Gas Distribution in Packed-Bed Columns with IMTP-Ring and Ralu-flow

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This work continues a series of investigations on the gas distribution ability of various types of random packings for packed-bed columns. Four varieties of metal packings IMTP-Ring with size 25, 40, 50 and 70 mm, and two sizes of plastic Ralu–Flow No. 1 and 2, are studied. The study is carried out with a test column 0.47 m in diameter. Velocity profiles are measured with thermoanemometer over the column cross-section at various packing heights, and the maldistribution factor is determined. The uniformity limit and penetration depth is obtained for all investigated packings as indicators for its distribution ability.

Keywords:
Packed-bed columns, gas distribution, maldistribution factor, uniformity limit, penetration depth

Introduction

The distribution ability of six metallic and two plastic packings Raschig-Super Ring has been a subject of our previous work.[1] An experimental installation with 0.47 m test column has been described there as well as the method of measurement. The velocity profile over the column cross-section has been measured with a thermoanemometer. For every packing height, the gas velocity has been measured at 44 points along two diameters, one in the direction of the axis of inlet gas device, and the other in perpendicular direction. The maximal packing height has been 0.8 m depending on packing type. At these limit sizes, the velocity profiles have been measured in 112 points regularly distributed over the whole cross-section. In this case the velocity has been measured in the center of a quadratic cell with 4 cm wall.

In the last few years along with Raschig Super-Rings the packings IMTP-Ring[2,3] and Ralu-Flow[5] are used in the chemical industry and oil refinery.

The aim of this work is to analyze the distribution ability of the metal packings IMTP-Ring (Fig. 1) and plastic Ralu-Flow (Fig. 2) and to determine that minimal height of the packing's layer, for which the best uniformity is achieved under the given conditions.

The packing characteristics are given in Table 1.

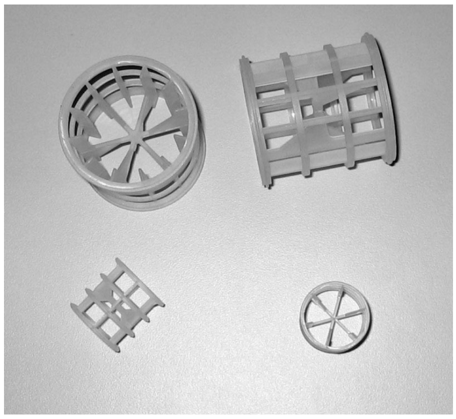
Experimental results

For the smallest size of metal IMTP–Ring 25 mm, the maldistribution factor *Mf* is determined for seven different heights of packing layer: without packing at 0.05 m over the supporting grid in order

