# Methodological analysis of gamma tomography system for large random packed columns

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## ARTICLE INFO

## ABSTRACT

Gamma ray tomography experiments have been carried out to detect spatial patterns in the porosity in a 0.27 m diameter column packed with steel Rashig rings of different sizes: 12.6, 37.9, and 76 mm. using a first generation CT system (Chen et al., 1998). A fast Fourier transform tomographic reconstruction algorithm has been used to calculate the spatial variation over the column cross section. Cross-sectional gas porosity and solid holdup distribution were determinate. The values of cross-sectional average gas porosity were $\varepsilon$=0.849, 0.938 and 0.966 for the 12.6, 37.9, and 76 mm rings, respectively. Radial holdup variation within the packed bed has been determined. The variation of the circumferentially averaged gas holdup in the radial direction indicates that the porosity in the column wall region is a somewhat higher than that in the bulk region, due to the effect of the column wall.

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## 1. Introduction

Random packed distillation and absorption columns are used extensively in chemical and petrochemical industries to perform highly efficient process separation. With the recent advances in computational fluid dynamics, it is now possible to model the effects of heterogeneities in the bed on flow profiles and hence on the mass transfer efficiency (Wang et al., 2001). Experimental data on porosity variation (gas holdup) of random packed columns are extremely useful because increasing the understanding of the fluid dynamics analysis (Chaouki et al., 1997). The porosity variation in these devices has long been recognized as a potential source of maldistribution and it has been studied extensively, since the early works focused on spherical particles and very little information is available on modern high efficiency packings. Chu and Ng (1989) and McGreavy et al. (1986) showed that the porosity distribution has a significant effect on the liquid flow distribution within a packed column near the wall region. Non-uniform distribution of porosity results in liquid flow maldistribution and a reduced separation efficiency.

Non-destructive methods as the X-ray and gamma ray computed tomography are the beginning to be used in the measurements of the porosity distribution in random packed beds (Chaouki et al., 1997; Chen et al., 2001). Early works as Niu et al. (1996) used the X-ray computed tomography to analyze the radial porosity distribution in a bed of randomly packed uniform spheres. The authors observed oscillations in the porosity distribution in the radial direction. More recently Toye et al. (1998) have used the X-ray computed tomography to measure the porosity distribution and liquid holdup in complex packed beds widely used in distillation and absorption. The results show that for the packings with complex geometrical shapes, the porosity distribution in packed beds was non-uniform, and the radial variation did not show oscillatory patterns such as those found for spheres.

At the Radiations Technology Center (CTR) of the Energy and Nuclear Research Institute (IPEN-USP), a computed tomography (CT) gamma ray scanner has been developed as a tool for the analysis of the spatial distribution of gas, liquid and solid phases in different types of packed columns such as absorption columns to obtain quantitative 2-D images of the phases (solid, gas or liquid) holdup distributions in these devices (Vasquez et al., 2007).

This paper presents the measurements of the porosity distribution in a 0.27 m column randomly packed with 12.6, 37.9, and 76 mm. Stainless steel Rashig rings with the gamma ray scanner at the plane $L/D$=2. A tomographic reconstruction algorithm has been used to calculate the spatial variation of porosity over the column cross section. The radial variation of the porosity within the packed beds was also obtained.

## 2. Experimental setup

The experimental system consists of a 0.27 m diameter column packed with steel Rashig rings of different sizes: 12.6, 37.9, and

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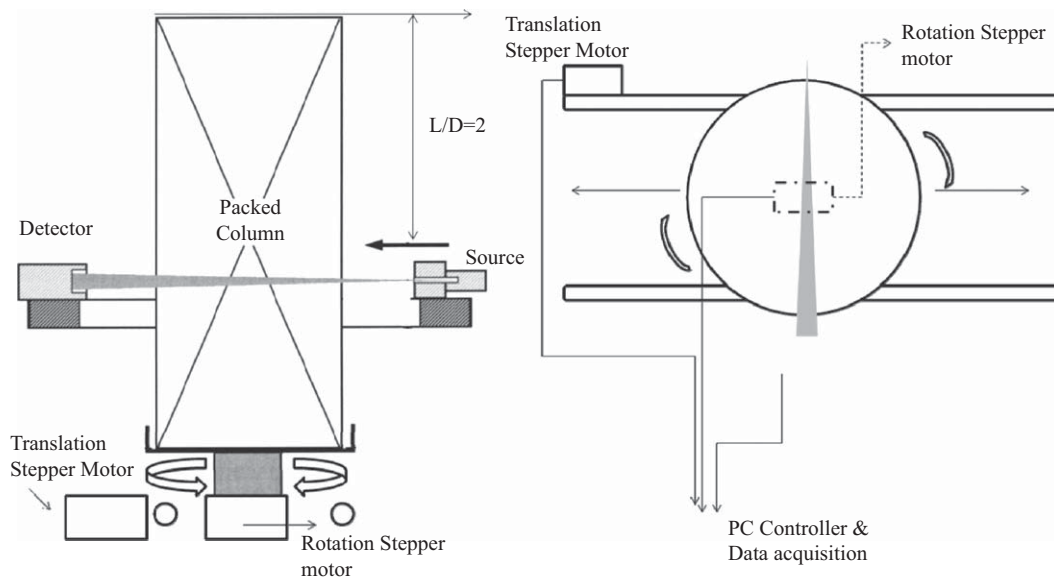E-mail address: mmhamada@ipen.br (M.M. Hamada).

