Comparison of experimental and model liquid distribution in large packed bed of Raflux rings 50-5

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Abstract. This work presents a continuation of our investigations on the radial liquid distribution in packed beds with open-structure random packings, by means of a dispersion model, in a scale, close to industrial one. Using experimental data for uniform initial irrigation, the optimal parameters’ values of the three parameters of the dispersion model are obtained by two-parameter identification. One of the parameters (the radial spreading coefficient) is calculated independently by using experimental data for a point source initial irrigation. The dispersion model solution at optimal parameters’ values is compared with both experimental and TUM WelChemCell model literature data for the liquid radial distribution in a packed column with a diameter of 1.2 m and random packing Raflux rings 50-5. The maldistribution factor of the liquid distribution is also calculated and compared. The comparison shows very good agreement between our results and the literature data and confirms the dispersion model capability to predict the liquid distribution in large columns with open-structure packings.

1. Introduction

In recent years, an increasing interest is observed in the investigation of the liquid phase maldistribution in packed columns with a large diameter [1-7], as well as in the application of open-structure random packings. These packings are characterized by a complex shape (a type of a 3D lattice, consisting of curved thin lamellae), low pressure drop, and high effective surface, which make them a worthy alternative to the structured packings, most often used in industrial scale transfer processes. Many of these packings are not investigated thoroughly, especially their radial distribution ability in columns with a large diameter. A series of our previous works is concerned with prediction of liquid distribution in metal random packings Raschig Super-Rings (0.7, 1 and 3") and metal Pall rings [4, 5, 7] by a dispersion model, but in columns with a diameter up to 0.6m. Our latest paper [6] was the first attempt to use the dispersion model for prediction of the liquid distribution at a large column diameter of 1.2m and for the metal RVT saddle rings 70-5, using the experimental data of [2]. The result encouraged us to continue and compare our results with recently published experimental and TUM WelChemCell Model results [3] for Raflux rings 50-5, obtained for the same column.

2. Problem formulation

As already mentioned, the experimental data for radial liquid distribution in a column with a diameter of 1.2m and a random metal open-structure packing Raflux-rings 50-5 (Figure 1) will be used in this study. The data are obtained at uniform initial distribution, liquid load $L_0=20$ m$^3$/(m$^2$h), gas load factor $F_g=1.3$ Pa$^{0.5}$, bed height $H=3$m, and measured with a Liquid Collecting Device (LCD) [3]. This data is used to verify the capability of the dispersion model to predict the liquid distribution in an industrial scale. The LCD consists of 7 concentric annuli, each of them (excluding the 1st one) is...
divided into 3 equal 120° segments, i.e. the LCD divides the column cross-section into a total of 19 collecting segments [1]. Annuli area ratios R1:R7 in % are (2.67, 8.00, 13.54, 18.67, 24.01, 29.35, 3.96). An extension of the TUM WelChemCell model is proposed in [3] and validated against experimental data for Raflux rings 50-5, showing good agreement for both uniform and point source initial liquid distribution.

![Figure 1](image)

**Figure 1.** Photography of a random metal packing Raflux ring 50-5.

As already stated in our previous works [4, 6, 7], the dispersion model solution needs identification of model parameters $B$, $C$ and $D$ for the respective packing and the current packing layer height $z = DH/R^2$, as can be seen in [6]. The solutions of the dispersion model for the dimensionless liquid density of irrigation, $f(r,z) = L_z/L_0$ and for the wall flow $W^w$, at uniform initial liquid distribution (superscript “u”), $r = r'/R$, have the form:

$$f^u(r,z) = A_0 + \sum_{n=1}^{n} \chi_n J_n(q_n r) \exp(-q_n^2 z), \quad W^w = \frac{1}{1+C} - 2 \sum_{n=1}^{n} \chi_n \left( \frac{J_1(q_n)}{q_n} \right) \exp(-q_n^2 z)$$

(1)

$$A_0 = \frac{C}{1+C}, \quad \chi_n = 2 \left( q_n^2 / B - 2C \right) \left[ \left( q_n^2 / B - 2C \right)^2 + q_n^4 + 4C \right] J_0(q_n)^{-1}$$

Following the procedure, presented in detail in [6], two independent approaches and two sets of experimental data (at uniform and point source initial irrigation) are used to identify the packing radial spreading coefficient $D$, $m$. Other two parameters are determined too, and comparison of dispersion model solution with experimental data and TUM WelChemCell Model results [3] is presented in the next section.

