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Analysis, Quantitative Estimates and Methods for Reducing of the Maldistribution Created from Gas Distribution Devices for Column Apparatuses

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Providing of good initial radial distribution of gas phase is of significant importance for efficiency of column apparatuses. The aim of the present work is to analyze and evaluate gas flow maldistribution in different types of gas distributing devices (GDD) and respectively their efficiency, based on experimental data for the output velocity profile. The experimental data capture measuring of velocity profile for two construction types GDD – with circular and local tube gas feed. For both several additional modifications are also investigated – with adding the redistribution grids and gauzes, the empty section after the GDD, in the presence of water mirror under the GDD, etc. By the help of MATHCAD, six types of quantitative estimations of GDD maldistribution are determined and then their sensibility toward several factors such as the type of GDD, the initial gas flow velocity, the number and dimension of measuring cells on the column cross-section, the measurement error and so on, are investigated. It is found that only two of the quantitative maldistribution estimations take into account the formation of maldistribution clusters, which deteriorated the efficiency of the processes in the column. A novel method for quantitative determination of these clusters as well as for identification of the zones at column cross-section, in which they appeared, has been developed. It is established that the measurement error and the dimension of measuring cell deeply influence as on the number, the area and spatial distribution of these zones on the cross-section, as well as on the values of maldistribution estimates. It is shown that with adding of supplementary redistribution devices like grids and gauzes, the GDD’s maldistribution can be reduced about 3 times, without significant increasing of pressure drop.

1. Introduction

The focus in recent years is orientated towards the design (Meng et al., 2008) and simulation of the performance of new GDD constructions (Turek et al., 2012), which avoid process efficiency loss (Billingham et al.,1997) due to worse distributed flows after the GDD.

Still a little attention is paid on the determining which factors exactly influence upon the indices of maldistribution. The most of the existing indices calculated for random and structured packings, depend mainly on the number of measurements of local gas velocities over the column cross-section and dimension of measurement cell, also from pressure drop per unit height, and are practically independent from initial velocity. But for GDD’s these factors are not studied in details. That provokes our interest to investigate and analyze six type of indices for maldistribution, calculated using experimental data for velocity profile, measured after two type GDD’s – with local and circular gas feed. The factors investigated are initial velocity, type of GDD feed, the spatial distribution of inhomogeneities over the cross-section, and measurement error.

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2. Indices of maldistribution and their calculation

Six indices are investigated, the first five of which are the kinetic energy coefficient N_k (Coriolis coefficient), quantity of movement M_k (Boussinesq coefficient), derivation between the local and mean dynamic pressures δp_d, Maldistribution factor M_f (also C_v), and Maldistribution index MI. The sixth one is the Coefficient of distribution CoD, recently formulated by Stemich and Spiegel, (2010). The last two estimates are determined from:

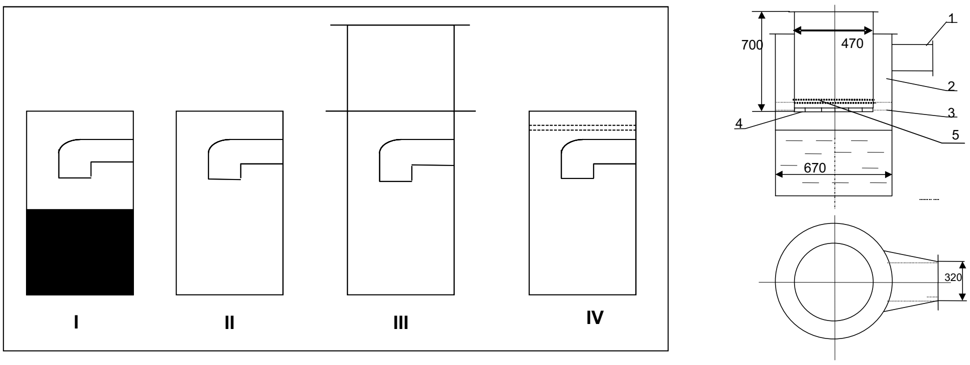
$$MI = \frac{C_v}{C_m}, \quad C_m = \sqrt{\frac{1}{F}\sum_{i=1}^{N} F_i \cdot \left(\frac{W_i - W_{0i}}{W_{0i}}\right)^2}, \quad W_{oi} = \frac{\sum \delta_{ij}\left(F_i W_i + F_j W_j\right)}{\sum \delta_{ij}\left(F_i + F_j\right)} \tag{1}$$

$$CoD = \frac{C_v}{\varphi}, \text{ where } \varphi = \frac{l}{l_{ref}} \tag{2}$$

