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Performance Analysis of Desiccant Dehumidifier using ANSYS Fluent

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Abstract: Traditional cooling systems based on vapor compression are ineffective in humid climates due to their inability to remove moisture below the dew point of the conditioned air, which involves additional effort in the form of an electrical power supply to run vapor compressors. A solid desiccant cooling system reduces power usage while simultaneously providing fresh and clean air. It is important to examine and analyze the performance of desiccant dehumidifiers using the Honeycomb pattern in the desiccant wheel that will help to develop a more efficient cooling system. The Ansys (CFD Analysis) software was used to predict the results of a dehumidifier. The blocks were made of Zeolite 13X with a honeycomb geometry. The present study focuses on the effect of the desiccant wheel on the system. Two different process air temperatures of 27.9 °C, 33.4 °C with Relative humidity of 85% and 70 % respectively, were investigated under constant regeneration air temperature of 70°C and 0.5-4 m/s inlet air velocity. As a result, CFD simulation techniques aid in saving to avoid the cost and time.

Keywords: Dehumidifier; desiccant materials; solid desiccant cooling; Computational fluid dynamics (CFD), CFD technique.

I. INTRODUCTION

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(Rambhad et al., 2021). A desiccant cooling system can be used in a wider range of climates. They can be run on an open heat-driven cycle that includes a dehumidifier, a sensible heat exchanger, and evaporative coolers. In this environmentally friendly system, a desiccant wheel is used to dehumidify the air to a low humidity level so that evaporative cooling or other cooling options can be used effectively to reduce the temperature of the air. Thus, a desiccant cooling system plays an important role as an alternative to conventional heating and cooling systems. The desiccant cooling system not only decreases energy consumption but also reduces the heat rate, which is largely affected by the global environment. A solid desiccant rotor in a desiccant cooling system removes moisture from the air to improve the indoor air quality also (Bhabhor & Jani, 2021).

Desiccants can be classified as adsorbents which absorb moisture without considering physical and chemical changes or absorbents which absorb moisture by considering physical or chemical changes. Desiccants can be solids or liquids and can hold moisture through adsorption or absorption. Most absorbents are liquids and most adsorbents are solids. Several types of solid desiccants are mostly used in desiccant cooling systems; silica gels, lithium chloride and molecular sieves (Halid et al., n.d.).

1.1 Working of Desiccant Wheel Dehumidifier:

In Desiccant cooling systems moisture in air is removed by a desiccant that absorbs the moisture when air passes through it. These desiccants can be either solid or liquid. They can be used efficiently to overcome the latent part of the cooling load. Desiccant technology for moisture removal is appropriate where sensible heat ratio (SHR) is low as in high humid locations and applications where precise humidity control is required. In desiccant wheel dehumidifier, the

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desiccant material usually a silica gel or some type of zeolite, is impregnated into a supporting structure. This looks like a honeycomb which is open on both ends.

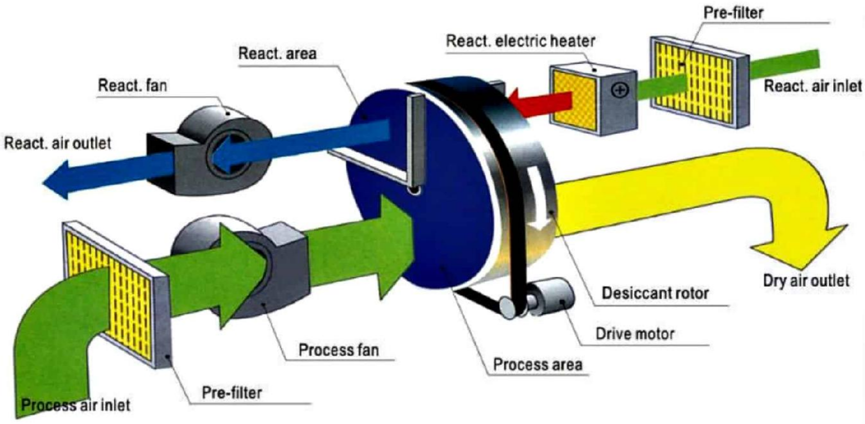

Figure 1.3.1 Working of Desiccant Wheel Dehumidifier

Air passes through the honeycomb passages, giving up moisture to the desiccant present in the walls of the honeycomb cells. The wheel constantly rotates through two different air streams. The first stream, namely the process air, is dried by the desiccant. During this process the heat of absorption is released to the air. The second air stream, called reactivation or regeneration air, is heated. It dries the desiccant. The regeneration air can be heated by solar collectors, electric heaters, gas burners, or waste heat sources (Halid et al., n.d.).

Table 1.1Specification of a desiccant dehumidifier and material properties

Specification and property	Base value
Wheel length(L)m	0.125
The diameter of wheel(D)	0.2
The thickness of the wall(δ)m	0.001
Porosity, ε	0.3585
The pitch of flow passage, b (m)	0.003
Height of flow passage, a (m)	0.00346
A volume ratio of desiccant, (U)	
The area ratio of airflow passage to the total area of one channel, (Ar)	
The density of matrix material, ρm (kg/m3)	640
Thermal conductivity of zeolite 13x, kd (W/mK)	0.15
Pore Diameter, (	10
Specific heat of zeolite 13x, cd (J/kg K)	230

II PERFORMANCE CRITERIA

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

Inlet Temperature (K)	Inlet Relative Humidity (g/kg)	Regeneration Temperature (K)
301.05 K	20.63	343.15
306.55 K	23.36	343.15

Effectiveness of desiccant, which is defined as;

$$\varepsilon_D = \frac{\omega_{pro,in} - \omega_{pro,out}}{\omega_{pro,in}}$$

III. SIMULATION OF DESICCANT WHEEL

For a two 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 19.2, 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 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 H_20 were 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 shown in table 3.1.

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 in figure 3.1.

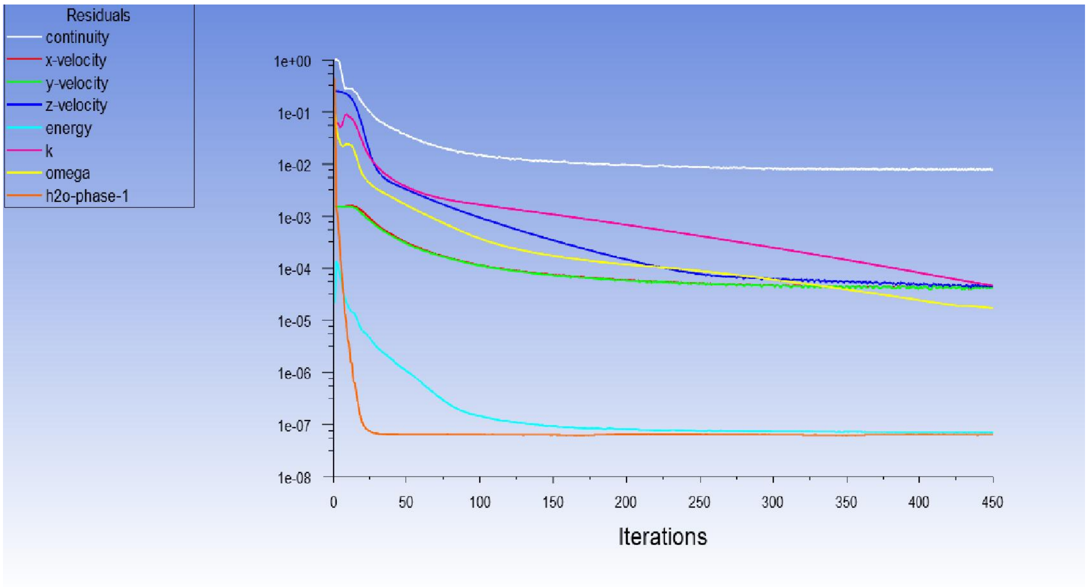

Figure 3.1 Residual Plot

Table 3.1 Summary of simulation work details

Details	Minor Operation Theatre	
General	Type	Pressure based
	Velocity Formulation	Absolute
	Time	Steady
	Gravity Force	On
Fluid Models	Multiphase	VOF
	Energy	On
	Viscous model	k - omega
	Near wall treatment	Standard wall functions
	K-Epsilon Model	Standard wall functions

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Boundary Conditions	Mass Fraction of H2O	2.06%
	Inlet Velocity	0.5-4 m/s
		301.05 K
	Temperature	306.55 K
Solution Method	Gradient	Least Squares cell based
	Pressure	PRESTO
	Momentum	Second Order Upwind
	Turbulent Kinetic Energy	Second Order Upwind
	Turbulent Dissipation Energy	Second Order Upwind
	Energy	Second Order Upwind

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

1. The residuals reduce below 10e-04
2. Mass flow and Energy between the inlet and outlet is conserved.

Upon ensuring these criteria, the simulation results were obtained in terms of contour plots and are plotted in below. Simulation results shows there are increment in outlet temperature and decrement in relative humidity of process air at outlet of desiccant wheel with different velocity.

