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Dehumidification Performance of LiCl in Falling Film Type Liquid Desiccant Dehumidifier

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Abstract: In the present study, CFD analysis of falling film type liquid desiccant dehumidifier is carried out to predict its performance In these simulations it is studied how the flow pattern of liquid desiccant effects the interaction between the moist air and the liquid desiccant.Two dimensional model was simulated by using the software ANSYS (FLUENT). The volume of fluid (VOF) was selected as the multiphase method for the simulation process. The water vapor/humidity content in the air is given by using species transport model and the variation of amount of water hold by the air is simulated. The liquid desiccant considered for study is LiCl with 30% concentration and the mass fraction of water vapor used in air is varied from 0.01 to 0.02. The properties of LiCl at 30% concentration were calculated and inlet parameters of air and desiccant are fed to the software as input. The model was subjected to different inlet mass fractions and determined the dehumidification effectiveness.

Index Terms: Dehumidification, Liquid Desiccant, Falling Film, Dehumidifier.

NOMENCLATURE

c_p= specific heat of mixture.
P= pressure
ω= humidity ratio
u= velocity
T= temperature
E= energy term
k_{eff} = effective thermal conductivity
α = volume fraction
μ= viscosity of fluid
ρ= density of fluid

I. INTRODUCTION

The traditional air conditioning system causes lot of environmental hazards and requires high grade energy for operation. Air conditioning system with liquid desiccant based dehumidifier has the ability to replace the existing VCR based air conditioning system and it is relatively environmental friendly. Desiccant dehumidification can be carried out by using either solid desiccants or by liquid desiccants, but the solid desiccants causes higher pressure difference compare to liquid desiccants. In case of liquid desiccant based system, moist air is flown over liquid desiccant. The concentrated liquid desiccant absorbs moisture from the moist air and becomes weak. The weak liquid desiccant is passed through the regenerator in which it is treated with the hot air. The hot air separates the water from the liquid desiccant and thus the weak liquid desiccant converts to concentrated liquid desiccant and this concentrated liquid desiccant is again passed through the dehumidifier and the cycle continues.

The main advantage of the liquid desiccants is that it has lower pressure drop compared to solid desiccants and also the temperature required for regeneration is less so renewable energy like solar can be used. Liquid desiccants availability is high and are cheaper. They are stable in nature with less corrosiveness, less flammability and free from odour and toxic content. Surface tension has a vital role in these liquid desiccants. Commonly available liquid desiccants are LiCl, LiBr, $CaCl_2$, potassium formate etc. Recently, many researchers are using CFD analysis to understand the feasibility of using different liquid desiccants in dehumidification and some of the studies are mentioned below.

Luo et al. [1] studied the interaction between the liquid desiccant and the air and numerically investigated heat and mass transfer between them by using the VOF model. The study was carried out by considering LiCl as the liquid desiccant, falling film as model for simulation without neglecting the effect of gravity, surface tension and viscosity.

Ronghui et al. [2] investigated the effect of contact angle of liquid desiccant on the dehumidification rate. Experiment with the LiCl and LiBr liquid desiccants on the stainless steel plate as a falling film was performed and found out that increase in mass concentration or decrease in temperature of the liquid desiccant influenced the contact angle and the contact area of the liquid desiccant which indirectly influenced the dehumidification rate.

Sreelal and Hariharan [3] has done a numerical simulation for a flat plate counter flow dehumidifier by using two-dimensional model for dehumidification of air. The results indicate the variation of volume fraction at different velocities and at different temperatures of air. The simulations were carried out using transient, multiphase method considering volume of fluid (VOF) method in ANSYS (fluent).

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Luo et al. [4] established a numerical model to study the performance of liquid desiccant based dehumidifier under different flow rates and different temperature conditions desiccant, with and without the internal cooling.

It was found that the dehumidification performance is low at high temperatures and also the dehumidification performance was more for internal cooled rather than the model without cooling.

Run-ping [5] developed the model for the simulation of simple cross flow and analyzed for the characteristics effecting heat and mass transfer by using the relevant equations. Lithium chloride liquid desiccant was used for the simulation purpose and the results from the numerical simulation are found satisfactory.

Emhofer et al. [6] analyzed the liquid desiccant dehumidification system in cross flow condition with LiBr as a liquid desiccant. He developed a mathematical model where it takes into the account of heat and mass flux properties between the the liquid desiccant and air. He discussed the problems related with the current geometry and provided a remedy for that.