### 3. Results and discussion

The first approach to determine the packing radial spreading coefficient $D$, $m$ is the so called single-jet method [8], which requires experimental data for point source initial irrigation. It is explained in detail in [8] and applied in [6] to an example with a random RMSR 70-5 packing, the same LCD and the same column diameter as those considered in [1]. For brevity, here only the final results for radial spreading coefficient $D$ of Raflux rings 50-5 are presented in Figure 2.

![Figure 2](image)

**Figure 2.** Values of $ln(q)$ versus $(r^2)^n$ according to the single-jet method for determination of radial spreading coefficient $D$ for Raflux rings 50-5, $H=1$m, point source initial irrigation data [3].
It was found that the mean average value of this coefficient is $D=0.00939$ m at 3 different liquid loads – 5, 10 and 15 m³/(m².h), at $G=0$ and $H=1$ m. It is seen that, in contrast to the metal RVT saddle rings 70-5 [6], here the coefficient of radial spreading for Raflux rings 50-5 slightly increases with increasing of the liquid load. Practically, the Raflux rings have a quite different structure, which resembles that of the Pall rings. Compared to them, the structure of RVT saddle rings 70-5 is more open to the liquid flow.

The second approach to find $D$ independently is the two-parameter identification procedure, minimizing the residual variance between model and experimental mean densities of irrigation in all 7 segments of the LCD. This method needs experimental data for radial liquid distribution at uniform initial irrigation, and the value of the parameter $C$ (see Equation (1)). The parameter $B$ is a criterion for exchange of liquid between the column wall and the packing; the parameter $C$ expresses the equilibrium distribution of entire liquid flow between the wall and the packing when equilibrium state is attained $z \to \infty$. The latter can be determined from experimental data of the wall flow at uniform initial irrigation and at least 3 different packing heights. In the dispersion model definition it is assumed that at some packing height the wall flow growth stabilizes (reaching a plateau), which corresponds mathematically to the case $z \to \infty$, and the formula $C = \left(1 - \frac{W_{z \to \infty}}{W_{z 
rightarrow \infty}}\right)$, developed in [7], can be used. Here, the value $C=7.12$ was calculated using the experimental data for the wall flow in a bed of Raflux rings 50-5 at uniform initial irrigation, $L_0=20$ m³/(m².h), $F_g=1.3 Pa^{0.5}$, and packing heights 1, 1.5, 2.5 and 3 m.

The two-parameter identification of $B$ and $D$ are performed, and the results are given in Figure 3, as a 3D plot (a) and as a contour plot (b) of residual variance versus different values of $B$ and $D$. The minimum of residual variance $S_2^2$ between model and experimental density of irrigation in each segment of LCD is obtained as 0.198e-01 for the optimal values of the parameters $B=1.15$, $D=0.01$m and $C=7.12$. As is seen, the obtained value for $D$ from two-parameter identification (0.01m) is close to this, determined by single jet method earlier (0.00939m). For these optimal values of the parameters, the solution of the dispersion model as well as that for the wall flow (Equation (1)), were obtained. The results are compared with data for radial liquid distribution from physical experiment and calculations with TUM WelChem Cell model for Raflux rings 50-5 (both from [3]).

