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A study of liquid spreading in laboratory scale random packing column with an optical method supplemented with liquid holdup characteristics

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ABSTRACT

The paper introduces an alternative optical-based methodology allowing to investigate a liquid spreading process inside packed beds. In particular it allows determining the boundary between the wetted and the dry region inside the packing section. Due to optical nature of the approach it can be applied only when both column and its internals are made of transparent materials. The proposed experimental procedure has been used to investigate the liquid distribution inside the packed bed composed of 6 mm Raschig rings made of glass. Distilled water was adopted as a flowing medium and was injected into the column from a source point. The obtained results allowed performing qualitative assessment of the process and allowed determining both the contact distance (required for the liquid to reach the column wall) and the wetted volume of the column as a function of the liquid Reynolds number. The experiment has been also supplemented with measurements of a liquid holdup performed with the use of two different methods.

1. Background and motivation

The intensity of radial mass transfer of a liquid inside a packed bed is an important parameter, which indicates the quality of a packing material. It is particularly important when the contact area between phases is a crucial parameter e.g. in absorption [1,2] or stripping [3,4] processes. In such case packing material is required to ensure both the high radial transport of the liquid and the reduction of local liquid maldistribution [5–7].

Currently there are two main approaches allowing to investigate the liquid spreading process within packed beds. First one utilises set of collectors located on the bottom of the column to estimate liquid flow rate radial profiles. An accuracy of this method is determined by a number of the collectors installed. Such a measuring technique can be regarded as non-intrusive, however, its application is limited the measurement of the liquid distribution at the bed outlet only. The second available method is to use a one of available variants of tomography techniques, e.g. X-ray or gamma ray. This approach allows to study packing hydrodynamics inside a column at any set of online conditions without the need to interrupt the spreading process. With this method measurements at different locations in the packed bed can be conducted simultaneously without the need for changing the bed height, which is of advantage over the liquid collecting method. However, tomography-based techniques suffers from a few major problems: high cost, complex post-processing and special safety precautions that must be taken when dealing with high-energy radiation.

There are few research papers devoted to use of these methods (mostly with the use of the former one) in the study of liquid distribution inside packed beds conducted with some interesting findings. One of the first works related to the liquid distribution reported in the literature was paper of Baker et al. [8]. Authors analysed various random packing types as saddles, spheres, etc. It was found, that the diameter of the column affects the liquid distribution within the packed bed. Scott [9] investigated the water distribution through the column with Lessing rings of two dimensions 6.35 mm and 12.7 mm. Water was supplied from the nozzle located in line with the axis of the column. Tendency of water accumulation on column walls was correlated with the rise in the packing section height as well as with the character of the packing structure in near wall region. Porter and Templeman [10] analysed the liquid spreading in a cubic column with transparent plastic walls for various packing types such as: 12.7 mm and 25.4 mm ceramic Raschig rings, 15.9 mm Pall rings, and 12 mm saddles. The experiment

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Nomenclature

a	specific packing surface area (m^2/m^3)
A_{RR}	area of single Raschig ring (m^2)
Bo	Bond number (–)
d	Raschig ring outer diameter (m)
d_e	equivalent particle diameter
d_l	characteristic length (m)
D	column diameter
Fr_L	Froude number (–)
h_{LD}	dynamic liquid holdup (–)
h_{LS}	static liquid holdup (–)
h_T	total liquid holdup (–)
K	coefficient taking into account the particle to the column diameter ratio (–)
Q_L	liquid volume flux (m^3/s)
Re_L	Reynolds number for liquid phase (–)
t	residence time (s)
u_L	superficial velocity of liquid phase ($m^3/m^2 \cdot s$)
V_c	packed bed volume (m^3)
V_L	volume of the liquid kept in bed (m^3)
V_{RR}	volume of single Raschig ring (m^3)
ε	void fraction (–)
μ_L	dynamic viscosity of the liquid phase (Pa·s)
ρ_L	density of the liquid phase (kg/m^3)
σ	standard deviation (%)
σ_t	surface tension (N/m)
φ_P	form factor – the proportion of the perforated surface area of a packing element (–)
ψ_0	drag coefficient (–)