Fig. 1. Front and top views of the experimental setup for the CT scanning system.

76 mm. The gamma ray tomograph (CT scanner) consists of a NaI (Tl) detector with and an encapsulated $^{137}$Cs radioactive source located opposite to the center of a collimated detector. The detector and the source are mounted on fix support and the column was rotated and dislocated by two stepping motors controlled through a microprocessor. The collimator is made of lead, which is 4.5 cm in depth and 5 cm in height so that the detector is completely shielded by the collimator. There is a rectangular hole of $2.38 \times 4.38$ mm at location appropriate to the detectors for sampling the beam. In each movement, the column was rotated by 2.78° (130 views). To obtain statistical significant results and to reduce the effect of the position, the CT scans were obtained by scanning 360° using a collecting numerous beam path attenuations (approximately 13 780 projections). The source collimator provides a perfect gamma ray beam horizontal plane. The source is further collimated using a 4.5 cm lead brick with a central slit. The radioactive source used was 50 mCi of Cs-137. Fig. 1 shows the schematic diagram of the CT facility.

In the vertical direction, the measurements were carried out on one plane $L/D=2$. The measurements were first made for the empty column to obtain the base line data for the scanning plane. The same measurements were later made for the packed columns. The average porosity along each chord was then calculated based on these measurements as outlined in the next section.

### 2.1. Basic principle of tomography

A narrow beam of radiation travelling along a straight path through an object gets attenuated primarily by absorption and scattering. When the monoenergetic gamma rays pass through a medium, the gamma ray attenuation integrated along the path is measured by the detector. The intensity of the radiation through a homogeneous material can be expressed by the Beer–Lambert law (Chen et al., 1998):

$$T = \frac{I_o}{I} = e^{-\mu \rho L} \qquad (1)$$

where $T$ is the transmission ratio, $I_o$ is the incident radiation, $I$ is the detected radiation, $\mu$ is the mass attenuation coefficient, $\rho$ is the medium density, and $L$ is the path length through the medium. If the medium is made of two materials with mass attenuation coefficients $\mu_1$ and $\mu_2$, densities $\rho_1$ and $\rho_2$, and thickness $L_1$ and $L_2$, respectively, the net attenuation $A$ is:

$$A = \mu_1 \rho_1 L_1 + \mu_2 \rho_2 L_2 \qquad (2)$$

If $\varepsilon$ is the phase holdup then $L_1 = \varepsilon_1 L$ and $L_2 = \varepsilon_2 L$ where $L = L_1 + L_2$, then:

$$A = [\mu_1 \rho_1 \varepsilon_1 + \mu_2 \rho_2 (1 - \varepsilon_1)]L \qquad (3)$$

The measured quantity $\ln(I_o/I)$ is equal to the integral sum of the attenuation through the material along the beam path. For tomography, attenuations are measured along a number of such beam paths through the object from different directions around it. Given a set of attenuation measurements, the density distribution (image) can be reconstructed by using a suitable reconstruction algorithm. In this work, the filtered back-projection (FBP) is used for image reconstruction (Vasquez et al., 2007).

### 3. Results and discussion

#### 3.1. Cross-sectional porosity distribution

The reconstructed image, processed from data obtained through CT scans, provides the cross-sectional time-averaged porosity distribution at $L/D=2$ axial level. Fig. 2 shows the cross-sectional porosity and the solid holdup distributions for 12.6, 37.9, and 76 mm steel Rashig rings, respectively. The porosity distribution for all systems is almost symmetric and depends of the size of the packing; with a higher porosity near the wall and a lower gas holdup in the center.

