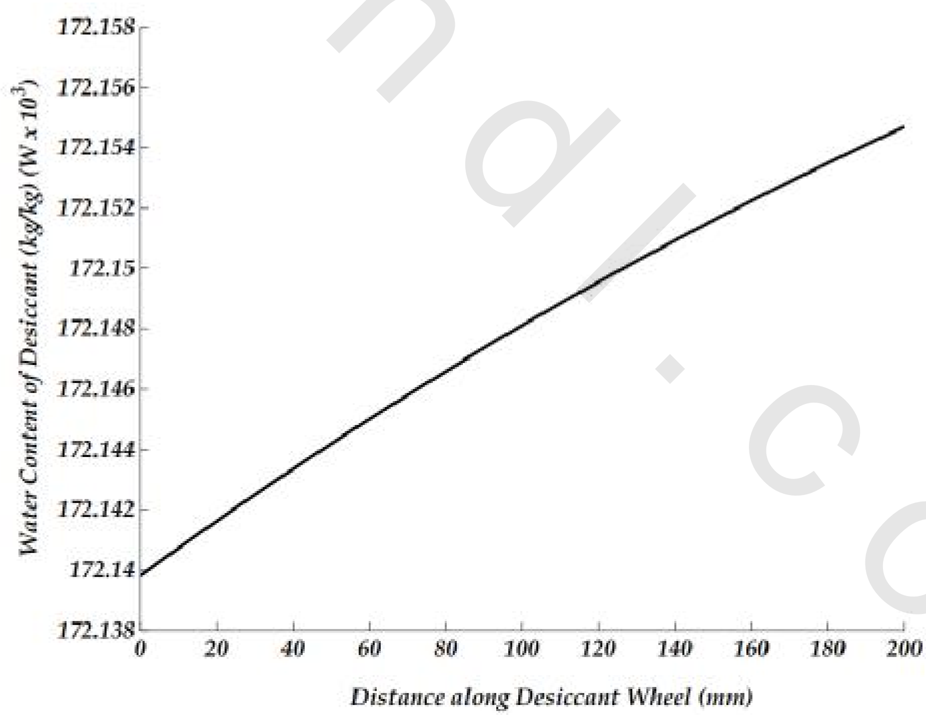

Figure 4.11 Water Desiccant Content along the Desiccant Thickness for Air mass flow rate of 74.3 kg/hr and Air Velocity of 3.38 m/s

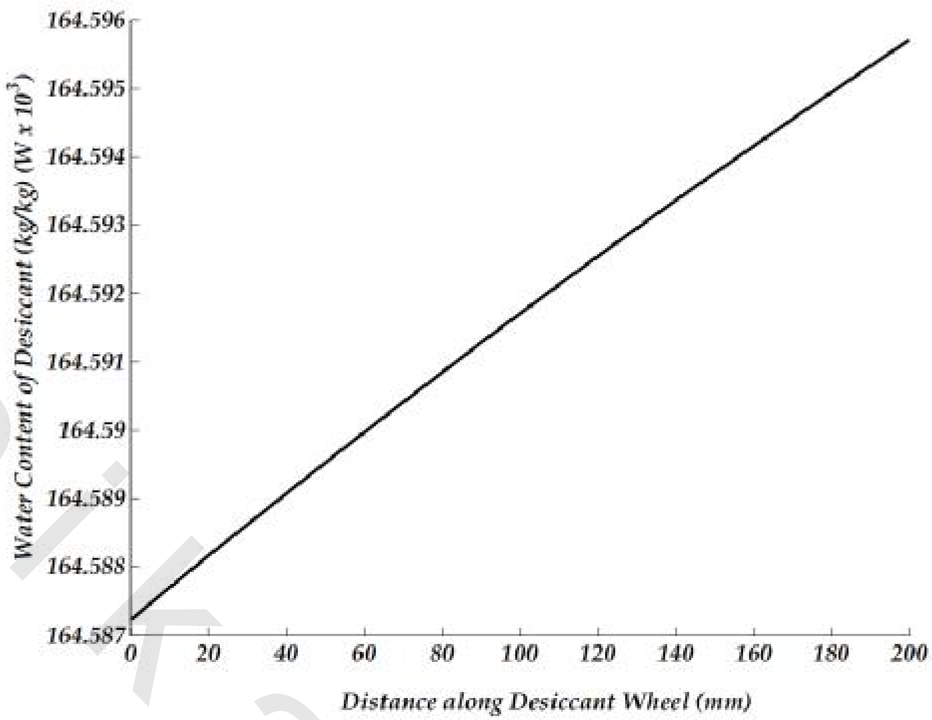

Figure 4.12 Water Desiccant Content along the Desiccant for Air mass flow rate of 100.3 kg/hr and Air Velocity of 4.57 m/s

4.2 Parameters Affecting Dehumidification Rate

After validating the proposed mathematical model, the dehumidification rates of the air streams are plotted against the dry bulb temperature of the inlet air. The dehumidification rate is equal to decrease the change in humidity ratio of the stream of the moist air after crossing the desiccant multiplied by the air mass flow rate in kg/hr. The Figures 4.13 to 4.17 show the relation between dehumidification rate and the dry bulb temperature at fixed relative humidity of air and fixed values of air mass flow rate and air velocity. To create the above mentioned group of figures, the program was run for a range of temperature between 0 °C and 30 °C as shown in figures, while the relative humidity was fixed at certain value. The relative humidity was changed between 10 % and 90 % with increment of 10%. The larger the dry bulb temperature, the larger the dehumidification rate as noticed from figure. On the other hand; the increase of relative humidity causes an increase of the dehumidification rate. The rate of change increases as the temperature increase and so does with the increase of the relative humidity as can be noticed from the slopes of the curves in Figures 4.13 to 4.17.

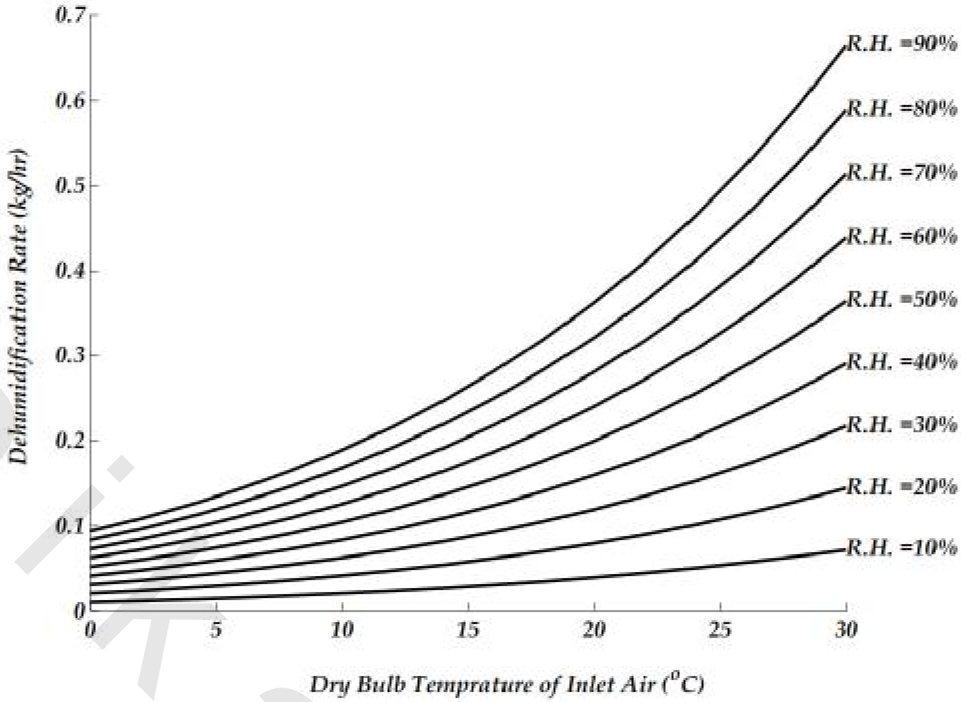

Figure 4.13 Dehumidification Rate versus Dry Bulb Temperature for Different RH values and Air mass flow rate of 34.3 kg/hr and Air Velocity of 1.56 m/s