Climatic Condition 1

For, Inlet Temperature = 301.05 K and Relative Humidity = 85 % with different velocity 0.5-4 m/s

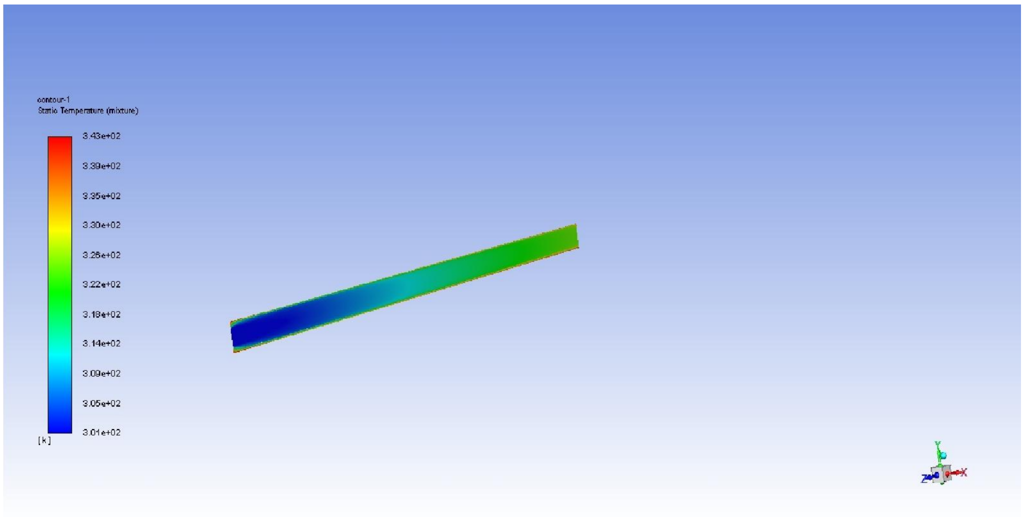

Figure 3.2 Representation of Temperature,Relative humidity at velocity magnitude 0.5 m/s

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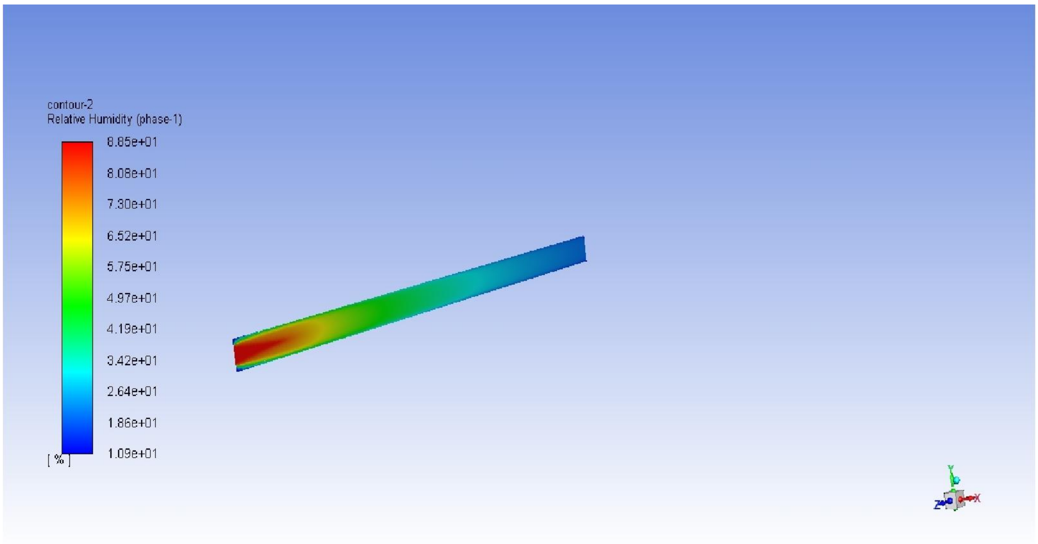

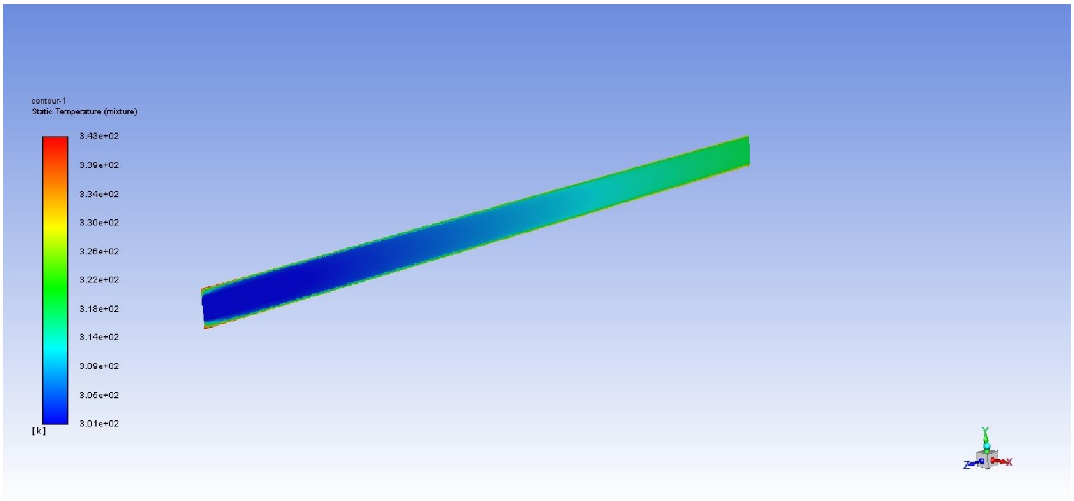

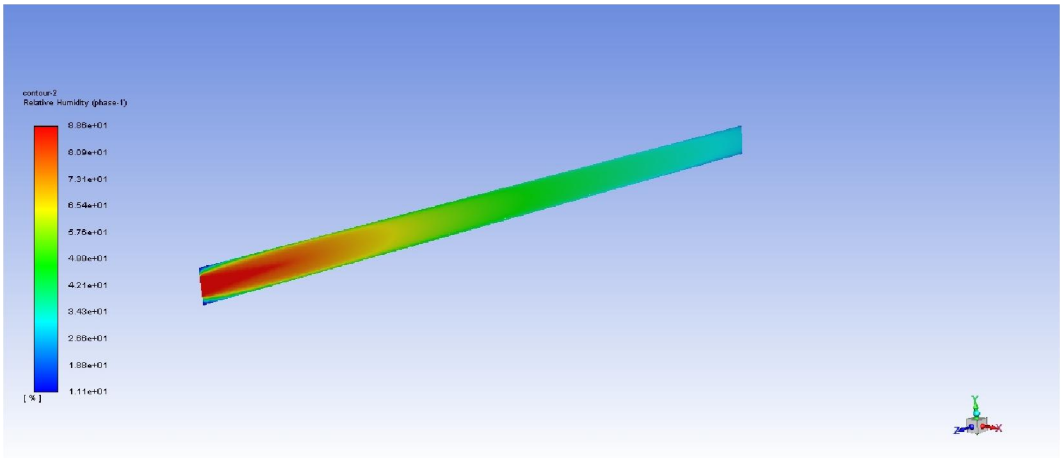

Figure 3.3 Representation of Temperature, Relative humidity at velocity magnitude 1 m/s

