

**INFLUENCE OF INLET GAS FLOW VELOCITY
ON THE OUTLET MALDISTRIBUTION COEFFICIENT OF GAS FLOW
AFTER FOUR TYPES GAS DISTRIBUTION DEVICES**

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Abstract:

Gas flow velocity profiles after four Gas Distribution Devices (GDD), mounted in column with diameter 0.5 m, have been measured experimentally. It is shown that the value of gas flow maldistribution factor (M_f) after each GDD depends on the initial gas flow velocity. The minimal values of M_f for every GDD at the investigated range of initial velocities have been determined. The lowest value for M_f (about 0.16) is reached for GDD №3 at lowest initial velocity (1.3 m/s) and for middle and highest one (1.6 and 2 m/s respectively) lowest M_f have been registered at GDD №4 (about 0.2 ÷ 0.22).

Key words: gas distribution device, velocity influence, gas maldistribution factor

1. INTRODUCTION

The distribution of gas flow in the packed bed columns is realized when the gas flow first passed through the gas distribution device (GDD), and then it is fed to the packing layer. The degree of maldistribution of gas flow at the outlet of both the GDD and the packing layer, is perceived to be assessed quantitatively by so called Maldistribution factor (Coefficient of maldistribution) etc. M_f (Petrova 2008, Muir and Briens 1986, Petrova et al. 2007, Porter et al. 1993, Yuan and Li 1997). It is calculated according to the most commonly used formula:

$$M_f = \sqrt{\frac{1}{n} \sum_{i=1}^n \left(\frac{w_i - w_0}{w_0} \right)^2}, \quad (1)$$

where W_i is the local gas velocity, measured in the i-th cell, (m/s), w_0 is the mean velocity in the whole cross-section, (m/s), and n is the number of the cells, in which all column cross-section area is divided. In (1) it is assumed that the cross-section has been divided virtually to n cells with equal area, because in another choice of sampling cells in the upper formulae in place of $1/n$ the weighted ratios F_i/F appeared; where F_i , (m²) are the areas of measuring cells and F , (m²) is the area of all cross-section, respectively (Petrova 2008, Petrova et al. 2010).

Because of properties of some type of packings to be very sensitive to initial flow maldistribution, especially in the industrial columns with large dimensions (Edwards et al. 1999), it is important to study of which factors exactly depends on the flow maldistribution after the GDD, then to select the

appropriate GDD or if this is unacceptable, what measures can be applied to the specific GDD to reduce its M_f to the recommended 10-20% (Edwards et al. 1999).

Lately, the attention is paid to the research and modelling of the GDD performance, as well as to the factors that have influenced on the maldistribution, that they created (Petrova et al. 2010, Xu-Guang Li et al. 2007, Lei Meng et al. 2008, Zeng Jiang Tao et al. 2009), focusing in recent years to the design and simulation of the performance of new GDD constructions. It is known that the manner of gas transmission in the GDD (tangential or ring-shaped), the distance from the inlet pipe of GDD to the bottom of the column and packing layer significantly affect the value of M_f (Muir and Briens 1986, Yuan and Li 1997, Darakchiev and Dodev 2002). To ensure a good uniformity of output flow after the GDD it is recommended (Yuan and Li 1997) for the distance from the GDD to the column bottom to be equal to $1.5 \div 1.7 D$, and for the diameter of the GDD inlet pipe to be within $0.4 \div 0.6 D$, where D is the diameter of the column apparatus. Also there is an evidence of the formation of reverse flows in the packing, located directly above the GDD, if not met ratio $0.15/0.18 D$ for the distance between the GDD pipe and packing layer (Idel'chik 1982, Darakchiev and Dodev 2002). Adding of equalization devices such as grids, piercing tubes and so on to GDD can also improve the velocity profile after the GDD (Idel'chik 1982, Darakchiev and Dodev 2002, Kabakov and Rozen 1984, Rozen and Kostanyan 2002, Titel'man et al. 1970), if they do not increase too much pressure drop in the GDD and are expensive to manufacture and complicated to install.