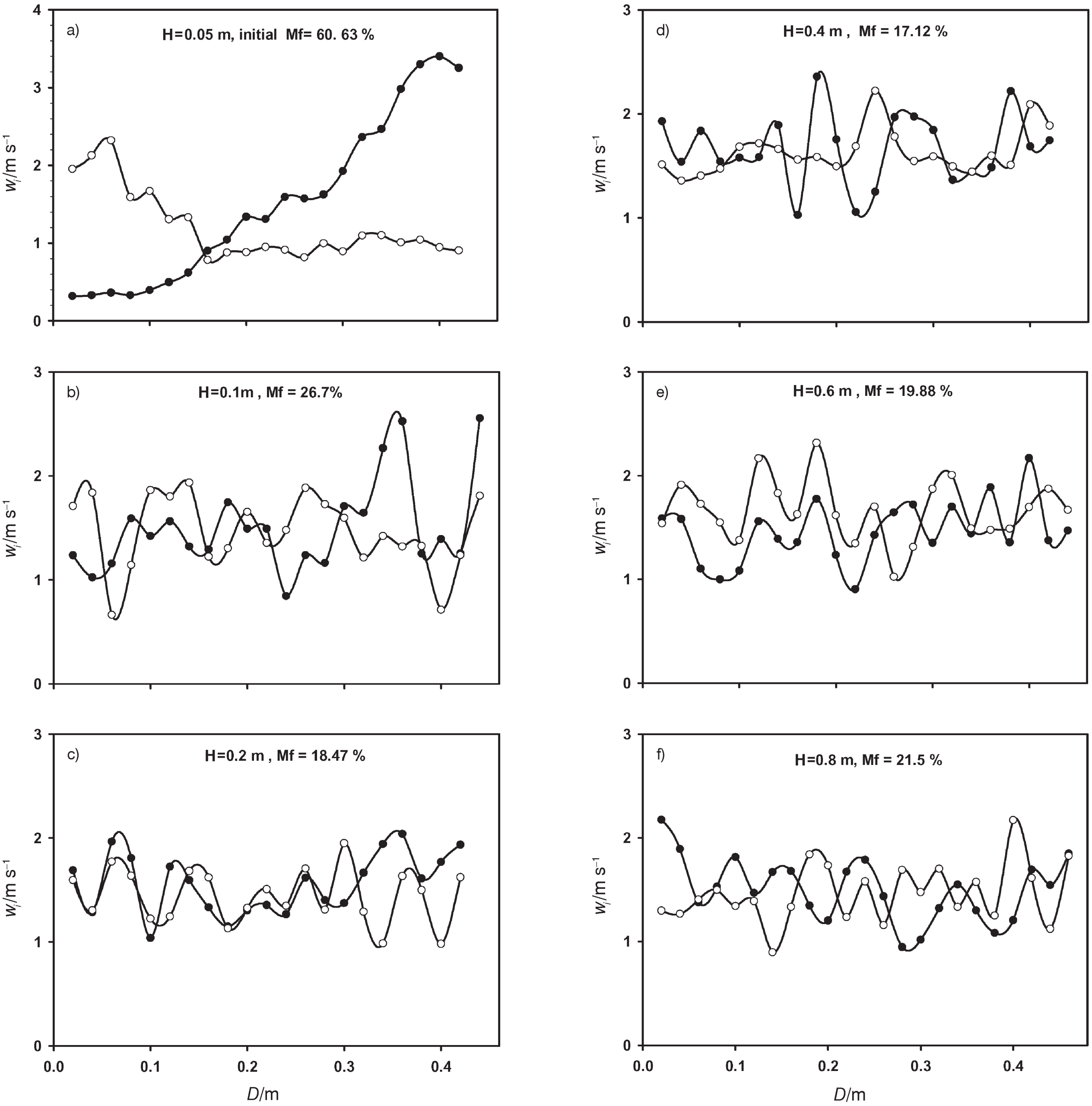
T a b l e 1 – *Main characteristics of investigated packings*

Type of packing	Material	Nominal diameter, D / mm	Specific surface area, a / m^2 m^{-3}	Free volume, ε / %	Weight, kg m^{-3}	Number concentration, m^{-3}
IMTP- Ring 25	metal	25	200	96	312	125 000
IMTP- Ring 40	metal	40	150	97	243	51 000
IMTP- Ring 50	metal	50	98	97	156	15 000
IMTP- Ring 70	metal	70	52	97	103	4 100
Ralu Flow No.1	plastic	25	165	95	55	33 000
Ralu Flow No. 2	plastic	50	100	95	54	4 600

F i g . 1 – *A photograph of metal elements IMTP-Ring*



F i g . 2 – *A photograph of the plastic packings Ralu-Flow*



F i g . 3 – *Velocity profiles on two perpendicular diameters at various heights (a-f) of packing IMTP-Ring 25. Full black points are measured on d_1, empty points – on d_2*

to determine the initial maldistribution, and with packing layers of 0.1; 0.2; 0.4; 0.6; 0.8 and 1.3 m.

The maldistribution factor has been calculated according to the expression

$$\mathrm{Mf} = \frac{\sigma}{w_0} = \frac{1}{w_0}\sqrt{\frac{\sum_{i=1}^{n}(w_i - w_0)^2}{n-1}}, \qquad (1)$$

where w_i and w_0 are local and mean velocity, n is the number of measurements.

