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Effect of interfacial phenomena on mass transfer performance of an absorber packed closely with cylindrical packing

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HIGHLIGHTS

- An absorber packed closely with cylindrical packing was designed in this study.
- The wetting of packing surface is a key factor for absorber performance.
- The Marangoni effect can be triggered in the system with continuous liquid phase.
- The surface stress increases significantly as TEG concentration exceeds 92 wt.%.
- The larger flow rate of TEG solution weakened the Marangoni effect.

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ABSTRACT

The mass transfer performance is usually affected by the wetting of the packing surface with absorbent solution, and the wetted surface can be affected by interfacial disturbances resulting from the gradient in surface tension between water vapor and absorbent solution. In order to discuss the effects of interfacial phenomena on mass transfer performance of water vapor absorbed by triethylene glycol (TEG) and lithium bromide (LiBr) solutions, an absorber packed closely with cylindrical packing was designed in this study and the packing material was polyvinyl chloride. In addition, the interfacial behaviors were observed from water droplet positioned on the surface of absorbent solution, and the surface stress was defined and calculated to analyze how mass transfer performance was affected by the stress. Experimental results show that surface stress increases with increases in concentration of TEG solution. The surface stress increases significantly when the concentration of TEG solution exceeds 92 wt.% The area of packing wetted by TEG solution increases as the concentration of TEG solution and humidity increase. Therefore, the mass transfer performance also increases with the higher concentration and higher humidity.

1. Introduction

A face of contact by two or more phases is called an interface. The behaviors of mass transfer and fluid flow are always affected by the components and density of the interface. One such effect is Marangoni convection, which results from the gradient in surface tension. The gradient in surface tension can be affected by changes in temperature and concentration. Table 1 shows some studies related to interfacial flow, induced by changes in temperature or concentration. Table 1 also reveals that the Marangoni effect can be triggered in mass transfer systems with continuous liquid phases. The Marangoni effect can also be induced spontaneously by mass and heat transfer processes. For example, the mass transfer performance of carbon dioxide absorbed into and desorbed from organic solvents was discussed by Sun et al. [5]. Their experimental results showed that the mass transfer performance was enhanced by interfacial disturbance caused by the process of carbon dioxide absorbing into and desorbing from organic solvents. Similar to the spontaneous Marangoni effect, which results from the concentration gradient, the thermal Marangoni effect can also be triggered spontaneously, such as in the evaporation of water, as discussed by Chang and Velev [9]. As long as the gradient in surface tension is high enough, the Marangoni effect will be induced. In addition to liquid droplets used in horizontal absorption cell, vapor can also contribute to a absorption system to produce the gradient. In order to discuss the interfacial disturbance resulting from the gradient in surface tension independently, a horizontal absorption system was developed by Wu et al. [2], Agble and Mendes-Tatsis [3], Kang and Kashiwagi [4], and Sun et al. [5] to reduce external interference. Other mass transfer processes, such as condensation, discussed by Vemuri et al. [8], and evaporation, discussed by Chang and Velve [9], can apply the Marangoni effect to increase mass transfer as a result of sufficient

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Table 1
Interfacial flow induced by vapor or additives.

System	Solutions	Vapor or additives	Authors
Horizontal absorption cell	EG (or DiEG) + $C_{12}E_{10}$($C_{12}E_4$)	Water vapor	Cachile et al. [1]
	55 wt.% LiBr	*n*-octanol droplet	Wu et al. [2]
	Water	Organic droplet	Agble and Mendes-Tatsis [3]
	Water	*n*-octanol vapor	Kang and Kashiwagi [4]
	Methanol, toluene, chlorobenzene, and isobutanol	CO_2	Sun et al. [5]
Wetted wall column	53.5 wt.% LiBr	*n*-octanol vapor	Kashiwagi et al. [6]
Bubble absorber	Water	Hexanol, octanol	Kim et al. [7]
Steam condensation	Water	2-ethyl-1-hexanol	Vemuri et al. [8]
Evaporation	Water	Temperature	Chang and Velev [9]

difference in surface tension. On the basis of the concept that the Marangoni effect triggered in the system with continuous liquid phase, the aim of this study is to design an absorber with close cylindrical packing and to examine the effects of interfacial phenomena on mass transfer performance. In addition, the wetting of the packing surface with absorbent solution is also discussed in relation to the concentration of TEG solution and ambient humidity.