The existed literature reports show examples, that even short packing layers can successfully reduce the initial maldistribution, generated by the GDD (Porter et al., 1993) but there are a lot cases in industrial installations, where this inequality is maintained (Kabakov and Rozen 1984, Rozen and Kostanyan 2002), instead of increasing packing layer up to 15 m and finally this strongly degrade the column efficiency. The packing layer ability to reduce quickly the initial maldistribution, without having to increase the height of the layer and consequently the cost, depends exclusively on the very type of packing. There is also evidence that with increasing rate of incoming gas flow rate the value of gas maldistribution factor after of 3 types GDD does not change significantly in the column with a diameter of 0.1 m (Haghshenasfard et al. 2007). Another authors (Yuan and Li 1997) were reached to the similar conclusion, but they were studied the influence of various factors including the rate of inlet flow on the maldistribution factor, calculated after structured packing Mellapak 250-Y for 5 different types of GDD in column with diameter of 1 m. Interestingly, however, what would be the value of M_f and velocity profile after only GDD in the column with larger diameter than that in (Haghshenasfard et al. 2007).

This work aims to investigate the influence of the initial gas flow rate on the maldistribution factor M_f and on the velocity profile, obtained after four different modifications of one GDD, and to determine which minimum values of this coefficient can be achieved for each of the modifications, depending on the rate of inlet gas flow.

2. EXPERIMENTAL

In the column with a diameter of 0.5 m a series of experiments to measure the velocity profile of the gas flow (air) at the outlet after each of the four modifications of the GDD (Fig. 1, a-b) for three different initial rates of gas flow (1.3, 1.6 and 2 m/s), have been carried out. The air enters the column body 1 and moves along the duct 2 of the fan plant, goes through tared flow meter 3 and the valve 4 and enters the column through the gas inlet pipe 5 with equivalent diameter of 0.16 m. The rate of air flow delivery is controlled by the flow meter and is recorded with liquid U - shaped differential manometer 6. After each modification of the GDD (I ÷ IV) the local velocities w_i of output gas flow is measured by thermoanemometer 7 in $n=123$ equal area cells 0.04×0.04 m, covered all cross-section area of the column to which the modifications are installed. The used thermoanemometer is Kurz, model 440 (USA) with an accuracy $\pm 2\%$. The thermoanemometer readings is converted by special

written program to velocity for each cell; the value of the local velocity is an average of 100 instantaneous measurements, then this value is recorded and registered on the computer. Based on the resulting velocity profile in 123 cells after each modification for all investigated range of initial gas flow rates, the coefficient of maldistribution of gas output flow has been calculated by the (1). For each of the initial velocities at least 3 parallel experiments for the output velocity profile at each GDD's modification are made, and then the obtained values for the M_f are averaged.

