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POSTER COMMUNICATION

Effect of bed configuration and fluid properties on dispersion in solid foams

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Abstract
The results of a study on axial dispersion in commercially available open cell metal (Nickelchromium) and ceramic (Vukopor A) foams with different pore density are presented. Residence time distributions were determined using tracer pulse experiments applying the convolution method to post process the recorded tracer concentration signals. The influence of liquid viscosity (water and 45 wt.% glycerol solution) and bed length (from 0.1 to 0.9 m) on axial dispersion was tested. It was found that fluid velocity, viscosity and foam morphology affected axial dispersion. Moreover, the axial dispersion coefficient for solid foams is lower than that of packed beds.

Keywords
solid foams, residence time, axial dispersion

1. INTRODUCTION

The reactor optimization is often carried out based on reactor modelling instead of experiments. Because dispersion phenomena affect mass and heat transfer: higher axial dispersion can lead to lower selectivity and process efficiency; knowledge of axial dispersion is crucial for a correct mathematical description of the reactor. Although the first works on axial dispersion in solid foams appeared several years ago, there are still only few papers focusing on this topic (e.g. Hutter et al., 2011; Mirdrikvand et al., 2020; Stemmet et al., 2007). However, these works present research results usually for one (or two) selected bed length using solid foams made of one (or two) type(s) of material and with water as the liquid phase (for a single liquid flow). Therefore, the aim of the work was a comprehensive approach to the axial dispersion phenomenon for a single flow of liquids (differing in physicochemical properties) through solid foams (differing in pore density and material) for different bed heights. The basic equation representing dispersion model, which takes account of all deviation from ideal plug flow of fluid that flow in z-direction, is presented at the attached poster. The solution of this equation, assuming the so-called open boundary conditions (Levenspiel, 1999), according to Hill (1977) has the form presented at the attached poster.

2. METHODS

The experiments were performed for metal and ceramic foams differing in pore densities: in the range of 6–10 and 27–33 PPI (pores per inch) for NC0610 and NC2733 respectively, and for ceramic foams it was 10, 20 and 30 PPI (according to manufacturers). The morphological parameters of tested foams are presented in the Table (see poster, section "Materials and Methods"). In this section, the details of the RTD experiments and the experimental set-up are also presented. The experiments were performed under ambient conditions. The experiments were carried out using the pulse input method, which assumes that the curve of inlet tracer concentration vs. time corresponds to the Dirac δ-function (peak width equals zero and the area under the curve equals one). In this case the residence time distribution is:

$$E(t) = \frac{C_{\text{pulse}}(t)}{\int_0^\infty C_{\text{pulse}}(t)\,\mathrm{d}t} \tag{1}$$

In real experiments, the signal recorded at the inlet always differs from the ideal shape of the Dirac δ-function. Moreover, experiments were carried out applying the so called open boundary conditions (premixing zone), which also affected the inlet pulse shape of the tracer: the lower the fluid velocity, the wider the tracer concentration peak. Therefore, each experimental point (repeated at least three times), was post-processed using the convolution method (Hutter et al., 2011; Mao et al., 1998). In this method, the fast Furier transform (FFT) was applied to analyze the tracer response recorded at the reactor outlet. This signal is a convolution of $E(t)$ and $C_{\text{in}}(t)$:

$$C_{\text{out}}(t) = \int_0^t C_{\text{in}}(t')E\,(t-t')\,\mathrm{d}t \tag{2}$$

Because the evaluation of $E(t)$ from Eq. (2) is difficult, therefore the following steps were applied: (1) transformation from

time domain to the frequency domain using FFT, (2) determination of the residence frequency distribution using low-pass filter, (3) the inverse transformation from frequency domain to time domain using FFT. An example of $E(t)$ curve is shown in Figure (see attached poster). The red line represents post-process data, and the blue one is the fitted curve using the dispersion model with the axial dispersion coefficient D_{ax} and the mean residence time τ as free parameters.

