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# Hydrodynamic and mass transfer efficiency of ceramic foam packing applied to distillation

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ABSTRACT

In addition to a high void volume and specific area, solid foams possess other properties (low density, good thermal, mechanical, electrical, and acoustical behaviour) that make them attractive for applications such as heat exchangers and reformers. Applications using foams as catalysts or structured catalyst supports have demonstrated higher performance than classical catalysts. Several studies have explored the hydrodynamic behaviour of foams in monophasic and countercurrent systems and have reported very low pressure drops. This paper describes the application of ceramic foam to distillation. The $\beta$-SiC foam contains 5 pores per inch (PPI) with a 91% void volume and a surface area of 640 $m^2/m^3$. Performance parameters including pressure drop for the dry and wet packing, flooding behaviour, and dynamic liquid hold-up were measured in a column of 150 mm internal diameter. The mass transfer efficiency in terms of the height equivalent to theoretical plate (HETP) was determined by total reflux experiments using a mixture of *n*-heptane and cyclohexane at atmospheric pressure. The experimental results were used to develop a set of correlations describing pressure drop and liquid hold-up in terms of a dimensionless number. The hydrodynamic performance and mass transfer efficiency were compared with classical packing materials used in distillation.



## 1. Introduction

Solid foams (either ceramic or metal-based) have been known for many years and have a wide range of applications due to their low density and attractive thermal, mechanical, electrical, and acoustical properties. In the last decade, there has been growing interest in these foams for applications such as heat exchangers, reformers, mixing improvement, and as catalysts or structured catalyst supports (Pestryakov et al., 1996, 2007; Richardson et al., 2000, 2003; Sirijaruphan et al., 2005; Winé et al., 2006; Chin et al., 2006). Foams or other high-porosity cellular materials represent a very promising new class of structural materials. Hydrodynamic measurements reported in the literature (Richardson et al., 2000; Lacroix et al., 2007; Despois and Mortensen, 2005; Bhattacharya et al., 2002; Giani et al., 2005; Dukhan, 2006; Leong and Jin, 2006; Topin et al., 2006; Incerra Garrido et al., 2008) have typically been obtained in monophasic or occasionally biphasic (air/water) systems in cocurrent operation. These studies defined the permeability of the foams and confirmed that foam hydrodynamics follows the Forchheimer relationship (Lacroix et al., 2007):

$$\frac{dP}{dZ} = \frac{\mu}{K}u + \beta\rho u^2 \quad (1)$$

A noteworthy finding of these studies was a low pressure drop in both monophasic and cocurrent biphasic systems. Stemmet et al. (2005) initiated the study of countercurrent hydrodynamics in foams. They also observed a low pressure drop (on the order of a few mbar $m^{-1}$ for liquids with mass velocities in the range of 0–17 $kg\,m^{-2}\,s^{-1}$ and gas flux in the range of 0–1 $kg\,m^{-2}\,s^{-1}$) with a biphasic system in countercurrent operation. The flooding behaviour was similar to the Sulzer KATAPAK structured packing (Ellenberger and Krishna, 1999). In a later paper, (Stemmet et al., 2007) studied cocurrent gas–liquid mass transfer in terms of an overall volumetric gas–liquid mass transfer coefficient ($k_L a_{GL}$). This coefficient was found to be relatively high, ranging up to 1.3 $s^{-1}$. However, the column used in this study was rectangular with a cross section of 30 cm×1 cm. This does not correspond to a realistic situation in distillation and led to significant side effects.

These promising results were the starting point of our study of the application of ceramic foam as a distillation packing material. Several important parameters are required to characterize a new distillation packing material. This paper describes the experimental

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steps necessary to validate the use of new packing materials, including measurement of the hydrodynamic characteristics to estimate the operating range, pressure drop, and flooding point; and determination of the mass transfer efficiency.

## 2. Foam structure

Ceramic foams in the form of silicon carbide ($\beta$-SiC) studied in this work, exhibit advantageous properties such as high mechanical strength, high heat conductivity, and high resistance to corrosive media. $\beta$-SiC foams have medium surface area (15–20 $m^2\,g^{-1}$) and a void volume between 88% and 92%. The foam preparation method developed by the Sicat company, (Patent US 5,429,780; US 5,449,654; EP 0 624 560; EP 0 880 406 B1; US 5,958,831; US 6,251,819; FR2860992, FR2860993, US20050159292, FR2834655) is based on the impregnation of a polyurethane foam with a homogeneous mixture of silicon, charcoal, phenolic resin, and oxygen supplier. After polymerization of the resin, the material is calcined at 1300 °C in an inert atmosphere. The final $\beta$-SiC foam product is a reticulated cellular material that replicates the morphology of the polyurethane foam. This method permits the synthesis of $\beta$-SiC foams with controlled cell sizes close to the pores per inch (PPI) of the starting polyurethane material. The structural parameters amenable to modification include the pore size (characterized by PPI number), the void volume, and the apparent density. This allows the manufacture of materials with a wide variety of hydrodynamic properties. For this type of foam, the open void fraction is not dependent on the PPI number; in fact it is possible to maintain a constant open void fraction over the entire range of PPI numbers. Conversely, for the same pore diameter, it is possible to have different open void fractions. This may be visualized using the cubic representation of the cells (Fig. 1) described by Giani et al. (2005). The size of the struts (solid phase between the cells) can be changed to obtain a different void volume without changing the PPI number.