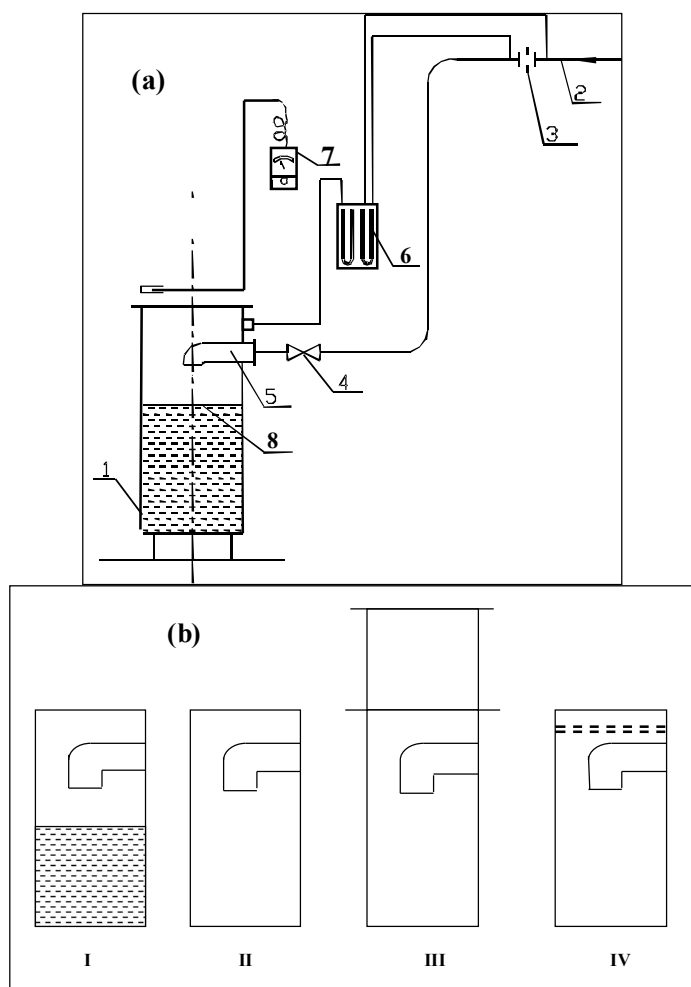


Figure 1. Schemes of the experimental installation (a) and of GDD's modifications (b)

(a) 1 -column, 2- duct (pipe-line), 3 – flow-meter, 4 – valve, 5 – gas inlet pipe, 6– U-shaped liquid differential manometer, 7 – thermoanemometer, 8 – water mirror;

(b) – modification I – with water mirror placed 0.2 m above the gas inlet pipe; modification II – without the water mirror; modification II is modification II with added empty column section with height 0.5 m ; modification IV is modification II with added 2, 4 or 6 Holpack grids respectively mounted at the distance about 0.15 m from the column body above the gas inlet pipe.

The gas inlet pipe 5 (bend toward the column bottom) is the same in each of the modifications (Fig. 1 (b)) together with the body of the column 1 and both form a "basic" GDD. Modification I is the "basic" GDD with added water mirror 8, reaching to 0.2 m below the gas inlet 5. Modification II is

like as I, but without water mirror and modifications III and IV are variants of modification II by adding an empty section with a height of 0.5 m or a different number of grids over the gas inlet 5. In modification IV of about 0.15 m above the gas inlet were added respectively 2, 4 or 6 grids of structured packing Holpack, with equivalent diameter 0.256 m (Darakchiev and Semkov 2010). In the grids arrangement the rule each next grid to be mounted at 90° to the previous one has been kept. Free volume of one grid is 0.96 and the grid's diameter is equal to that of the column. It was proved preliminary that the adding of an empty section or even 6 Holpack grids does not affect significantly the overall pressure drop of modifications III and IV.

Preliminary tests were carried out in a random cell of the column cross-section to what extent the measured value of the local velocity in that cell depends on the duration of measurement and on the distance from the thermoanemometer sensor to the measuring lattice (Fig. 2), separating the column cross-section to the 123 cells with equal area. The moving board was also constructed with a hole for thermoanemometer sensor by which the measuring in all cells located in one vertical column of the lattice was done much easily. The lattice clings close to the column body end and over it the board is placed. It was proved that presence of the board does not affect on the values of local velocities measured in the cells, which are closest to the column wall.

It was found that the duration of the measurement does not affect the thermoanemometer reading (Fig. 3) for initial gas rates 1.6 and 2 m/s. During the experimental tests it was observed that at lowest initial rate more than 3 parallel experiments is required, since then a strong flow instability is observed. The distance from the thermoanemometer sensor to the lattice also had a strong impact on its readings; after the preliminary experiments a distance of 2 centimetres was chosen.

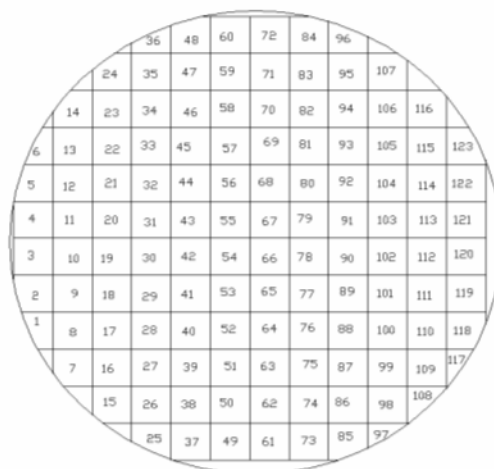


Figure 2. Sketch of the measuring lattice– 123 cells, 0.04 x 0.04 m for each cell