The initial flow non-uniformity before entering the packing layer is illustrated on Fig. 3(a). The gas velocities are shown along two diameters: one in direction of the entering flow (following the axis of gas inlet device) – d_1, and the other is perpendicular – d_2. The initial distribution is created by the inlet, which is bent to the column bottom.[1] The inlet body itself, being placed at the flow way, provokes greater non-uniformity (Mf = 70.67 %) over the corresponding diameter. The maldistribution on the perpendicular direction is smaller (Mf = 37.37 %). For all investigated sizes of IMTP-Ring the initial maldistribution is 60.63%.

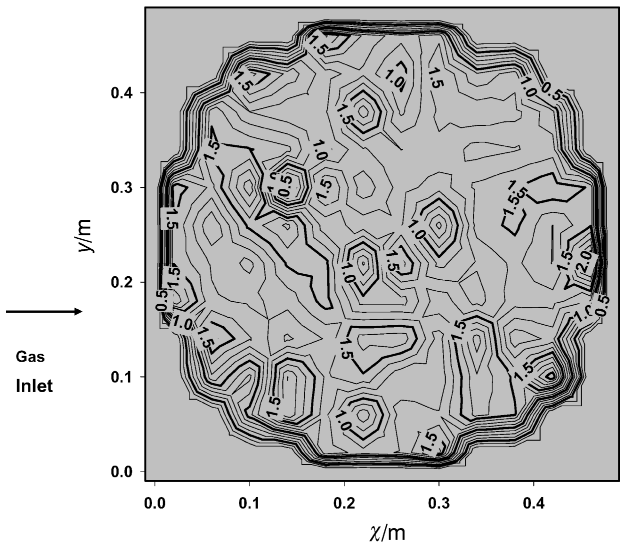
The velocity profiles over layers of packing IMTP-Ring 25 with heights 0.1; 0.2; 0.4; 0.6 and 0.8 m are shown at corresponding figures 3(b) to 3(f). The peculiarities of local velocity measurements described by *Darakchiev* et al.[1] are valid here, too. The values of mean velocity and dispersion are somewhat approximate estimation of the real values. For example, when the flow-meter reads 2 m s^{-1} as a value of mean superficial velocity (this is the operational velocity for this type of packing), the calculated mean velocity is about 1.5 – 1.6 m s^{-1}. Nevertheless, by comparison of flow uniformity, the equalizing action of different packing layers can be estimated.

In Figs. 3(b) and 3(c), the flow uniformity quickly becomes relatively good as compared to the initial non-uniformity. It can be concluded that only about 0.2 m layer of this packing size is needed to equalize the flow velocity.

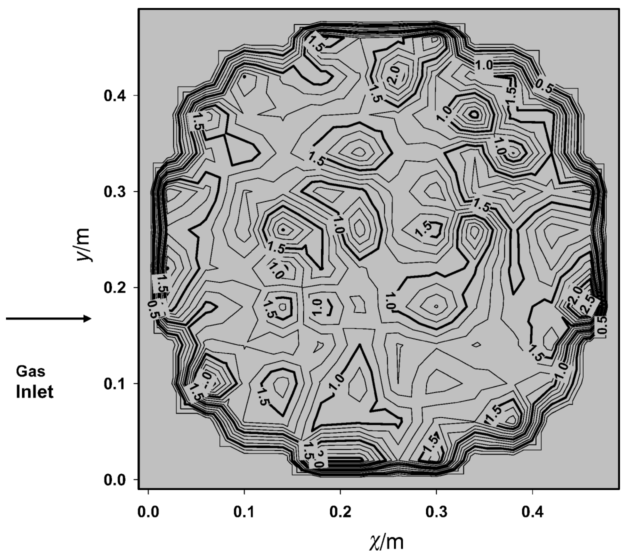
The packing heights 0.8 and 1.3 m are illustrated in details as contour maps of velocity iso-lines at Figs. 4 and 5. The local velocities are measured in 112 points over the cross-section.