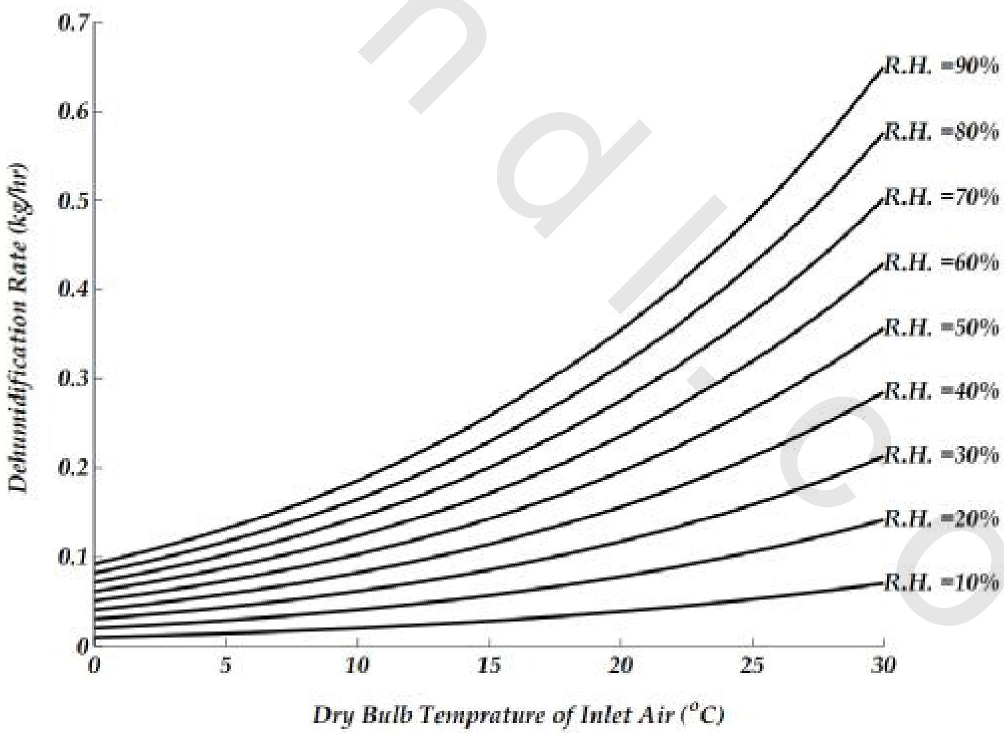

Figure 4.14 Dehumidification Rate versus Dry Bulb Temperature for Different RH values and Air mass flow rate of 36.4 kg/hr and Air Velocity of 1.66 m/s

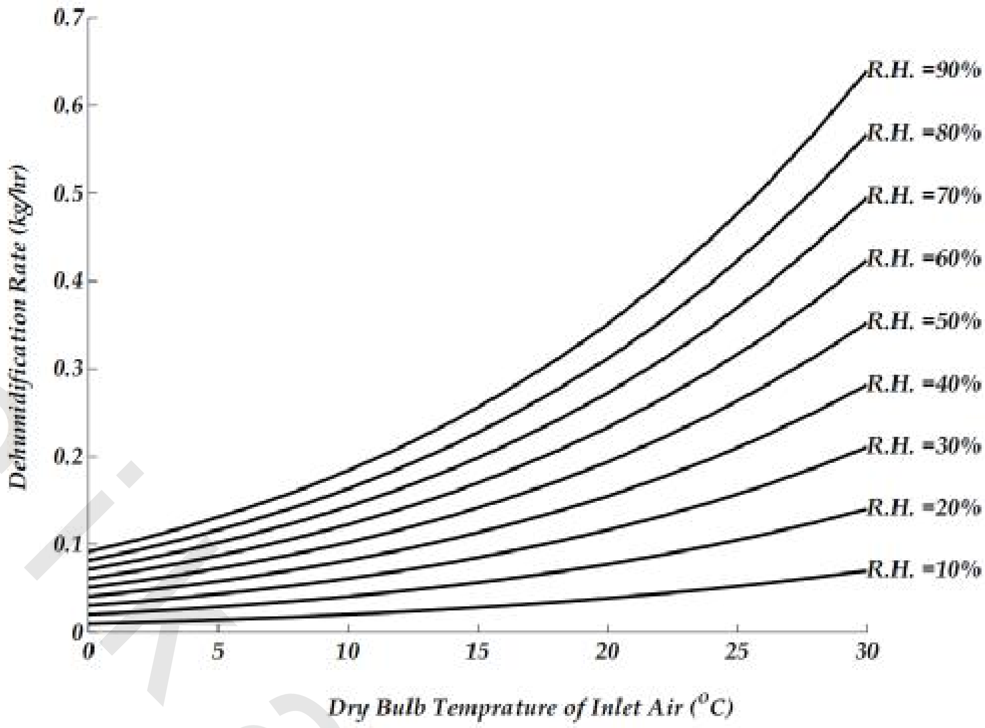

Figure 4.15 Dehumidification Rate versus Dry Bulb Temperature for Different RH values and Air mass flow rate of 49.4 kg/hr and Air Velocity of 2.25 m/s

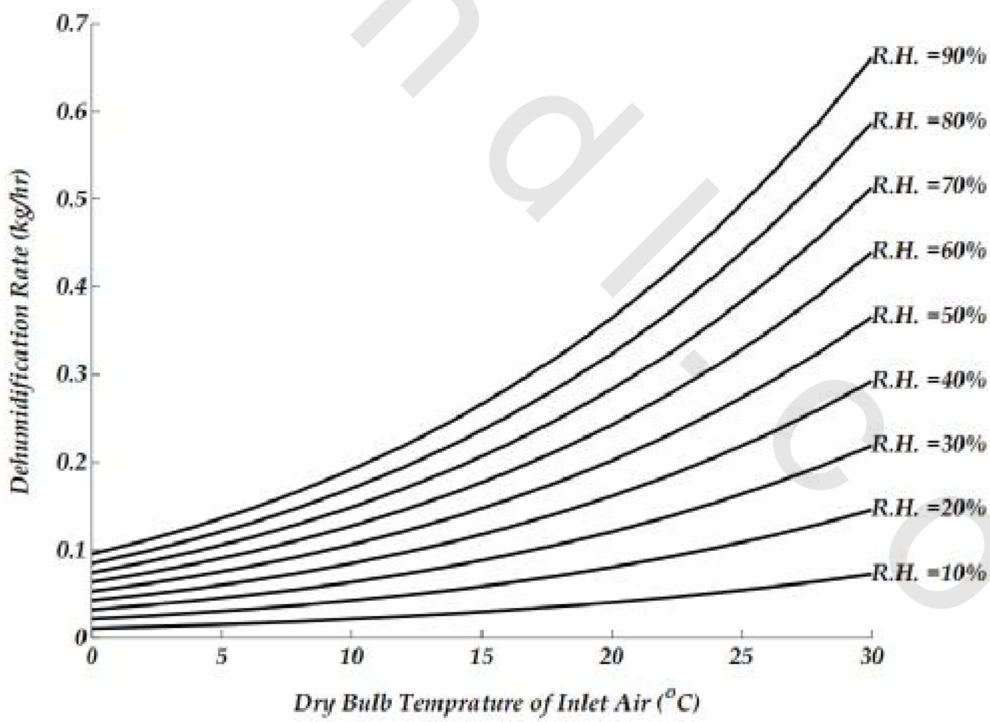

Figure 4.16 Dehumidification Rate versus Dry Bulb Temperature for Different RH values and Air mass flow rate of 74.3 kg/hr and Air Velocity of 3.38 m/s

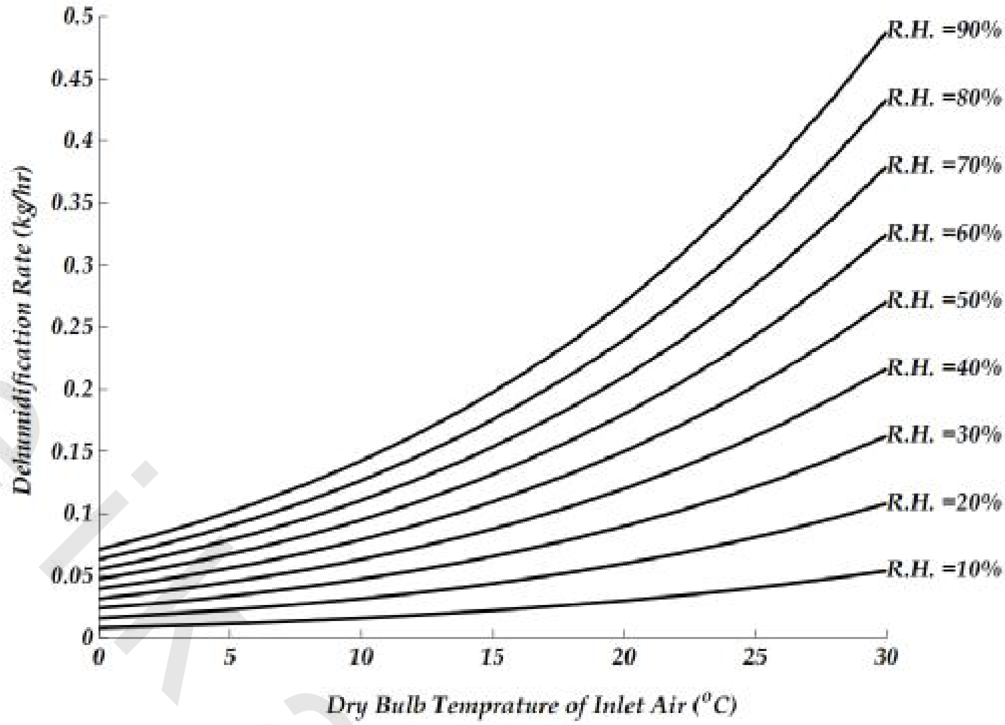

Figure 4.17 Dehumidification Rate versus Dry Bulb Temperature for Different RH values and Air mass flow rate of 100.3 kg/hr and Air Velocity of 4.57 m/s

To see the other side of the relation between the dehumidification rate and the relative humidity of the air, Figures 4.18 to 4.22 are introduced. To create these figures; the MatLab program was run such that the dry bulb temperature was fixed at values and the relative humidity was changed between 10% and 90% with a step of 5%.