In Eq.(1) W_i is local velocity, (m/s), $\delta_{ij} = 1$ if i and j are adjacent cells and $\delta_{ij} = 0$ otherwise. The dimensionless φ value characterizes spatial distribution of flow local irregularities over the given cross-section. Here l is the length of the contact line between regions of different local velocities, and it is made dimensionless by relating it to a characteristic length scale, i.e., the hydraulic diameter l_{ref}. Here N is a number of measuring cells and F_i, F are areas of local measuring cell and for whole column cross-section, (m^2), respectively. C_v is called Coefficient of variation, C_m is the modified C_v, accounting formation of flow variations in large groups, i.e., clusters (Olujić, 2011). Using MATHCAD programming tool different modulus to calculate the indices MI and CoD from experimental data (rectangle matrix $i\ x\ j$ with local velocities) are created. These two estimations pretend to quantify the large scale maldistribution due to appearance of clusters in velocity profile. For MI it is accounted by different mean local velocity in every cell, depending for the number and magnitudes of velocities of adjacent cells, and for CoD it is achieved with spatial distribution coefficient φ. Besides an identification of contact line numbers in matrix cells, program modulus for CoD includes a new method for determining the number and the exact place of the zones (cells) in which there are equal velocities, i.e., contact lines do not exist. The internal matrix is covered up by the new one with equal cells and the result directly shows in which part of the matrix there is not exist a radial mixing. Also an additional option in the modulus is worked out, accounting for the influence of local velocity measurement error in current cell i, j on the number of contact lines and respectively, on CoD.

3. Experimental data for velocity profiles and GDD`s

The experimental data for gas velocity profile, measured on the cross-section of the column with diameter 0.47 m, after two types of GDD – with local and circular gas feed, are used (see Figure 1, (a) and (b)). For the first GDD, four configurations I-IV were studied in order to reduce the initial maldistribution; the best result was obtained by adding of 6 grids of Holpack (Petrova, 2011). For second GDD the reducing of initial maldistribution were achieved by combination of different redistributing lattices and several layers of plastic gauze (Dodev et al., 1999). Here three modifications of distributing lattices are considered (Variant 1 - two identical metal sheet plates with free cross-section of 25 %; Variant 2 - two different metal sheet plates with free cross-section of the lower is 25 % and the upper – 45 %; Variant 3 - one metal sheet plate with 25 % free cross-section). The number of measuring cells N for the first GDD is 123, and 97 for the other one. The hydraulic pressure drop for both GDD's and their modifications are investigated. Appending of supplementary grids and gauzes did not affect significantly the final pressure drop measured (see Table 1).



(a) (b)

Figure 1: (a) GDD with local gas feed (bent tube) and its configurations I-IV; Configuration I –with water mirror, Configuration II – without water mirror, Configuration III – with empty section 0.5 m over the tube, Configuration IV – with 6 grids of Holpack; (b) GDD with circular gas feed; 1- inlet velocity feed, 2 – GDD circular camera, 3 – gas distribution lattices, 4 - supporting grid, 5 - layers of fine plastic gauze and three modifications of gas distribution lattices