Wen et al. [7] studied the effect by adding non-toxic additive (polyvinyl pyrrolidine PVP-K30) into liquid desiccant Lithium chloride. The results show that it reduced the contact angle and improved the wetting ratio by using additive. Also, the dehumidification rate and effectiveness shows a better result than the single liquid desiccant and performed better than the normal desiccant. Also due to this surfactant the film thickness along the flow is decreased thereby increased the dehumidification capability.

In the present study, the performance of falling film type dehumidifier with LiCl as liquid desiccant is studied for different environmental conditions.

II. MODELLING AND SIMULATION

Falling film (counter flow) type of dehumidification model has been considered in the present study. In this model the air and the liquid desiccant interact in counter flow in which the liquid desiccant enters from the top and flows along the left face as film and the air enters from the bottom. Figure 1 shows the physical model.

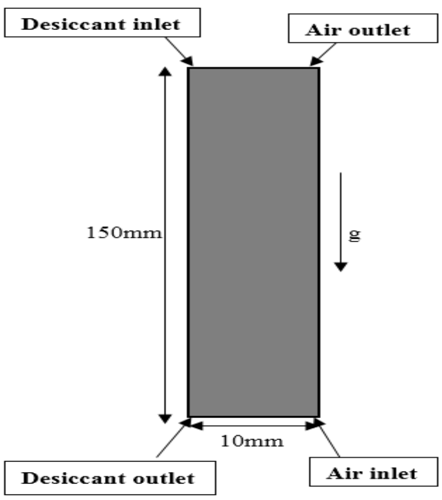

Figure 1: Falling film (counter flow) type of dehumidifier

A 2-D CFD model is developed by assuming the uniform flow, heat transfer and mass transfer conditions within the chamber. The volume of fluid (VOF) was selected as the multiphase method for the simulation process. Here the water and air is mixed by using species transport model in which the mass fraction of water in air is specified along with the volume fraction. SIMPLE and Pressure interpolation scheme PRESTO are used for handling pressure–velocity coupling. First order up wind differencing is selected for solving the momentum and energy equations to speed up the calculation. The gravitational effect is not neglected here as it is a vertical chamber.

Conservation equations used for simulating dehumidification process includes mass, momentum and energy.

As it is a 2-phase gas-liquid system, volume fractions of liquid and gas are to be incorporated in the mass and momentum conservation equations. Density ρ and viscosity µ in each cell of computational domain is represented by

$$\rho = \alpha_l \rho_l + \alpha_g \rho_g$$

$$\mu = \alpha_l \mu_l + \alpha_g \mu_g$$

The volume fraction relationship between the liquid and gas is given by

$$\alpha_l + \alpha_g = 1$$

Volume fraction is given as

If the computational cell is with 100% liquid

$$\alpha_l = 1$$

If the computational cell is with zero liquid

$$\alpha_l = 0$$

If the cell is mixture of liquid and gas

$$0 < \alpha_l < 1$$

The mass conservation equation is given as

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho u) = 0 \qquad (1)$$

The conservation equation for momentum is given as

$$\frac{\partial(\rho u)}{\partial t} + \nabla.(\rho u u) = -\nabla P + \nabla.(\mu(\nabla u)) + \rho g \qquad (2)$$

where, P is the pressure between the phases.

The thermal energy equation is given by

$$\frac{\partial(\rho E)}{\partial t} + \nabla.(u(\rho E + P)) = \nabla.(k \nabla T) + S_E \qquad (3)$$

where S_E is the energy source term. The equation for E is given by

$$E = \frac{\sum_{q=1}^{n} \alpha_q \rho_q E_q}{\sum_{q=1}^{n} \alpha_q \rho_q} \qquad (4)$$

Where, E_q is obtained at the q[th] phase by using specific heat and temperature

The specific heat of the fluid is calculated by:

$$c_p = \rho^{-1}(\alpha_l \rho_l c_{p,l} + (\alpha_g)\rho_g c_{p,g}) \qquad (5)$$

For the species transport equations

$$\frac{\partial}{\partial t}(\alpha_q \rho_q x_{k,q}) + \nabla.(\alpha_q \rho_q u x_{k,q}) = S_{j,gk} \qquad (6)$$

Where q=1to n k=1 to m

$$S_{j,gk} = K_g(\omega_{gb} - \omega_{ge}) \qquad (7)$$

where $x_{k,q}$ is the mass fraction of the component k in the q[th] phase. $S_{j,gk}$ is the mass transfer source and $(\omega_{gb} - \omega_{ge})$ represents the difference in specific humidity with the equilibrium specific humidity.

