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Pressure drop of high performance random Intalox Metal Tower Packing

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INTALOX Metal Tower Packing (IMTP) is one of the best random packings designed especially for use in distillation operations. The advantages realized in distillation have been abundantly applied in absorption, liquid-liquid extraction and direct contact heat transfer operations as well. There is no universal methodology for calculating the performance characteristics of this packing. The constants of the existing equations for practical calculations are obtained for each separate packing size. The present work presents and generalizes own experimental data for the pressure drop of 4 sizes of IMTP packing with nominal diameters of 25, 40, 50, and 70 mm. The experimental data for dry packing pressure drop are described by an equation with a mean deviation of 5.1%. Equations for determination of pressure drop of irrigated packing, up to the loading point and above it, are also obtained. These equations reflect not only the influence of the packing geometry, but also the column redumping.

Keywords: Packed columns; Random packings; Packing pressure drop; Equations for dry and irrigated IMTP.

INTRODUCTION

Packed bed columns are apparatuses with long history of exploitation for heat and mass transfer processes in gas-liquid systems. The actual level of technological development and the increasing number of international regulations which deal with environmental protection further expand the application field of packed columns. The main advantages of the random packings are their easy production using highly effective technology and easy dumping in the apparatus. Their great disadvantages are the higher pressure drop in comparison to the structured packings and the not very good distribution properties.

INTALOX Metal Tower Packing (IMTP) is a modern high capacity random packing characterized by high void fraction, low pressure drop [1, 2] and high mass transfer efficiency [3, 4]. IMTP is widely used in distillation towers: from deep vacuum towers, where low pressure drop is crucial, to high-pressure towers, where capacity easily surpasses that of conventional trays. Many absorption and stripping towers, especially those aiming at high capacity or close approach to equilibrium, rely on IMTP packing. The low pressure drop, high specific heat-transfer coefficient, as well as the fouling resistance of IMTP packing contributes to its success in heat transfer towers [1]. It was shown in [2], on the basis of a comparison of specific pressure drop, capacity, height equivalent to a theoretical stage, and pressure drop per theoretical stage between corresponding sizes of random packings, that the third generation random packings IMTP offer a noticeable advantage in comparison to the second generation Pall-Rings. However, the Raschig Super-Ring packing (RSR) offers a further evident benefit in comparison to the third generation random packings–this is why it is called ‘fourth generation’ [2]. The effective area, a_e, of IMTP can be much higher than the specific area [4, 5]. But at comparable values of the specific area and the liquid superficial velocities, RSR juxtaposed to IMTP [4], have about 15% higher effective area and over 35 % lower pressure drop versus effective area, at the same gas velocity.

The present paper aims at deriving more precise equations for evaluation of the pressure drop, taking into account such very important quantities as specific surface area and void fraction which carry the influence of the packing construction and dimensions,-as well as the dumping of the packing in the column [6].

EXPERIMENTAL DETAILS

The geometric characteristics of the investigated packings are given in Table 1. A photograph of one of them – IMTP 70 is presented in Fig.1. The packing elements are built of three types of lamellas, Fig.1: 1- main narrow lamellas, 2- lamellas specially bent at 90º, and 3- wide lamellas.

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The geometrical characteristic denotes the minimal width of lamellas 2 in their narrowest part, Fig. 1. The nominal diameter d_n is the diameter of the inscribed circle in the packing element. All other geometrical characteristics are defined as averages obtained from triplicate redumping of the packing in a single column section.

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

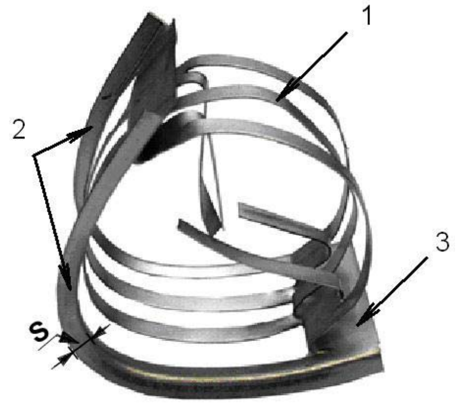

Fig.1. IMTP 70 packing

All experiments were carried out in a column with a diameter D=470 mm and a packing height of 2400 mm**.** The liquid phase distributor ensured 923 drip points per m^2. For the pressure drop investigation the liquid superficial velocity varied between L=10 and 120 $m^3/(m^2$ h) in an air – water system. The packing pressure drop was measured by means of a special optical differential manometer with an accuracy of 0.1 Pa. At a pressure drop higher than 200 Pa, a conventional U-tube differential manometer was used.

