Chemical Engineering & Processing: Process Intensification xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Chemical Engineering & Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep

Significantly enhanced vapor-liquid mass transfer in distillation process based on carbon foam ring random packing

Xingang Li, Xinwei Yang, Hong Li, Qiang Shi, Xin Gao*

School of Chemical Engineering and Technology, National Engineering Research Center of Distillation Technology, Collaborative Innovation Center of Chemical Science and Engineering (Tianjin),Tianjin University, Tianjin 300072, China

ARTICLE INFO

Keywords:
Process intensification
Distillation
Foam materials
Flow behavior
Mass transfer

ABSTRACT

Applications using foam material as distillation column internals have been demonstrated higher performance than classical mass transfer units, except for the operation range. In this paper, the novel Foam Ring Random Packing (FRRP) made of Carbon foam material has been developed to overcome this disadvantage. The hydraulic performance and the mass transfer efficiency of FRRP are measured as 300 mm i.d. diameter column. The experimental values of FRRP are compared with the values of traditional ring random packing. In general, the comparison results indicate that the hydrodynamics and mass transfer performances of FRRP has been intensified by the foam materials (best HETP 0.24 m and additional 20% operation range). In order to explain the cause of intensification, flow behavior experiments were also carried out on both FRRP and Raschig ring packing. Special emphases on the effects of orientations, liquid flow rate and feed point on wetting area were investigated. Compared with other traditional random packing, the results show that the FRRP has some advantages, such as better extensive wetting area (maintain no less than 80%) and more uniform wetting distribution (fluctuate within 20%). Finally, an analysis of wetting process on single FRRP was presented to help understand the flow pattern on the packing. All results indicate that FRRP has outstanding performance, which will be a potential candidate used in distillation process.

1. Introduction

Distillation column is one of the most important unit operation equipment for mass and heat transfer between gas-liquid and liquid–liquid systems. The type of distillation columns contains packing columns and plate columns. Packing columns are widely used due to their great advantages such as high separation efficiency, low pressure drop and large operation range [1].

Random packing is known as its easily installation, blocking resistance and acceptable-efficiency devices for distillation columns [2]. However, the increasingly demanding requirements for random packing of their properties lead to the development of new type random packing [3]. In the last century, over 4 generations of random packing have been created, from 1st generation, for instance, classical Raschig ring, Pall ring and Intalox saddle to new modern lattice type random packing – 3rd and 4th generation. Their forms have changed distinctly (ring/saddle to polyhedron/lattice) and materials have changed simultaneously (coke/stone to metal/ceramics/polymer) over decades [4]. Moreover, in order to improve efficiency, it is necessarily to optimize the geometry of random packing with lager wetting area or to find a better material [5].

Carbon foam material which have been recognized as a new promising class of structural inorganic material in these years, which proves to have outstanding mechanical, thermal, electrical, and acoustical properties as well as their high voidage, low density, high specific area and good thermal stability [6]. Therefore, there are many applications in carbon foam material such as heat exchangers, catalyst supports, energy storage, and electronic components [7–10]. In the field of distillation, current research focus on the gas-liquid flow, pressure drop, liquid hold up and mass transfer capability of solid foam proved excellent performances of solid foam materials and contributed to the popularity of the applications of solid foams [11–13]. The mass transfer efficiency of foams structure packing with 4–5 theoretical stages per meter exceeded classical packing (M250, CY, and Pall ring), while the hydrodynamic performance in aspects of flooding behavior and pressure drop per meter was relatively low [14–16].

Therefore, it is a consequential work to develop a novel packing that combines the advantages of random packing and foams material. The previous research in our group focused on the SiC foam as the material of the packing [14,17–21], but in the consideration of the complex

* Corresponding author.
E-mail address: gaoxin@tju.edu.cn (X. Gao).

https://doi.org/10.1016/j.cep.2018.01.005
Received 23 August 2017; Received in revised form 27 November 2017; Accepted 9 January 2018

Please cite this article as: Li, X., Chemical Engineering & Processing: Process Intensification (2018), https://doi.org/10.1016/j.cep.2018.01.005

Notation ***Latin symbols***

HETP	Height equivalent of theoretical plate [m]
Nt	The theoretical plate number
ΔP	Pressure drop of the packing [Pa]
x_D	Composition of the top liquid phase
x_B	Composition of the bottom liquid phase

Greek letters

α	Mean relative volatility
α_D	Relative volatility of the top of the column
α_B	Relative volatility of the bottom of the column
φ	Orientation angle of ring packing [°]

production and the higher cost of SiC foam, we chose carbon foam material as the material of our packing. At the meantime, the structure packing with foam material had attracted a lot of attention in recent years, but the investigation of foam material random packing was rare.

