Original Research Paper

Measurement of Gas-Phase Mass Transfer Coefficients in a Humidification Column through Random Packing

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Abstract: Packed columns are an important part of the broad selection of mass and heat transfer equipment. Nowadays, the use of packed columns is increasing, which is because of its lower pressure drop, higher capacity and higher mass transfer in comparison to tray columns. The experiential tests and the hypothetical analysis display that the chemical dehumidification of air by hygroscopic salt solutions confirms the stable reduction in humidity ratio, which is appropriate for uses to air conditioning or drying processes The mass transfer factors in the pulse were found to correspond nearly to the factors that would be achieved in the distributed bubble flow regime In the present study, parameters that affect column performance, such as, fluid retention and gas-phase mass transfer coefficient in a humidification column using random packing in towers with 0.1 m and 0.2 m diameters and 1m height, were measured Air velocity was 1.32 to 3.92 m^3 per hour and liquid velocity was 10 to 70 m^3 per hour. In this research, the Nakajima model was used to calculate the effective area. Thereafter, experimental values for gas-phase mass transfer coefficients were compared to Zech, Shi, Grouff, Shulman, Billet and Ondamodels The mean relative errors of these models with the present study's experimental findings were 7%, 15%, 29%, 21%, 45% and 195%. Findings showed that by decreasing the column diameter, the gas-phase mass transfer coefficient (K$_g$.ae) also increases Further, the obtained retention values showed that retention in the column with a 0.1 m diameter was higher than the column with a 0.2 m column.

Keywords: Packed Column, Random Packing, Mass Transfer Coefficients, Effective Area, Liquid Retention, Humidification Column

Introduction

Many different types of research and studies by scientific organizations and packing manufacturing companies on random packing was initiated in 1930 (Gładyszewski and Skiborowski, 2018). Mass transfer relations have been stated based on theoretical data that have different operational accuracies, limitations and ranges (Treybal, 1968; Shulman and de Gouff, 1915). In this study, mass transfer relations and parameters that are depended upon these relations such as mass transfer effective area, are presented, then the experimental values are presented and compared to these models (Sugiyama *et al*., 2008). Heating or cooling of major surface region products is often made in systems containing of arrays of round or slot nozzles, through

which air affects vertically upon the product surface. The alteration of local transfer ratios is graphically shown. It also inspects how to use these equations in the heat exchanger and dryer plan as well as in optimization. External variables affecting heat and mass transfer in influencing flow relies on mass flow rate, kind and state of the gas and on the figure, size and position of the nozzles relative to each other and to the solid area (Fan *et al*., 2018). The aim of this evaluation paper is to summarize the significant published articles on the increase of the forced convection heat transfer (Darakchiev *et al*., 2016). This article describes a general survey accentuating the engineering requests and experimental equations, offered for the prediction of heat and mass transfer coefficients within a great and technologically essential range of inconstants (Schaefer *et al*., 1997). Heating or cooling of great surface zone supplys is often carried out in devices including of arrays of round or slot nozzles, through which air effects vertically upon the product surface (Zhang, 2012). The alteration of local transfer factors is graphically demonstrated. It also investigates how to use these equations in heat exchanger and dryer design as well as in optimization (Coker, 2010). The flow field of affecting flow is diagrammatically showed. External uncertain affecting heat and mass transfer in influencing flow relies on mass flow rate, kind and state of the gas and on the figure, size and position of the nozzles relative to each other and to the solid surface (Kishimoto *et al*., 2011). The plan of high-proficiency arrays of nozzles is also considered. The airflow is laminar and constant and has a temperature much higher than the water, causing a composed heat and mass transfer attended with water evaporation into the airstream. Computations are performance with and without attention of the air property alterations caused by the air temperature and humidity alters near the water surface and in the airflow direction. The consequences display that the heat and mass transfer factors both diminish with enhancing water surface temperature, i.e., enhancing mass flux. The air property variation has a significant and intricate relic on heat transfer factor but an inconspicuous effect on mass transfer factor (Goldstein *et al*., 2006).