#### 3.2. Radial gas holdup distribution

Fig. 2 shows the time-averaged radial porosity and the solid holdup profiles obtained by azimuthal averaging of the data at $L/D=2$ for 12.6, 37.9, and 76 mm steel Rashig rings, respectively. The radial gas porosity profile is different in shape for all cases (Fig. 3). The porosity takes significantly higher values near the column wall and then decreases rapidly when moving towards the column center for 37.9 and 76 mm packing sizes.
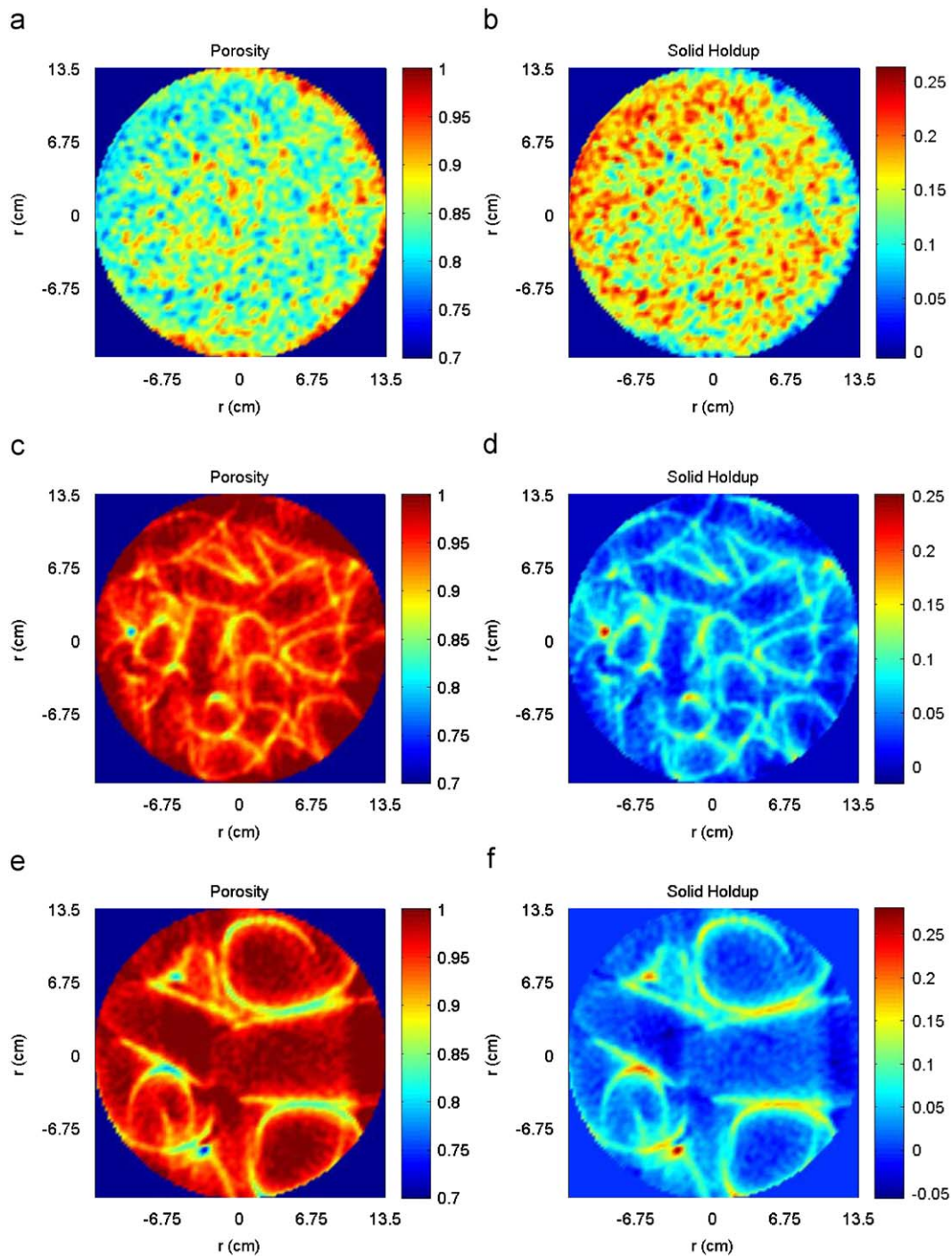
**Fig. 2.** Cross-sectional porosity and solid holdup distributions by $L/D$=2. (a,b) 12.6 mm; (c,d) 37.9 mm and (e,f) 79 mm.

The measured values fluctuate around the mean porosity fraction value, but the curve does not present any periodic behavior as it does in the case of spherical particles (Niu et al., 1996).