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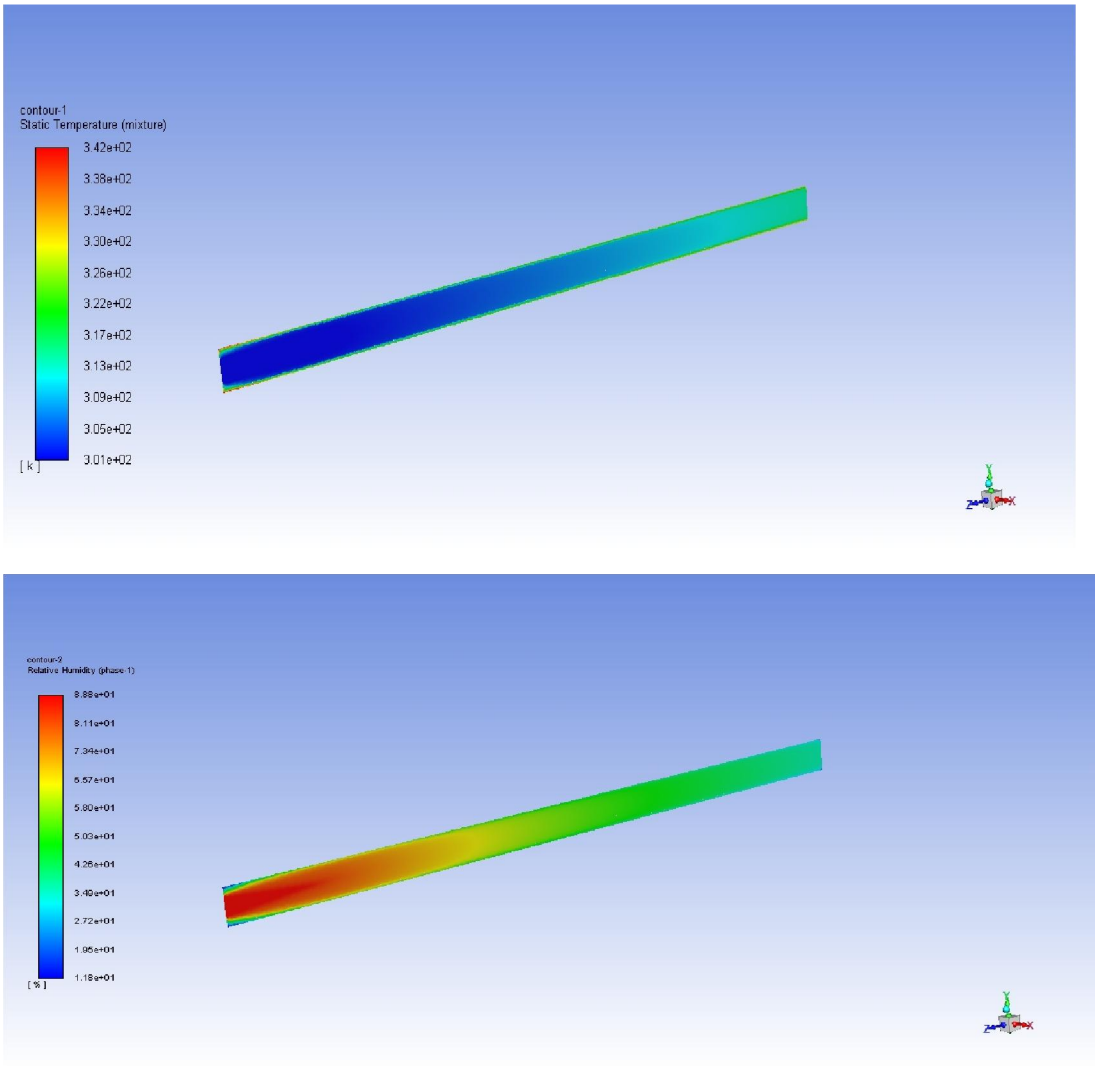
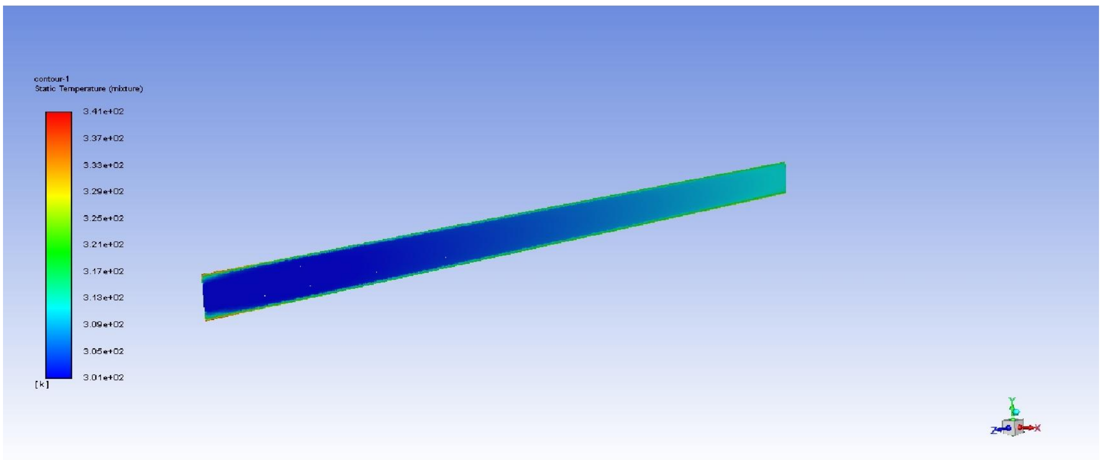


Figure 3.4 Representation of Temperature, Relative humidity at velocity magnitude 1.5 m/s



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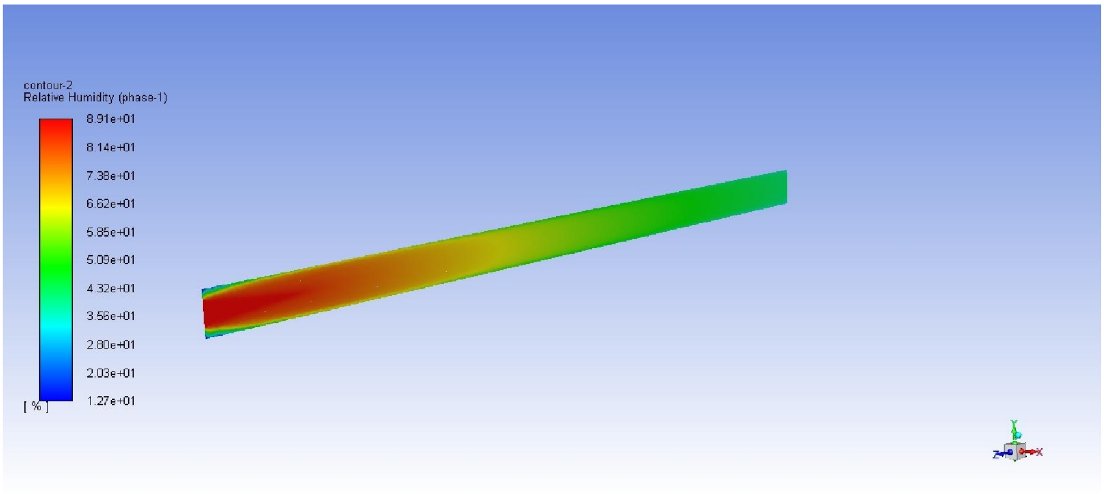
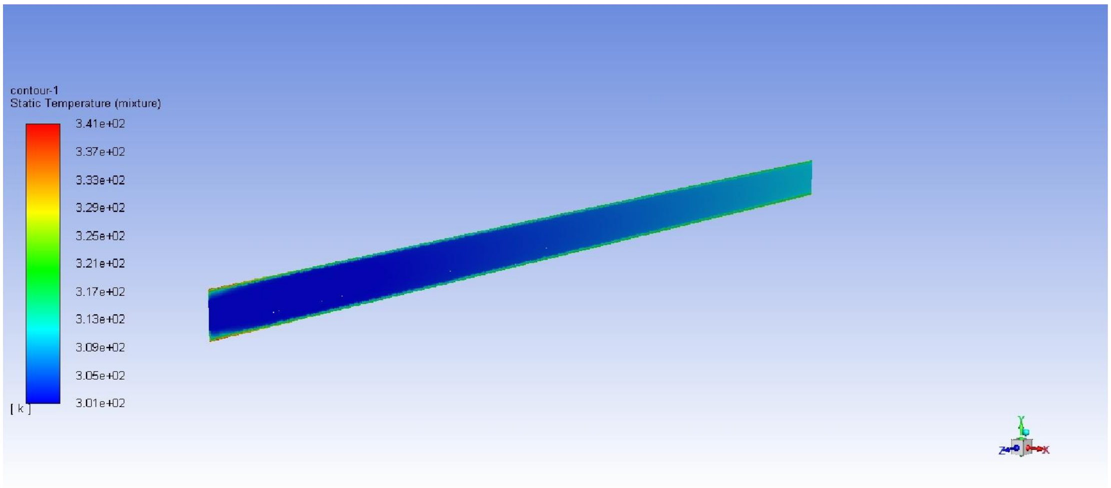


Figure 3.5 Representation of Temperature, Relative humidity at velocity magnitude 2 m/s



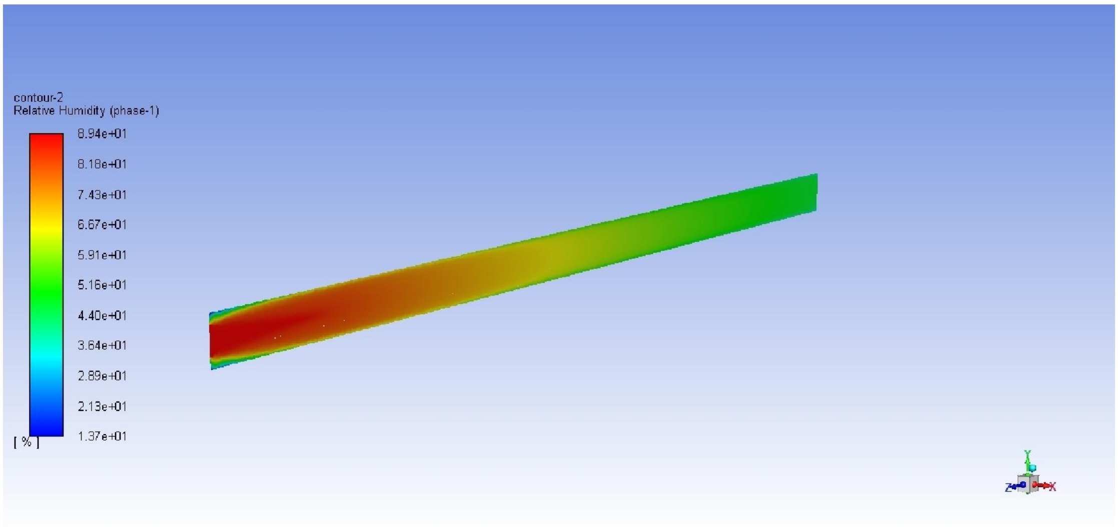


Figure 3.6 Representation of Temperature, Relative humidity at velocity magnitude 2.5 m/s