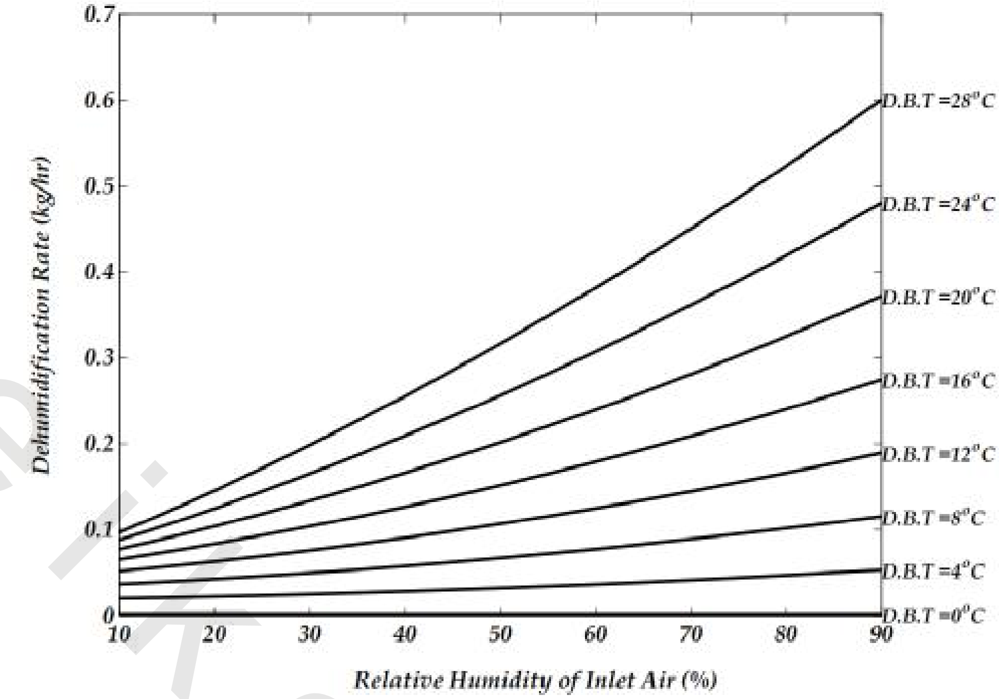

Figure 4.18 Dehumidification Rate versus Relative Humidity values for Air mass flow rate of 34.3 kg/hr and Air Velocity of 1.56 m/s

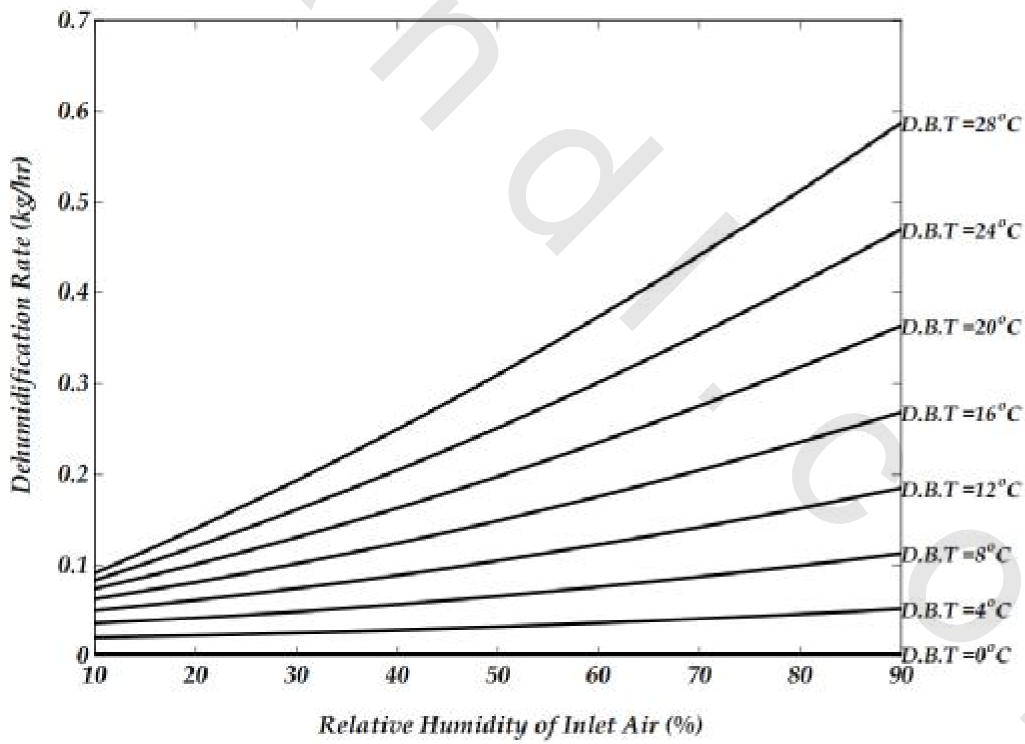

Figure 4.19 Dehumidification Rate versus Relative Humidity values for Air mass flow rate of 36.4 kg/hr and Air Velocity of 1.66 m/s

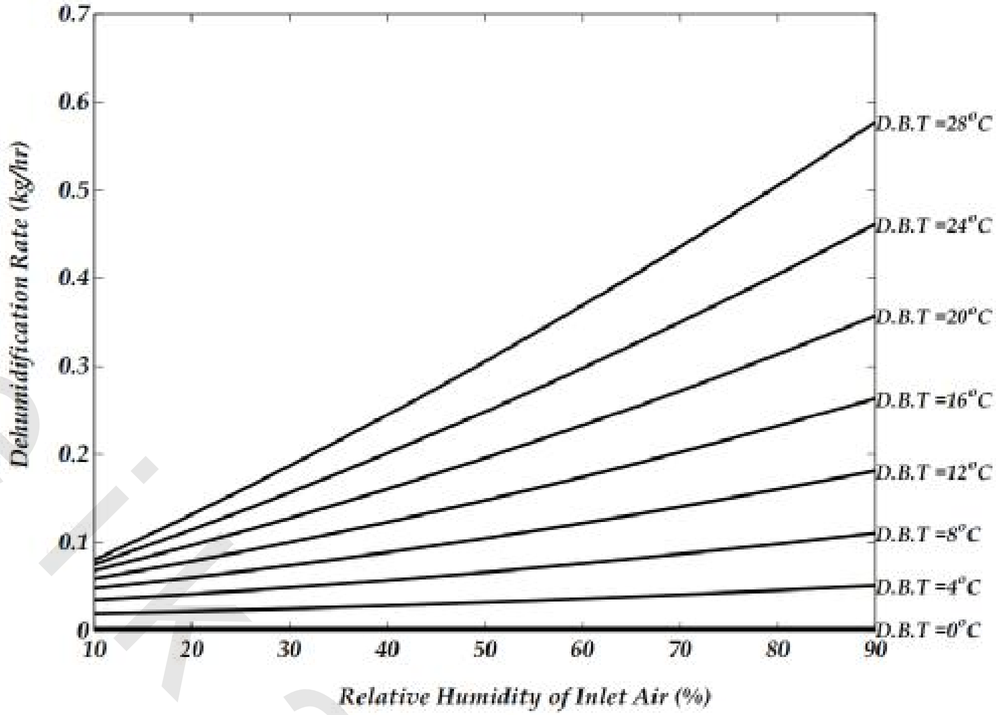

Figure 4.20 Dehumidification Rate versus Relative Humidity values for Air mass flow rate of 49.4 kg/hr and Air Velocity of 2.25 m/s

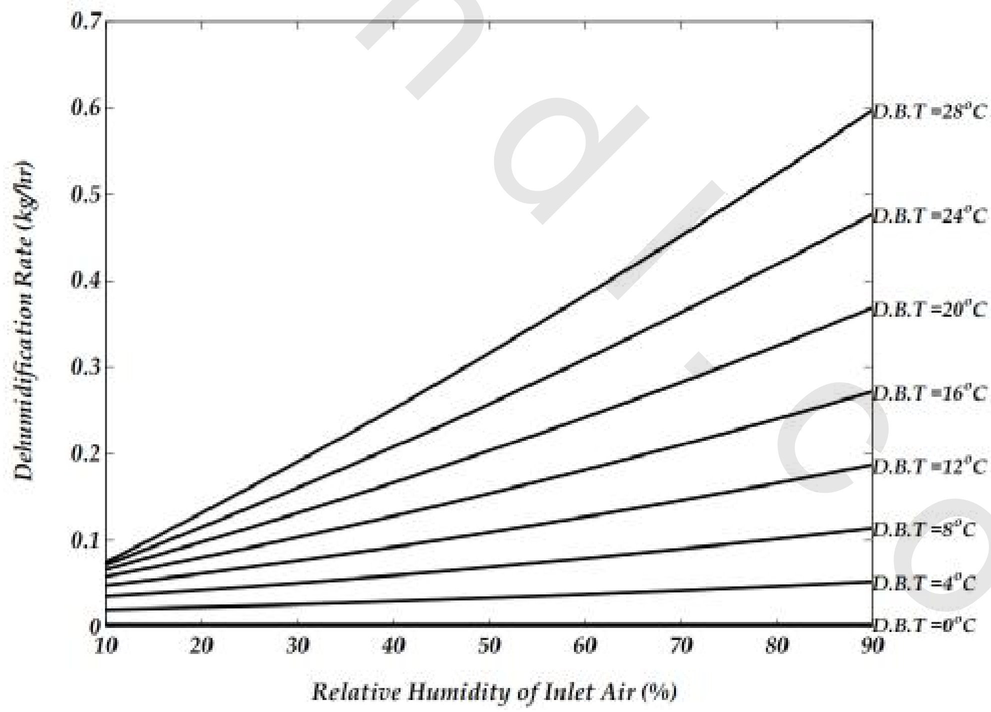

Figure 4.21 Dehumidification Rate versus Relative Humidity values for Air mass flow rate of 74.3 kg/hr and Air Velocity of 3.38 m/s