Our study is focused on open celled SiC foam with a single PPI number and porosity with the intrinsic characteristics summarized in Fig. 2. The specific area was calculated from the cell diameter and void volume using the following equations (Lacroix et al., 2007), in which $a = \phi/2.3$ and $\phi$ is the cell diameter; $a$ represent the window diameter. The difference between cell diameter and window diameter is illustrated in Fig. 3. The value obtained for specific area is of 640 $m^2/m^3$:

$$ds = \frac{a[(4/3\pi)(1-\varepsilon)]^{1/2}}{1-[(4/3\pi)(1-\varepsilon)]^{1/2}} \tag{2}$$

$$a_c = \frac{4}{ds}(1-\varepsilon) \tag{3}$$

## 3. Experimental set up and methods

### 3.1. Hydrodynamics pilot plant

The experimental setup for hydraulic studies is illustrated in Fig. 4. Foam cylinders were placed in a glass column with an internal diameter of 150 mm and a packing height of up to 90 cm. The column was operated in a countercurrent mode with an air–water system. The studies were carried out at room temperature under atmospheric pressure.

The liquid flowed from a tank through a pump and flowmeter and was supplied to the top of the column via a plate distributor containing 2716 holes per square metre for liquid flow to assure good

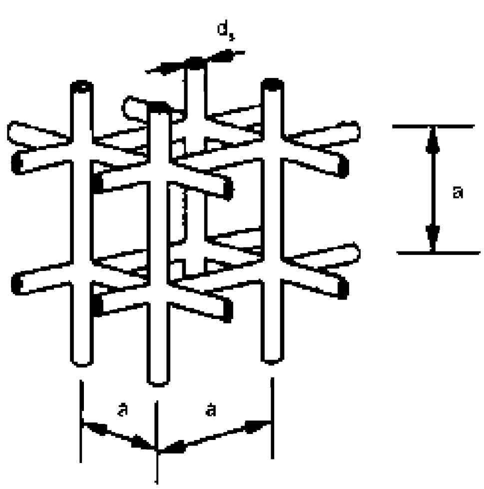


**Fig. 1.** Representation of cubic model of Giani et al. (2005).

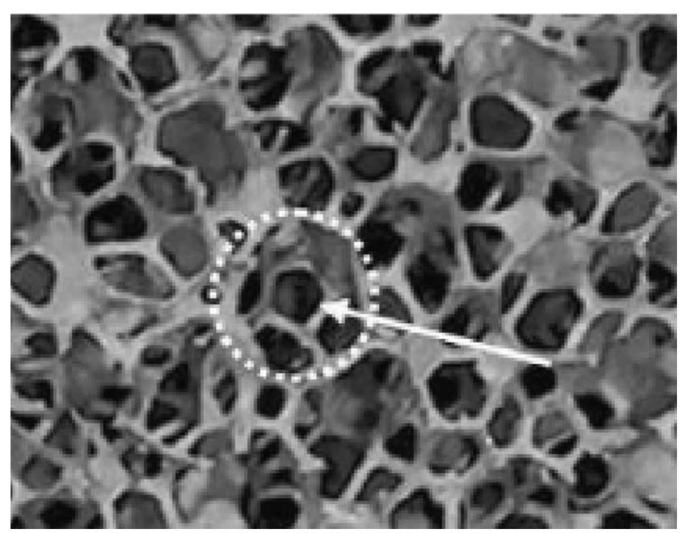

**Fig. 3.** Optical picture of SiC foam. Dotted circle show the cell diameter whereas white arrow indicate a pentagonal window.

Company: Sicat
Materials: β Silicium Carbide
Average cell diameter: 5 350 μ (5 PPI)
Cylinder diameter : 139 à 146 mm
Height : 92-99 mm
Apparent density: 130-140 g/l
Void volume: 92%
Specific area: 640 $m^2/m^3$

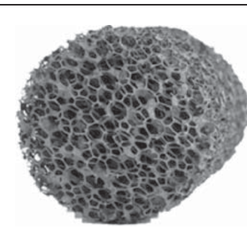

**Fig. 2.** Characteristics of $\beta$-SiC foam studied.