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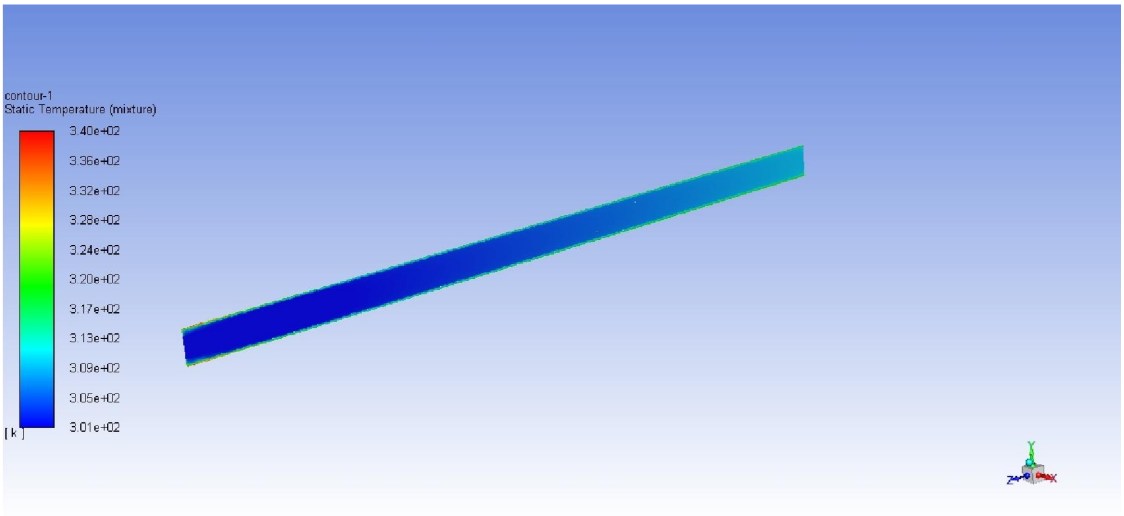


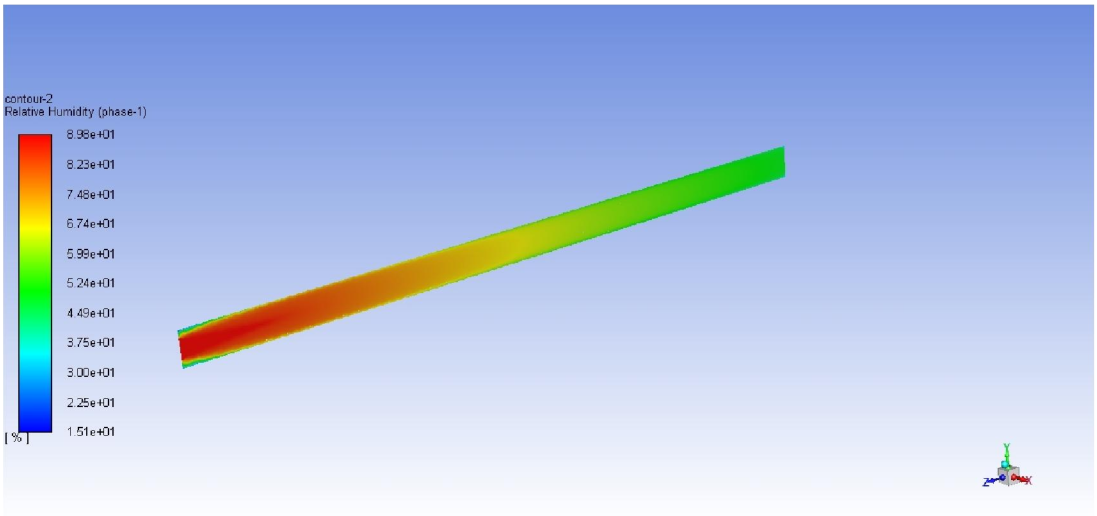
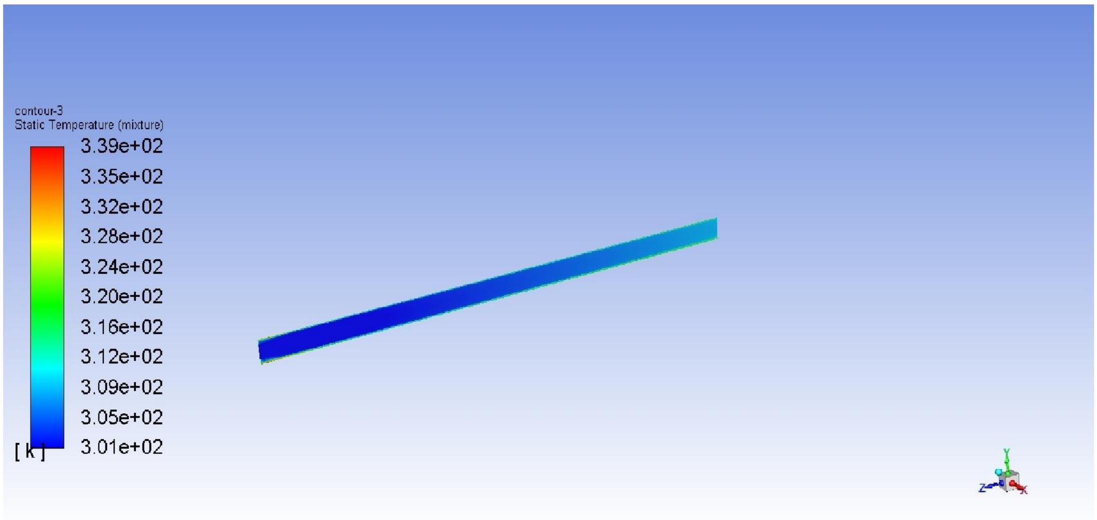


Figure 3.7 Representation of Temperature, Relative humidity at velocity magnitude 3 m/s



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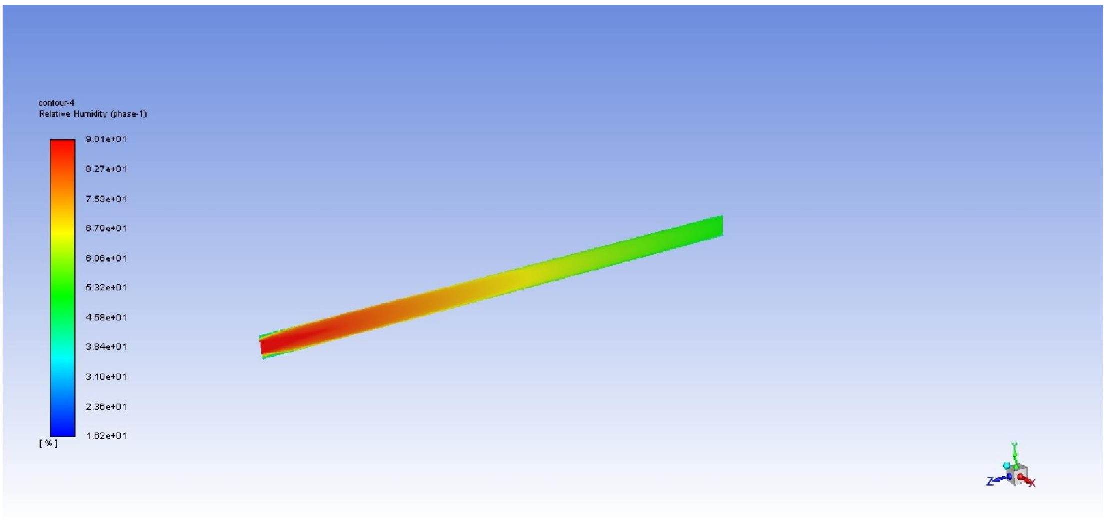
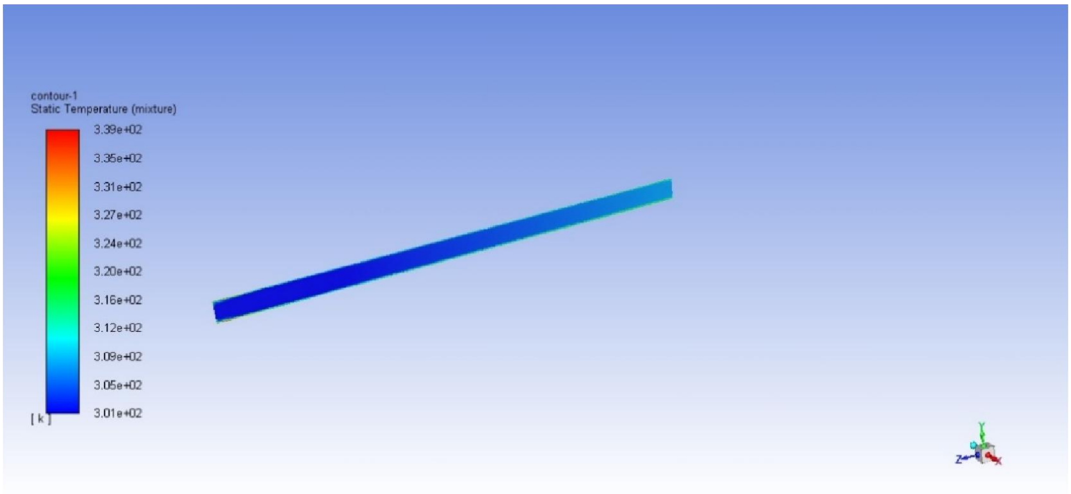


Figure 3.8 Representation of Temperature, Relative humidity at velocity magnitude 3.5 m/s