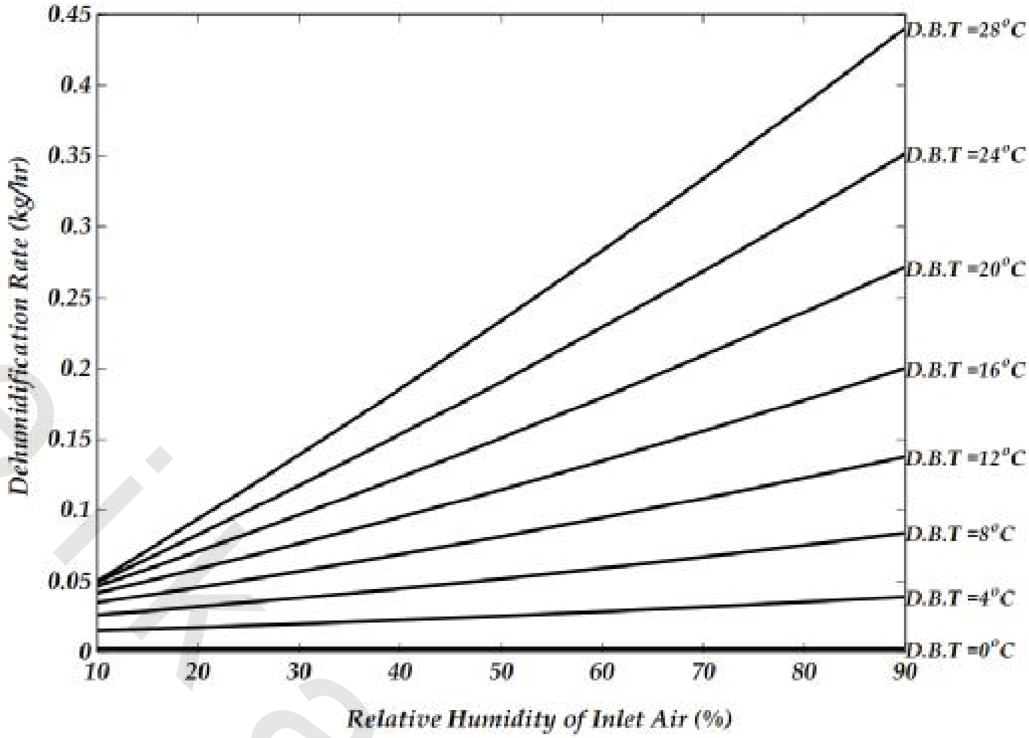

Figure 4.22 Dehumidification Rate versus Relative Humidity values for Air mass flow rate of 100.3 kg/hr and Air Velocity of 4.57 m/s

In Figures 4.18 to 4.22, it is noticed that the dehumidification rate increase with the increase of the relative humidity while the inlet air temperature is fixed. Comparing the group of Figures 4.13 to 4.17 with the Figures 4.18 to 4.22, it is clear that the change in air temperature on the dehumidification rate is more effective than that of relative humidity change.

To study the effect of the air mass flow rate on the dehumidification rate, Figures 4.23 to 4.26 are plotted. These figures are surface plotting of the dehumidification rate versus the dry bulb temperature at fixed values of relative humidities while the mass flow rate changes between 34.3 and 100.3 kg/hr.

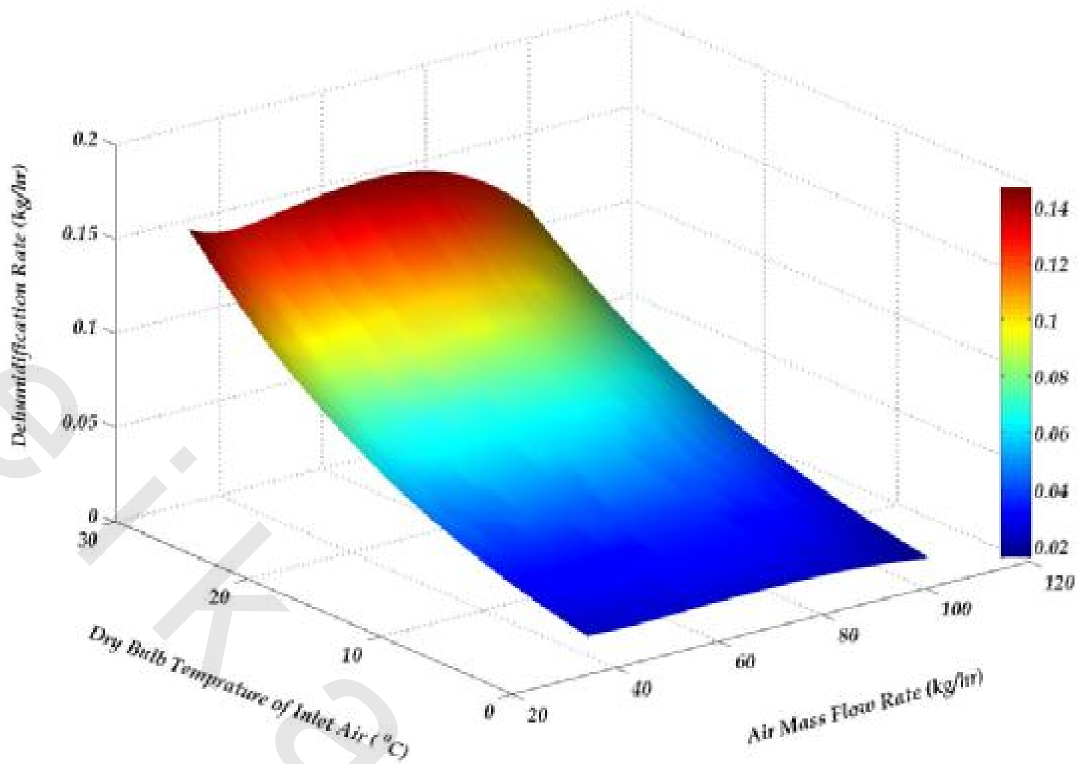

Figure 4.23 Dehumidification Rate versus Dry Bulb Temperature and Mass Flow Rate for Relative Humidity of 20 %

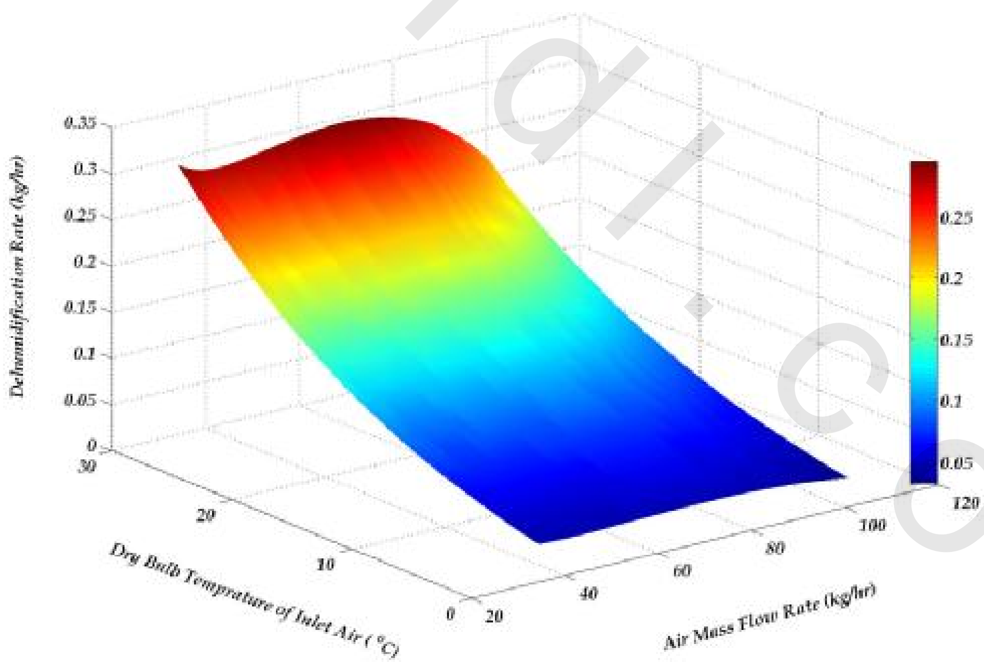

Figure 4.24 Dehumidification Rate versus Dry Bulb Temperature and Mass Flow Rate for Relative Humidity of 40 %