## 4. Conclusions

This study has demonstrated that the porosity and its spatial distribution in a large scale metallic packed column can be measured with adequate spatial resolution using the gamma ray tomography technique. The experiments have been carried out successfully to measure the spatial porosity distributions in a 0.27 m diameter packed column using three different sizes of stainless steel Rashig rings 16, 25 and 38 mm by $L/D$=2. A tomographic reconstruction algorithm used to calculate the spatial variations over the column cross section, and the radial porosity variation has shown good performance and faster convergence. The results indicate that the spatial porosity distribution in random packed columns is not uniform. There are always some pockets in the packed beds, where the porosity is higher than the average value. For the circumferentially averaged radial porosity distribution, the porosity in the column wall region tends to be higher than that in the bulk region, due to the effect of the column wall.
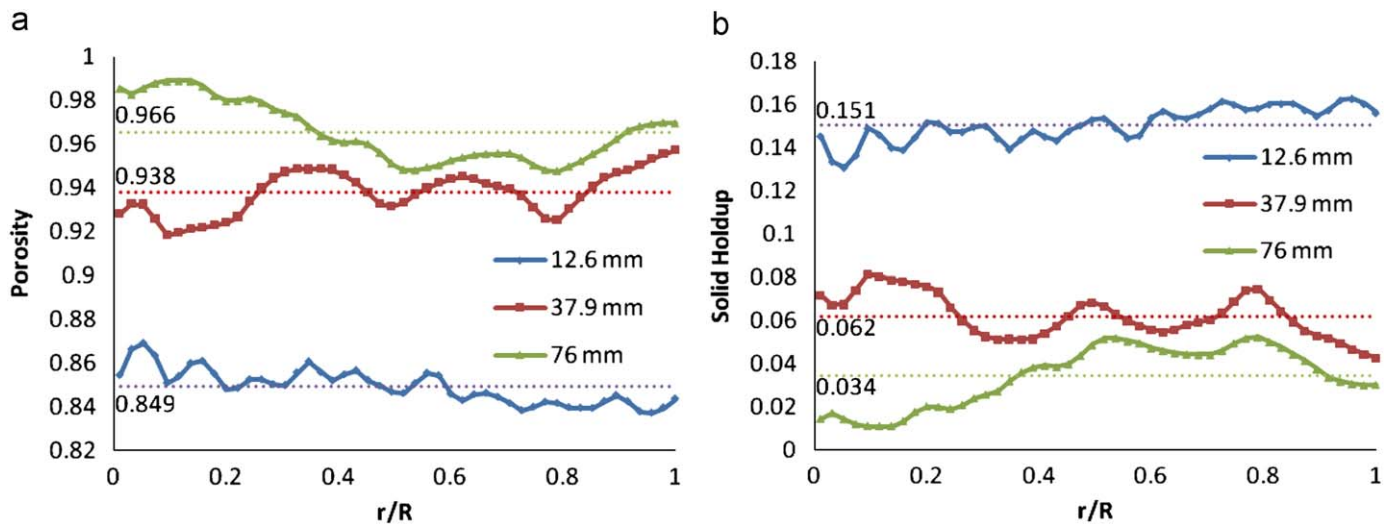
**Fig. 3.** (a) Radial porosity and (b) solid holdup distributions with average values by $L/D=2$. Rashig rings 12.6, 37.9 and 79 mm.

## Acknowledgments

## References

Chaouki, J., Larachi, F., Dudukovic, M.P., 1997. Noninvasive tomographic and velocimetric monitoring of multiphase flows. Ind. Eng. Chem. Res. 36, 4476–4503.

Chen, J., Rados, N., Al-Dahhan, M.H., Dudukovic, M.P., Nguyen, D., Parimi, K., 2001. Particle motion in packed/ ebullated beds by CT and CARPT. A.I.Ch.E. J. 47 (5), 994–1004.

Chen, J.W., Gupta, P., Sujatha, D., Al-Dahhan, M.H., Dudukovic, M.P., Toseland, B.A., 1998. Gas holdup distribution in large diameter bubble columns. Flow Meas. Instrum. 9 (2), 91–101.

Chu, C.F., Ng, K.M., 1989. Flow in packed tubes with a small tube to particle diameter ratio. A.I.Ch.E. J. 35, 148–156.

McGreavy, C., Foumeny, E.A., Javed, K.H., 1986. Characterization of transport properties for fixed bed in terms of local bed structure and flow distribution. Chem. Eng. Sci. 41, 787–797.

Niu, M., Akiyama, T., Takahashi, R., Yagi, J., 1996. Reduction of the wall effect in a packed bed by hemispherical lining. A.I.Ch.E. J. 42, 1181–1186.

Toye, D., Marchot, P., Crine, M., 1998. Local measurements of void fraction and liquid holdup in packed columns using X-ray computed tomography. Chem. Eng. Proc. 37, 511–520.

Vasquez, P., Mesquita, C., Hamada, M., 2007. Phantom study using a first generation tomography system. In: Proceedings of 2007 International Nuclear Atlantic Conference—INAC 2007, Santos, SP, Brazil, September 30–October 5, 2007.

Wang, Z., Afacan, K., Nandakumar, K., Chuang, K., 2001. Porosity distribution in random packed columns by gamma ray tomography. Chem. Eng. Process 40, 209–219.