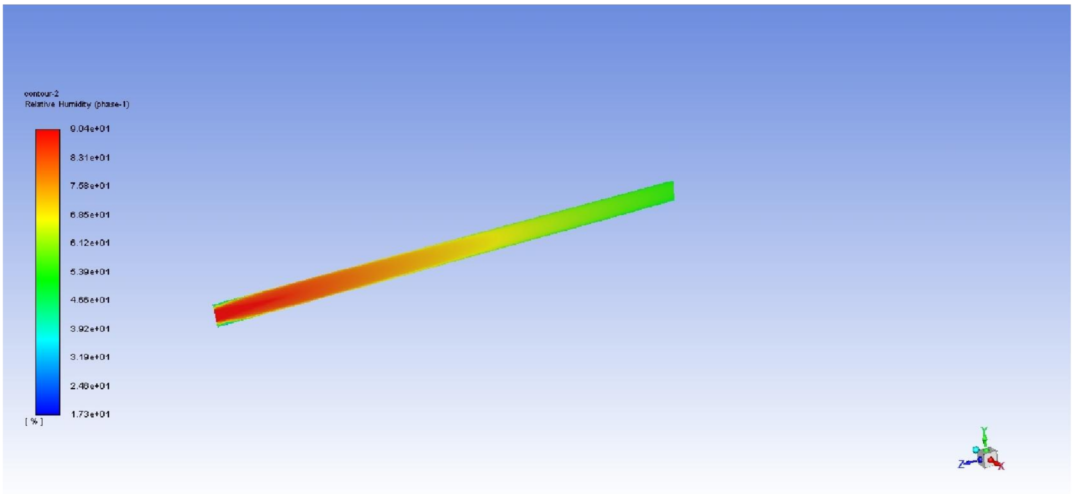


Figure 3.9 Representation of Temperature, Relative humidity at velocity magnitude 4 m/s

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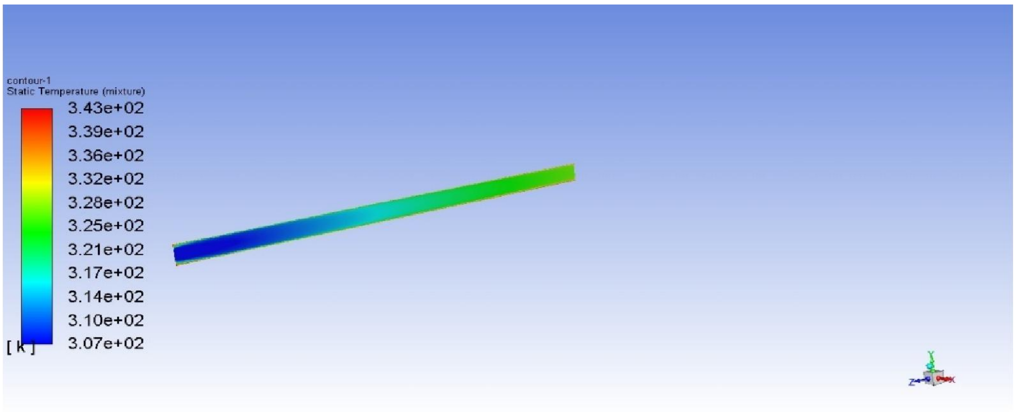
Climatic Condition 2

For, Inlet Temperature = 306.55 K and Relative Humidity = 70 % with different velocity 0.5-4 m/s



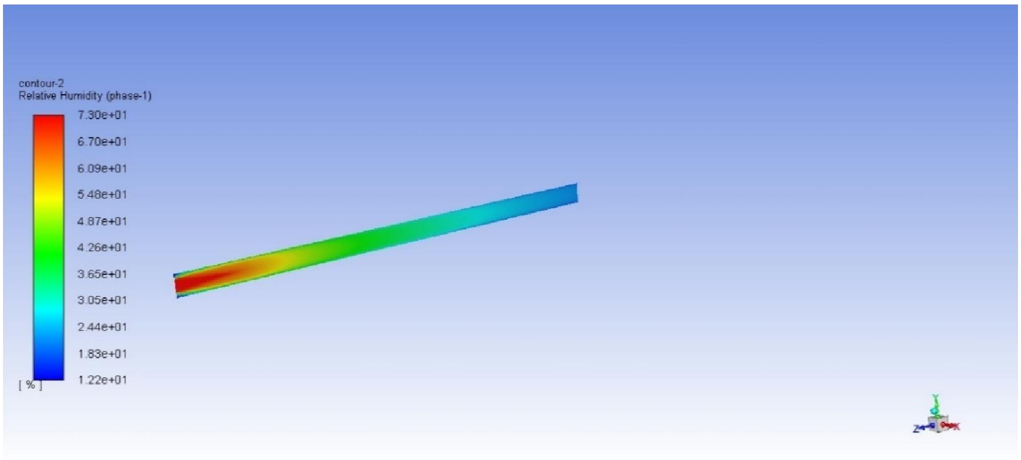
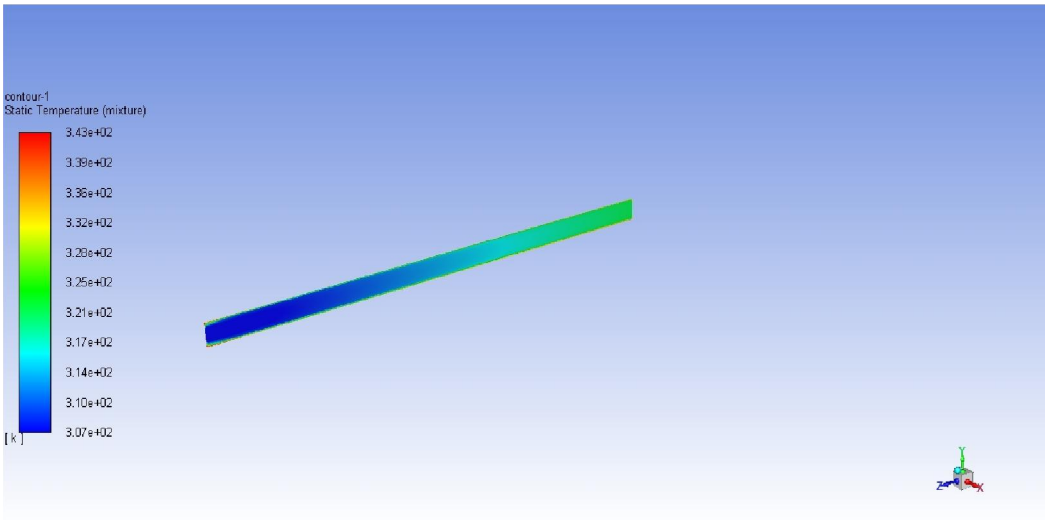


Figure 3.10 Representation of Temperature, Relative humidity at velocity magnitude 0.5 m/s



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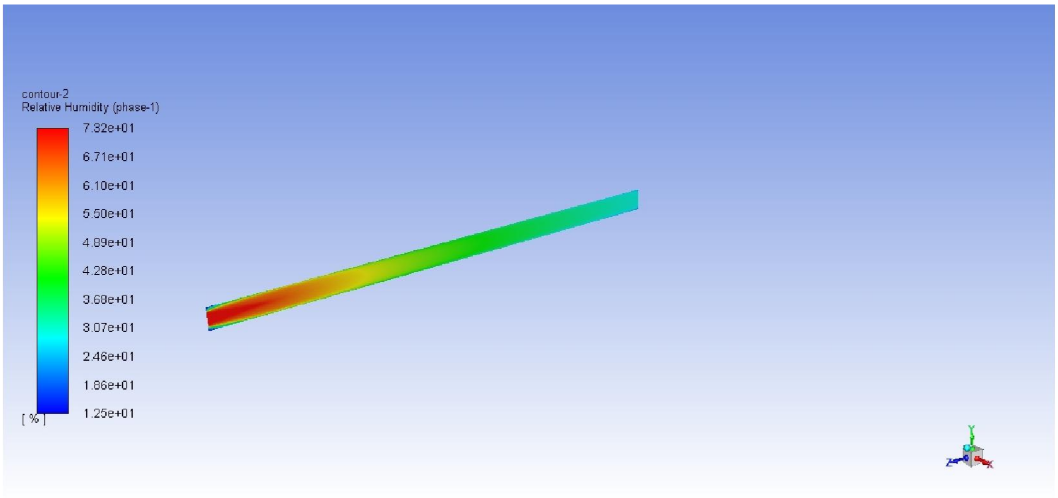

Figure 3.11 Representation of Temperature, Relative humidity at velocity magnitude 1 m/s

