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Quantitatively Measure and Assess Maldistribution in Industrial Packed Towers

(Abstract)

Simon X. Xu
Tru-Tec Services, Inc.
11005 West Fairmont Parkway, La Porte, Texas 77571
Phone: (281)-471 8715; Fax: (281)-471 0078
E-mail: xus@kochind.com

Abstract*: Maldistribution of liquid in packed towers can impact dramatically mass- and heat-transfer efficiencies of distillation, absorption and stripping operations. Latest development in gamma computer-aided tomography (CAT-Scan) has made it possible to obtain an image of cross-sectional density distribution inside packed beds. Further work is needed for characterizing the scale of maldistribution from the CAT-Scan images. In this paper an image analysis approach is developed for quantitatively assessing the maldistribution from the CAT-Scan images. Concept of the micro- and macro-distribution variances is discussed. Various coefficients for assessing flow variation are compared and a generalized distribution scale is proposed for quantitatively assessing the maldistribution in packed beds. Applications of the generalized distribution scale for industrial packed towers are presented.*

Liquid distribution plays an important part in the efficient operation of a packed tower. Poor distribution reduces the effective wetted packing and promotes liquid channeling. From an operating standpoint, the practical effects of maldistribution are declines in performance due to poor liquid/vapor contact efficiency. Variations in the liquid/vapor ratio in a cross-section of packed bed reduce the effective interfacial area for mass and heat transfer, translating to a higher HETP. Under extreme conditions, low L/V ratios may result in local composition pinches, possibly even localized coking or sintered chemical deposits within the packed bed.

A packed column has a reasonable tolerance for random maldistribution. Random maldistribution is characterized by small-scale variations in mass flows across the column area. Generally, lateral mixing of the liquid traffic in the packed bed can redistribute the random flows and counterbalance any ill effects. However, the impact of large-scale, non-random maldistribution is much more severe. In this case, the amount of lateral mixing that takes place is not sufficient to redistribute the much greater volume of maldistributed liquid or vapor, unless extra portion of the packed bed is sacrificed for the redistribution.

Non-random maldistribution is a result of poor design, faulty installation, or compromised mechanical integrity to either the distributor or the packing. Common examples of large-scale liquid maldistribution in industrial columns include design or manufacture defects (drip point layout and welding faults), distributor levelness (tilted pans or troughs), damage or plugging (warped pans and fouled packing), and process disturbances (solids carryover into the column). Industry's experience has shown that the water testing and proper inspections after installation are still the most dependable way to pinpoint the problems in design and installation (Olsson, 1999). However, as soon as the column is put into operation, the maldistribution problems are much more difficult to diagnose.

The only possibility to get the distribution information inside a packed bed from non-invasive techniques is the use of high-energy gamma rays (Bowman, 1993). Grid scanning has been widely applied to evaluate the overall distribution and internals placement in a column. A grid scan is a succession of four equal-chord gamma scans, which are oriented in a grid pattern. If all four scans are seeing a packing bed with even liquid distribution, then all four scan lines should overlay or crisscross on top each other. The lack of coincidence of the four scan lines is an indication of the maldistribution. Nevertheless good coincidence does not mean a good distribution, since an annular maldistribution (for instance the wall flow phenomena) will show an well-overlaid grid scan plot (Figure 1).

Figure 1. Gird-Scan Lines and Maldistribution Patterns (Annular, Chordal and Irregular)

Latest development in gamma computer-aided tomography (CAT-Scan) has made it possible to obtain an image of cross-sectional density distribution inside packed beds (Xu, 1999). The gamma CAT-Scan is performed by rotating a gamma source and a radiation detector outside the column circumference and measuring the density of all matter that interferes the scan lines between the source and detector. A polynomial-based algorithm has been used for the data reconstruction, which has been proven to be adequate for diagnosing macro-maldistribution in industrial scale columns (Xu etc., 1999). Figure 2 shows two different methods of presenting the CAT-Scan results, the 3D contour and 3D surface.

Figure 2. Two Methods of Presenting CAT-Scan Results

For most troubleshooting applications, the CAT-Scan images are usually sufficient for identifying the severe maldistribution problems, like the wall flows and low-irrigation spots in packing beds. However when applied for analyze the distribution quality or hydraulic performance, the images themselves are not convenient for assessing the liquid distribution quantitatively. This paper will present a numeric scale, or the coefficient of variance as a complementary parameter for appraising the distribution performance.

The coefficient of variance Cv is the most widely used for reporting distribution quality of liquid distributors. It has also been used extensively in studies of gas and liquid flow patterns leaving packed beds. The concept has not been applied for liquid flows inside the beds, because there were no way to measure the liquid distribution inside beds except by used of CAT-Scan.