3. RESULTS

The values of axial dispersion coefficients determined for the bed with a length of 0.1–0.5 m are comparable, while for a longer bed (0.9 m) higher D_{ax} values were obtained, which is consistent with the results presented by Hutter et al. (2011) (see Figure in the attached poster). The influence of liquid viscosity on D_{ax} values was observed for higher interstitial liquid velocity for the foam with the lowest pore density (PPI). In this velocity range, the D_{ax} values increase with decreasing foam PPI, but this effect is visible only for the glycerol solution (higher viscosity). Comparing the axial dispersion coefficient for foams made from different materials, it was found that for metal foams the D_{ax} values were lower than those of ceramic foams. This is probably the result of quite significant differences in the morphology of both types of foam – ceramic foams are characterized by struts with a larger diameter and, at the same time, larger dimensions of cells and windows compared to metal foams (cf. the table and images presented in the attached poster). However, the causes of this phenomenon require a deeper analysis. Nevertheless, the D_{ax} values obtained for all tested foams are lower than those of packed bed.

4. CONCLUSIONS

Axial dispersion definitely increases as the velocity of liquid increases. Some effect of liquid viscosity, foam morphology and foam material was also observed. Lower axial dispersion for solid foams than for packed beds indicates that solid foams seem to be promising catalyst carriers for a variety of catalytic processes.

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EFFECT OF BED CONFIGURATION AND FLUID PROPERTIES ON DISPERSION IN SOLID FOAMS

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Introduction

Many important information about the nature of fluid flow provides the residence time distribution (RTD). Aside from the mean residence time, the RTD curve provides information about the axial dispersion, i.e. deviations from the ideal plug flow, occurring due to channeling, recycling of the fluid or by creation of semi-stagnant regions in the reactor, additionally influencing the mass and heat transfer. All of those deviations are described by the dispersion model, which characterizes mass transport of the tracer in the axial direction [1]:

$$D_{ax}\frac{\partial^2 C}{\partial z^2} - u\frac{\partial C}{\partial z} = \frac{\partial C}{\partial t} \quad \text{solution (open boundary conditions)} \quad E(t) = \frac{1}{2\tau\sqrt{\pi\left(\frac{D_{ax}}{u\cdot L}\right)\left(\frac{t}{\tau}\right)}}\, e^{-\left\{\left[1-\left(\frac{t}{\tau}\right)\right]^2 / \left[4\left(\frac{D_{ax}}{u\cdot L}\right)\left(\frac{t}{\tau}\right)\right]\right\}}$$

where D_{ax} is the dispersion coefficient, z – axial coordinate, C – tracer concentration, t – time, u – interstitial fluid velocity, L – packing length and τ – mean residence time.

Materials and Methods

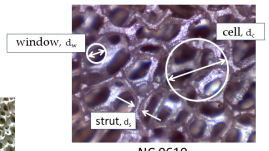
Nickelchromium (NC 2733 and NC 0610, Recemat B.V., The Netherlands) and Vukopor A (Lanik s.r.o. Czech Republic) foams with different pore densities were chosen for testing. Experiments were performed in a cylindrical column of 0.057m I.D. packed with the metal foam discs stacked up to the height in the range within 0.10 – 0.90 m. At the inlet and outlet of the test section two electrodes were installed to record the concentration of the tracer (KCl solution) injected as a pulse. The experiments were carried out for the single phase flow of water and 45 wt.% glycerol solution (density ρ = 1111.18 kg/m^3 and viscosity μ = 4.14·10^{-3} Pas). Based on the concentration signals, the residence time distribution ($E(t)$) can be determined:

for ideal case: $E(t) = \frac{C(t)}{\int_0^\infty C(t)dt}$

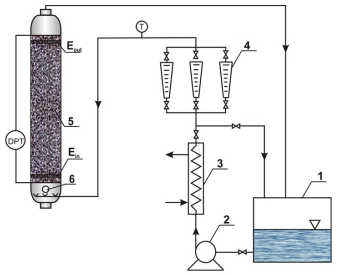
for real case: $C_{out} = \int_0^t C_{in}(\tau)E(t-\tau)$ - in this case $E(t)$ was determined using the Fast Fourier Transform (FFT) deconvolution method [2].

