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Research paper

The effect of Dixon rings on direct contact evaporative heat transfer performance

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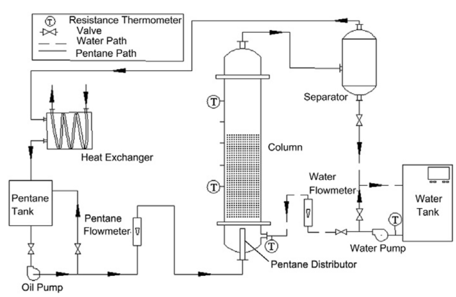
HIGHLIGHTS

- Optimal column height is obtained and analyzed in detail.
- The effect of packing on heat transfer performance is analyzed.
- The effect of packing under lower temperature difference is larger.
- Packing increases volumetric heat transfer coefficient.
- Packing decreases optimal column height.

GRAPHICAL ABSTRACT



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ABSTRACT

Experimental study was conducted to investigate the effect of packing on performance of direct contact evaporative heat transfer for n-pentane and water operated in a bubble column with concurrent upward flow. The optimal column height and volumetric heat transfer coefficient with and without Dixon rings were examined and compared under the conditions of different flow velocity ratios of n-pentane to water, temperature differences between water and n-pentane and distributor apertures. It is found that packing enables optimal column height to decrease significantly. Optimal column height considerably reduces maximally by 25% under temperature difference less than 8 °C and flow velocity ratio 0.265. Volumetric heat transfer coefficient is 100–450 kW/(m^3 °C) with packing while 40–150 kW/(m^3 °C) without packing. Especially when the flow velocity ratio is 0.265 and 0.192, volumetric heat transfer coefficient with packing is nearly twice as much as that in bubble column without packing at the temperature difference below 8 °C. The effect of packing at temperature difference below 8 °C is more pronounced. Besides, backmixing observed in the experiment was demonstrated, and its significant influence on evaporative heat transfer performance was also analyzed.

1. Introduction

During the past decades, energy shortages and environment pollution problems have become extensively globalized in consideration of their existence and impacts threatening human survival. After noting the growth of international awareness of these issues, many researchers have been focusing on direct contact heat exchangers for its advantages like no metal heat transfer surface, high heat transfer coefficient, little corrosion and fouling and simple structure etc. Therefore, direct contact heat exchangers are widely used in desalination [1,2], low temperature recovery [3,4], energy conversion [5–7],etc.

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Various types of columns, such as bubble columns, packed columns and baffled columns, etc. can be applied as direct contact heat exchangers. Bubble column has been particularly concerned because of its simple internal structure. And then considerable researches have been devoted to studying the performance of single droplet evaporation and swarms of droplets evaporation [8–16]. It is worthwhile to note that there are some disadvantages of bubble column that cannot be ignored. For example, Robert F. Boehm [17] pointed out that a certain amount of backmixing occurred inside bubble column and the flow pattern might deteriorate at some of distance from the distributor under many situations due to its simplicity. For single dispersed phase droplet evaporating in continuous phase, Sideman and Gat [8] put forward that backmixing resulted in the experimental heat transfer coefficient less than the theoretical one. Also, better distribution and dispersion of droplets need more energy consuming. As a consequence, the heat transfer in bubble column is not so satisfactory and further solutions are still desired.

Baffled columns and packed columns are preferred as alternatives to improve performance of bubble columns. Multiple engineering applications of these two columns reflect their effective performance in the mass transfer process. Then increasing attention of these columns has also been received in the field of heat transfer. The baffled column includes sieve-plate column, perforated plate column and float valve column. Robert F. Boehm [17] demonstrated that baffle could rearrange flow during the evaporation process of droplets because it contributed to increasing interfacial areas and strips away droplet wakes at each tray, and that was deemed to enhance heat transfer performance. Baffled columns are, however, more subject to flooding and entrainment. Alternatively, random packing or structure packing placed in columns always enlarges interfacial areas and prolongs residence time of droplets. As the early work of Robert F. Boehm [17], backmixing and droplet wakes were alleviated after adding the packing. The author also stated that packing could be used in liquid–liquid systems to assist in removing the wakes from dispersed phase and increasing heat transfer coefficient. Besides, F. Alnaimat et al. [18] proved that packing provided high surface area and produced an important effect on heat transfer when studying solar diffusion driving desalination with water and air in packed column. Kakusaburo Onda et al. [19] evaluated the mass transfer coefficient on the liquid and gas side with tested correlation. An analogy between heat transfer and mass transfer was applied to determine the liquid and gas heat transfer coefficients. J. F. Klausner et al. [20] developed the analysis of evaporative heat transfer and mass transfer with the packed bed via varying flow conditions. Finally, In spite of various benefits of packing, the pressure drop, high operation requirement and trade-off between cost and performance should be also taken into account.