![Figure 3. Visualization of two-parameter identification of model parameters with the minimum of residual variance as a criterion $S_2^2=0.198e-01$, at $D=0.01$ m, $B=1.15$, $C=7.12$, $H=3$m, for metal Raflux rings 50-5; (a) – 3D plot, (b) – contour plot.](image_url)
The comparison is presented in Figure 4. As a whole, both models are in very good agreement with the experimental data. The relative errors in %, in segments R1÷R7 between the dispersion model predictions and the experimental data are 0.3; -2.4; -14.1; 4.3; -10.2; 11.6; -0.8, respectively. The dispersion model wall flow fits better to the experimental data (-0.8%), the predictions have accuracy of -14.1%/11.6%, which is quite reasonable for this column scale.

In [3, at figs.11-13] a detailed explanation about the deviations was given for the whole experimental database used (4 type of random packings, 4 packing layer heights, a wide range of liquid loads and gas load factors). It was noted there, on the base of an analysis of the parity plots for both of their models (original WelChem cell model and enhanced TUM WelChem Cell model) [3, see figs.12-13], that the original one does not take into account the liquid load and countercurrent gas flow effects, and moreover a simplified assumption for the wall flow is considered. The enhanced TUM WelChem Cell Model accounts for these effects and the wall flow assumption was refined by increasing packing porosity at the column wall.

Figure 4. Comparison between experimental data for radial liquid distribution (blue rhombs), TUM WelChemCell model (red line) (both from [3, fig.11]) and dispersion model predictions (black line), for random metal Raflux rings 50-5, \( H=3 \text{m}, \) column diameter 1.2m, liquid load \( L_0=20 \text{ m}^3/(\text{m}^2\text{h}), \) gas load factor \( F_g=1.3 \text{ Pa}^{0.5} \)

The maldistribution factors of the experimental and model liquid distributions are calculated by the following formula [1,5]:

\[
M_f = \frac{1}{F_0} \sum_{i=1}^{ns} F_i \left| \frac{L_i - L_0}{L_0} \right|
\]  

In equation (2) the ratio \( F_i/F_0 \) represents the ratio of the area of the respective segment \( i \) to the entire area of the LCD (i.e. column cross-section), \( m_i^2 \), \( ns \) is the number of segments of the LCD, \( L_i/L_0 \) is the dimensionless theoretical or experimental irrigation density in the segment \( i \) of LCD, limited between the radii \( r_{i-1} \) and \( r_{i} (r_{i} > r_{i-1}) \).

In Figure 5 the maldistribution factors for the random packing Raflux rings 50-5, \( H=3 \text{m}, \) are calculated and they almost completely coincide; the relative error is 2.5%. Also, our latest calculation results for the maldistribution factors are added based on the results in [6] for a random packing RMSR 70-5, and a packing bed height of 1 m and 2.5 m. For this packing the calculated values are \( M_f \)
= 0.172 for $H=1\text{m}$, and $M_f=0.242$ for $H=2.5\text{m}$. The corresponding experimental ones are $M_f=0.198$ for $H=1\text{m}$ and $M_f=0.265$ for $H=2.5\text{m}$. The comparison between model results for liquid distribution and the respective experimental data at two packing heights shows good agreement - the relative errors are 13.1% and 8.6 % at $H=1\text{m}$ and 2.5 m, respectively. The comparison shows good agreement between predicted and measured maldistribution factors for both packings in industrial scale column size.

4. Conclusions
In this work a modeling of radial liquid distribution in packed column with a diameter of 1.2 m and random metal packings Raflux rings 50-5 by the dispersion model is performed. Identification of the model parameters and comparison of obtained results with both experimental and TUM WelChem Cell model data [3], are presented. It was observed, that our predictions showed very good agreement with the results of [3]. The relative errors in %, in the segments of the LCD between the dispersion model predictions and the experimental data do not exceed 15 %, which is quite reasonable at this column scale. The relative error between the model and experimental maldistribution factors for Raflux rings 50-5 is 2.52%, and for RMSR 70-5, 13.1% and 8.6 % at $H=1\text{m}$ and 2.5 m, respectively. The obtained results confirm the dispersion model capability to predict the liquid distribution and maldistribution in large columns with open-structure packings.

5. References
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