showed a random character of the flow, moreover, local streams faced each other and merged together creating a larger stream and larger streams split into several smaller streams. Bemer and Zuiderweg [11] investigated the influence of surface tension on liquid distribution in a packed bed. The results showed that the surface tension did not affect the liquid spreading process. However, the statement about the lack of the liquid surface tension impact on spreading process in the packed bed is in contradiction with the conclusions formulated by Onda et al. [12] who observed that the intensity of radial distribution of the liquid increases with the rise in surface tension. Hoek et al. [13] conducted an experimental investigation of liquid spreading in a column of 0.5 m diameter and 2 m height for three different random packing materials i.e. Pall rings, Raschig rings and Intalox saddles. It was observed, that the liquid distribution did not depend on the height of the bed. It was also proven that each packing material analysed was characterised by its own liquid distribution pattern. Dutkai and Ruckenstein [14] and Kouri and Sohlo [15] analysed the liquid spreading inside packed beds under the countercurrent gas-liquid flow conditions. In both works, the relation between the gas flux and the intensity of radial liquid distribution was observed. Kundu et al. [16] performed the extensive analysis of liquid distribution in a glass column for several random packing types under the countercurrent flow condition and varying liquid density. It was found, that the decrease in liquid density results in increase in the radial liquid distribution. It was also observed that with the increasing gas load the amount of the liquid phase close to the column walls was reduced. It was also observed, that the structure (geometry) of the bed significantly affects the liquid distribution. Fourati et al. [17] employed gamma ray tomography system to investigate liquid holdup distribution during the countercurrent gas-liquid flow through the column of 400 mm diameter equipped with structured packing Mellapak 250 X. The experimental data allowed to formulate the relation between the global liquid holdup and liquid load taking into account liquid viscosity. This relation was further used to determine a spread factor with the support of simple dispersion model. It was observed, that the spread factor was not varied with the liquid load. The key conclusion from the research was, that the spread factor depends on the packing geometry only.

The present paper introduces an alternative optical-based approach allowing to investigate the liquid spreading process inside a packed bed. The proposed approach is not as accurate as commonly applied computed tomography techniques, however it is much less expensive and, as such, may be an interesting alternative for other researchers. This paper also demonstrates the use of the proposed approach in investigation of liquid distribution inside a random packed bed. The study is additionally supplemented with results of static and dynamic liquid holdups aimed at providing a more details about hydrodynamic characteristics of the analysed packing material. The experimental results obtained in the present work may be particularly useful in verification of advanced computational fluid dynamics (CFD) models of liquid spreading process, e.g. [6,18–20].

2. Experimental setup

The measurements of hydrodynamic parameters of the packed bed were performed with the use of a laboratory stand presented schematically in Fig. 1. The transparent column (7) equipped with glass Raschig rings (8), characterised by the parameters collected in Table 1, is placed between two walls (17) dividing the darkroom (15) into two separate chambers. On the one side of the column there is a light source

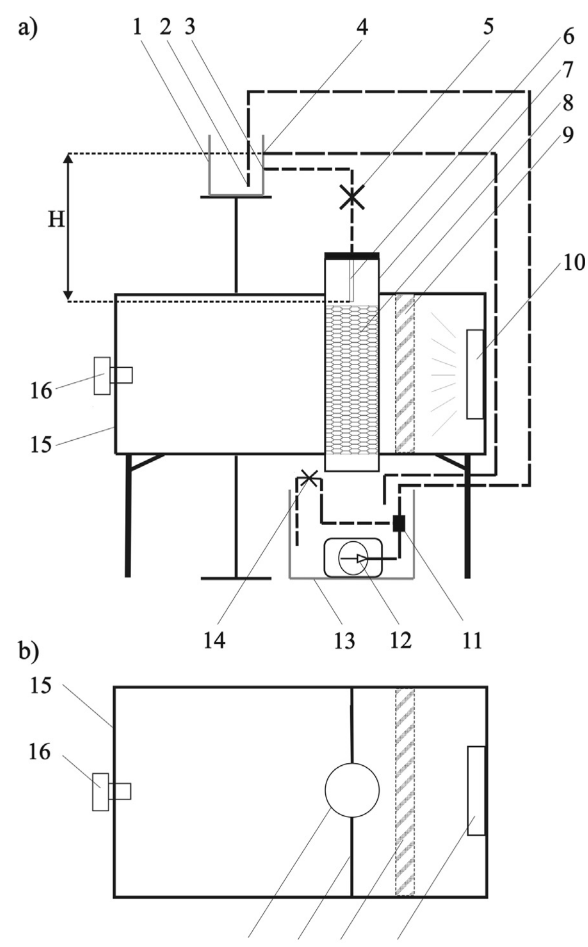

Fig. 1. Experimental stand, side view (a) and top view (b).