The data for all investigated packings at different liquid superficial velocities *versus* the gas velocity factor are presented in Figs. 2 to 5. The lines obtained are similar to those already established for the well-known random packings, but the measured lower pressure drop shows improved performance parameters and higher loading and flooding points.

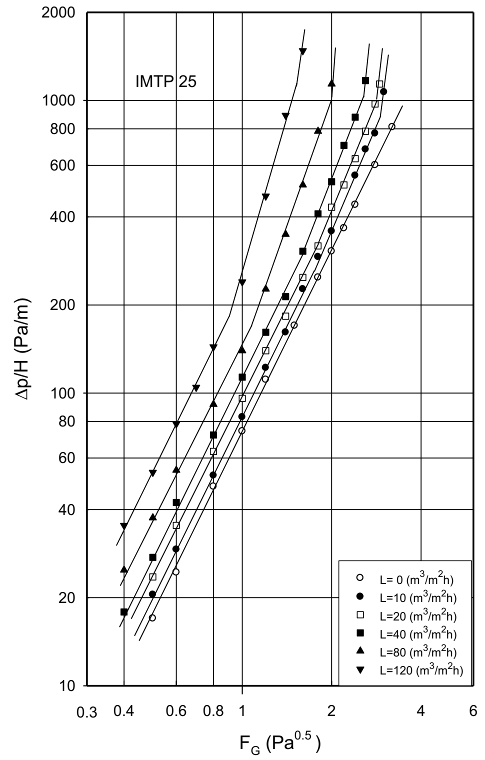

Fig.2. Pressure drop of IMTP 25 at various superficial liquid velocities vs. gas velocity factor.

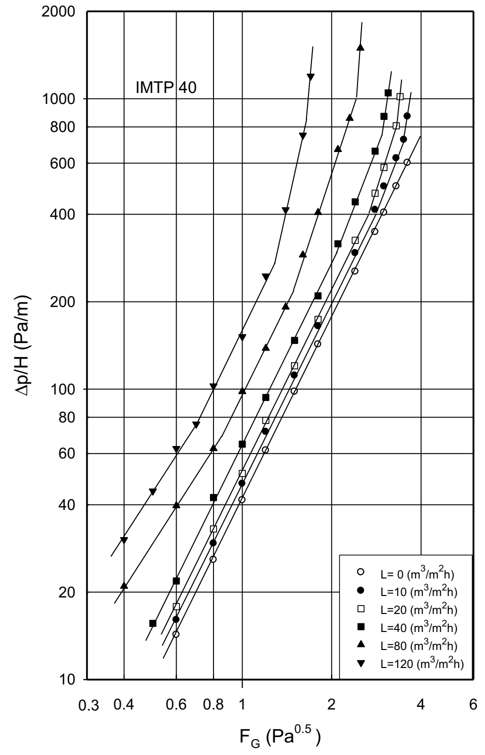

Fig.3. Pressure drop of IMTP 40 at various superficial liquid velocities vs. gas velocity factor.

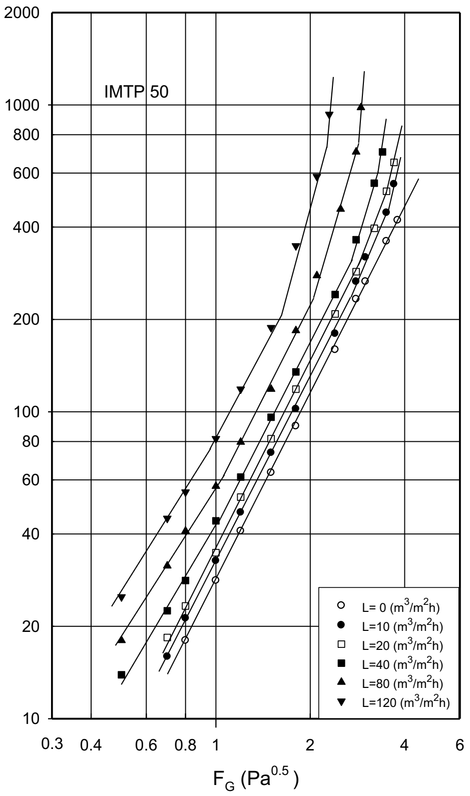

Fig.4. Pressure drop of IMTP 50 at various superficial liquid velocities vs. gas velocity factor