Properties of lithium chloride at 298 K and 30% concentration are mentioned in table 1 and inlet conditions are provided in table 2. Flow chart for the simulation procedure is provided below.

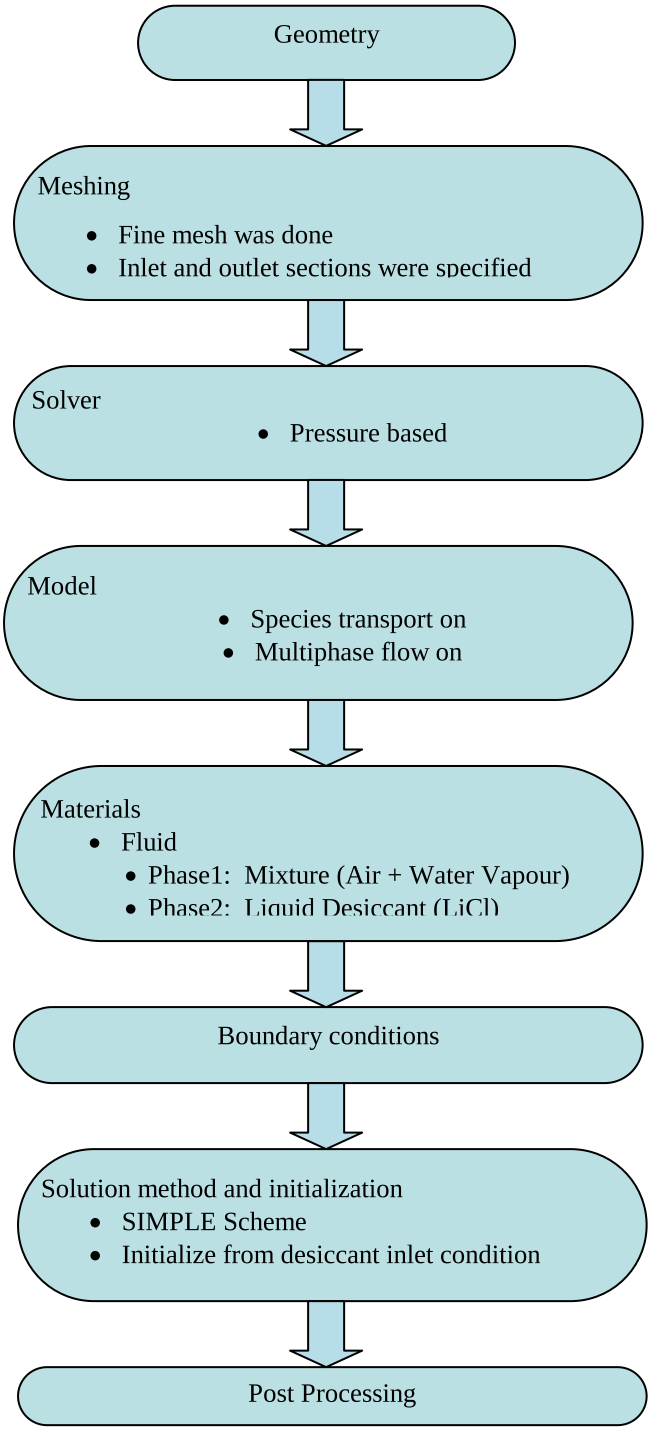

Table 1 Properties of lithium chloride

Density (kg/m3)	1180
Viscosity (kg/m-s)	0.00359
Surface tension (N/m)	0.0893
Specific heat capacity (J/kg K)	2933
Molecular weight (kg/kmol)	42.35
Thermal conductivity(W/m-k)	0.45

Table 2 Inlet conditions

Parameters at inlet	Air	Desiccant
Temperature (K)	305	298
Velocity(m/s)	0.2	0.07
Mass Fraction (%)	1-2	30

Model for the dehumidifier is created in Ansys and the meshing of the model is done with fine relevance throughout as shown in figure 2.