Comparing Figs. 3(f) and 4, rather close values of maldistribution factor are seen. The difference is slightly over 1 % being comparable to the experimental error. For this reason the measurements for 0.8 m layers are taken only over two perpendicular diameters.

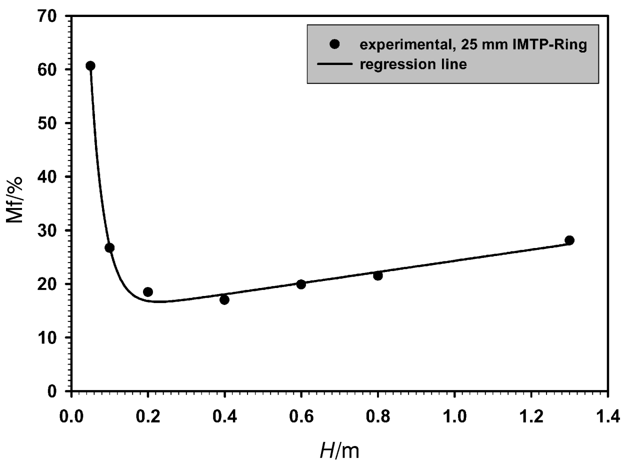
Fig. 6 represents the maldistribution factor for IMTP-Ring 25 as depending on layer height. The



F i g . 4 – *Contour map of velocity iso-lines for packing IMTP-Ring 25 with 0.8 m height. Numbers from 0.5 to 2.0 denote the values of local velocities over the entire cross-section*



F i g . 5 – *Contour map of velocity iso-lines for packing IMTP-Ring 25 with 1.3 m height. Numbers from 0.5 to 2.5 denote the values of local velocities over the entire cross-section*



F i g . 6 – *Influence of packing height on maldistribution factor of IMTP-Ring 25* flow ameliorates remarkably its uniformity after passing through 0.2 m layer. The optimal layer thickness is about 0.23 m. At larger height the uniformity is not kept at the same low level, even slightly gets worst. Although this tendency is already clearly seen, we have made exclusive experiments with considerably higher layer (1.3 m), which confirm this observation. For this reason, in the following experiments the largest packing height has been limited to 0.8 m.

According to the results obtained, the penetration depth of IMTP-Ring 25 is about 0.23 m, and its uniformity limit is estimated to be about 16.6 %.

Figs. 7 and 8 illustrate the maldistribution factor Mf of packings IMTP-Ring 40 and IMTP-Ring 50 at different heights (H = 0.05; 0.1; 0.2; 0.4; 0.6 and 0.8 m). Clear minimum of Mf, e.g., uniformity limit is seen at 20.3 % and 21.4 %, correspondingly. The values of penetration depth are 0.16 m and 0.18 m. These packing sizes keep the tendency to worsen the flow uniformity after the penetration depth, which is registered also with other random packings in investigations of *Darakchiev* et al.[1] and *Kouri* and *Sohlo*.[4]