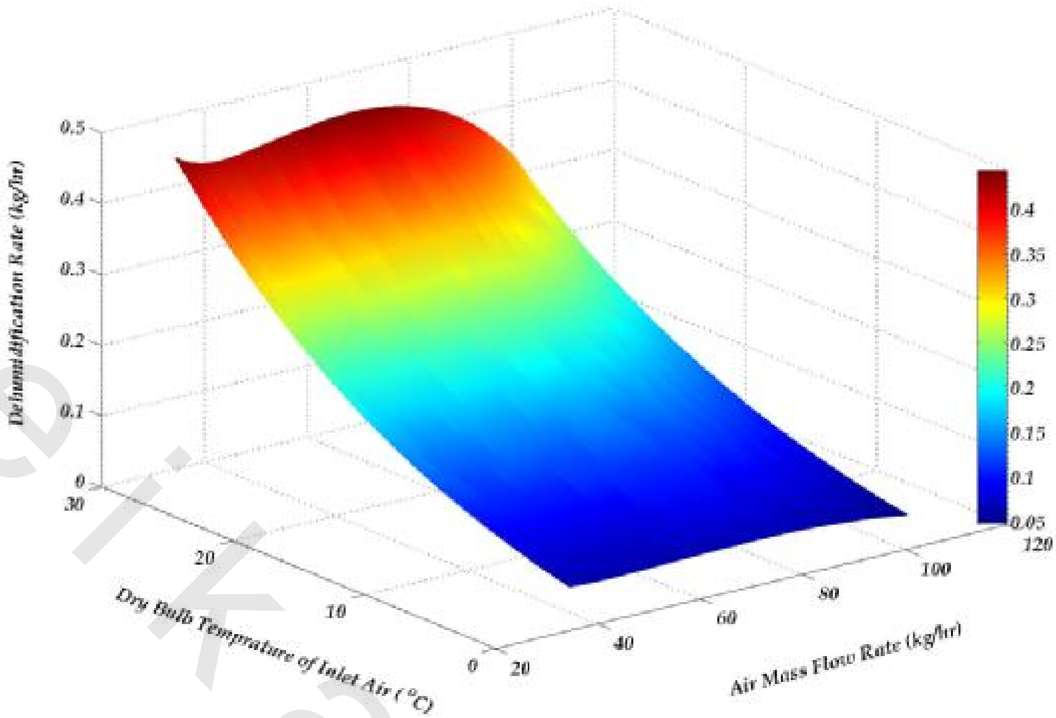

Figure 4.25 Dehumidification Rate versus Dry Bulb Temperature and Mass Flow Rate for Relative Humidity of 60 %

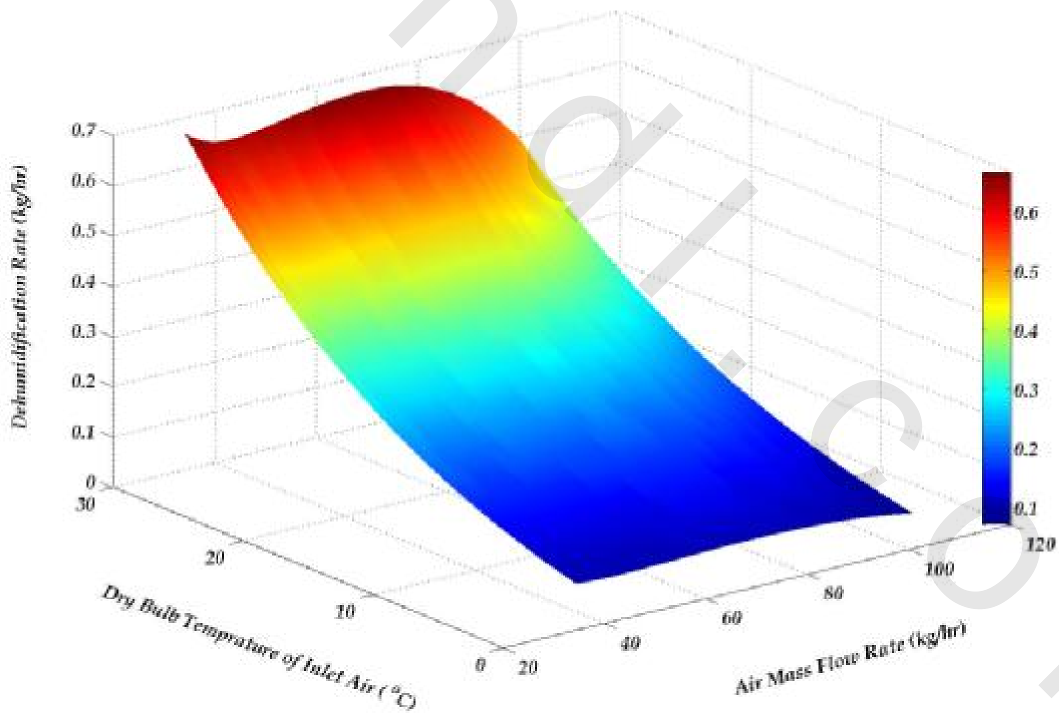

Figure 4.26 Dehumidification Rate versus Dry Bulb Temperature and Mass Flow Rate at Relative Humidity of 90 %

From the previous figures, it is noticed that regardless of the value of the relative humidity of the dehumidified air, the surface plots topographies are the same and the only changes are in the values of the dehumidification rates. Noticing the topography of surface plotting in the above five figures, one can find that there's a certain combination of temperature and mass flow rate to get the optimum dehumidification rate. For readability and comparison, the surface plots for relative humidity values ranges between 10 % and 90 % are collected in Figure 4.27. Figure 4.28 shows the curve of best combination between the mass flow rate of the air and its dry bulb temperature for optimum dehumidification rates. Notice that the best mass flow rate ranges between 69 kg/hr and 70 kg/hr such that one can get the best dehumidification rate. Also notice that the higher the dry bulb temperature, the smaller the air mass flow rate required for optimum dehumidification rate as shown in Figure 4.28. Notice also that as the relative humidity of the dehumidified air increases the dehumidification rate increases.

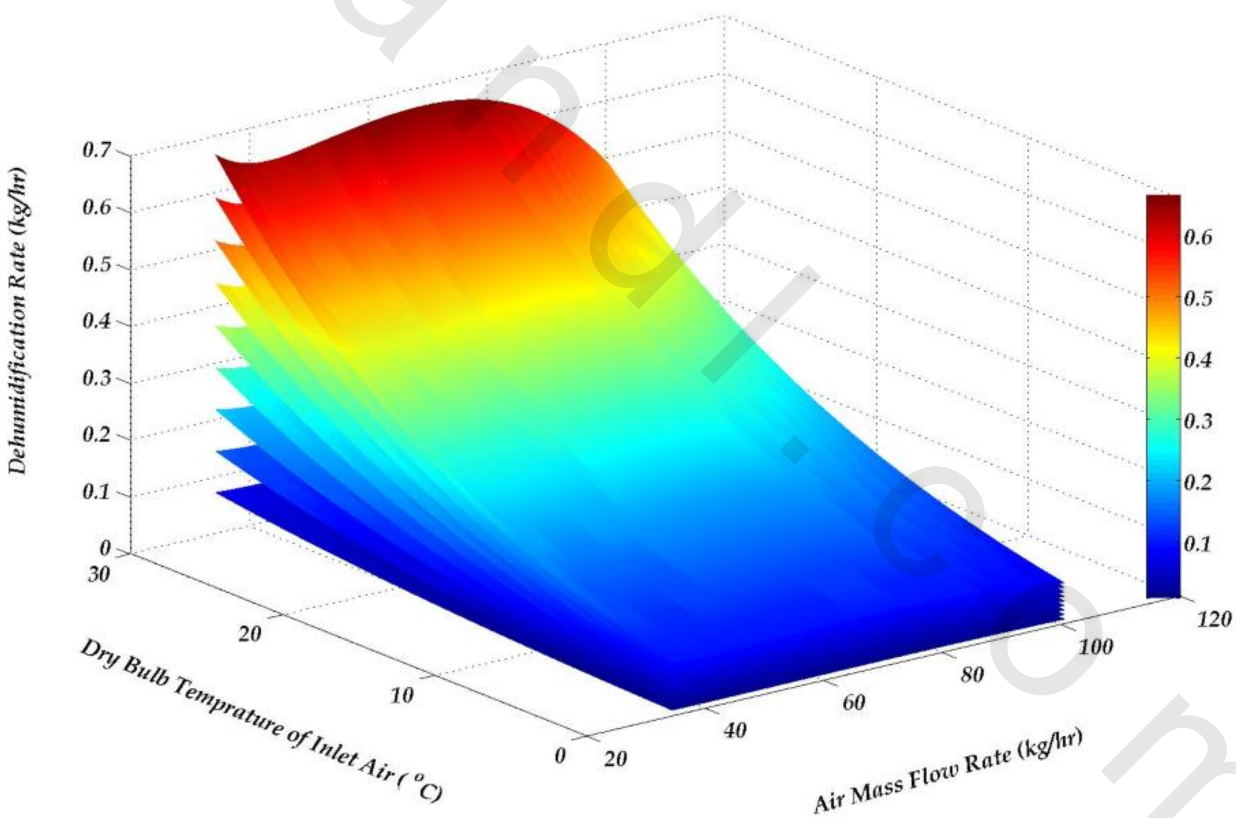

Figure 4.27a Dehumidification Rate versus Dry Bulb Temperature and Mass Flow Rate for Relative Humidities of 10 % to 90 %