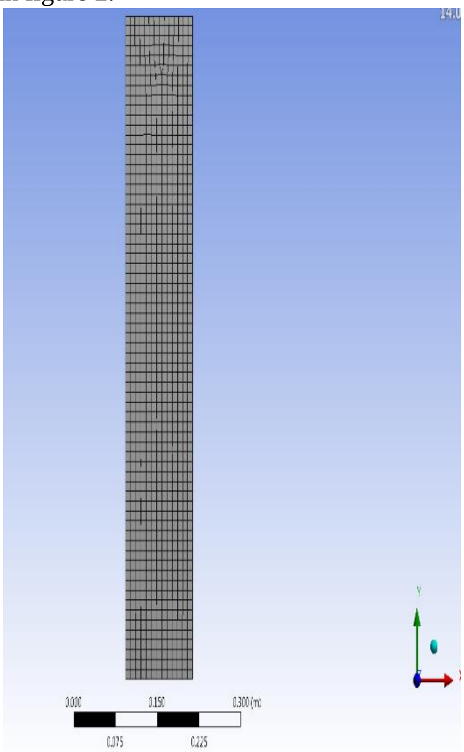

Figure 2: Meshed Model

III. RESULTS AND DISCUSSION

CFD simulations of the model is carried out and the results pertained to mass fraction of water vapor and temperature was analyzed. Six different inlet mass fractions of vapor in air were considered from 0.01 to 0.02 in increments of 0.002 for the analysis. The simulations were carried out for 10 seconds. Figures 3 to 8 shows the mass fraction contour of water vapor in air for different inlet mass fractions. Table 3 shows the values of inlet mass fraction of water vapor in air, outlet mass fraction of water vapor in air and the mass fraction absorbed by desiccant. It is observed that the amount of water collected from air increased with the increase of inlet mass fraction of water vapor in air. This is due to the fact that when the inlet mass fraction of water vapor in air is increased, the vapor pressure of the air is increased which in turn increased the mass transfer. Dehumidification effectiveness is evaluated using the following equation.

$$\varepsilon_d = \frac{\omega_{a,in} - \omega_{a,out}}{\omega_{a,in} - \omega_{a,eq}}$$