The experiential set-up is fully demonstrated together with measurements, methods, data reduction and precision. A scientific model of the packed column and the respective simulation computer code was extended to anticipate the implementation of the system and to analysis the system sensitivity to the primary running parameters (Wang *et al*., 2007). The consequences disclose a large temperature drops at the wall area and the temperature drop relies on the axial distance from the inlet. In this procedure, this instrument allows the taking of mean and oscillating flow and temperature values at any point of the bed. Relationships for the

total pressure drop, the pressure drop across the pulse and for the pulse velocity are received. The ratio of the vaporization to absorption factor, accurate for diversities in diffusivity, is found to be immediately proportional to the ratio of the total holdup to the running holdup in verification of the presented model in which the effective interfacial zone for each type of running is proportional to the holdup of the liquid active for that performance (Weiss and Wieltsch, 2005). Computational fluid dynamics as a simulation tool permits taking a more particularitied view of the fluid flow and heat transfer mechanisms in fixed-bed reactors, through the resolution of 3D Reynolds averaged transport equations, together with a turbulence model while required (Peychès-Bach *et al*., 2009; Bartelmus *et al*., 1998). Column applying water vaporization and methanol sorption (Sun *et al*., 2011). One of the effective parameters on mass transfer is the effective interfacial area. In these experiments, water and air were used as liquid and gas phase (Aferka *et al*., 2011).

Materials and Method

Mass Transfer Coefficients Measurement Method

In order to obtain mass transfer coefficients, first the number of NTU transfer units should be calculated and in the present study, the Adiabatic Humidification method was used (Xu *et al*., 2015). This is a very unique state in which the liquid is entered into the system at the input gas's adiabatic saturation temperature (Andreev *et al*., 2007). This transformation can be conducted by continuously entering the column's output liquid (without adding or reducing its heat) into the column (Zaidiza *et al*., 2015). For preventing heat loss, the column has been insulated (Shulman *et al*., 1955; Onda *et al*., 1968). Air is cooled in an adiabatic humidification procedure and then in turn, the similar air is applied to decrease – via a heat exchanger – the temperature of the second stream of air, whose moisture content accordingly persists unaltered (Zhang *et al*., 2010). The cooling outcome is individually intense when the air to be humidified is the ambient air being released. A way and device for heat and mass transfer are related applying a moving gas, such as air at a fixed and atmospheric pressure, to prepare a continual change in a vapour-liquid equilibrium between accurate but regularly changing gas and liquid temperatures within energy transferring chambers (Seibert *et al*., 2011). The heat exchanger prepares for heat transfer between the first and the second substance materials of corresponding parts of the first and second chambers. This heat conduct can

permit condensation causing further evaporation in the corresponding chamber sector terminating in reusing of energy (Li *et al.*, 2006). Simultaneous with the temperature differences, the fragment wetting can further let wetting substance condensations caused by evaporation, selective concentration, or sorption to alter between wetted parts. Using experimental relationships to evaluates different parameters applied in a mathematical model is unavoidable (Gómez-Castro *et al.*, 2018). In this article, a mathematical model is extended for a packed-bed air dehumidifier and the effect of some popular experimental relationships existent in literature is assessed on the model's predictions and precision (Longo and Gasparella, 2005).

Gas-Phase Mass Transfer Coefficients

In our experiments, the column's diameter was 0.2 m, its height was 1m, the liquid phase was water and the gas phase was air and the air velocity was 1.32 to 3.93 m^3 per second and were performed in four liquid velocities of 10, 30, 50 and 70 m^3 per hour. The thermometer's accuracy in the laboratory was +0.1 centigrade degrees (Parrish and Fehsenfeld, 2000).

The used packing was a 16 mm plastic Paul ring packing, which Fig. 1 is an image of this packing in different views. In Table 1, the specifications of this packing is shown.

The number of NTU_g transfer units were obtained through measurement of the temperatures. Figures 2 and 3 the HTU_g per F_g graph for gas capacity coefficient and mass transfer coefficients are shown, respectively ($F_s = u_{gs} \sqrt{\rho_g}$) (Dubrawski *et al.*, 2013).