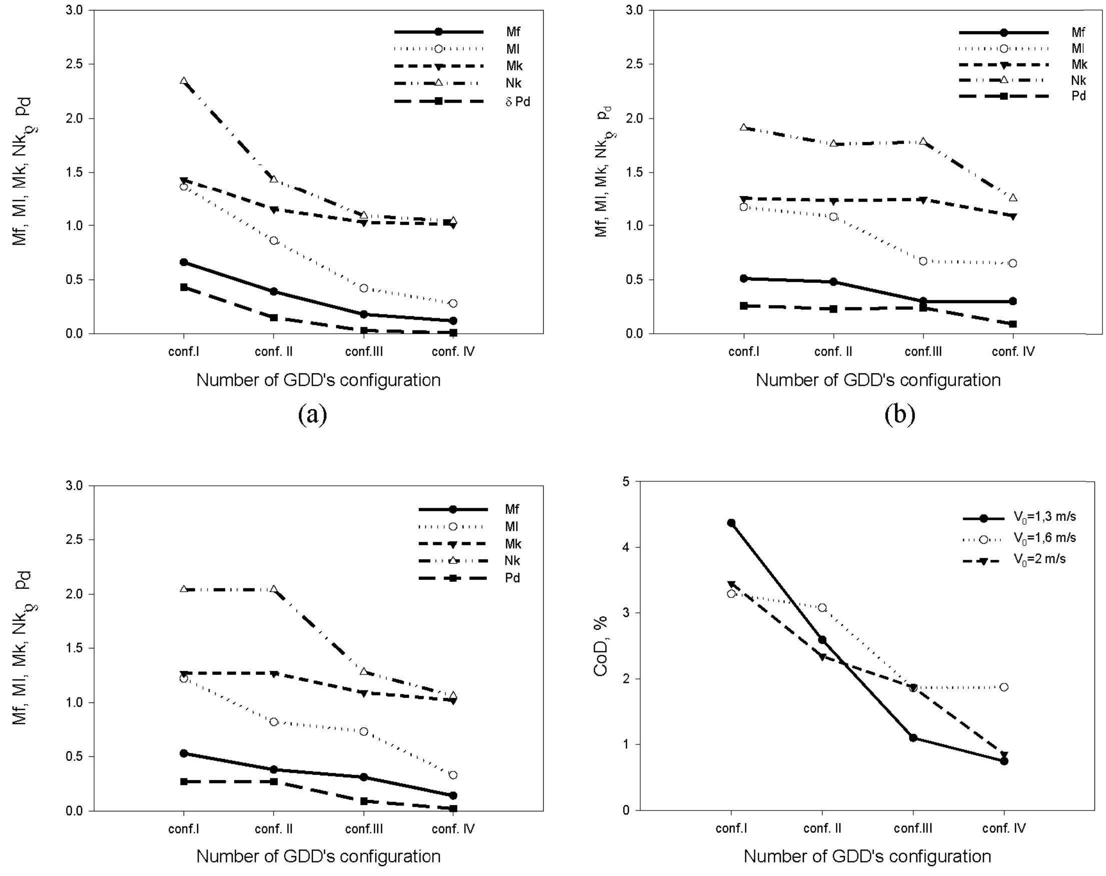
Table 1: Pressure drop of the GDD's and theirs modifications

				Δp , Pa			
w_0 , m/s	Config. I	Config. II	Config. III	Config. IV	Variant 1	Variant 2	Variant 3
1	48.06	48.06	48.06	54.24	24	14	12
2	79.31	79.31	79.31	109.28	86	52	45.5

4. . Analysis of results and discussion

The comparison of sensibility of all six indices (including the data for maldistribution factor M_f has been performed by Petrova (2011), which was initially investigated by Dodev et al., (1999). The evaluated dependences ware those on the GDD's type, from number and dimension of measuring cells, as well as from initial velocity and measurement error, too. The results are presented in Figures 2-4. All indices are sensible to modifications in geometry of two types of GDD. The elimination of water mirror for local feed GDD is essential for reducing of initial maldistribution, as well as adding of lattices and gauzes for circular feed GDD. All indices depend on the number and dimension of measuring cells (Petrova et al., 2008). With increasing of initial velocity the most visible changes in all indices are observed for configurations I-III, local gas feed GDD. For conf. IV only N_k and MI change; M_k , δp_d and M_f practically remain unchanged. Values of MI for configurations I - III are greater than 1 (the limit value for uniform distribution); for conf. IV MI is less than 1, and C_m is kept constant between 0.4 and 0.5 for both GDD's. From Figure 2, (d) it is seen that CoD slightly depends on increasing of initial velocity, but the range of obtained values for conf. III and IV are about 2 % and φ is about 15-16, which confirm uniform spatial distribution and M_f about 20 % (Stemich and Spiegel, 2010). Increasing of initial velocity for GDD with circular gas feed does not affect the indices - after the reducing of initial maldistribution for variants 1-3 and more than 6 layers of plastic gauze all indices remain the same (see Figure 3, fitted lines). The values of all indices after the sixth gauze are consistent with the requirements of distribution closed to uniform, as it was noted in Petrova, (2011).