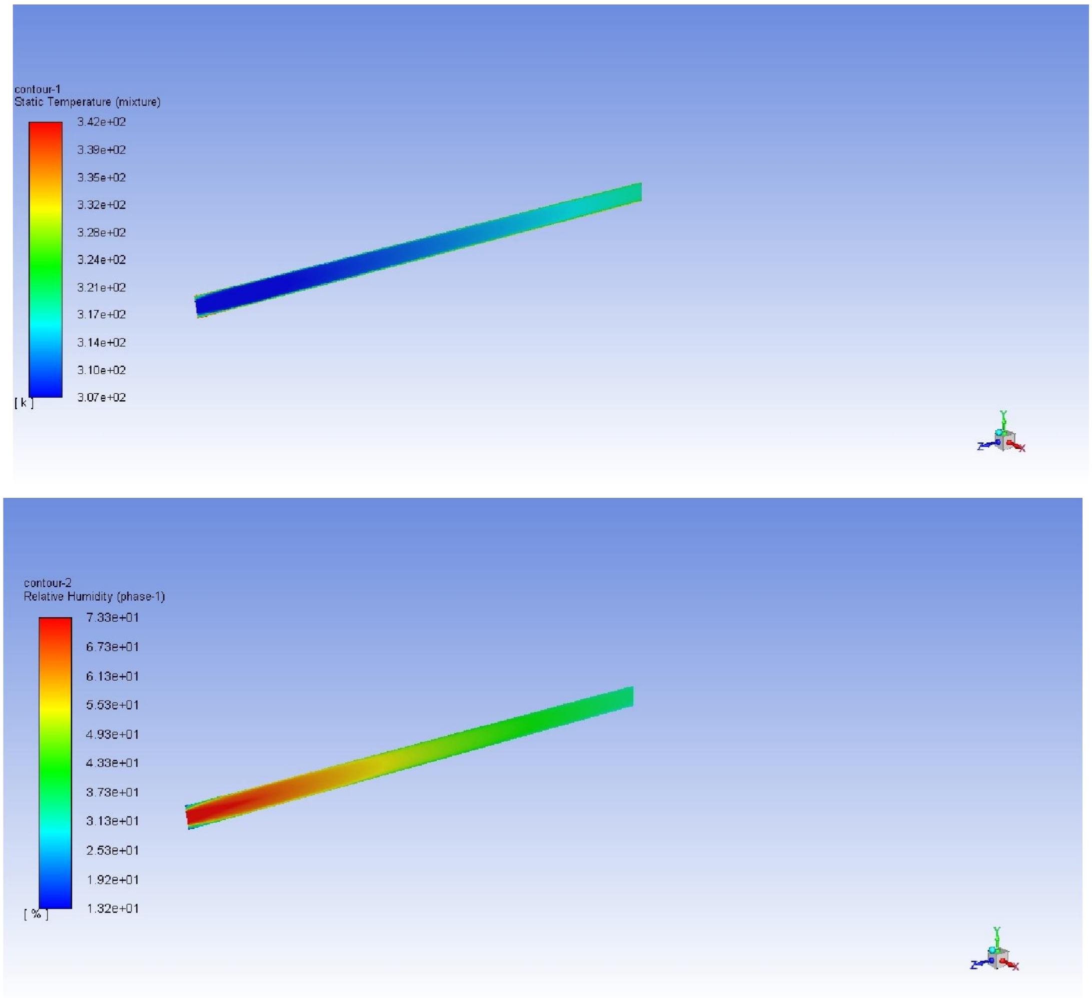

Figure 3.12 Representation of Temperature, Relative humidity at velocity magnitude 1.5 m/s

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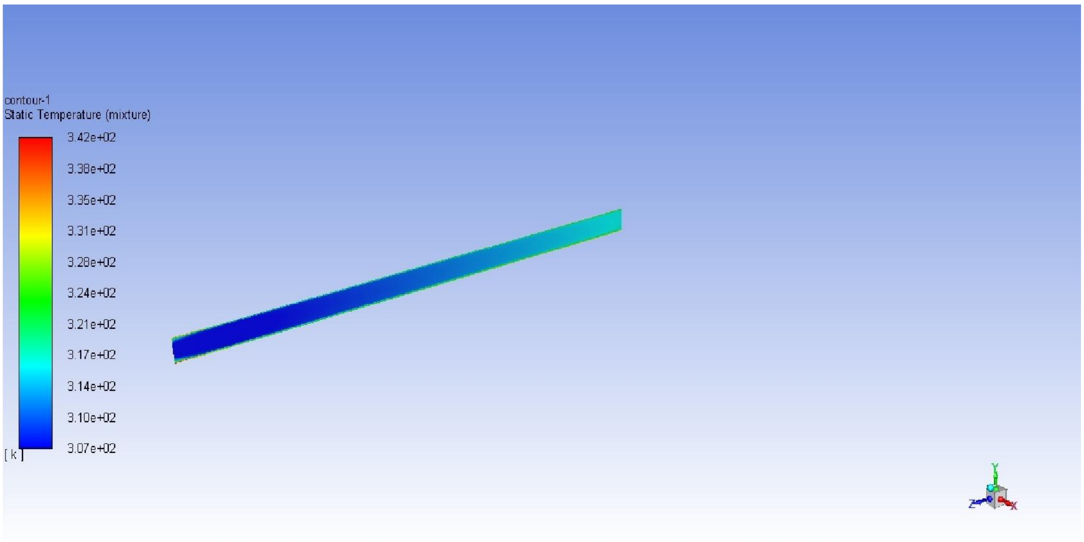


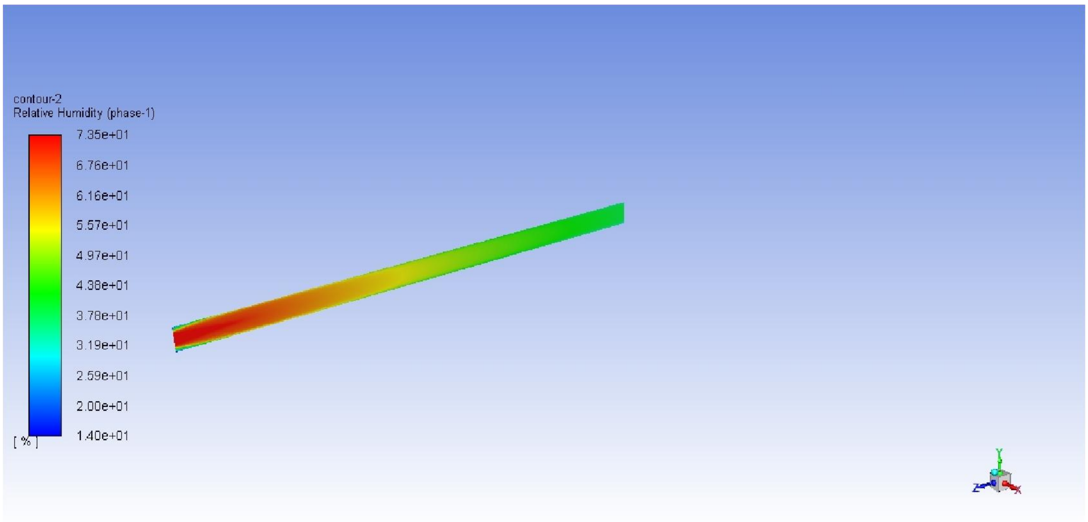
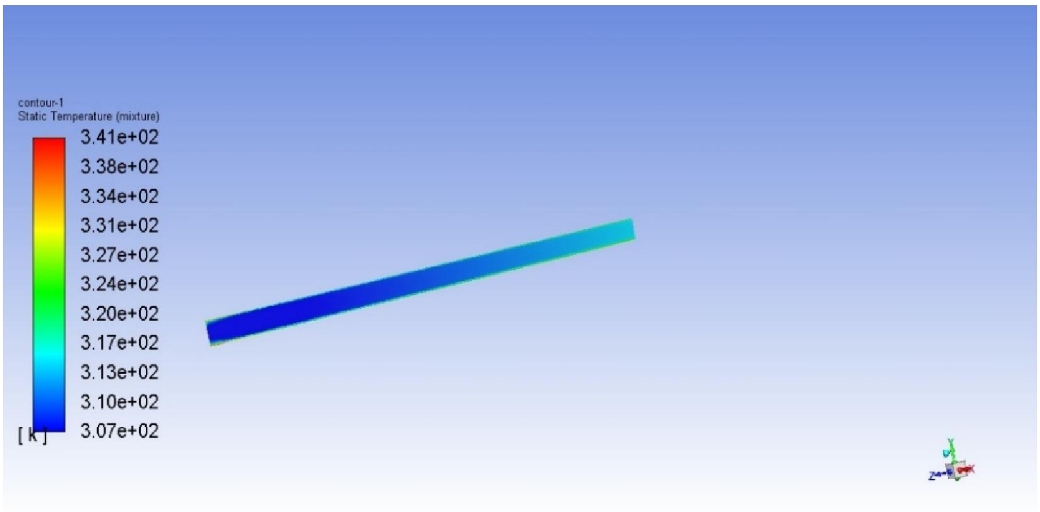


Figure 3.13 Representation of Temperature, Relative humidity at velocity magnitude 2 m/s



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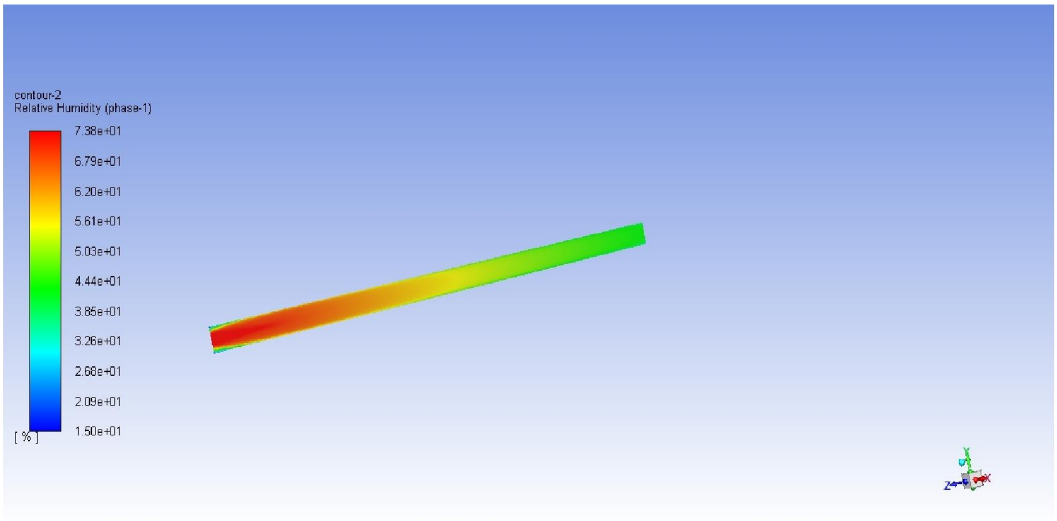

Figure 3.14 Representation of Temperature, Relative humidity at velocity magnitude 2.5 m/s

