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Dynamic hold-up of modern high-performance packings

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Metal Raschig Super-Ring (RSR) and Intalox Metal Tower Packing (IMTP) are modern high-performance packings that combine efficient mass transfer, large interfacial surface area and regular phase distribution over the cross section of the column apparatus. This work presents and summarizes original experimental data of the dynamic hold-up of 4 IMTP sizes and 7 RSR sizes. Dimensionless criterion equations are proposed for both types of packings to calculate their dynamic hold-up for regimes below the loading point. The average arithmetic error of the IMTP equation is 7.5% and of the RRS equation is 4.6%. The proposed equations not only take into account the geometry of the packings, but also the effect of the dumping of the packing in the column.

Keywords: Packed columns; Random packings; Dynamic hold-up of the packing; Experiments.

INTRODUCTION

Packed columns are the most commonly used apparatuses for CO_2 capturing from the flue gases of power plants by absorption technology. A common way to increase their efficiency is to replace existing traditional packings with new, modern highly efficient packings, designed specifically for this purpose. High-performance random latest-generation packings with a special lamellar geometry, such as Raschig Super-Ring (RSR) [1] and Intalox Metal Tower Packing (IMTP) [2], have the potential to increase unit productivity at lower operating expenses, while reducing capital costs.

RSR and IMTP are modern packings that combine efficient mass transfer, large interfacial surface area and uniform phase distribution over the cross section of the apparatus [3]. Both types of packing, due to their open structure, are characterized by the ability to operate at high loads with low pressure drop at the same time [4, 5]. It should be noted that the hydrodynamic optimization of the RSR geometry [1] results in up to 15% higher effective surface area in comparison to IMTP at equal specific surface area.

Dynamic hold-up is an essential packing characteristic in the overall hydrodynamic characterization of a type of packing. This is the amount of fluid retained in the packed bed in the operating mode that runs down after stopping the liquid input. For industrial column apparatuses, the dynamic hold-up is practically equal to the total one, due to the small amount of the static hold-up [6, 7]. In addition to the fact that the hold-up is the volume in which the slow chemical reactions (if any), accompanying the absorption process take place, knowledge of this parameter is necessary for the strength analysis of the packing support grid, as well as for the sizing of the collecting reservoir of the column.

There is no universal methodology for calculating this performance characteristic of the packings. A widely used approach [8] accepts that the free volume for the liquid flow can be treated as many parallel channels, with the same specific geometrical surface area as that of the packing. Some authors, on the basis of experimental data from lab-scale columns, proposed semi-empirical equations with individual constants for each type and size of a packing. Another approach was proposed in [9] for structured packing. The experiments were carried out in a miniaturized set-up (several and single packing sheet), where the thickness of the liquid film over a plate with smooth surface and surface with the microstructure of the packing was studied. The total dynamic hold-up was determined by a geometrical scale-up model. The employment of CFD models also gives good possibilities for determining the dynamic hold-up of the packings. For example, in [10] a two-phase Eulerian CFD model was proposed, based on the porous media concept for simulation of the gas–liquid flow through packed beds. A very good agreement of the calculation results with the experimental data was reported there, especially for low liquid and gas loads.

The aim of the present study is, on the basis of own experimental data obtained in a semi-industrial column, to propose more precise equations for the dynamic hold-up of high-performance IMTP and metal RSR.

These equations take into account such very important values as specific surface area and void

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fraction, and represent the influence of the packing construction and dimensions, as well as the dumping of the packing in the column.

EXPERIMENTAL DETAILS

Figs. 1 and 2 are photographs of individual elements of the two types of packings, and Table 1 and Table 2 show the geometric characteristics of the packings examined [4, 5]. As it can be seen from the tables, experiments were carried out with 11 packing modifications, 4 IMTP and 7 RSR, differing in size and specific geometric characteristics. The geometric characteristic for IMTP packing *s* denotes the minimum width of lamellas 2 in their narrowest part, Fig. 1. For the RSR packings h_s denotes the lamella width, and *h* - the height of the packing element, Fig. 2. The nominal diameter d_n for both types of packings is the diameter of the inscribed circle in the packing element. All other geometric characteristics are defined as averages, obtained from triplicate redumpings of the packing in a single column section.

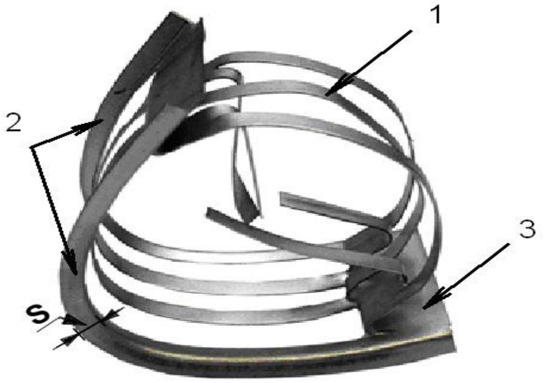

Fig. 1. IMTP packing element. 1- narrow lamellas, 2-lamellas, bent at 90°, 3- wide lamellas.