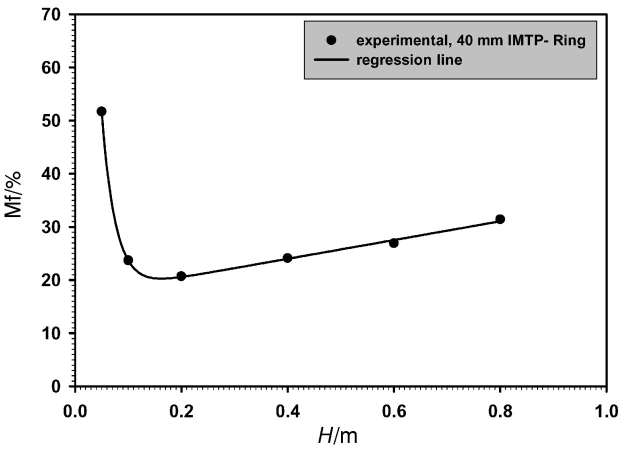


Fig. 7 – *Influence of packing height on maldistribution factor of IMTP-Ring 40*

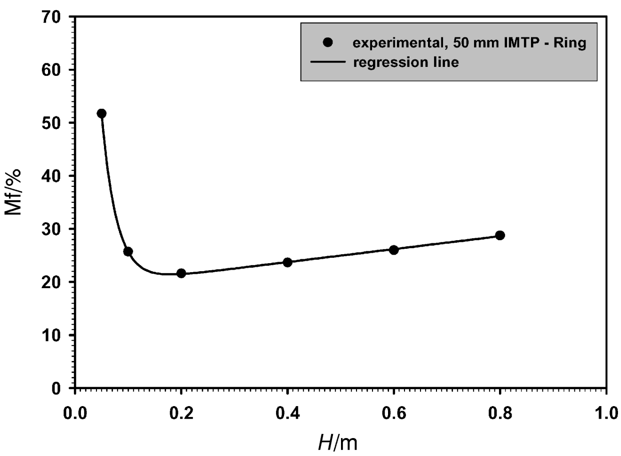


Fig. 8 – *Influence of packing height on maldistribution factor of IMTP-Ring 50*

Analogous results for the largest size IMTP-Ring 70 are given on Fig. 9. Due to its larger free volume, it shows smaller equalizing ability (penetration depth about 0.32 m). Unlike all previous sizes, it keeps constant flow uniformity at rising packing height.

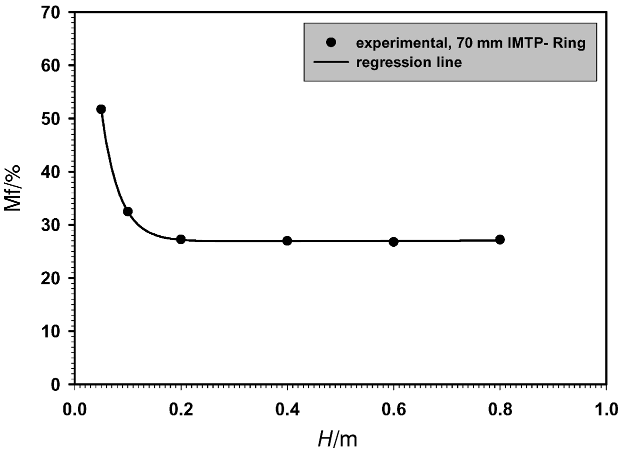


Fig. 9 – *Influence of packing height on maldistribution factor of IMTP-Ring 70*

All experimental data for Mf = $f(H)$ are fitted by a regression equation (2) with correlation coefficients R over 0.99:

$$\mathrm{Mf} = y_0 + a \cdot \exp(-b \cdot H) + c \cdot H \qquad (2)$$

with $b > 0$, where a, b, c and y_0 are regression coefficients (Table 2).

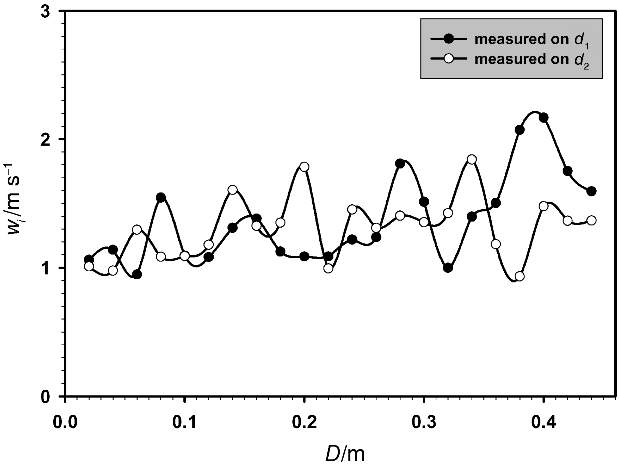
Table 2 – *Coefficients and correlation coefficient R from regression curve (2) for investigated packings*