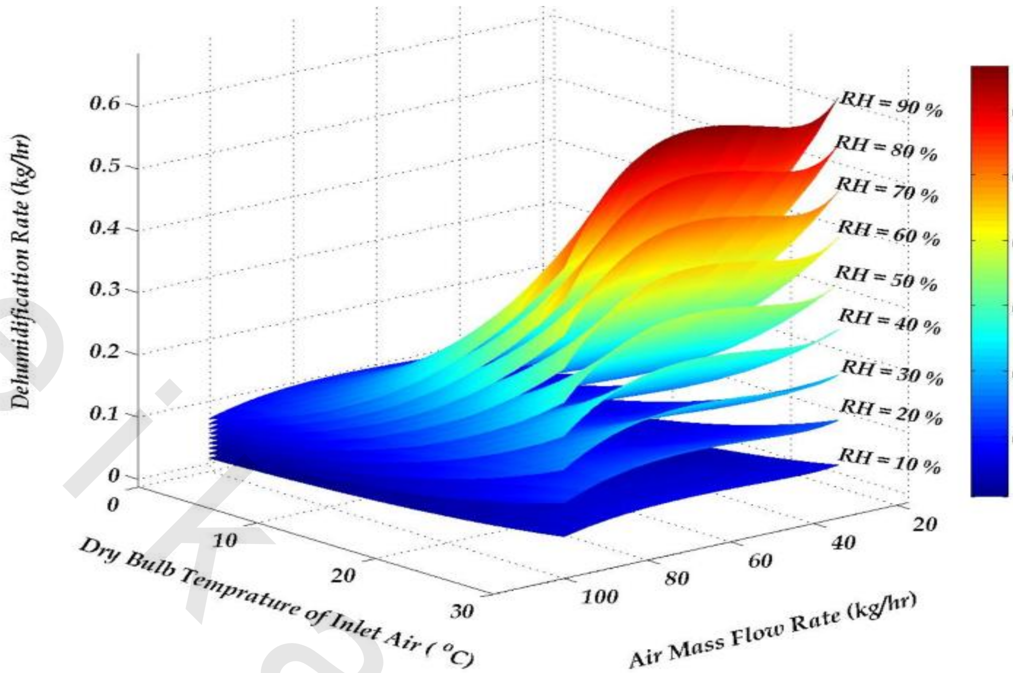

Figure 4.27b Dehumidification Rate versus Dry Bulb Temperature and Mass Flow Rate for Relative Humidities of 10 % to 90 % (Another View)

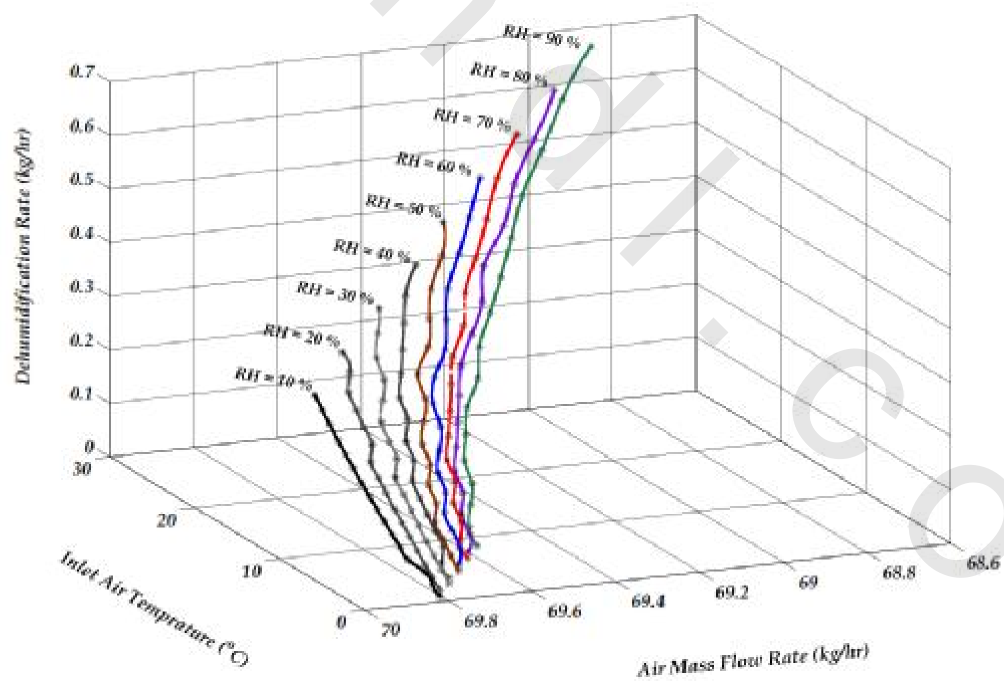

Figure 4.28 Optimum Dehumidification Rate versus Dry Bulb Temperature and Mass Flow Rate at Relative Humidities of 10 % to 90 %

From the above shown figures and discussion, one can create a mathematical relation between the dry bulb temperature, the relative humidity and the dehumidification rate. The dry bulb temperature and the relative humidity will be considered the independent variables in this relation while the dehumidification rate represents the dependent variable. The function created based on seven selected combinations of the dehumidification rates, dry bulb temperatures, and relative humidities. The other combination points were plugged into the created form to check the validity of the created function. After iteration, we found that the polynomial function is a good choice for this relation as the terms of fourth power and higher are truncated. These truncated high order terms cause a singularity problem. Besides; the existence of these terms has a very trivial effect on the dehumidification rate. The general form of the proposed relation is

$$\textit{Dehumidification Rate} = C_1 + C_2\,T + C_3T^2 + C_4\Phi + C_5\Phi^2 + C_6T\,\Phi + C_7T\Phi^2 + C_8\Phi\,T^2 \qquad (4.2)$$

Where;

T refers to the dry bulb temperature of air stream in Celsius

Φ is the relative humidity of the inlet air

The values of the coefficients C_i's are listed in table 4.1. Notice that the coefficient of the terms of relative humidity is so small compared to the other coefficients, while the coefficient of the relative humidity squared is zero. This means that the contribution of the relative humidity to the dehumidification rate polynomial is trivial. The pseudo-linear relation between the dehumidification rate and the relative humidity at fixed temperature (Figures 4.18 to 4.22) strengthen this reality.

It is noticed that the values of the coefficients C_i's vary as the mass flow rate and air velocity inside the desiccant channel vary. Thus, we proposed that these coefficients will be related to the mass flow rate and the air velocity inside the desiccant channels as done with K_{mCoef} factor. The proposed coefficients will augment the dehumidification rate polynomial such that the change in the air velocity and mass flow rate are considered beside the basic independent parameters (T, Φ). The proposed relations of the coefficients with the air mass flow rate and air velocity inside desiccant channel are derived based on four of the conducted experiments listed in Appendix A, while the fifth experiment was used for validation purpose. The error between the coefficients of the polynomial created at mass flow rate of 36.4 kg/hr and air velocity of 1.66 m/s and those calculated from the proposed polynomials of those coefficients are listed down in Table 4.2. For easiness of comparison, the errors between the original values of the coefficients and those calculated from the proposed polynomials are calculated and added as another column to the table.

Table 4.1 The Values of The Dehumidification Rate Polynomial Coefficients

Polynomial Coefficients	**Process 1**	**Process 3**	**Process 4**	**Process 5**
	$\dot{m}_a = 34.3\frac{kg}{hr}$ $U_{ch} = 1.56\ m/s$	$\dot{m}_a = 49.4\frac{kg}{hr}$ $U_{ch} = 2.25\ m/s$	$\dot{m}_a = 74.3\frac{kg}{hr}$ $U_{ch} = 3.38\ m/s$	$\dot{m}_a = 100.3\frac{kg}{hr}$ $U_{ch} = 4.57\ m/s$
C_1	0.0024679474	0.0026022117	0.0028329312	0.0021901022
C_2	0.00450808	0.0042328	0.0043146	0.0031349
C_3	0	0	0	0
C_4	-0.00009807	-0.0001149	-0.0001311	-0.0001052
C_5	0	0	0	0
C_6	0.00106795	0.002483866	0.00345321	0.00316948
C_7	0.00050981	0.0005178	0.0005522	0.0004185
C_8	0.00714345	0.0052179	0.0043919	0.0025286

Table 4.2 The Values of the Dehumidification Rate Polynomial Coefficient at Mass Flow Rate of 36.4 kg/hr and Uch of 1.66 m/s (Process 2)

Polynomial Coefficients	**Original Coefficients**	**Calculated Coefficients**	**Error** x 10^{-5}
C_1	0.0024698046	0.002475749	0.59446
C_2	0.0043819649	0.00443169	4.97298
C_3	0	0	0
C_4	-0.000101063	-0.0001004	0.06619
C_5	0	0	0
C_6	0.00140840745	0.001308435	-9.99724
C_7	0.00050529503	0.000508008	0.271277
C_8	0.0065720663	0.00676245	19.03804

The generic form of the proposed polynomial for each coefficient of the dehumidification rate polynomial as a function of U_{ch} and $\dot{m}_a$ is

$$C_i = C_{i1} + C_{i2}U_{ch} + C_{i3}U_{ch}^2 + C_{i4}\dot{m}_a + C_{i5}\dot{m}_a^2 + C_{i6}\dot{m}_a U_{ch} + C_{i7}\dot{m}_a U_{ch}^2 + C_{i8}U_{ch}\dot{m}_a^2 + C_{i9}\dot{m}_a^3 + C_{i10}U_{ch}^3 \quad (4.3)$$

Figures 4.29 - 4.34 show the plotting of these polynomials versus the air velocity inside the desiccant channel and the air mass flow rate.