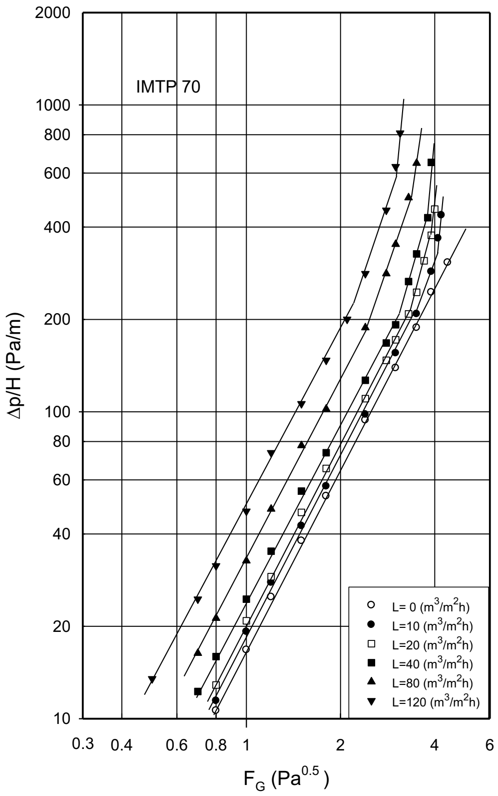

Fig.5. Pressure drop of IMTP 70 at various superficial liquid velocities vs. gas velocity factor.

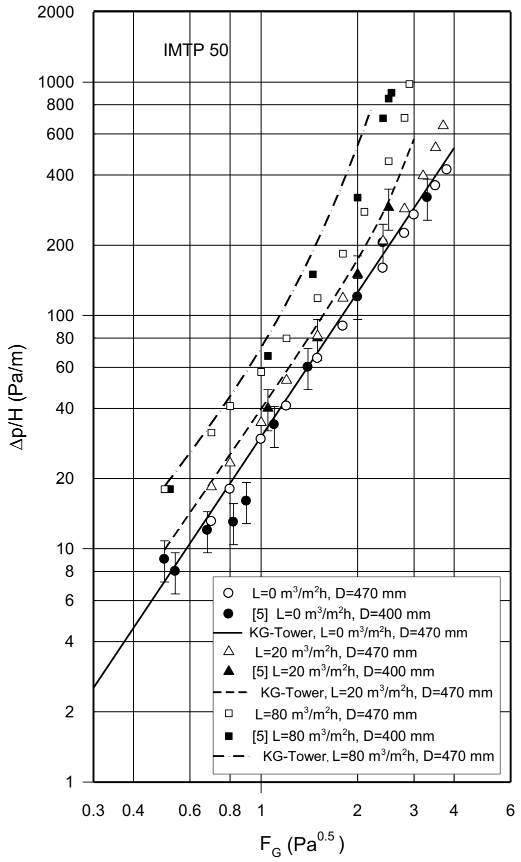

Fig.6. Pressure drop of dry and wetted IMTP 50 vs. gas velocity factor. Comparison with data from [5] and the manufacturer software KG- Tower 3.2.

DATA CORRELATION

Most of the equations for calculation of the pressure drop of irrigated packing need relation for the pressure drop of a dry one.

For practical calculation of the pressure drop of a dry packing Billet [7] proposed the equation

$$\frac{\Delta P_0}{H} = C_d F_G^e, \qquad (1)$$

where ΔP_0 is packing pressure drop in Pa; H denotes packing height in m; $F_G = w_o\sqrt{\rho_G}$ is the factor of vapour (gas) velocity in $Pa^{0.5}$; w_o is gas velocity related to the entire column cross section in m/s and ρ_G is gas density in kg/m^3. The experimental constants C_d and e take into account the influence of the packing dimensions and especially of the void fraction ε and are determined not only for each packing type, but also for each element size. Their values are given in [7] for a number of modern highly effective packings, but not for IMTP.