Table 1: Plastic Paul ring packing specifications

ε(%)	$a_p(m^2/m^3)$
87	341

Fig. 1: Plastic paul ring packing used in this experiment
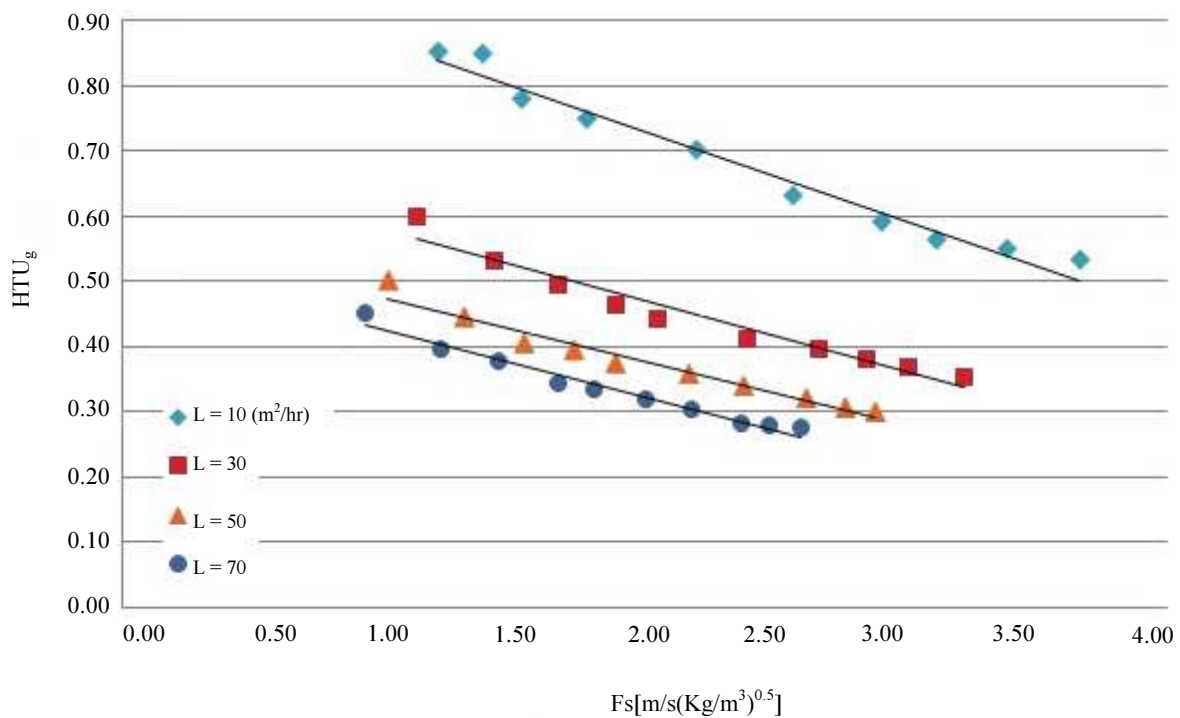

Fig. 2: HTU_g per F_g graph for gas capacity, 0.2 m column diameter
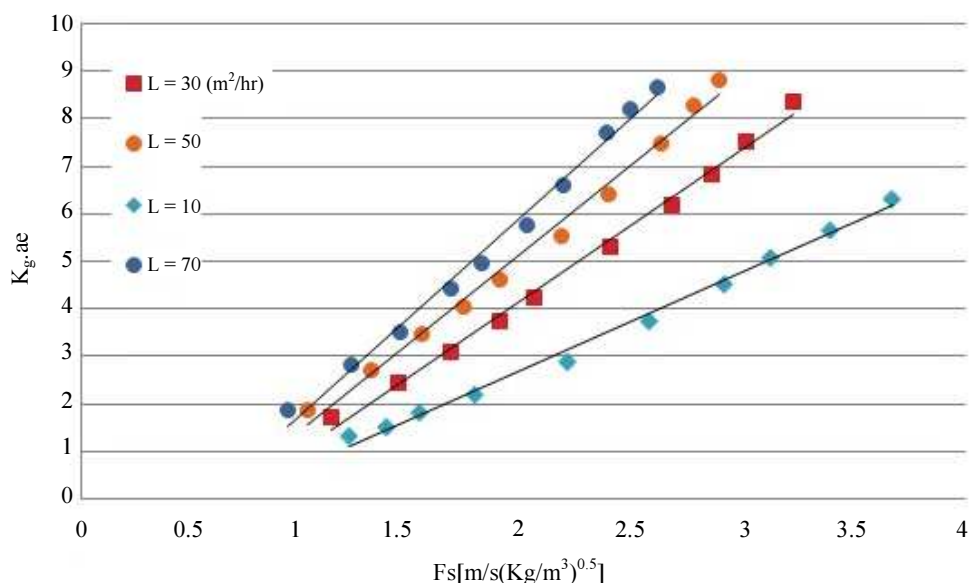
Fig. 3: Kgae per F_s graph for gas capacity coefficient, 0.2 m diameter column

