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Application of CFD Model in Analyzing the Performance of a Liquid Desiccant Dehumidifier

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Abstract

The dehumidifier of a liquid desiccant air conditioning system was the research object of present paper. A model was established on the basis of CFD. The interior heat and mass transfer processes were simulated with the model. Intensive analysis was conducted to investigate the influence of some factors, including the inlet desiccant temperature, desiccant flow rate and internally cooling.

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Keywords: CFD model; Liquid desiccant dehumidifier; Less assumptions; Intensive analysis

1. Introduction

Along with the living standards improves, more and more attention has been paid in the building environment, which relies almost on the large consumption of fossil fuels [1]. To reduce the dependency, people have always tried to improve energy utilization efficiencies of indoor devices [2] or turned to renewable energy [3-5].

For the traditional air conditioner, it was reported that about 30～50% of the total energy consumption was due to the condensation dehumidification. Thus, the liquid desiccant dehumidification unit was proposed to be integrated with the traditional air conditioner. It is the liquid desiccant air conditioning system, which can realize the separate control of temperature and humidity. Unlike the traditional air conditioner, the latent heat is controlled by removing the moisture from the air with liquid desiccant. As it needs not to reduce the air temperature to the dew-point temperature, the evaporative temperature of the

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cooler is increased so as the cooler COP in the liquid desiccant air conditioning system is higher than that of the traditional air conditioner [6].

The major component of interest in the liquid desiccant air conditioning system is the dehumidifier in which the process of heat and mass transfer occurs between humid air and liquid desiccant. Until now, several kinds of simulation models have been developed to predict and assess the performance of the dehumidifier [7-9]. However, most of the models did not take the flow into consideration. To simplify the heat and mass transfer process, lots of common assumptions have been made for the above models. Moreover, most of the study focused on the inlet and outlet parameter changes rather than the interior condition of the dehumidifier.

To fill the research gap, a model on the basis of CFD was established to study the performance of the dehumidifier under different conditions. With the model, the interior heat and mass transfer process could be obtained. Intensive analysis was conducted to investigate the influence of some factors, such as inlet desiccant temperature, desiccant flow rate and internally cooling.

2. Mathematical model

2.1. Geometric model

Numerical simulations were conducted for the unsteady two-phase flow with free liquid surface in the channel between two flat plates. The simplified geometric constructions are presented in Fig. 1.

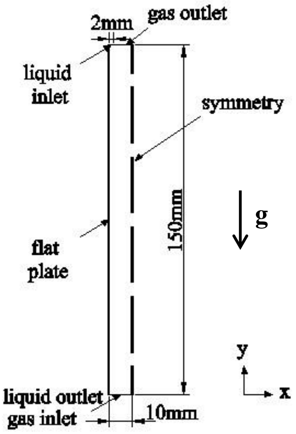


Fig. 1. simplified physical model

2.2. CFD equations

The basic principles of CFD are mass conservation, momentum conservation and energy conservation.

(1) Mass conservation

$$\frac{\partial}{\partial t}(\rho)+\nabla\cdot(\rho\boldsymbol{u})=0 \tag{1}$$

In present paper, the mass transfer source $S_{\mathrm{lg,k}}$ is the water absorbed from the humid air by the solution,

$$S_{\mathrm{lg,k}} = K_{\mathrm{g}}(W_{\mathrm{g,b}} - W_{\mathrm{g,e}})A \tag{2}$$

(2) Momentum conservation

$$\frac{\partial}{\partial t}(\rho \boldsymbol{u})+\nabla\cdot(\rho \boldsymbol{u}\boldsymbol{u})=-\nabla P+\nabla\cdot(\mu(\nabla \boldsymbol{u}+\nabla \boldsymbol{u}^T))+\rho \boldsymbol{g}+\boldsymbol{F} \tag{3}$$

(3) Energy conservation

$$\frac{\partial}{\partial t}(\rho E)+\nabla\cdot(\boldsymbol{u}(\rho E+P))=\nabla\cdot\left[k_{\mathrm{eff}}\nabla T-\sum h_{\mathrm{k}}J_{\mathrm{k}}\right]+S_{\mathrm{E}} \tag{4}$$

where S_{E} is the energy source term, which is the latent heat generated by the mass transfer and is presented as follows,

$$S_{\mathrm{E}}=\sum_{k=0}^{m-1}S_{\mathrm{lg,k}}H_{\mathrm{lg,k}} \tag{5}$$

3. Material properties

The basic state of LiCl solution was set as follows: temperature 298 K, mass concentration 30%. CFD software Fluent provides the user custom interface where the files of various properties of LiCl solution at different concentrations and temperatures can be compiled with the program, including the density, thermal conductivity, mass diffusivity, viscosity, and so forth. For the moist air, the database of Fluent contains all of its physical properties. The users only need to set the two components- air and water vapor and mix them together with the relevant formulation contained by the software.