Fig. 6 presents a comparison of experimental and calculated data for the pressure drop of dry and irrigated IMTP 50 in the system air-water, at two liquid loads L = 20 and 80 $m^3/(m^2\ h)$. In all experiments the column operates at atmospheric pressure and room temperature. In [5] the column diameter is 400 mm and the height of the packing bed is 1500 mm. The figure shows that the pressure drop data obtained in the present investigation, the data from [5] and the values predicted with the manufacturer software KG-Tower 3.2 are in good agreement for dry packing and under the loading point in wetted conditions. Over the loading point the pressure drop in [5] grows more rapidly with the increase of F_G, reaching over 30 % deviation and KG-Tower gives higher values reaching over 50% deviation from our experimental results. For the present generalization of the experimental data the dimensionless pressure drop of dry packing ψ is used [8, 9],

where $\psi = \dfrac{\Delta P_0 d_h}{2H\rho_G (w_0/\varepsilon)^2}$ is the dimensionless pressure drop equivalent to Euler number; $d_h = \dfrac{4\varepsilon}{a}$ is the packing hydraulic diameter, m; ε is the packing void fraction, m^3/m^3 and a - the packing specific surface area, m^2/m^3.

By using dimensional analysis and processing all data for the dry packings by the least squares technique, the following equation was obtained:

$$\psi = 0.96\left(\frac{s}{d_n}\right)^{0.27} \tag{2}$$

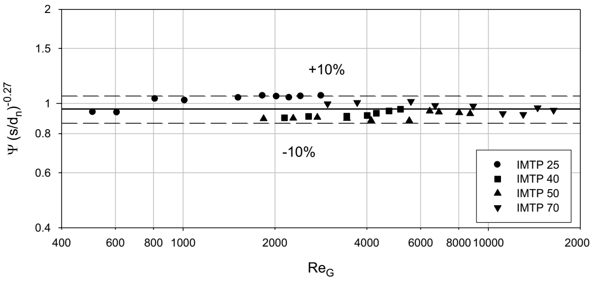

Fig.7. Comparison of experimental data for dry packings with results calculated by Eq. (2).

Fig. 7 presents a comparison of equation (2) with the data obtained for all studied packings, where $Re_G = \dfrac{w_0 d_h}{\nu_G.\varepsilon}$ is the Reynolds number for the gas phase and ν_G is the gas phase kinematic viscosity in m^2/s . The mean deviation of equation (2) is 5.1%. The precision of the obtained experimental constants at 95% statistical reliability is given below:

0.96 ± 0.094; 0.27 ± 0.052.

To determine the pressure drop of the wetted packing *ΔP*, the well known relationship proposed by Zhavoronkov *et al.* [10], was used:

$$\Delta P = \frac{\Delta P_0}{(1-A)^3}, \tag{3}$$

where A is a dimensionless value related to the liquid holdup which accounts for the effect of the part of free column cross section occupied by the liquid. To determine this value, the following additive relationship [10, 11] was used:

$$A = A_0 + \Delta A \tag{4}$$

where A_0 indicates the A value under the loading point, and ΔA is the increasing of A over this point.

Applying the dimensional analysis to the experimental data for packings pressure drop below the loading point the following expression was obtained:

$$A_0 = 2.5\,\mathrm{Re}_L^{-0.1} Fr_L^{0.44} Eo^{0.21} \tag{5}$$

where $Re_L = \dfrac{4L}{a\nu_L}$ is the Reynolds number for the liquid phase; L - liquid phase superficial velocity, m/s; $Fr_L = \dfrac{L^2.a}{g}$ - Froude number for the liquid phase; $Eo = \dfrac{\rho_L.g}{a^2\sigma}$ - Eötvos number and σ is liquid surface tension, N/m.

The mean deviation of equation (5) regarding $\Delta P/\Delta P_0$ is 2.6%. The precision of the obtained experimental constants at 95% statistical reliability is given below:

2.5 ± 0.14; -0.1 ± 0.061;
0.44 ± 0.012; 0.21 ± 0.014.