Result and Discussion

In common, it was terminated that the heat transfer coefficients were more sensitive to the temperature diversity for downwards flows than for upwards flows. As well as, there was no considerable relic on temperature diversity on the heat transfer ratios for upwards flows. It was also found that the downwards and upwards vertical directions were almost autonomous of the temperature diversity. With regard to the tendency trace, it was found that in common, it reduced with an enhance in temperature diversity but reduced with an enhance in mass flux and vapour quality. In addition, it was found that the heat transfer coefficient reduced with an enhanced in this temperature diversity. The orption procedure is forcefully effected by the impressive contact area. Very good compromise is achieved between the empirical and simulated consequences (number of mass transfer units *NTU*m). Common studies largely concentrate on dehumidification system under particular heat and mass transfer capability. In addition, a simulation model is expanded, which is accredited by experiential data and past research consequences. The heat and mass transfer capability of the system should be evaluated in the sketching procedure of flow path configuration to take an impressive proficiency for different range of NTUm. The result of liquid viscosity (μL) on both the operative mass transfer area (ae) and the liquid film mass transfer factor (kL) of packings is needed to auspicate mass transfer rate and plan the absorber and stripper. The evaporator and absorber are relative parts inside an Absorption Heat Transformer, because the refrigerant attains a high latent heat, which is absorbed by the strong binary mixture at high pressure for taking the beneficial heat (Kunze *et al.*, 2015). Their heat transfer coefficients effect on the design and execute of an Absorption Heat Transformer. The inconstants investigated for this analysis were the heating temperature, the mass flux rate, pressure and condensations. The parameter explaining gas-liquid mass transfer severity (volumetric mass transfer coefficient kLa) becomes than the key parameter (Chabanon and Favre, 2017). These popular equations brief the physical and thermophysical attributes of the air, the solution and the contactor, which make them able to be applied for parametric studies prepared they are fitted in a wide range of experiential data that contain all the properties involved (van der Ham *et al.*, 1994). The experiential data taken at different air superficial velocities and solution flow rates were coordinated to the general relationships and collations between the predicted and experiential consequences for both ratios are within ±10%, for both dehumidification and regeneration operations. As well as, the computed values of the outlet air humidity relation and temperature agree well with the experimental data for both procedures (Giorgetti *et al.*, 2017). A dimensionless group relationship of mass transfer coefficient is expanded and assessed. It was found that tendency notably effected the flow templates and the heat transfer coefficients (Dubois *et al.*, 2017).

Conclusion

One of the effective parameters in mass transfer is the effective interfacial area (Yoon *et al.*, 2009). In this

article, the Nakajima *et al.* model was used to calculate a_e. Through calculating the effective interfacial area, the mass transfer coefficients were calculated, then the experimental K_g values were compared to Zech, Shi, Shulman, Billet, Onda, Grouffmodels (Pinto *et al.*, 2016). The finding showed that in the Onda, Grouff, Billet models, the K_g values were higher than the experimental values and in the Shi and Shulman models were less than the experimental values. However, the Zech model had a relatively better prediction compared to other models and the obtained K_g values from this model were closer to the experimental values. The Zech model's calculated error with the experimental values was 7%.

In order to find the effect of column's diameter on mass transfer coefficients, experiments under equal conditions in a column with 0.1 m diameter were conducted.

Results showed that as the column's diameter decreases, the $K_g.ae$ increases. One of the reasons for the increase of $K_g.ae$ is that as the column's diameter decreases, liquid distribution is better and as a result, the mass transfer interfacial area increases. The other reason is the effect of the column's wall surface on mass transfer. As the diameter size decreases, the column's wall has more effectiveness on in creating an interfacial area for mass transfer, therefore, as the mass transfer interfacial area increases, $K_g.ae$ increases.

Results of the volume fraction dispensations of material components on the thermal responds, containing the temperature alteration, the movement and the stresses dispensations were considered (Kolev, 2006). The special equations for the heat and mass transfer coefficients can be applied to do parametric studies at various air surface velocities and solution flow rates with very well precision. Conclusions from this article can help amend the system plan and practice procedures of air-solution contactors. It is visible that the mass transfer coefficient enhances with the enhance of water/air mass flow ratio, but reduces with the enhance of inlet water temperature and inlet air enthalpy. The relic of pressure on heat and mass transfer is connected with air mass flow. The heat and mass transfer between the antifreeze solution and air at low ambient temperatures is a key point for proficiency increment.

Author's Contributions

All authors contributed to design the study, write and revise the manuscript.

Ethics

The present Study and ethical aspect was approved by Isfahan University of Technology. The present study was approved by Isfahan University of Technology.

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Research Highlights

- Measurement of mass transfer coefficients in a column with random packing (Onda *et al.*, 1968)
- Measurement of liquid retention