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Experimental studies on heat and mass transfer characteristics for R134a–DMF bubble absorber

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ABSTRACT

Experimental investigations have been carried out to study heat and mass transfer characteristics of Tetrafluoro ethane (R134a) in Dimethyl formamide (DMF) in a glass absorber. Effects of operational parameters viz., gas flow rate, solution flow rate, solution initial concentration, solution pressure, solution temperature and cooling water flow rate on absorber performance are analyzed. Absorption rate and heat transfer rate increase as the gas flow rate, solution flow rate, cooling water flow rate and solution pressure increase whereas they decrease as the solution initial concentration and solution temperature increase. Heat and mass transfer rates determined from the experiments are compared with numerical model and it is found that agreement is good. A correlation for mass transfer coefficient is presented from the experimental studies within ±20% error band.

Etudes expérimentales sur les caractéristiques de transfert de chaleur et de masse d'un absorbeur à bulles au R134a / DMF

Mots clés : Absorption ; R134a ; DMF ; Bulle ; Transfert de masse ; Transfert de chaleur

1. Introduction

Many environment friendly fluid combinations have been suggested by number of investigators in order to overcome some of the limitations of well known working pairs viz., ammonia–water and lithium bromide–water for the vapor absorption refrigeration systems (VARS). Though R22-organic solvent based absorption refrigeration systems have been extensively studied by Fatouh (1994), Karthikeyan (1995) and Sujatha (1997), HCFCs along with CFCs, are also covered by Montreal and other International Protocols and are being phased out. So environment friendly R134a based VARS are being investigated. Nezu et al. (2002) examined the possibility of testing R134a as a refrigerant in VARS with various organic solvents and showed that the R134a–DMA and the R134a–DMF systems are considered attractive as the working-

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Nomenclature

A	absorber cross-section area, m^2
D	absorber diameter, m
D_c	diffusion coefficient, $m^2\,s^{-1}$
h	solution enthalpy, $kJ\,kg^{-1}$
m	mass flow rate, $kg\,s^{-1}$
M	mass transfer coefficient, $kg\,m^{-3}\,s^{-1}$
p	solution pressure, bar
p_0	atmospheric pressure, bar
Q	heat transfer rate, W
Re	Reynolds number
Sc	Schmidt number
Sh	Sherwood number
T	temperature, °C
U_o	overall heat transfer coefficient, $W\,m^{-2}\,K^{-1}$
V	volumetric flow rate, $m^3\,s^{-1}$
X	liquid mass fraction, $kg\,kg^{-1}$

Subscripts

a	absorption
eq	equilibrium
g	gas
ht	heat transfer
i	inlet
l	liquid
mt	mass transfer
o	outlet
s	solution
v	volumetric
w	water
1	inner
2	outer

Greek symbols

μ	dynamic viscosity, Pa s
γ	kinematic viscosity, $m^2\,s^{-1}$
ρ	density, $kg\,m^{-3}$
η	mass transfer efficiency

fluid pairs for the absorption refrigeration system than other R134a–absorbent systems. Yokozeki (2005) studied theoretical performance of various refrigerant–absorbent pairs in a VARS cycle by the use of equations of state. Of these, R134a–DMF and R134a–DMA systems exhibit better performance, compared to other R134a–absorbent systems. Also the circulation ratio is less and COP is more for R134a–DMF system compared to R134a–DMA system. Mani (2009) carried out experimental studies on R134a/DMF based compact vapor absorption refrigeration system with plate heat exchangers and reported that this system could be very competitive for applications ranging from −10 °C to 10 °C, with heat source temperature in the range of 80–90 °C and with cooling water as coolant for absorber and condenser in the temperature range of 20–35 °C.

Absorber is considered as one of the crucial components in the vapor absorption refrigeration system. Kang et al. (2000) carried out analytical investigation of falling film and bubble type absorbers and found that absorption rate of the bubble type absorber was found to be always higher than that of the falling film mode. Bubble type absorber provides better heat and mass transfer coefficients, also good wettability and mixing between the liquid and the vapor (Kang et al., 2000).

Absorption process is characterized by simultaneous heat and mass transfer phenomena. These mechanisms, though complicated, influence the system performance significantly. Elperin and Fominykh (2003) studied combined heat and mass transfer mechanisms at all stages of bubble growth and rise in a bubble absorber, which can be useful in design calculations of gas–liquid absorbers. Lee et al. (2003) performed both the numerical and experimental analyses in the absorption process of a bubble absorber. Numerical model in these studies can be used for the optimum design of absorber. Merrill and Perez-Blanco (1997) developed an analytical model to predict bubble dynamics in binary sub-cooled solutions. This model improves the understanding of bubble absorption dynamics.

Sujatha et al. (1997a,b) carried out numerical analysis in a vertical tubular bubble absorber working with R22 as refrigerant and five organic fluids namely DMF, DMA, DMETEG, DMEDEG and NMP as absorbents. This model is validated by comparing with the results available in the literature. Based on these results, a correlation for mass transfer coefficient has been suggested for the vertical tubular bubble absorber. Sujatha et al. (1999) have also carried out experimental studies on a vertical tubular bubble absorber working with R22-DMF. Experimental pressure drop, heat transfer coefficient and mass transfer coefficient are compared with the results obtained from the numerical model.

Kang et al. (1998) developed a model for a bubble absorber with a plate type heat exchanger by considering the combined heat and mass transfer analysis in both liquid and vapor regions. All geometric variables such as distance between two plates, number of plates, and width of the plates could be selected optimally for given thermal conditions by the developed design model for ammonia–water combination.

Staicovici (2000a,b,c) used non-equilibrium phenomenological theory to evaluate gas–liquid interaction.

Design of bubble absorber, based on non-equilibrium thermodynamics could be suited to a modern compact plate type construction and offers better absorption efficiency and minimum pressure loss on the gas side. Suresh and Mani (2010) developed a numerical model on bubble dynamics, heat and mass characteristics of R134a/DMF based bubble absorber using phenomenological theory and validated by comparing with the results available in literature. Suresh and Mani also carried out experimental studies on bubble characteristics on a vertical glass bubble absorber and presented a correlation for bubble diameter during detachment.

Kang et al. (2002a) developed a correlation for initial bubble diameter, which can be used to calculate the interfacial area in the design of ammonia–water bubble absorber. Kang et al. (2002b) also developed an experimental correlation of mass transfer coefficient for ammonia–water bubble absorption.