For the experimental data for packing pressure drop over the loading point the following equation was obtained:

$$\Delta A = 7.10^{-4} Fr_L^{-0.16}\left(\frac{L\rho_L}{w_o\rho_G}\right)^{1.02} Eo^{0.14} \tag{6}$$

The mean deviation of equation (6) regarding $\Delta P/\Delta P_0$ is 3.8%. The precision of the obtained experimental constants at 95% statistical reliability is given below:

$7.10^{-4} \pm 5.10^{-4}$; -0.16 ± 0.020;
1.02 ± 0.047; 0.14 ± 0.021

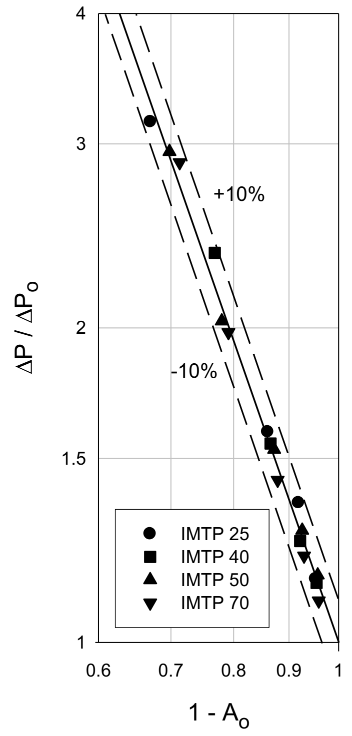

Fig.8. Comparison of experimental data for the pressure drop of the wetted packings below the loading point with results calculated by Eqs. (3) and (5).

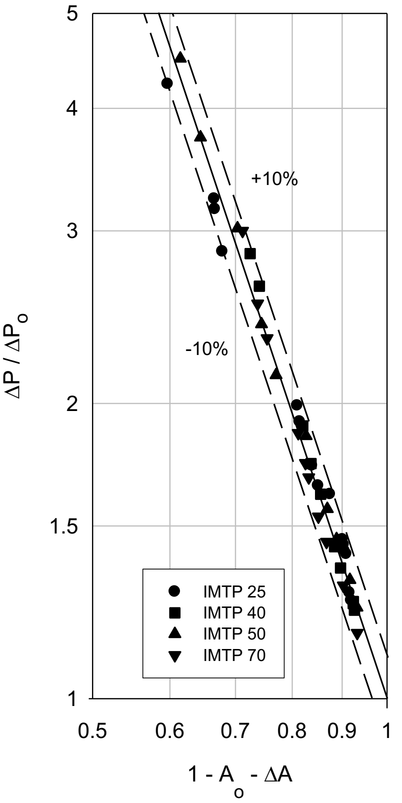

Fig.9. Comparison of experimental data for the pressure drop of the wetted packings above the loading point with results calculated by Eqs. (3), (4) and (6).

Figs. 8 and 9 present the comparison of the lines calculated with the proposed equations and the experimental data for gas velocities below and above the loading point for all investigated packings.

CONCLUSION

The pressure drop of four sizes of high effective IMTP packing is determined and summarized. The results confirmed the good performance of the investigated packings. More precise equations for prediction of the pressure drop at dry and wetted conditions are derived. They fit the experimental results with accuracy acceptable for practical use.

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ХИДРАВЛИЧНО СЪПРОТИВЛЕНИЕ НА ВИСОКОЕФЕКТИВНИЯ МЕТАЛЕН INTALOX ПЪЛНЕЖ ЗА КОЛОННИ АПАРАТИ

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(Резюме)

Пълнежът IMTP е един от най-добрите пълнежи, специално създаден за провеждане на дестилационни процеси. Предимствата, които е показал в този тип процеси, са разширили неговото приложение и при случаите на абсорбция, течно-течна екстракция и директен топлообмен. Все още не съществува универсална методика за изчисляване на работните характеристики на този тип пълнеж, като константите в съществуващите и използвани в практиката уравнения са получени за всеки отделен типоразмер пълнеж. В настоящата работа са показани и обобщени собствени експериментални данни за хидравличното съпротивление на 4 IMTP пълнежа с номинални диаметри 25, 40, 50 и 70 mm. Експерименталните данни за сухия пълнеж се описват с уравнение със средно отклонение от 5.1%. Получени са уравнения за определяне на съпротивлението и на умокрения пълнеж под и над точката на задържане. В предложените уравнения се отчита не само геометрията на пълнежа, но е взето предвид и влиянието на презареждането на колоната.