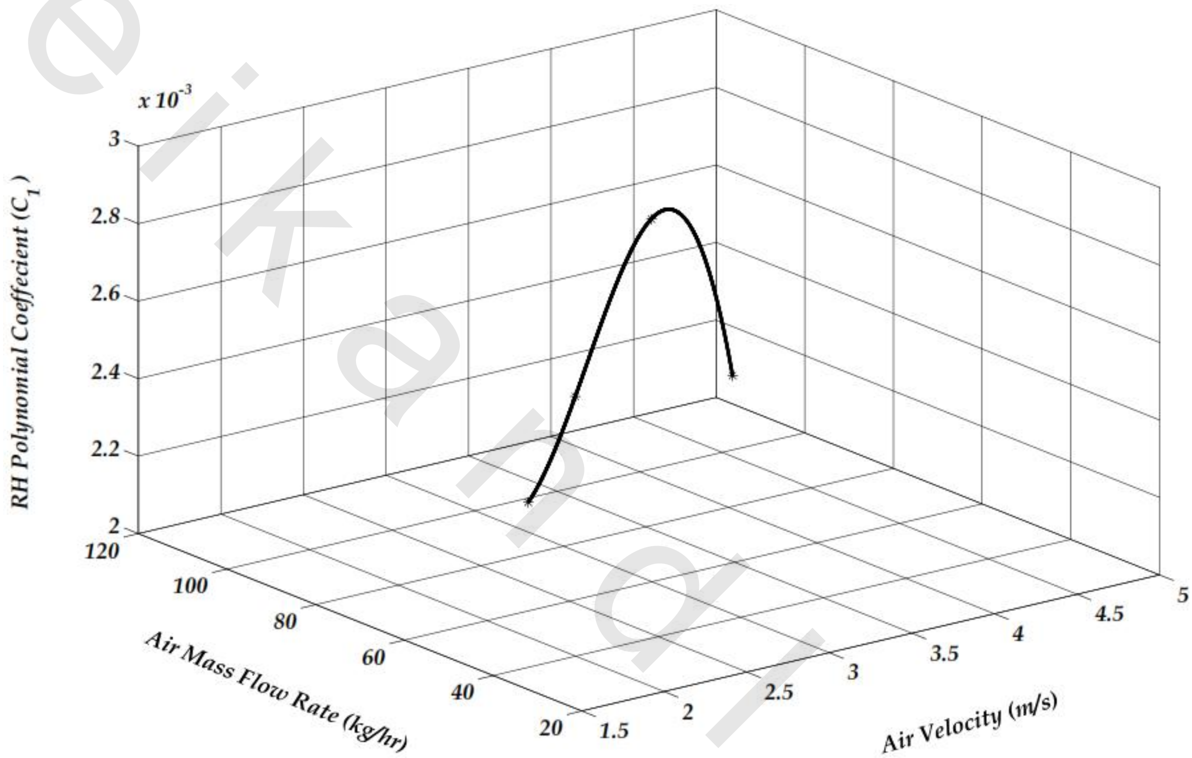

Figure 4.29 The Relative Humidity Polynomial Coefficient C_1

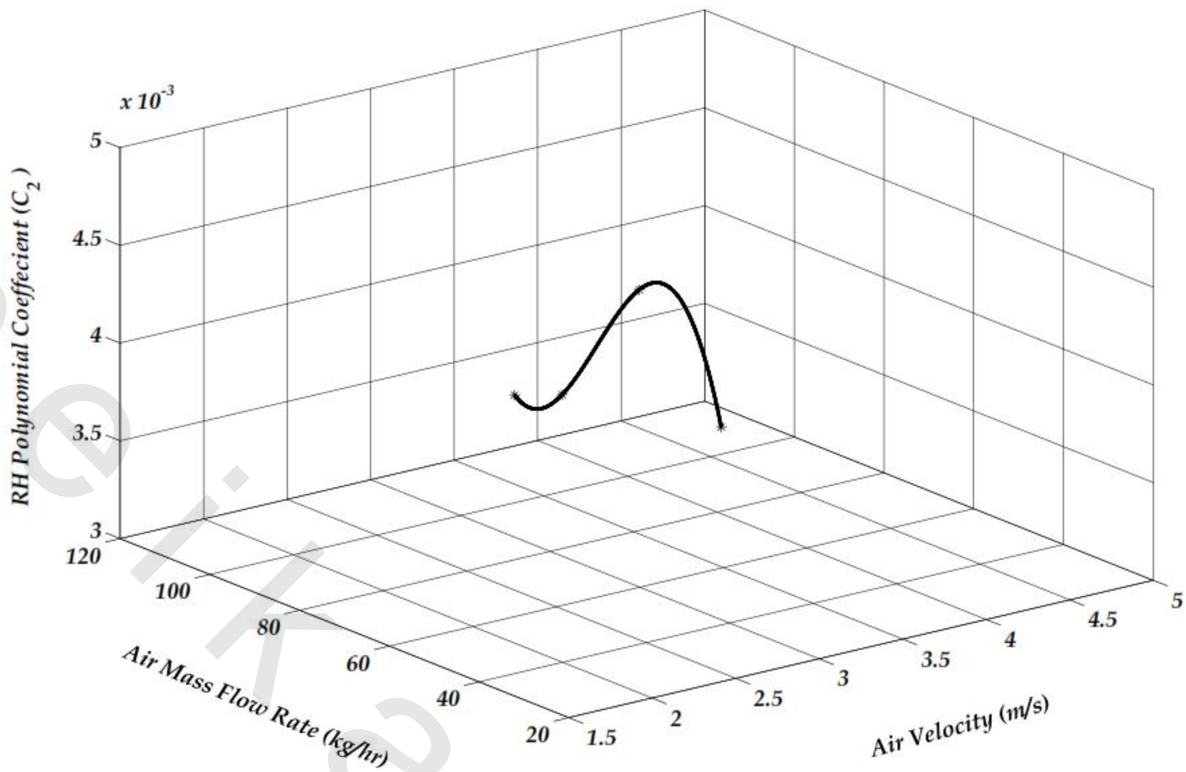

Figure 4.30 The Relative Humidity Polynomial Coefficient C_2

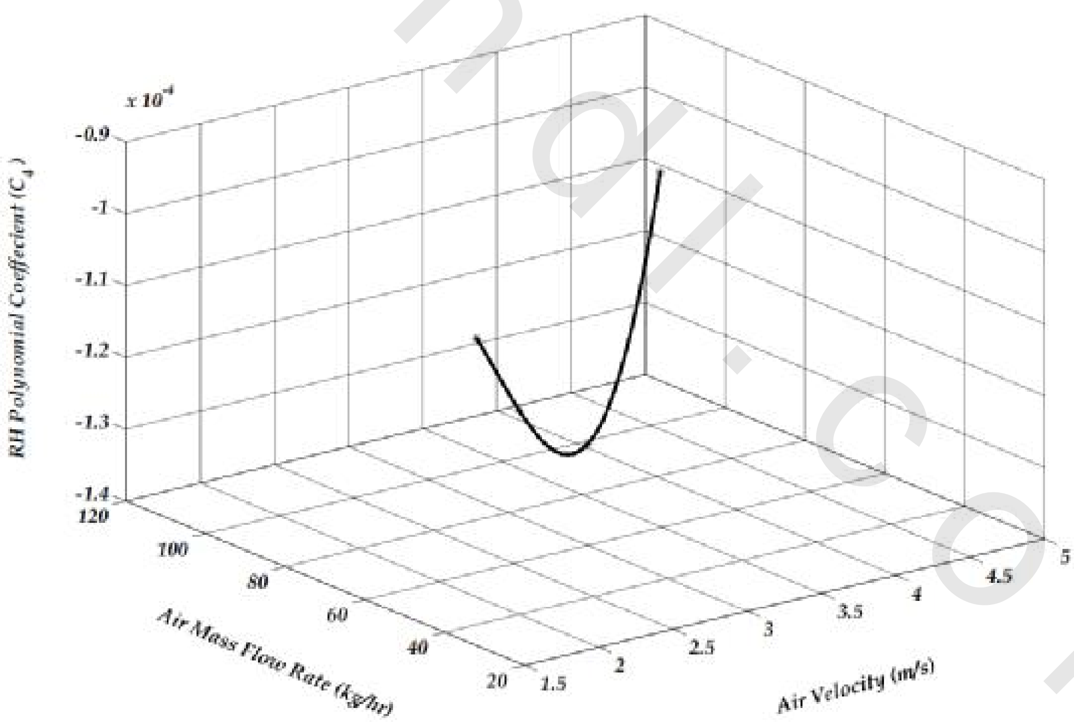

Figure 4.31 The Relative Humidity Polynomial Coefficient C_4