The coefficient of variance is the ratio of the standard deviation to the mean of a sample or a set of data points. When applied to a continuous flow profile on a cross section area of the column, the coefficient is:

$$C_v = \sqrt{\frac{1}{A_t}\int\left(\frac{u-\bar{u}}{\bar{u}}\right)^2 dA}$$

Where A_t is the total area and the mean velocity of liquid is calculated as:

$$\bar{u} = \frac{1}{A_t}\int u \, dA$$

For a steady state flow in a packing bed with uniform bulk density, the local liquid velocity u is proportional to the local liquid holdup or local density. The coefficient of variance can be rewritten as:

$$C_v = \sqrt{\frac{1}{A_t}\int\left(\frac{\rho-\bar{\rho}}{\bar{\rho}}\right)^2 dA}$$

Where □ is the local density that can be calculated from the polynomial function of the density profile:

$$\rho(x,y) = a_1 + a_2 x + a_3 x^2 + a_4 x^3 + a_5 x^4 + a_6 y + a_7 y^2 + a_8 y^3 \\ + a_9 xy + a_{10} x^2 y + a_{11} xy^2 + a_{12} y^4 + a_{13} x^3 y + a_{14} xy^3 + a_{15} x^2 y^2$$

The polynomial coefficients $a_1, a_2, \ldots a_{15}$ are determined by regressing the CAT-Scan data (Xu, 1999).

Figures 3-6 are the CAT-Scan density profiles of the simulated operations in a 3-ft ID column (Xu and Kennedy, 1999), for:

- Good distribution
- Chord maldistribution (more liquid flowing toward to one side)
- Center annular maldistribution (more liquid flowing toward to the center area)
- Outer annular maldistribution (more liquid flowing toward to the outer area).

The coefficients of variance for the CAT-Scan profiles are also marked on the figures.

Figures 3-6. Scan profiles and Cv

It can be seen that the Cv values are consistent with the distribution patterns, that is, the lower the Cv value, the better the distribution quality. For the good distribution patterns, the Cv is less than 15%, while for the poor distribution patterns the Cv is in a range of 25-45%. For the purpose of assessing industrial packed columns, the distribution quality can be graded as 5 levels, based on the Cv values:

Liquid Distribution Quality	The Coefficient of Variance
Excellent Distribution	< 10 %
Good Distribution	10-15 %
Fair Distribution	15-20 %
Poor Distribution	20-25 %
Very Poor Distribution	> 25 %

The Cv is only a complementary parameter for grading the overall distribution quality, not for replacing the images from CAT-Scans. For instance, a chordal maldistribution may have more impact on the packing performance than an annular maldistribution, although the Cv could be same.

Billingham etc. (1997) discussed limitations of various indices and coefficients for quantifying quality of liquid distributors and proposed a new index MI, the Maldistribution Index. The MI appears better than Cv in characterizing the micro-maldistribution by use of a local mean velocity, rather than just an overall mean velocity. Because of the inherent limitations, the polynomial-based CAT-Scan is NOT intended for evaluating the micro-distribution patterns (Xu, 1999) and hence the local distribution analysis is not recommended.

The coefficient of variance, together with the CAT-Scan images, can be used to assess the liquid distribution quality in a packing bed quantitatively. However it is not easy to correlate the distribution quality to mass transfer efficiency, since the efficiency depends on more other variables, like system properties, operation conditions and column internals. A practical way to evaluate the effect of distribution quality on efficiency is to compare with the baseline data, which document the CAT-Scans and process information when the column is in good performance.

References

1. Strigle, R.F. Jr., Random Packings and Packed Towers – Design and Applications, Gulf Publishing Co., Houston, 1987, p. 212
2. Kister, H. Z., Distillation Operation, McGraw-Hill, Inc., 1990, chapter 3
3. Killat, G. R. and T. D. Rey, Properly Assess Maldistribution in Packed Towers, Chem. Eng. Prog., May 1996, p. 69
4. Billingham, J.F., D.P. Bonaquist and M.J. Lockett, Characterization of the performance of Packed Distillation Column Liquid Distributors, Distillation and Absorption'97, Vol. 2, IChemE, 1997
5. Olsson, F. R., Detect Distributor Defects Before They Cripple Columns, Chem. Eng. Prog., October 1999, p. 57
6. Xu, S. X., Gamma CAT-Scans for Distillation Columns- from Theory to Practice, Paper Presented at the AIChE Annual Meeting, Dallas, November 4, 1999
7. Xu, S. X., G. Kennedy, C. Conforti, T. Marut and J. Dusseault, Troubleshooting Industrial Packed Columns by Gamma-Ray Tomography, Paper presented at the CE Expo'99, Houston, June 9, 1999
8. Xu, S. X. and G. Kennedy, Gamma-Ray Computer-Aided Tomography of Industrial Packed Columns, Paper Presented at the AIChE Spring Meeting, Houston, March 14, 1999