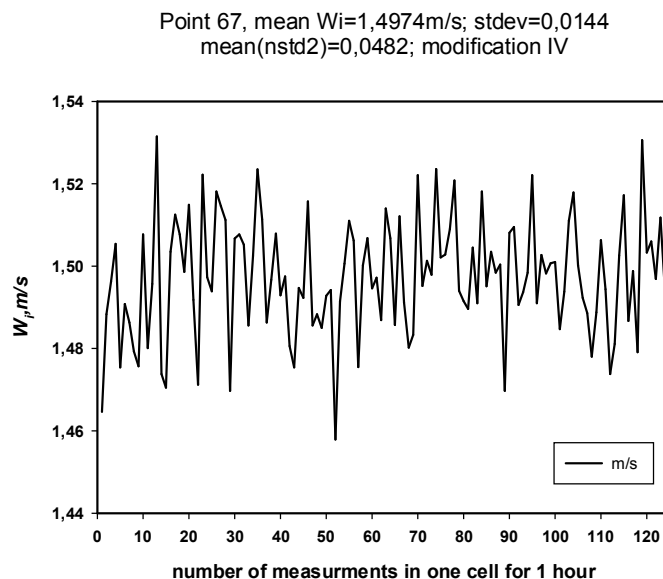


Figure 3. Influence of the duration of measurement over the thermoanemometer's readings in a randomly chosen cell №67 from the measuring lattice.

3. RESULTS AND DISSCUTION

As it was shown above, for each of the modifications I-IV, the values of the coefficient of maldistribution M_f in the studied range of initial gas flow rates $1.3 \div 2$ m/s were calculated and obtained. The results are presented in Fig. 4, which shows that the value of the coefficient of maldistribution M_f decreases with increasing inlet gas flow rate from 1.3 to 2 m/s for all four GDD modifications. Fluctuations in the values depending on the initial flow rate is observed mostly in modifications I-III, at modification IV these variations are much smaller for all initial gas flow rates. The lowest values of this coefficient are registered for modification III ($M_f = 0,16$) at the lowest initial rate. The next, slightly higher values of maldistribution (0.20-0.22) is achieved as for the gas flow rate of 1.3 m/s for modification IV with 2 grids of Holpack as well as at initial rate of 2 m/s for modification IV with 4 or 6 grids of Holpack. When the initial gas flow rate is increased to the 2 m/s, it was observed the stabilizing of all local velocities measured and finally the result is slowing down of M_f at the outlet of GDD modifications. Another important conclusion is that at the average and the highest inlet gas rates the increasing of grids number for modification IV does not substantially alter the value of M_f (Fig. 4).

As it is known (Edwards et al. 1999) only the value of M_f is not sufficient to assess the type of velocity profile of the output of a packing layer or of the GDD, so we can assess the improvement by comparing contour maps of local velocities in modifications I-IV for two of the initial flow rates - lowest and the highest (fig. 5 and 6). The observed strong asymmetry of velocity profile in modification I gradually smooths with subsequent modifications, as it is seen that at 1.3 m/s despite the lowest value of M_f (0.16) for modification III the profile is still asymmetric, but the asymmetry already occupies the greater part of the column cross-sectional area and decreased in intensity (from 3 to 1.8 m/s for the highest local velocities). In modification IV with 2 grids of Holpack slight increase in M_f is observed and high local velocities is concentrated in the middle part of column cross section and in part to the wall zone (Fig. 5, down, right). Adding of more grids to the modification IV leads first to the growth of M_f then for 6 grids the coefficient of maldistribution again decreases (fig.4).