4. Results and discussion

4.1. Influence of inlet desiccant temperature

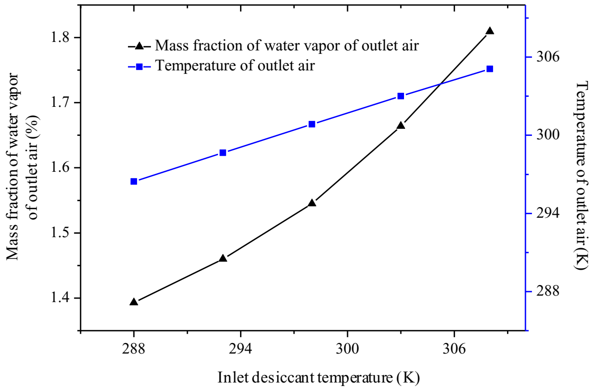


Fig. 2. mass fraction of water and temperature of outlet air

It was found that the desiccant temperature had great impact on the dehumidification performance. As shown in Fig. 2. One well known reason was that the surface vapor pressure of the desiccant with higher temperature was higher accordingly. Another reason could be explained by Fig. 3. It showed the influence of the inlet desiccant temperature on the temperature distribution of the channel. It was easy to observe that the temperature of the air was also affected significantly by the desiccant temperature due to the heat transfer. The above two factors resulted in the parabolical curve in Fig. 2.

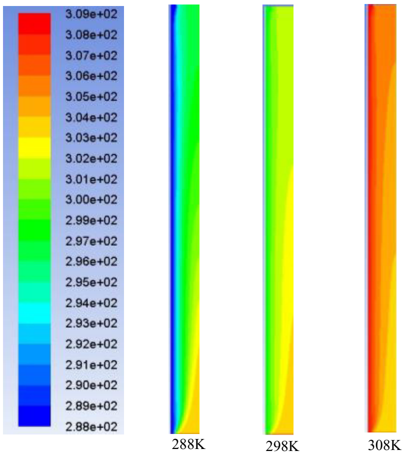


Fig. 3. Contour of temperature

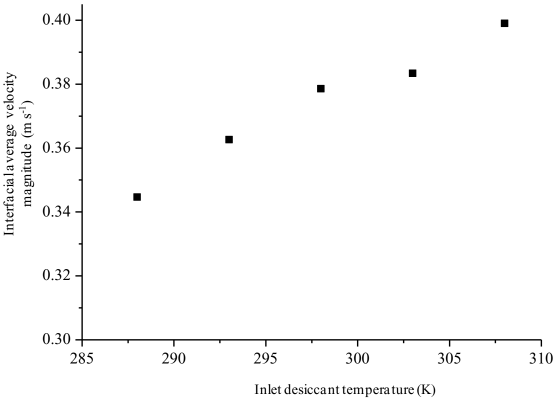
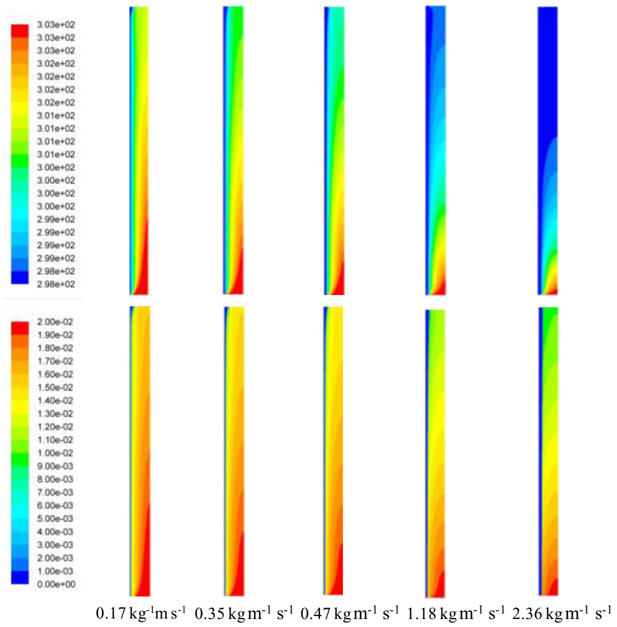


Fig. 4. interfacial average velocity magnitudes

In addition, the interfacial velocities under different inlet desiccant temperature were analyzed, as shown in Fig. 4. As the desiccant with higher temperature had lower viscosity, the corresponding interfacial velocity would be larger. The results demonstrated that the increase of the inlet desiccant temperature would enhance the interface velocity. It meant that the high temperature desiccant worsened the dehumidification performance, not only by reducing the mass transfer driving force but also through decreasing the contact time between the desiccant and air.