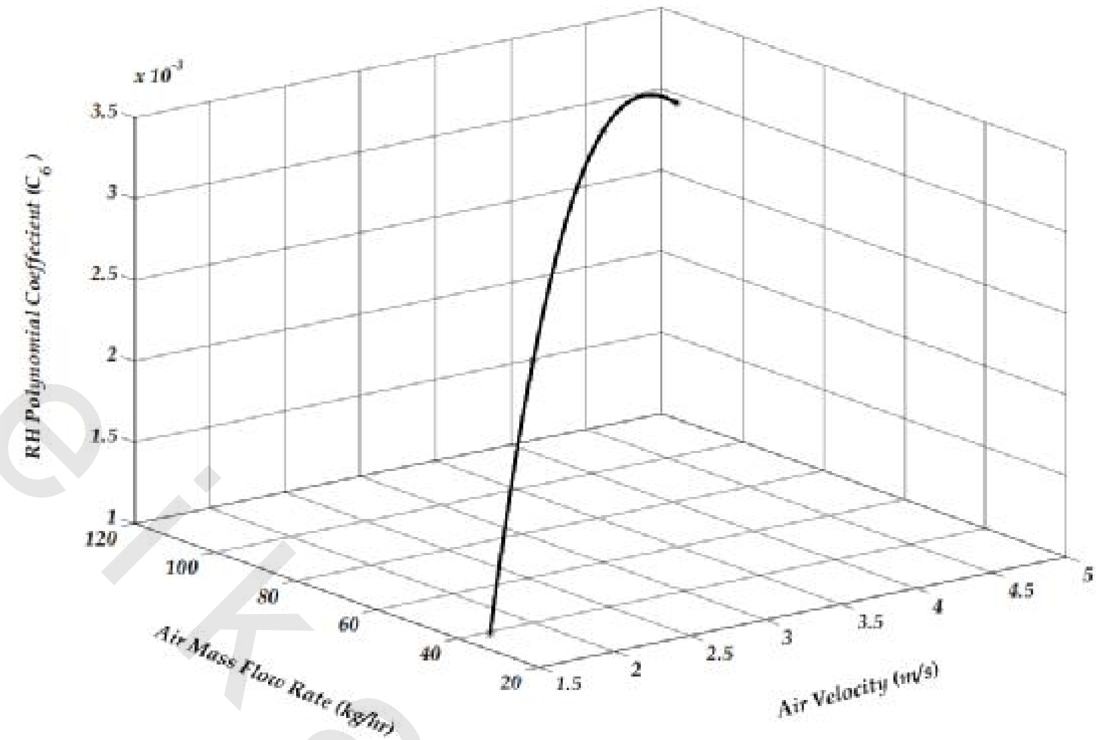

Figure 4.32 The Relative Humidity Polynomial Coefficient C_6

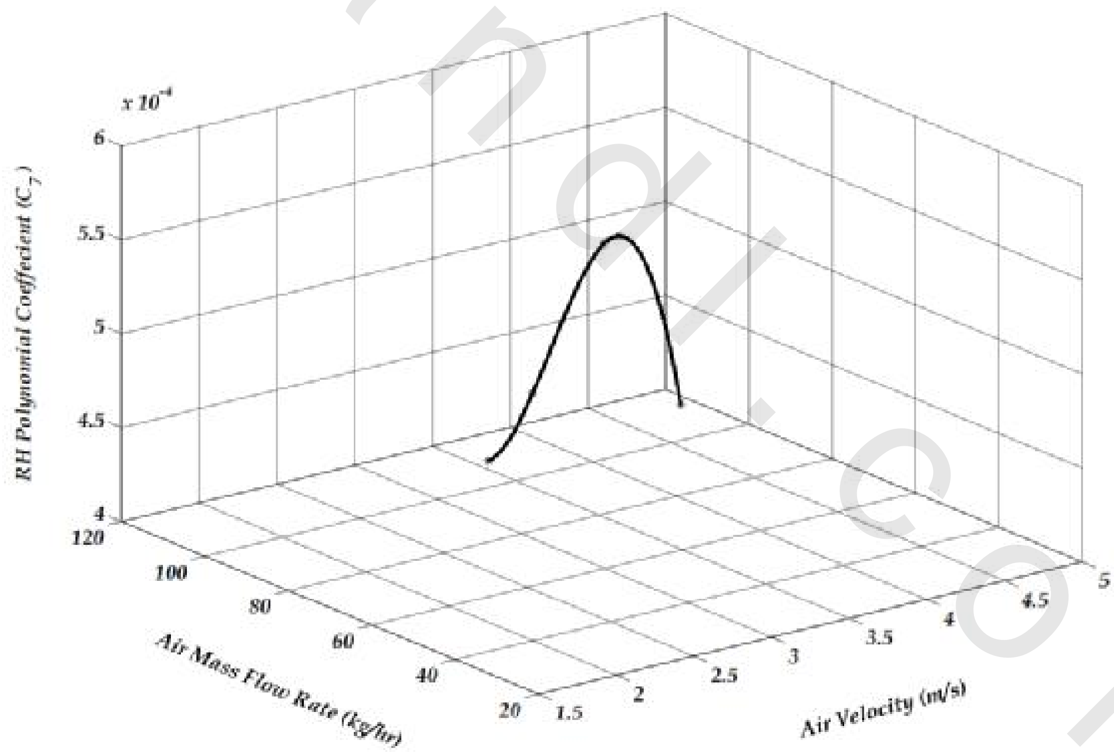

Figure 4.33 The Relative Humidity Polynomial Coefficient C_7

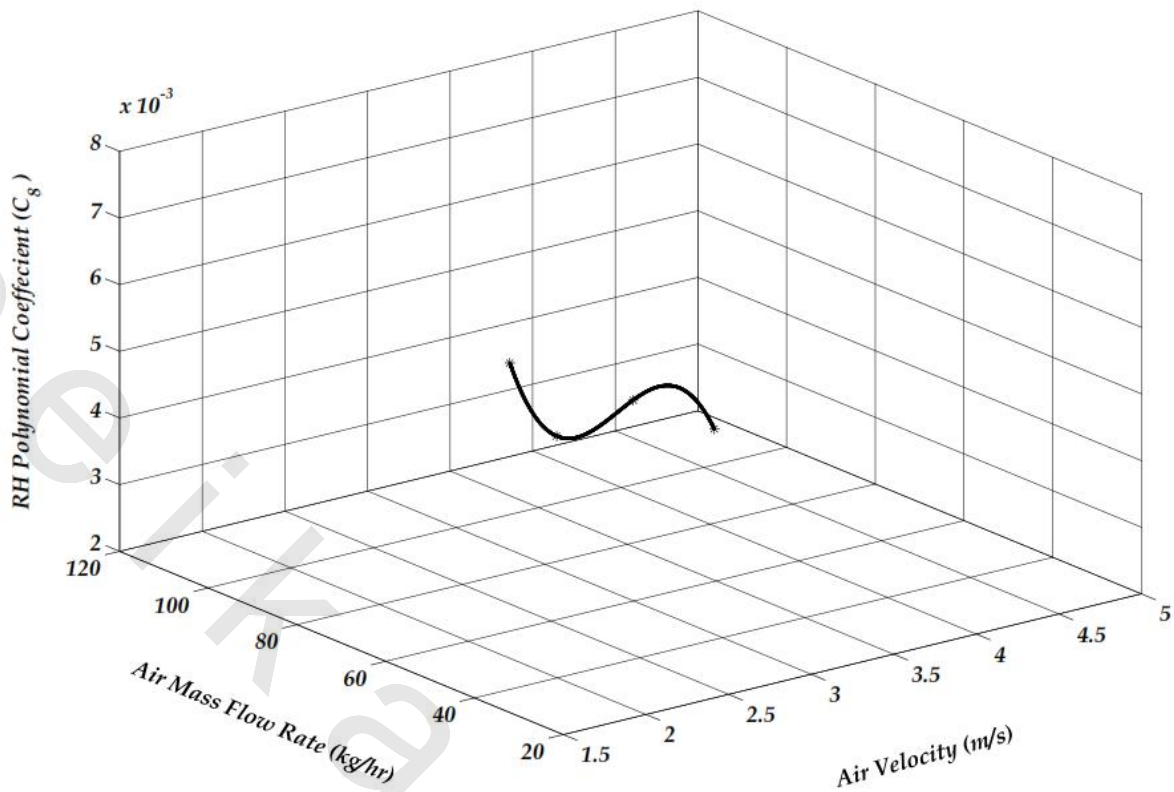

Figure 4.34 The Relative Humidity Polynomial Coefficient C_8