Type of packing	a	b	c	y_0	R
IMTP-Ring 25	175.98	26.76	10.39	13.89	0.9981
IMTP-Ring 40	228.96	38.21	17.63	16.93	0.9995
IMTP-Ring 50	184.41	34.88	12.19	18.86	0.9999
IMTP-Ring 70	109.57	29.66	0.26	26.82	0.9999
Ralu Flow No.1	201.81	33.94	9.64	14.26	0.9979
Ralu Flow No.2	49.26	12.28	1.19	24.62	0.9960

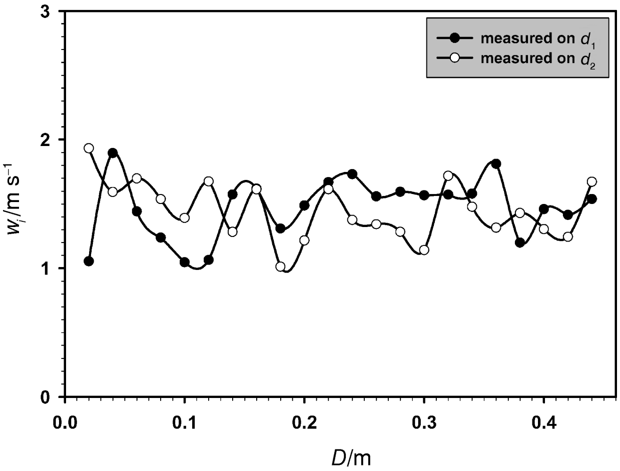
In this case the regression curve represents a qualitative description of the results, because, both, the penetration depth and uniformity limit are determined only approximately.

The distribution ability of plastic Ralu-Flow No.1 and 2 (Fig. 2) has been studied also. Table 1 contains the main packing characteristics. The gas distribution has been studied with five packing heights: 0.1; 0.2; 0.4; 0.6 and 0.8 m.

The velocity profiles on two perpendicular diameters for 0.1 m layer of Ralu-Flow No. 1 are given on Fig. 10. Although, the initial non-uniformity is significantly reduced (from 51.7 % to 22.09 %), the curves are slightly inclined, which indicates that some influence of initial non-uniformity still exists. Fig. 11 refers to 0.2 m packing height and demonstrates this expected improvement.



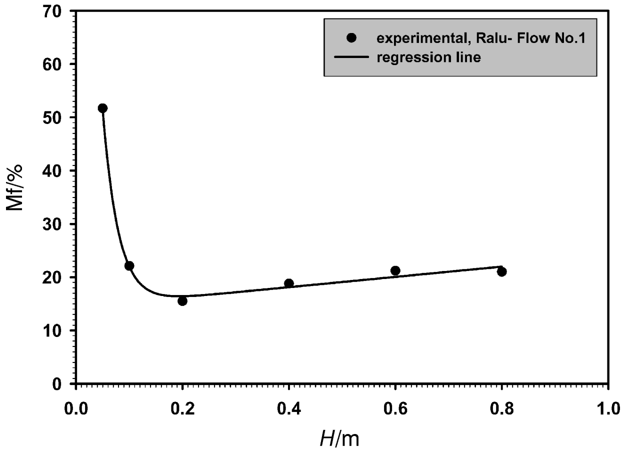
F i g . 1 0 – *Velocity profile on two perpendicular diameters. Layer of 0,1 m plastic Ralu-Flow No.1. Full black points are measured on* d_1*, empty points – on* d_2



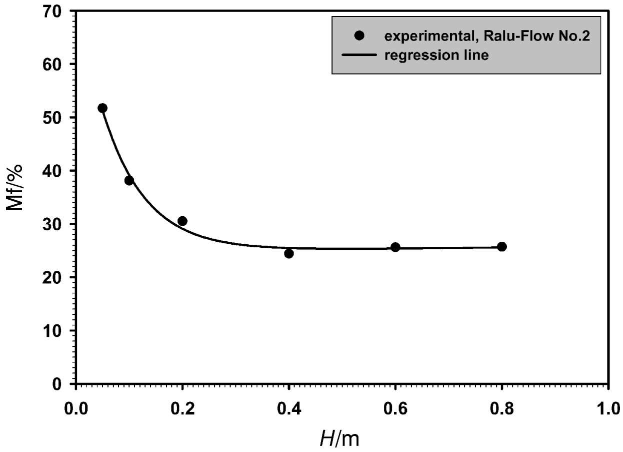
F i g . 1 1 – *Velocity profile on two perpendicular diameters. Layer of 0.2 m plastic Ralu-Flow No. 1. Full black points are measured on* d_1*, empty points – on* d_2