4.2. *Influence of inlet solution flow rate*

By looking into the contours of temperature and mass fraction of water vapor under different inlet solution flow rate in Fig. 5, a common point was found, that is, the thermal diffusion was faster than the mass diffusion. It meant $Le > 1$ for all the cases. In early research, through comparing the simulation results with the experimental data of Fumo and Goswami, Babakhani had pointed out that Le=1.1 instead of 1.0 was more preferable for the prediction of the performance of the dehumidifier. Thus, it could be verified that the present model possessed high accuracy.



0.17 kg^{-1}m s^{-1} 0.35 kg m^{-1} s^{-1} 0.47 kg m^{-1} s^{-1} 1.18 kg m^{-1} s^{-1} 2.36 kg m^{-1} s^{-1}

Fig. 5. Contours of temperature and mass fraction of water vapor

4.3. Influence of internal cooling

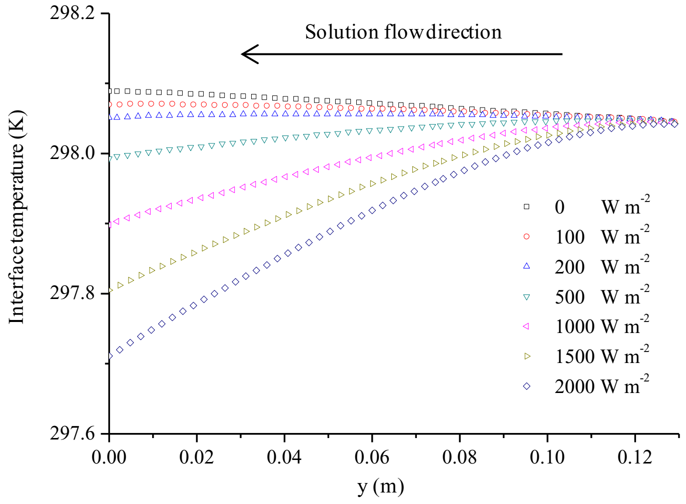


Fig. 6. interface temperature

In Fig. 6, the interface temperature along the flow direction under different heat fluxes is presented. It was observed that when the heat flux was lower, the interface temperature would increase along the flow direction, resulting from the generation of latent heat in the dehumidification process. But when the heat flux reached some value, not only the latent heat was removed, but also the temperature of the fluids in the channel was reduced.

It seemed that the cooling did not contribute too much to the dehumidification performance by seeing Fig. 7. From Fig. 6, it was found that in the flow direction of the air, the temperature difference of the solution between the two cases would decrease gradually. The solution temperature with cooling would be lower than that without cooling, which was beneficial for dehumidification. On the other hand, the water content in the air without cooling would be larger than that with cooling. In the bottom of the channel, the solution temperature was much lower with cooling than without cooling and the water content was equal for both cases, thus the driving force was higher with cooling than without cooling. In the upper part of the channel, the reverse was true. Except for the driving force, the mass transfer coefficient was another factor which decided the mass transfer amount. As the mass transfer coefficient increased with the decrease of the temperature, the mass transfer coefficient with cooling would be greater than that without cooling. Under the function of the above two factors, the dehumidification amount was a litter bigger with cooling than without cooling.

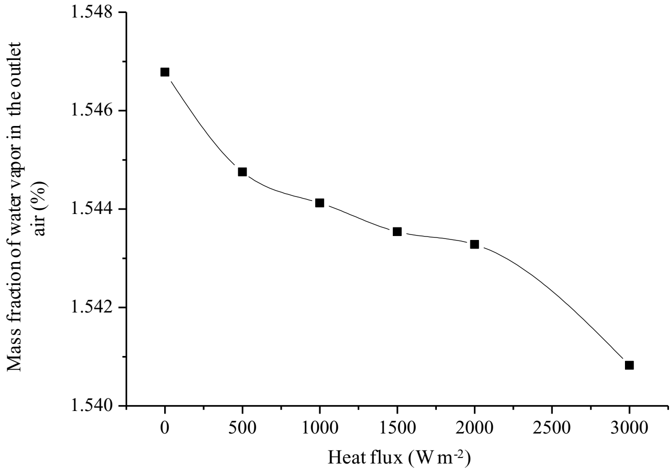


Fig. 7. water content of outlet air

5. Conclusions

The performance of the dehumidifier was investigated with the CFD model. Several conclusions were drawn as follows,

High temperature desiccant worsened the dehumidification performance, not only by reducing the mass transfer driving force but also through decreasing the contact time between the desiccant and air.

It was found that $Le > 1$ for the present simulation. The results showed good agreement with the previous experimental study.

For countercurrent flow, the dehumidification amount was only a litter bigger with cooling than without cooling in the present simulation.

6. Copyright

Acknowledgements

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Biography

Yuanhao Wang is a teaching fellow in Technological and Higher Education Institute of Hong Kong. He obtained the bachelor degree in Tsinghua University and Ph.D. in the Hong Kong Polytechnic University. His research interests focus on renewable energy applications and nanomaterial for green building.