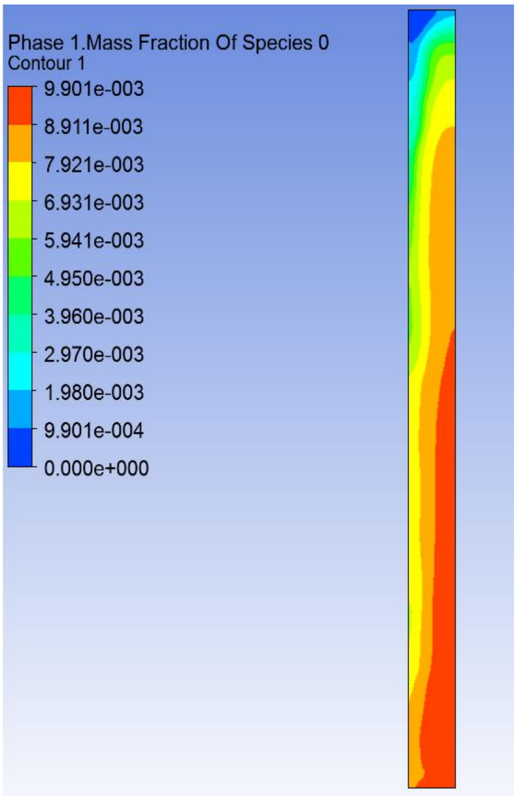

Figure 3: Mass fraction profile for 0.01 case

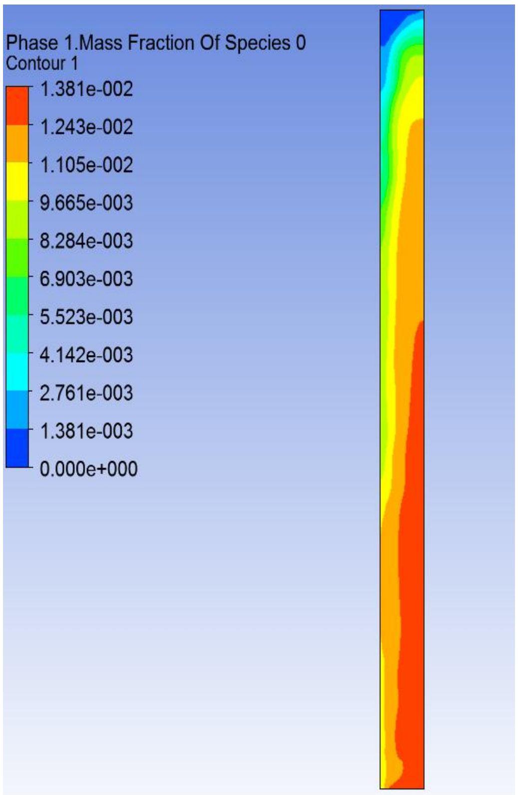

Figure 5: Mass fraction profile for 0.014 case

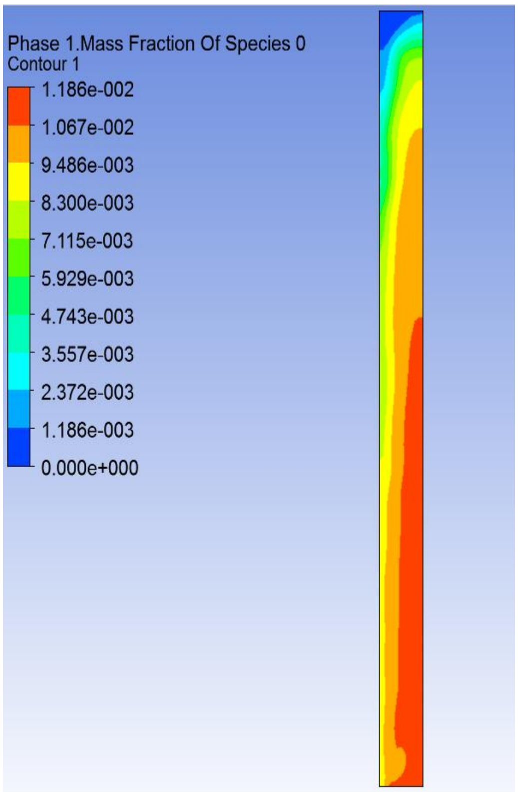

Figure 4: Mass fraction profile for 0.012 case

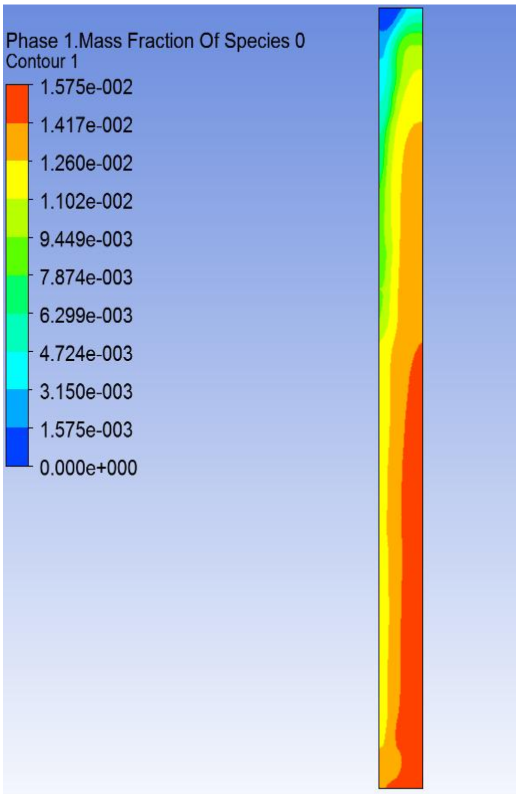

Figure 6: Mass fraction profile for 0.016 case

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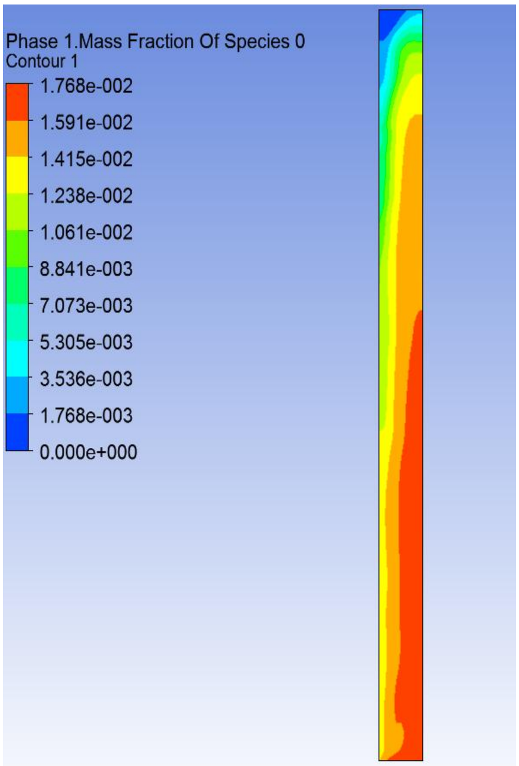