Fig. 12 illustrates the maldistribution factor *Mf* at different packing heights. Again, as for previous packing IMTP-Ring, about 0.2 m is enough to equalize the flow velocity. After 0.19 m the distribution becomes slightly worse.

Fig. 13 shows the same dependence for Ralu-Flow No. 2. Compared to Ralu-Flow No. 1, the packing size is twice larger and the equalizing



F i g . 1 2 – *Maldistribution factor as depending on packing height. Plastic Ralu-Flow No. 1*



F i g . 1 3 – *Maldistribution factor as depending on packing height. Plastic Ralu-Flow No. 2*

effect is smaller. The velocity profile becomes smooth after about 0.5 m layer, and the non-uniformity is about 25 %. Like IMTP-Ring 70, this packing size keeps a constant level of uniformity at increased layer height.

Table 3 collects the results for uniformity limit and penetration depth of all investigated packings.

T a b l e 3 – *Penetration depth and uniformity limit of investigated packings*

Type of packing	Penetration depth, m	Uniformity limit, %
IMTP-Ring 25 mm	0.23	16.6
IMTP-Ring 40 mm	0.16	20.3
IMTP-Ring 50 mm	0.18	21.4
IMTP-Ring 70 mm	0.32	26.9
Ralu Flow No. 1 (25 mm)	0.19	16.4
Ralu Flow No. 2 (50 mm)	0.51	25.3

Conclusion

The gas distribution is studied in a column with random packing of metal IMTP–Ring, four sizes, and plastic Ralu-Flow, two sizes. The uniformity limit and penetration depths are determined for all tested packings. The uniformity limit varies from 16.4 to 26.9 %, and the penetration depth is from 0.16 to 0.51 m. Generally, the uniformity goes slightly worse after reaching the penetration depth, that is why for the design of packed-bed columns, it would be good if the required for the process height of packing's layer is divided into several smaller sections according to the determined for packing penetration depth.

However, the largest sizes of both types of packing (IMTP-Ring 70 and Ralu-Flow No. 2) keep constant flow uniformity with further increase of packing height.

Nomenclature

a, b, c, y_0 – regression coefficients in Equation (2) and Table 2
D – column diameter, m
d_1=D – diameter in the inlet device direction
d_2=D – diameter, perpendicular to $\boldsymbol{d_1}$, m
H – packing height, m
Mf – maldistribution factor, %
n – number of measuring and calculated points, –
R – correlation coefficient (see Table 2)
w_i – local measured gas velocities, m s^{-1}
w_0 – mean gas velocity value, m s^{-1}
x, y – grid coordinates, m

Greek symbols

σ – standard deviation

Subscripts

i – summation index

Abbreviations

IMTP – Intalox Metal Tower Packing

References

1. *Darakchiev, R., Petrova, T., Darakchiev, S.*, Gas distribution in columns with Raschig-Super Rings, Chem. Eng. Proces **44** (2005) 827.
2. *Schultes, M.*, Raschig Super-Ring. Chem. Eng. Res. Des. **81** (2003) 48.
3. Norton, Intalox Metal Tower Packing (IMTP), Bulletin IM-82, 2M -150010302 –5/84.
4. *Kouri, R. J., Sohlo, J. J.*, Liquid and Gas Flow Patterns in Random and Structured Packings, Institution of Chemical Engineers Symposium Series **No104** (1987) B193.
5. Ralu-Flow®, Ein moderner Hochleistungsfüllkörper mit exzellenten verfahrenstechnischen Leistungsdaten, Raschig GmbH, Ludwigshafen, Germany, 1997.