Table 1
Physical properties of n-pentane.

Property (at 36.1 °C)	Value
Density(L)	610.2 kg/m^3
Density(G)	3.0 kg/m^3
Boiling temperature	36.1 °C
Latent heat	358.2 kJ/kg
Specific heat (L)	2.34 kJ/(kg °C)
Specific heat (G)	1.79 kJ/(kg °C)

Unfortunately, it is found that there exists little research on exploring how packing affects direct contact evaporative heat transfer performance in detail. The purpose of this work was to evaluate the effect of packing on direct contact evaporative heat transfer performance in bubble column. The optimal column height and volumetric heat transfer coefficient were analyzed in the experiment through varying flow velocity ratio of n-pentane to water, temperature difference and distributor aperture.

2. Experiment

2.1. Experimental setup

N-pentane and water are chosen as working fluids (the physical properties of pentane are shown in Table 1) and the

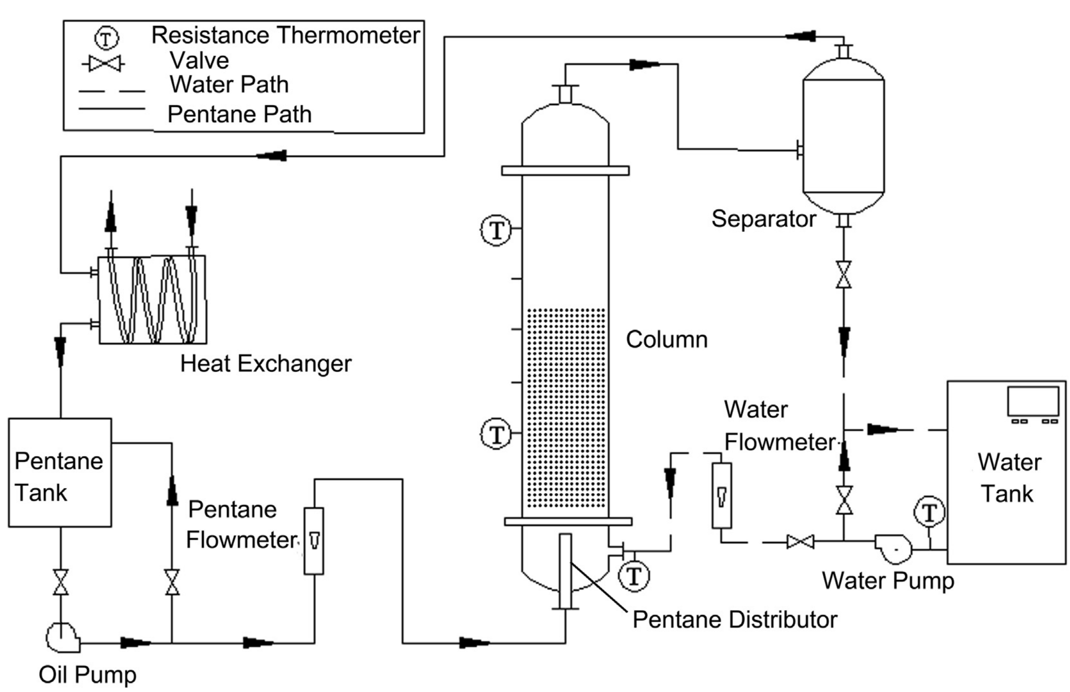

Fig. 1. Schematic diagram of experimental setup.