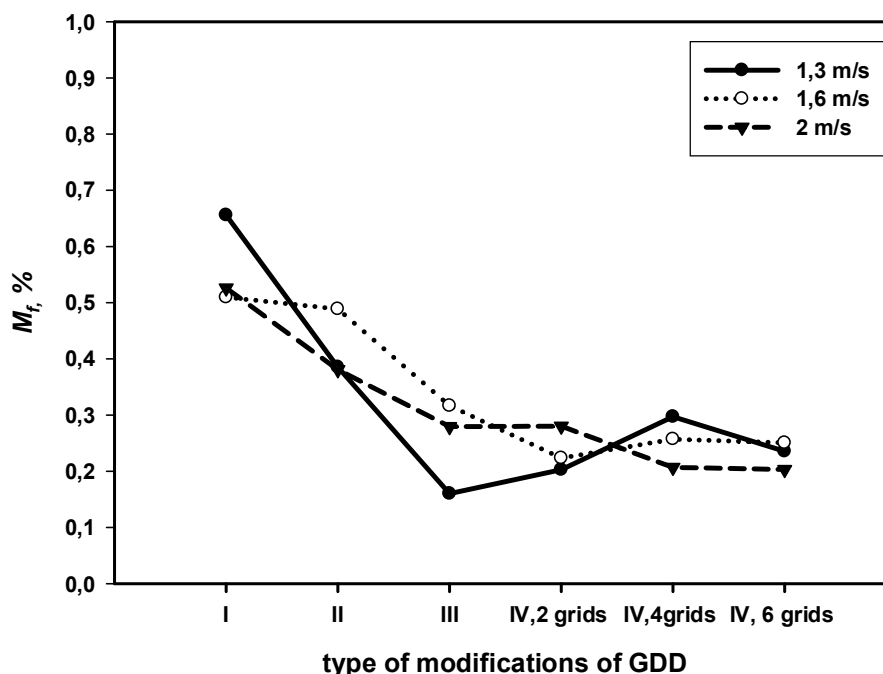


Figure 4. Influence of maldistribution coefficient from the initial gas flow rate for the GDD modifications I ÷ IV.

At initial flow rate 2 m/s, which is the real operating velocity in columns with such diameter, it is seen a clear peak with very high local velocities (up to 8 m/s) for modification I. This peak is managed to flatten in the later modifications and for modification IV the velocity profile asymmetry is already localized only in the wall zone; the main part of the cross-section has almost uniform distribution and the local velocities close to initial one (Fig. 6, down, right). For modification IV the residual asymmetry is expressed at a pronounced and well-visible wall zone with local velocities up to 3.5 m/s.

4. CONCLUSIONS

The experimental investigations of the distribution and the degree of maldistribution of gas flow velocity profile measured after 4 different modifications of the GDD with gas inlet pipe, bend toward the bottom of the column, for three different initial gas flow rates were conducted. The value of the coefficient of maldistribution M_f decreases from first to forth modification of GDD with increasing inlet gas flow rate from 1.3 to 2 m/s. It was found that the removal of water mirror substantially reduces the value of the coefficient of maldistribution M_f of subsequent modifications, which confirmed the recommendations in (Yuan and Li 1997) for the distance from the GDD inlet pipe to the column bottom. For modification II the increasing of initial flow rate leads to a change in the asymmetry of the velocity profile and its distribution over the column cross-section, but does not change the value of M_f . Adding an empty section in conjunction with the removal of water mirror (modification III) at the lowest initial flow rate decrease the value of M_f close twice, but at the expense of the still strong asymmetry of the profile. With increasing of initial rate the value of M_f for modification III increases, but the asymmetry begins to withdraw towards the zone close to the column wall and in the case of modification IV it is considerably reduced.