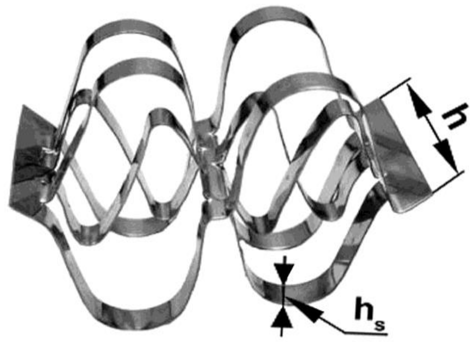

Fig. 2. RSR packing element

Table 1. Geometrical characteristics of the investigated types of IMTP packing

Name	Surface area a m^2/m^3	Free volume ε %	Size of lamellas 2 shown in Fig. 1 s mm	Nominal diameter d_n mm	Hydraulic diameter d_h mm
IMTP 25	242.8	97.1	2.0	18.6	16.0
IMTP 40	171.6	96.7	3.1	26.5	22.5
IMTP 50	107.1	97.8	4.1	37.5	36.5
IMTP 70	66.1	98.5	4.1	61.0	59.6

Table 2. Geometrical characteristics of the investigated metal RSR packing

Name	Surface area a m^2/m^3	Free volume ε %	Element height h mm	Number of strips n	Strip width h_s mm	Nominal diameter d_n mm	Hydraulic diameter d_h mm
Raschig Super-Ring No. 0.5	236.2	96.5	15	4	3.8	21	16.3
Raschig Super-Ring No. 0.6	180.5	97.5	20	6	3.3	27	21.6
Raschig Super-Ring No. 0.7	175.9	97.7	20	5	4.0	34	22.2
Raschig Super-Ring No.1	155.5	98.0	25	6	4.2	34	25.2
Raschig Super-Ring No. 1.5	105.8	97.9	30	5	6.0	48	37.0
Raschig Super-Ring No. 2	100.6	98.0	38	6	6.3	50	39.0
Raschig Super-Ring No. 3	74.9	98.0	50	6	8.3	65	52.3

The experimental results were obtained in a column with a diameter of 470 mm with water as a liquid phase in the absence of a gas flow. A detailed description of the scheme is presented in [3]. The liquid load ranged from 10 to 200 $m^3/(m^2h)$. The height of the packing layer was 2400 mm. The liquid distributor provided 920 drip points per square meter.

The packing hold-up was obtained by the method of measuring the difference in the liquid level in a level tank in the presence and absence of liquid irrigation [7]. The following procedure was applied. Prior to each series of experiments, the liquid was fed in the column at maximum liquid superficial velocity to ensure that the packing elements were completely wetted. The irrigation was then interrupted, and after a certain time to allow the liquid from the column to drain into the tank, the necessary liquid load was applied. After stabilizing the flow (the level of the liquid in the measuring tank was stationary), the liquid feed was stopped and after the liquid had drained the difference in the level of the tank was recorded. Having in mind the semi-industrial size of the column, the end effects (the volume of drops and trickles under and over the packing layer) were neglected because of insignificance. The dynamic hold-up was calculated as the liquid volume per unit volume of the packed bed.

Figs. 3 and 4 present the experimental results obtained for the dynamic hold-up of the studied packings as a function of the liquid load. The lines obtained are similar to those already established for well-known random packings. In both figures, it can be seen that an increase in the liquid load leads to an increase in the packing hold-up. Packings characterized by smaller geometric dimensions retain larger amount of liquid.

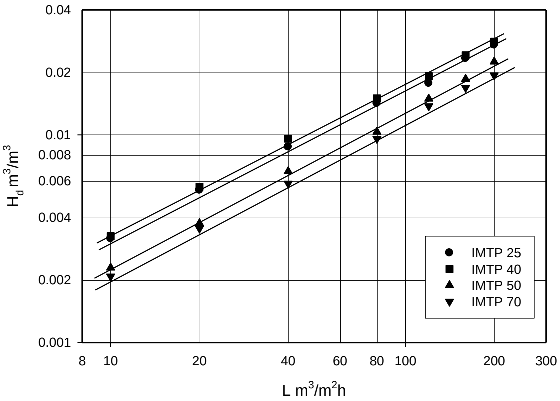

Fig. 3. Dynamic hold-up of IMTP packings related to the liquid superficial velocity in the absence of gas flow

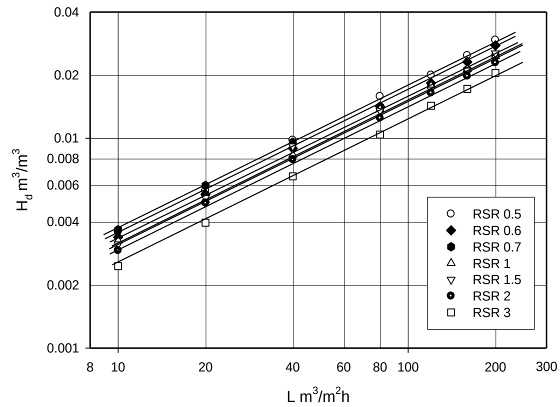

Fig. 4. Dynamic hold-up of RSR packings related to the liquid superficial velocity in the absence of gas flow

DATA CORRELATION

The analytical approach accepted in describing the obtained data is based on the multichannel flow in the packing layer [6, 8]. In [8], it is shown how the specific surface characteristics of the different packing types are taken into consideration by the introduced hydraulic surface area, and for each type and size of a packing a constant obtained from experiments in laboratory conditions is proposed.