The strong influence of measurement error can be proved only for CoD, as it is seen from Figure 4, because of contact lines definition; the values in adjacent cells are not compared with each other for the rest indices. It is easy to see that if the measurement error increase, the criterion for equality between two adjacent cells will be expanded, i.e., more cells will be identified as equal and the number of contact lines decreases. Then, for one and the same C_v (or M_f) it follows, that CoD will increase and the maldistribution will become worse. But really it means to what extent the area of unit cell is comparable with the area of clusters and is it possible to account these clusters in CoD. As it is seen from Figure 4, the clusters coincide with the zones with equal velocities on the contour maps and number of clusters increases with increasing of measurement error.



(a) (b)

(c) (d)

Figure 2: Influence of initial velocity and configuration geometry on the maldistribution indices for configurations I-IV of GDD with local gas feed : (a) – for initial velocity 1,3 m/s ;(b) for initial velocity 1,6 m/s; (c) – for initial velocity 2 m/s; (d) only for CoD *in velocity range*

5. Conclusions

On the base of experimental data for velocity profile after two GDD – with local and circular gas feed, an analysis of the sensibility of maldistribution indices of gas flow after GDD's in respect to number and dimension of measuring cells, as well as from initial velocity and measurement error, is made. It was shown for all modifications of GDD's, that initial velocity has no significant influence on the indices, excepting N_k, MI and somewhat CoD for local gas feed GDD. It is evident that only MI and CoD is able to account the clusters formation quantitatively, because of accounting whole cell neighborhood. The program modulus are developed by MATHCAD to calculate MI and CoD. For the latest a new method for identifying the number and exact position of these cells on the cross-section without contact lines, i.e., which are the clusters itself, it is created. Also the influence of local velocity measurement error in current cell i, j on the number of contact lines and respectively, on CoD is worked out like the additional option in the modulus. The supplementary redistribution devices like grids and gauzes added to GDD's, reduced maldistribution effectively without significant increasing of pressure drop. In a future work these maldistribution indices will be used to investigate the distribution ability of some modern random packings for columns, equipped with GDD, which has shown the most uniform distribution in this work.