Foam	d_c [mm]	d_w [mm]	d_s [mm]	ε [%]	S_v [m^2/m^3]
NC 0610	3.60	1.06	0.53	0.88	1298
NC 2733	0.86	0.29	0.14	0.87	3616
Vukopor A 10 PPI	6.32	2.65	0.77	0.78	859
Vukopor A 20 PPI	4.12	1.78	0.50	0.79	1088
Vukopor A 30 PPI	2.77	1.21	0.35	0.84	1374


Vukopor A 20 PPI

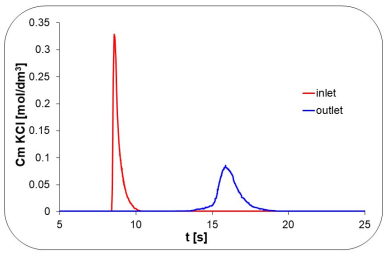


NC 0610

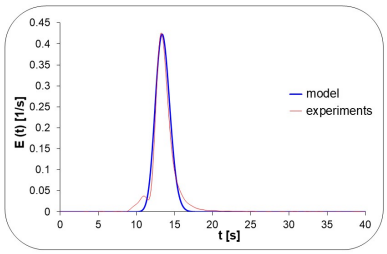


Scheme of experimental set-up: 1 - liquid tank, 2 - liquid pump, 3 - thermostat, 4 - liquid flow meters, 5 - packed column, 6 - tracer injection port, E_{in}/E_{out} - conductivity electrodes, DPT - differential pressure transducer.

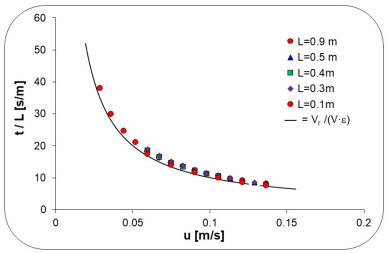
Results



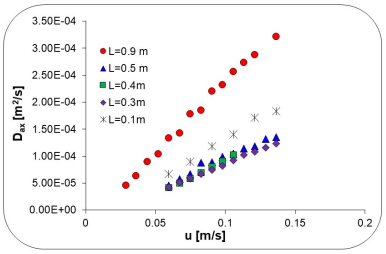
Example of the tracer signal at the inlet and outlet of the column (NC 2733, w=0.1 m/s, L=0.9 m, water).



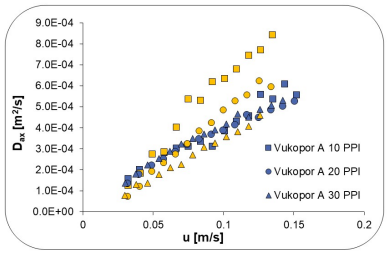
C_{out} experimental and obtained by the convolution method (NC 2733, w=0.1 m/s, L=0.9 m, water).



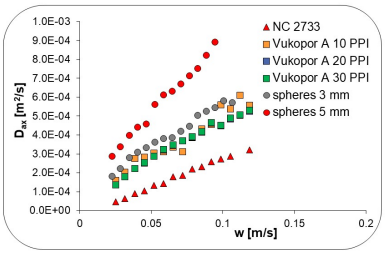
Comparison of the experimental and theoretical mean residence time per unit packing length (NC 2733, water).



Effect of the bed length, water, NC 2733 foam.



Effect of the foam morphology and liquid viscosity, blue points – water, yellow – 45% glycerol sol.



Dispersion coefficient for foams and fixed bed of glass beds, water.

Conclusions

Good agreement between experimental values and theoretically derived residence time excluded dead zones existence in the test reactor. The fluid velocity and viscosity has impact on the axial dispersion: D_{ax} increases with fluid flow and Reynolds number. The impact of the foams morphology is also visible. The influence of the bed length is rather weak. For the same superficial fluid velocity (w), the axial dispersion coefficients for solid foams are lower than for packed bed.

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