In this paper, we developed the novel foam ring random packing (FRRP). The packing was tested in a Φ300 mm distillation column within heptane/cyclohexane system and a set of ultraviolet fluorescence observation facilities. Mass transfer experiment measured the mass transfer efficiency and pressure drop of FRRP. Flow behavior experiment stated from 3 aspects (Orientation angle, liquid flow rate and feed point) examined the wetted ability with 3 types of ring packing. Furthermore, special phenomenon and flow pattern analysis were come up to illustrate the flow and wetted process of FRRP more clearly.

2. Experimental section

2.1. Materials

Fig. 1 shows the shapes and pillar ring structure of the packing which were obtained in the experiment. The FRRP was made from producing processes consisting of cutting, slurry impregnation and sintering of polyurethane sponge. Uncompressing and extending space of the inner structure leads to its high porosity and less weight. For comparison, ceramics Raschig Ring (CRR) and metal Raschig Ring (MRR) were selected as traditional random packing. In the part of representing feature of packing, the parameters of the different packing are shown in Table 1. We can see that the bulk density of FRRP is about one fifth of other random packing with solid materials. This feature makes FRRP easier to load in/out and reduces the endurance requirements of the tower.

2.2. Mass transfer

Total reflux distillation trials were invented to evaluate the mass transfer efficiency of FRRP. Mass transfer experiment equipment was shown in Fig. 2. The diameter of the column and height of the packing was 300 mm and 2 m. The mixture in the reboiler was heated with heat transfer oil provided by a 120-kW electrical generator, and mixture vapor in the condenser was cooled by circulating water at the top of the column. The system of the distillation was *n*-heptane/cyclohexane (molar ratio of 2:3) separation under 101.3 kPa. At the same time, the temperature was measured using thermocouple thermometers at the reboiler, cooler, and anywhere needs recording. The concentration of the sample was analyzed by using a WAY-2WAJ Abbe Refractometer at 35 °C.

The experiments were conducted at atmospheric pressure with standard cyclohexane/n-heptane mixture. At the beginning of experiment, flooding operation was operated in the column with FRRP (over 4 h). Then with different heating capacity of reboiler, the mixture was separated in the column under total reflux circumstance. Overhead product (gas phase) passed to the condenser and cooling product pumped back the top of the column by centrifugal pump. The liquid flow of the reflux liquid was controlled by glass rotameter. The temperature was recorded by thermocouple thermometer at the top and bottom of the column as well as the reflux tube which went back the top of column. We took a sample from the top and bottom sample point every 10 min, and terminated the experiment when three successive samples had the same composition. The values of U-tube manometer were also recorded.

The mass transfer efficiency of distillation random packing can be evaluated in many ways. In distillation process, the Height Equivalent of Theoretical Plate (HETP) was widely used to describe the overall efficiency of packing, which was handleed in this work. HETP is the reciprocal of theoretical plate number of the packing column. The theoretical stage was calculated by Fensk equation as below. x_D and x_B represent the top and bottom of the column liquid composition. α represents the geometrical average of the relative volatility at the top and bottom of the column.

$$\mathrm{HETP} = \frac{1}{N_t} \tag{1}$$

$$N_t = \frac{\ln\left[\frac{x_D}{x_B}\left(\frac{1-x_B}{1-x_D}\right)\right]}{\ln\alpha} - 1 \tag{2}$$

$$\alpha = (\alpha_D \times \alpha_B)^{0.5} \tag{3}$$

2.3. Flow behavior experiment

Flow behavior experiment equipment was shown in Fig. 3. A set of ultraviolet fluorescence observing facilities was applied to observe the surface flow pattern of the ring packing. An overall description of the test apparatus can be found elsewhere [19]. Single packing was placed

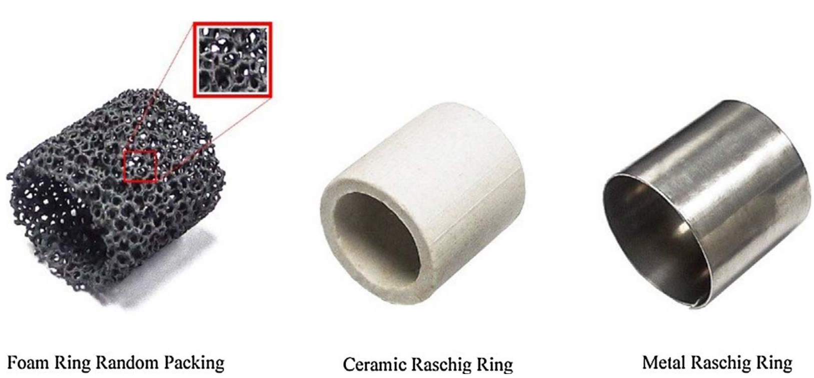

Fig. 1. Three kinds of ring packing used in the experiments.