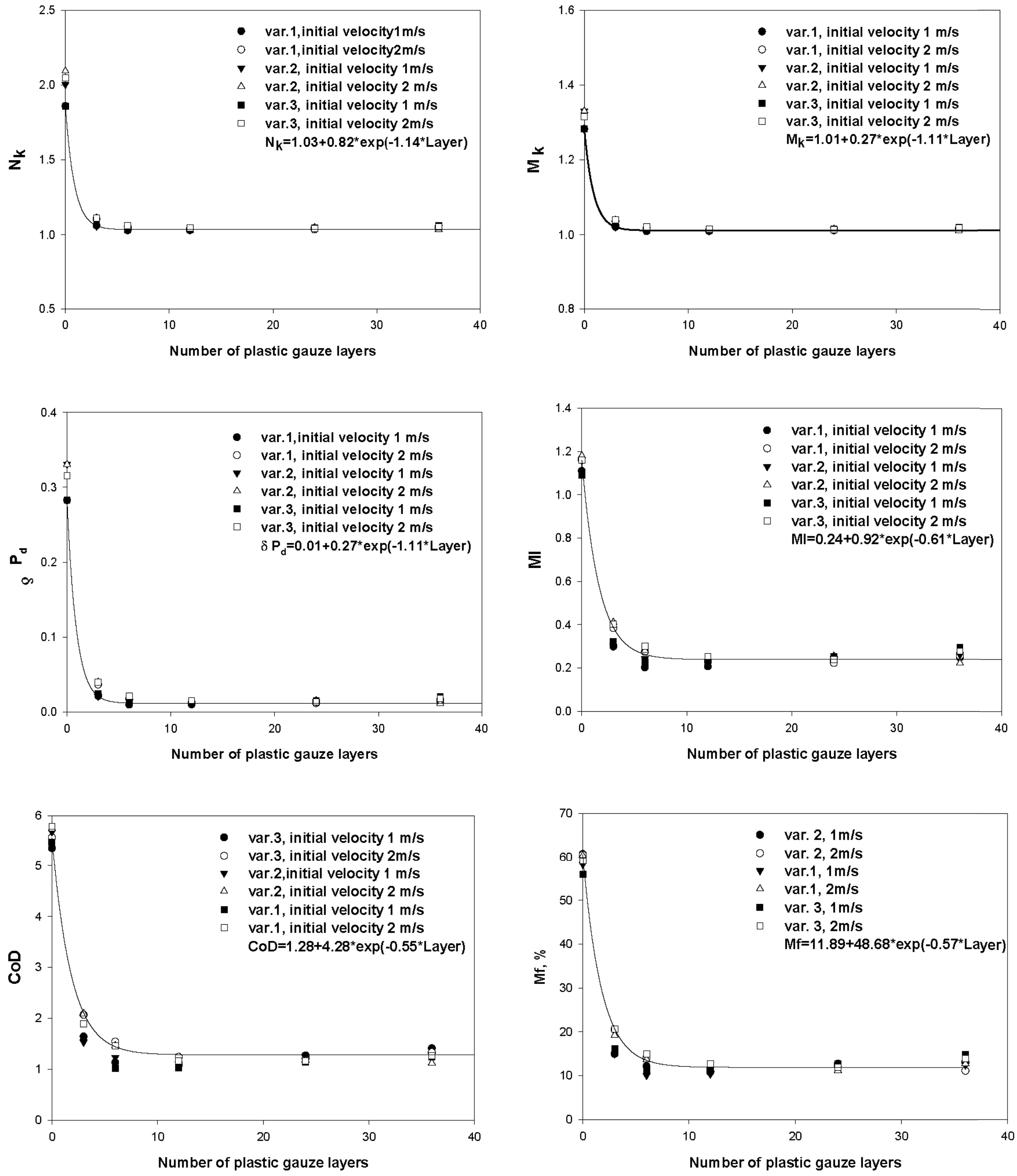


Figure 3: Influence of initial velocity and number of plastic gauzes on the maldistribution indices for variants 1-3 of GDD with circular gas feed

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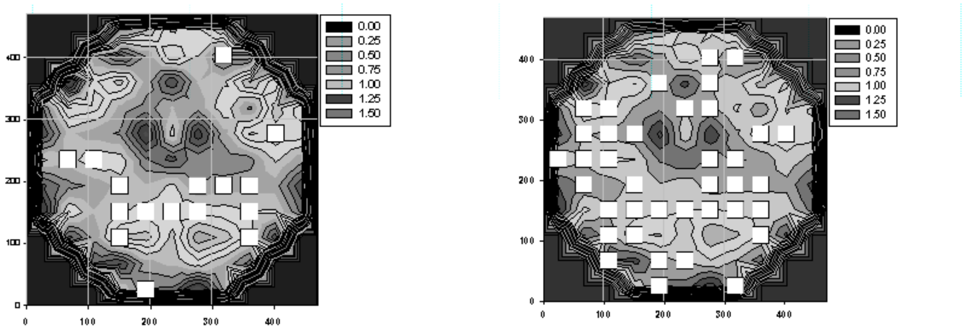
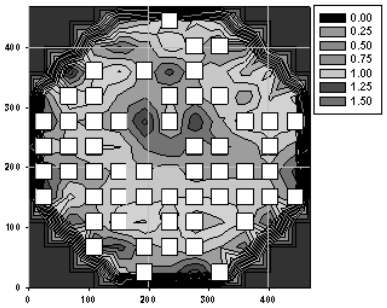


(a) 2 % error, l=156, φ=13.94, CoD=0.94 (b) 5 % error, l=129, φ=11.53, CoD=1.14



(c) 10 % error , l=100, φ= 8.94, CoD=1.47

Figure 4: Influence of measurement error on the CoD components for contour velocity map of GDD with circular gas feed, variant 2, 36 layers of plastic gauze, initial velocity 1 m/s. The empty squares denote the zones without contact lines, i.e., clusters with equal adjacent local velocities.

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