Figure 7: Mass fraction profile for 0.018 case

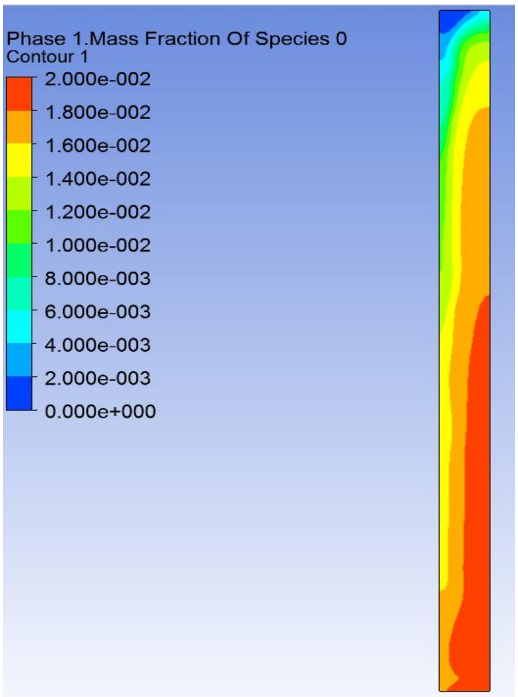

Figure 8: Mass fraction profile for 0.02 case

Dehumidification effectiveness increased with the increase in inlet mass fraction of water vapor in air as shown in figure 9 and reached up to 0.9. Temperature contours for all the cases are shown in Figures 10 to 15. It is clearly observed that desiccant temperature at the outlet is raised when compared to the inlet temperature of desiccant. This is due to the fact that the liquid desiccant dehumidification is an exothermic reaction, which is clearly observed in the present study.

Table 3 Mass fractions and water vapor absorbed by desiccant

Mass fractions		Water Vapor absorbed
Inlet	Outlet	
0.01	0.001198	0.008703
0.012	0.000977	0.010881
0.014	0.001375	0.012431
0.016	0.002985	0.012763
0.018	0.002211	0.015471
0.02	0.003056	0.016944