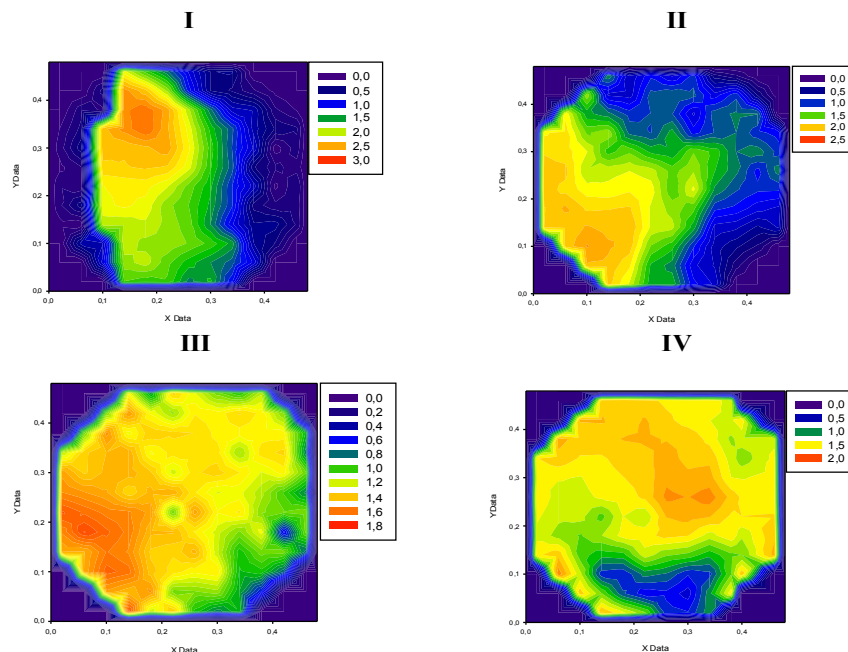


Figure 5. Contour maps of gas flow velocity isolines, measured at the outlet of GDD's modifications for gas inlet rate 1.3 m/s

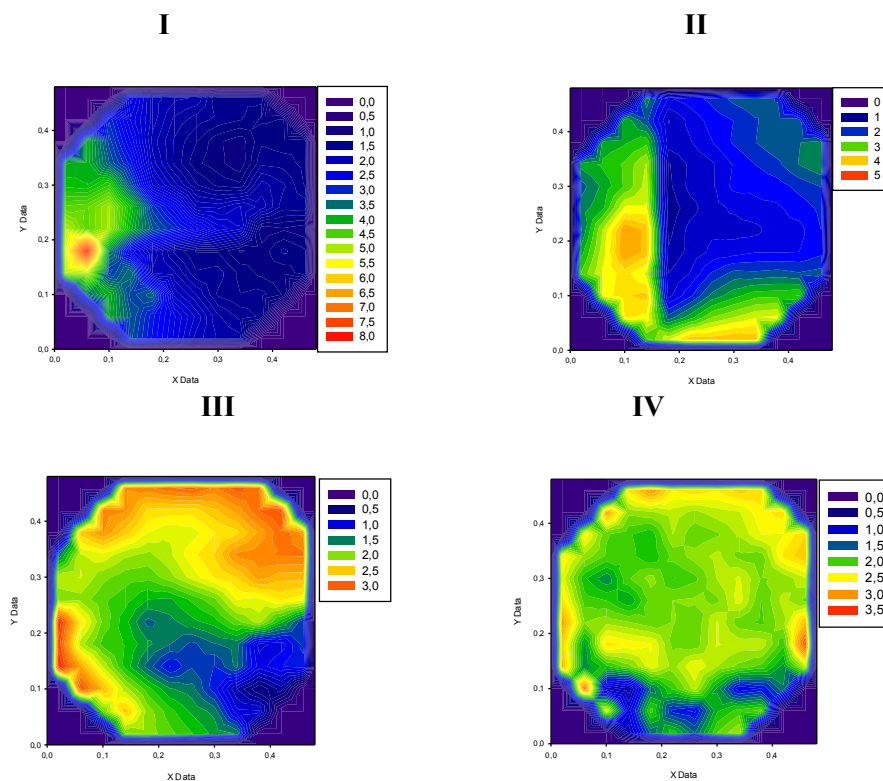


Fig.6 Contour maps of gas flow velocity isolines measured at the outlet of GDD's modifications for initial flow rate 2 m/s

By increasing the initial flow rate the adding of different numbers of grids, made of structured packing Holpack (2, 4 or 6) in modification IV does not affect significantly the value of M_f , but successfully equalized the residual asymmetry of the velocity profile (Fig. 6, bottom right).

The obtained results confirm the technological measures to improve initial maldistribution at GDD, recommended in the literature. In addition, the measuring of pressure drop for each of the modifications was done. The removing of water mirror, addition of an empty section or several grids does not increase significantly the pressure drop through the investigated modifications of the basic bend type GDD, which is another prerequisite for their use because they do not require additional energy costs.

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