Zarzycki and Chacuk [10] pointed out that interfacial tension or lateral stress is an important factor that affects mass transfer mechanisms of absorption, distillation, and extraction. The gradients resulting from the differences between concentration and temperature are called solutal and thermal Marangoni effects respectively. If the Marangoni effect is induced by adding a surface additive, it is called an artificial Marangoni effect; if the Marangoni effect is induced by a mass transfer process, it is called a spontaneous Marangoni effect. Table 2 shows the types of differences of surface tension and the methods by which they have been induced in the open literature. For a single-component liquid, the density and surface tension are dependent on temperature. The liquid layer was heated from the bottom by Kamotani and Masud [16] and from the centerline by Kalitzova-Kurteva et al. [17] to activate fluid flow. Since the density and surface tension were changed by changes in temperature, the induced fluid flow was called the artificial thermal Marangoni effect. Table 2 shows that the artificial Marangoni effect is often applied to absorption systems. Spontaneous Marangoni effects have been found in absorption, distillation, and extraction systems. The mass transfer performance of a horizontal absorption cell [5,18,19] and a packed-distillation column [20–22] are affected by the spontaneous Marangoni effect; however, little research in the open literature has focused on the effects of a spontaneous Marangoni effect on the mass transfer performance of a packed-bed absorber. Mentioned above, an absorber packed with cylindrical packing was design to discuss the spontaneous Marangoni effect, and the difference in surface tension between absorbent solution and water vapor was used to induce the Marangoni effect in a packed-bed absorber. The concentrations of absorbent solution and air humidity were controlled to examine the mass transfer performance affected by the Marangoni effect.

Clearly, the Marangoni effect can be induced by sufficient difference in surface tension in the mass transfer devices with a continuous liquid phase. Since the absorption system can be used as an air cleaning equipments and for an absorption heat pump, enhancement of mass transfer performance is an important issue for an absorption system. The coverage of the packing can be increased and surface renewal can be promoted by the Marangoni effect. The falling-film and the packed-bed absorbers are two absorption system commonly used. Since the surface is wetted completely in the falling-film absorber, the Marangoni effect applied to the falling-film absorber is just to promote surface renewal. However, the channeling effect always causes inhomogeneous wetting in the packed-bed absorber. If the Marangoni effect is applied to raise the amount of packing that is wetted, the mass transfer performance will be increased. In addition, the liquid surface can also be renewed by interfacial disturbance. Therefore, the effect of a spontaneous Marangoni effect on the mass transfer behavior in the process of water vapor absorbed by TEG solution was discussed in this study.

Table 2
Type of difference of surface tension and the induced method.

Mass transfer devices	Type of difference	Induced method	Authors
Horizontal absorption cell	Solutal	Artificial	Wu and Chung [11]
			Yang et al. [12]
			Kim et al. [13]
			Lu et al. [14]
			Vazquez et al. [15]
Horizontal liquid layer	Thermal	Artificial	Kamotani and Masud [16]
			Kalitzova-Kurteva et al. [17]
Falling film absorber	Solutal	Artificial	Kashiwagi et al. [6]
Liquid–liquid system	Solutal	Artificial	Agble and Mendes-Tatsis [3]
Horizontal absorption cell	Solutal	Spontaneous	Sun et al. [5]
			Warmuzinski and Tanczyk [18]
			Chung et al. [19]
Packed-distillation column	Solutal	Spontaneous	Proctor et al. [20]
			Patberg et al. [21]
			Moens and Bos [22]
Packed rectification column	Solutal	Spontaneous	Martin and Perez [23]
Falling film absorber	Solutal	Spontaneous	Dijkstra and Drinkengburg [24]
			Imaishi et al. [25]
			Brian et al. [26]
			Maroudas and Sawistowski [27]
Liquid–liquid extraction	Solutal	Spontaneous	Bakker et al. [28]