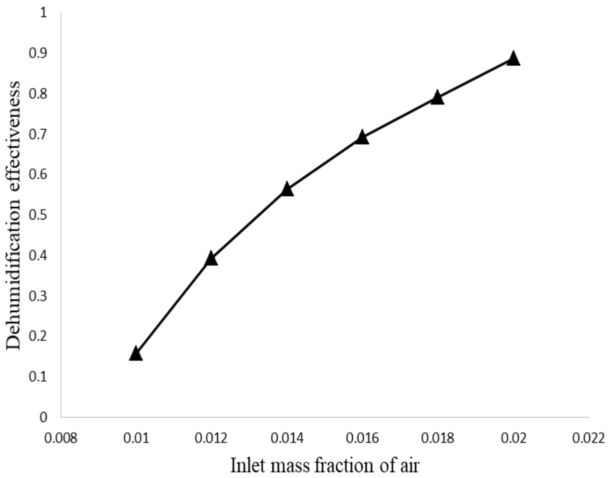

Figure 9: Dehumidification effectiveness

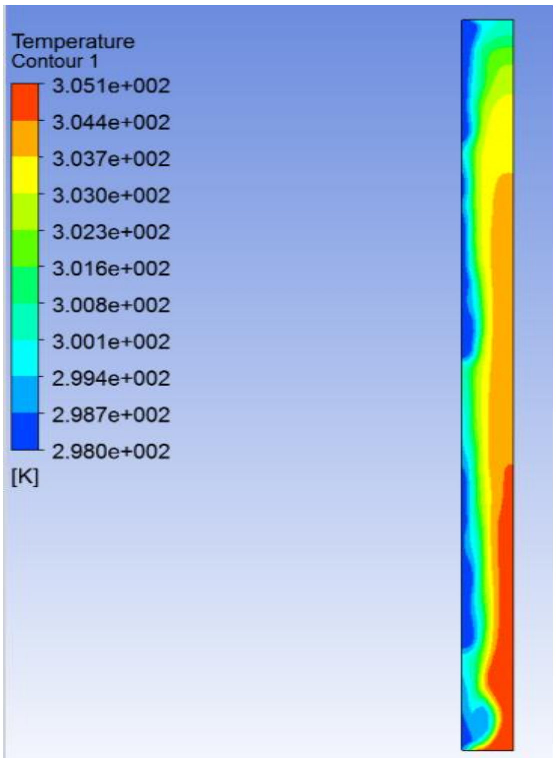

Figure 10: Temperature profile for 0.01 case

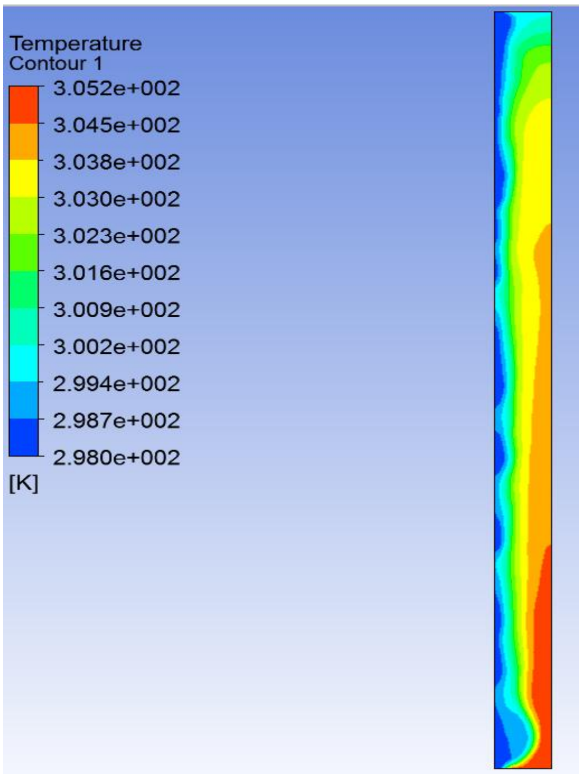

Figure 111: Temperature profile for 0.012 case

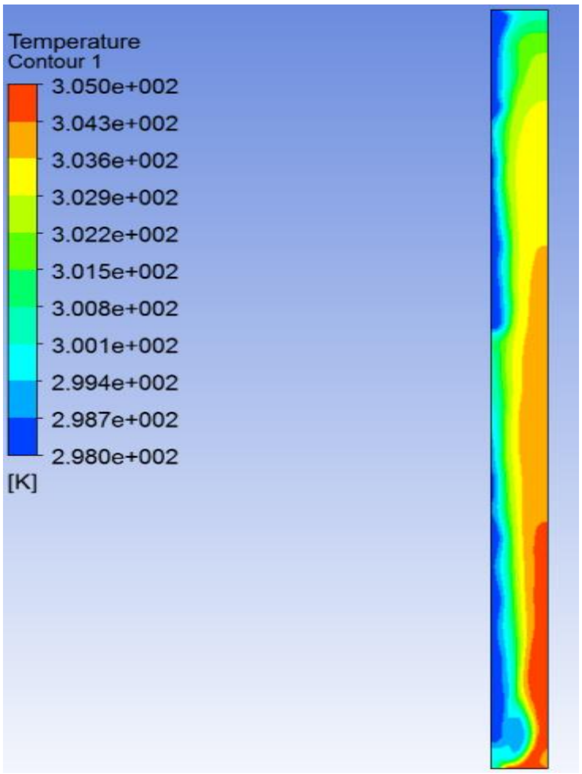

Figure 10: Temperature profile for 0.016 case

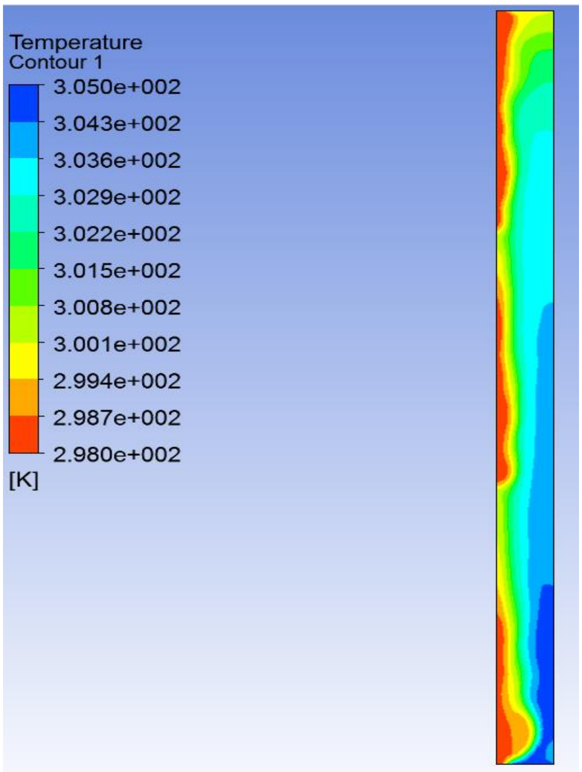

Figure 12: Temperature profile for 0.014 case

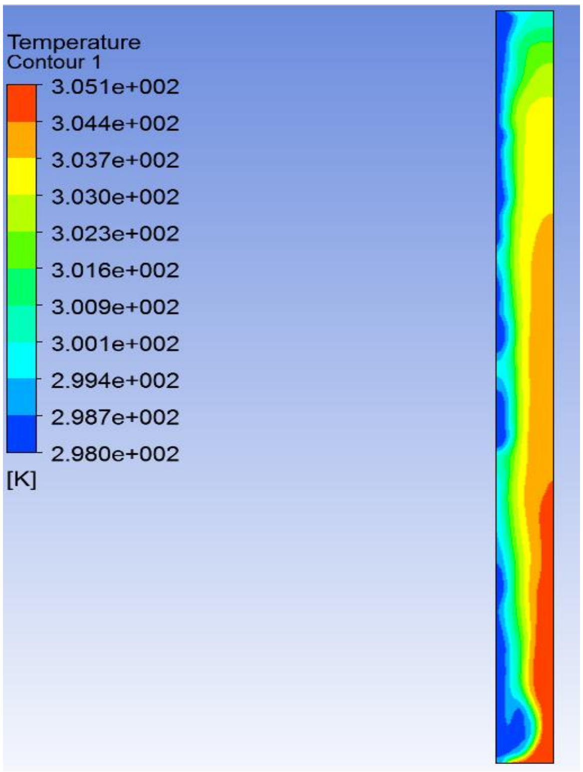

Figure 10: Temperature profile for 0.018 case

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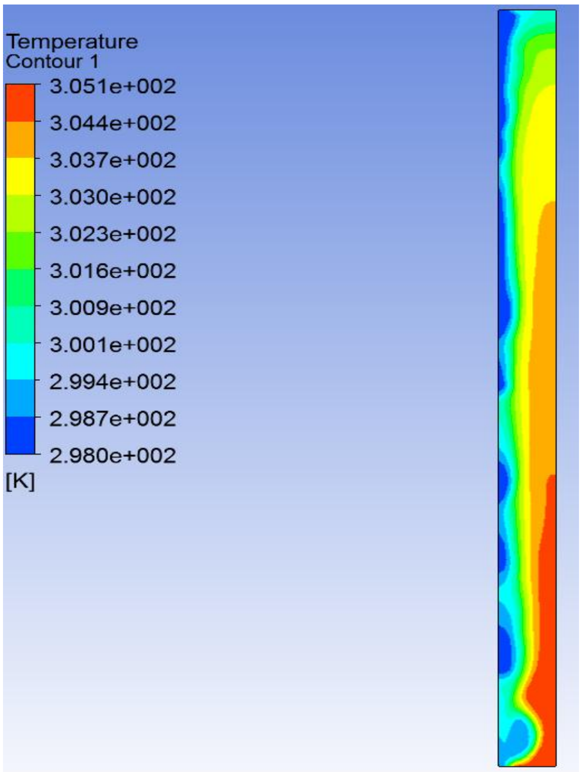

Figure 10: Temperature profile for 0.02 case

IV. CONCLUSION

Following conclusions are the outcome of the computational investigation

- It is observed that the dehumidification effectiveness is higher for humid air which indicates that LiCl desiccant is highly suitable for high humid climatic regions.
- Carry-over of the liquid desiccant is observed at high velocities that demand the further study to identify the relative operating velocities of air and the LiCl desiccant.
- Increase in temperature of LiCl desiccant is observed during the dehumidification process that may result into the rise of air temperature which in turn effect the COP of the liquid desiccant air conditioning system.

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