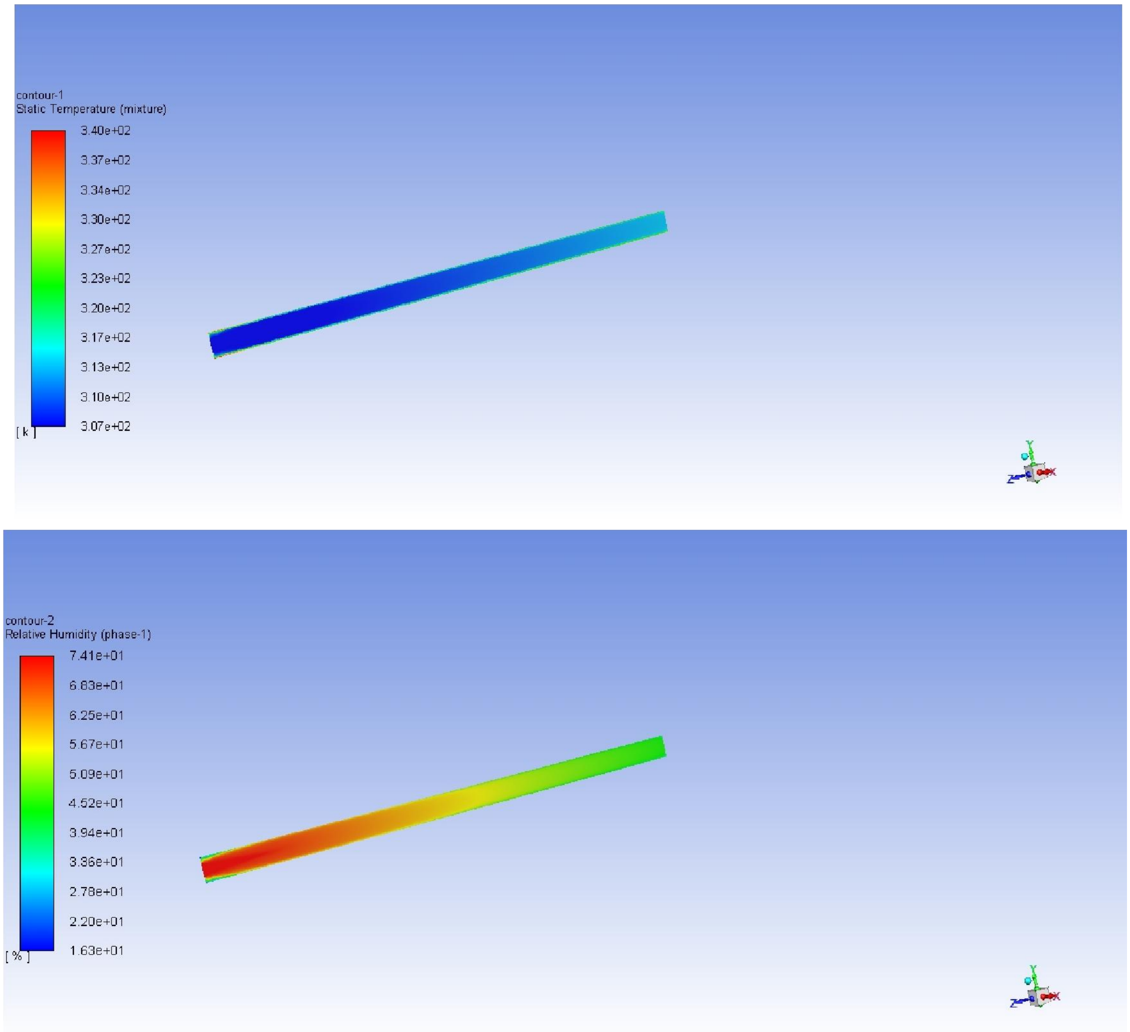

Figure 3.15 Representation of Temperature, Relative humidity at velocity magnitude 3 m/s

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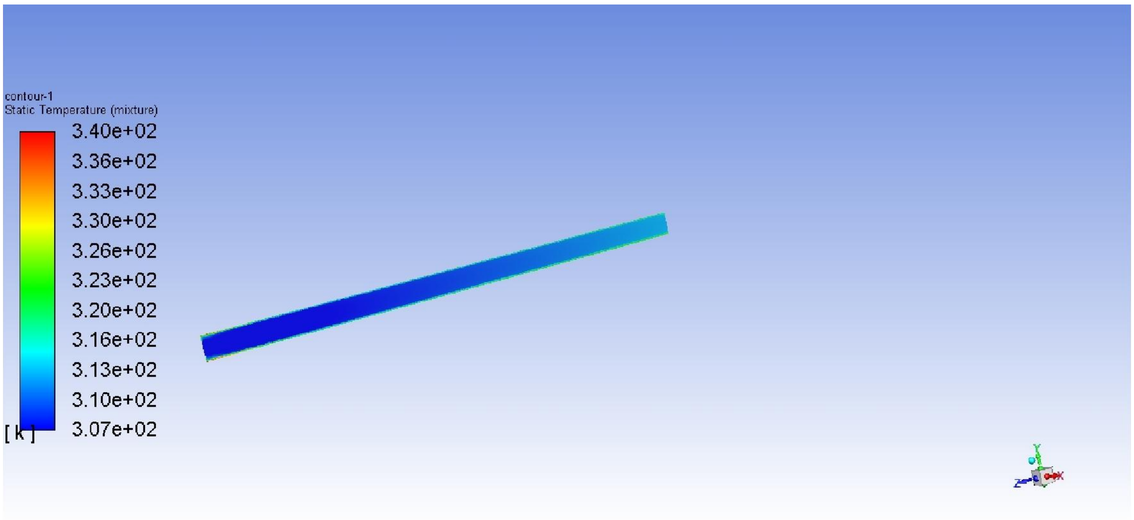


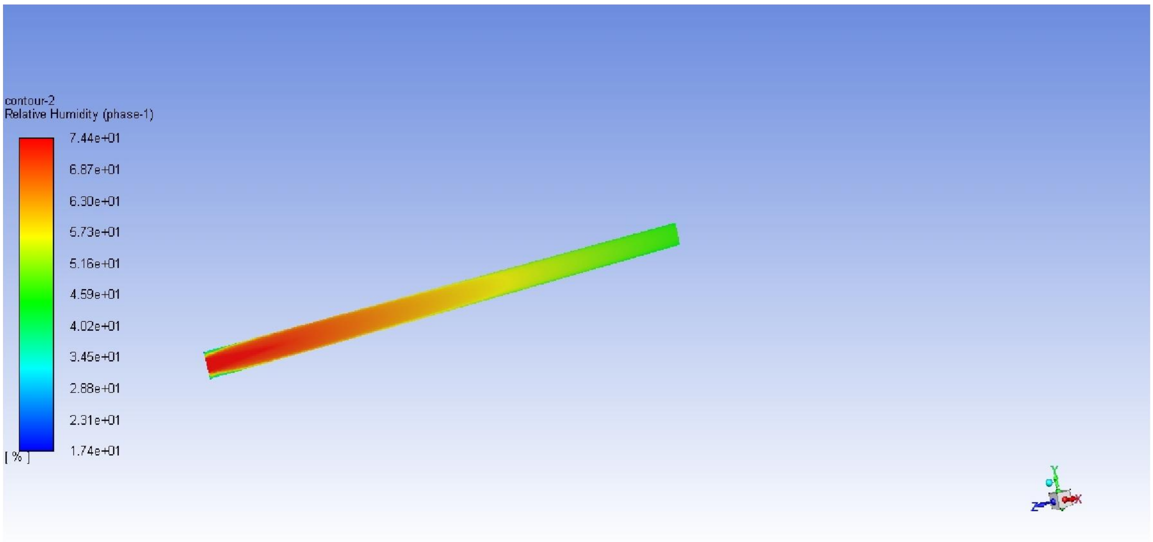
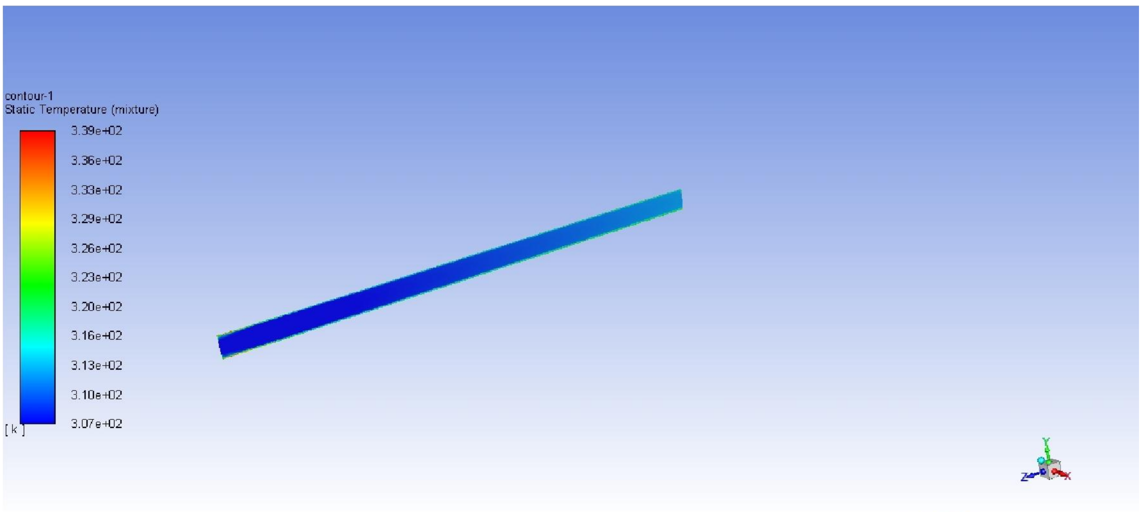