In the present study, two criterion equations for the two different packing types are derived, taking into account their specific geometric characteristics.

The dynamic hold-up below the loading point is determined in the absence of a gas phase and can be represented as a function of the liquid load and their geometric characteristics as:

For IMTP:

$$H_d = f\,[Fr_{L,}\,(s/d_n)] \tag{1}$$

For RSR:

$$H_d = f\,[Fr_{L,}\,(h.a)] \tag{2}$$

where: $Fr_L = \frac{L^2.a}{g}$ - Froude number for the liquid phase; L - liquid phase superficial velocity, m/s; $d_h = \frac{4\varepsilon}{a}$ - the packing hydraulic diameter, m; ε is the packing void fraction, m^3/m^3; a - packing specific surface area, m^2/m^3; s - minimal width of lamellas 2, Fig. 1, m; and h – packing height, Fig. 2, m.

Applying dimensional analysis and processing by regression analysis the experimental data for the packing dynamic hold-up below the loading point, the following expressions were obtained:

For IMTP:

$$H_d = 0.067 Fr_L^{0.35} \left(\frac{s}{d_n}\right)^{-0.03} \tag{3}$$

The mean arithmetic error of Eq. (3) is 7.5%.

The precision of the obtained experimental constants at 95% statistical reliability is given below:

0.067 ± 0.0013;

0.35 ± 0.0145;

-0.03 ± 0.0087.

For RSR:

$$H_d = 0.12 Fr_L^{0.329} \left(h.a\right)^{-0.4} \quad (4)$$

The mean arithmetic error of Eq. (4) is 4.6%.

The precision of the obtained experimental constants at 95% statistical reliability is given below:

0.12 ± 0.0174;

0.329 ± 0.0062;

-0.4 ± 0.1057.

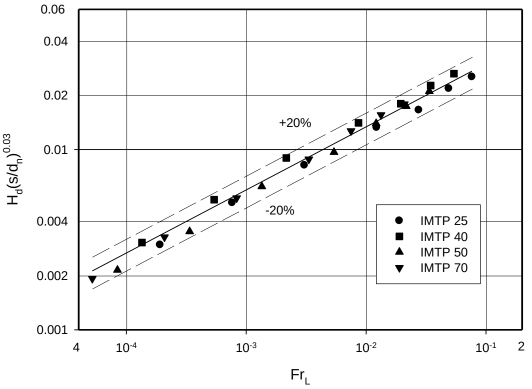

Fig. 5. Comparison of experimental data for IMTP packing with the results calculated by Eq. (3).

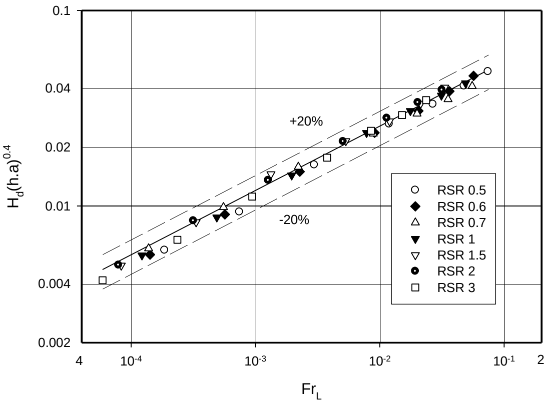

Fig. 6. Comparison of experimental data for RSR packing with the results calculated by the respective Eq. (4)

Figs. 5 and 6 present a comparison of the experimental data with the equations thus obtained. From both figures it can be seen that the proposed equations describe the experimental results adequately in the whole wide range of experimental liquid loads. An important advantage of these equations is that the resulting constants in them are derived for a packing type, describing all of the packing sizes. Moreover, they are obtained on the basis of experiments in a semi-industrial installation and also take into consideration the dumping of the packing in the column.

CONCLUSION

An experimental study was conducted to determine the dynamic hold-up of two types of advanced metal high performance packings, IMTP and RSR, in a semi-industrial installation. A total of 11 packing modifications, IMTP - 4 and RSR – 7, were studied, differing in size and geometric characteristics. More precise equations for prediction were proposed for both packing types for the dynamic hold-up below the loading point. They fit the experimental results with accuracy acceptable for practical use and can be successfully applied for design and correct constructive sizing of industrial apparatuses.

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