Figure 3.16 Representation of Temperature, Relative humidity at velocity magnitude 3.5 m/s



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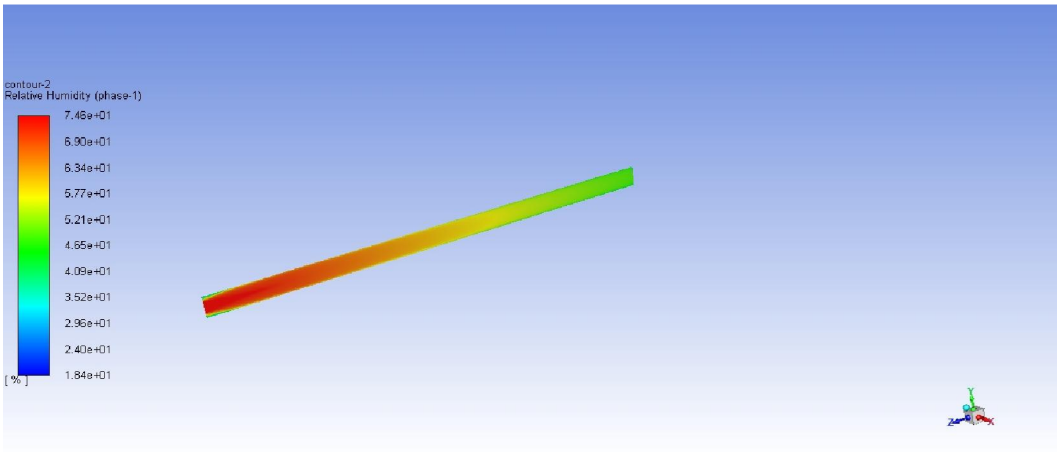

Figure 3.17 Representation of Temperature, Relative humidity at velocity magnitude 4 m/s

IV RESULTS AND CONCLUSIONS

Climatic Condition 1;

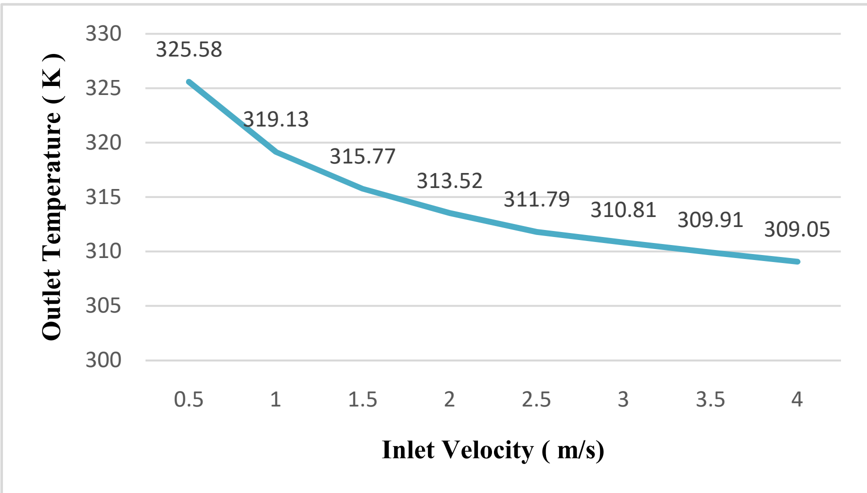

Figure 3.18 Velocity Magnitude Vs Outlet Temperature

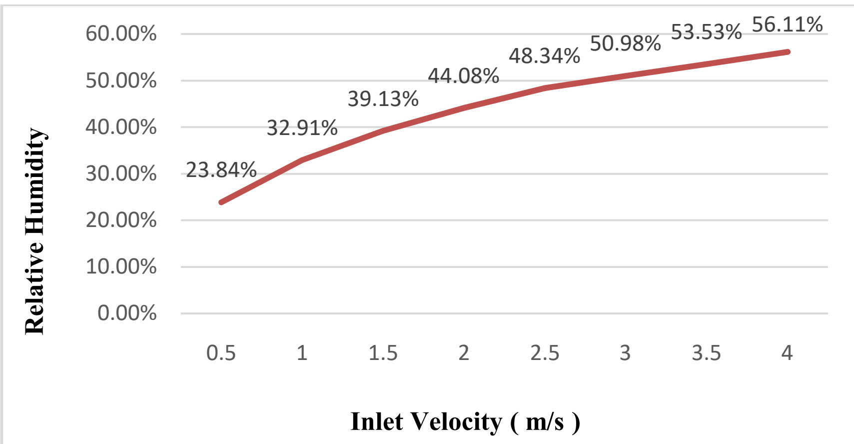

Figure 3.19 Velocity Magnitude Vs Outlet Relative Humidity

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Climatic Condition 2;

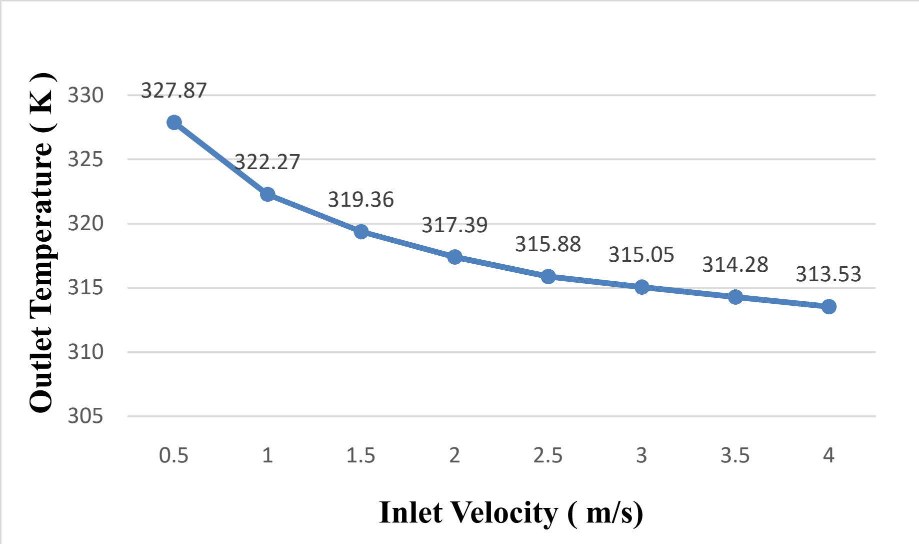

Figure 3.20 Velocity Magnitude Vs Outlet Temperature

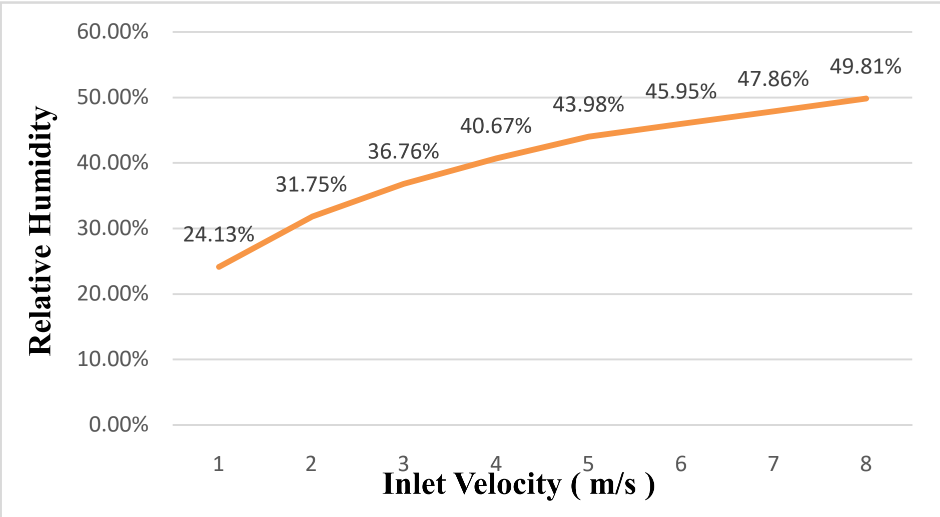

Figure 3.21 Velocity Magnitude Vs Outlet Relative Humidity

Table 3.2 Effectiveness of Desiccant Wheel

The simulations of three-dimensional desiccant wheel model carried out for a wide range of working conditions. The analysis is in terms of Effectiveness of desiccant wheel. The simulations are carried out in order to investigate the effect of the variation of velocity magnitude on the temperature distribution of solid desiccant wheel. The absorbed water vapour is usually removed from the desiccant by regeneration in which desiccant is exposed to a regeneration airstream having temperature between 60 and 150°C.we use the Zeolite, DH-5, DH-7 instead of using silica gel for better a adsorption rate. There are different simulation techniques used to achieve the better results at minimum cost.

Nomenclature

$\varepsilon_D = Effectiveness\ of\ desiccant\ wheel$

$T_{pro,in} = Process\ air\ inlet\ temperature$

$\omega_{pro,in} = Humidity\ ratio\ of\ process\ air\ at\ the\ inlet$

$\omega_{pro,out} = Humidity\ ratio\ of\ process\ air\ at\ the\ outlet$

$T_{reg} = Regeneration\ temperature$

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