Measuring the Scale of Segregation in Mixing Applications

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Abstract

The scale of segregation is one of three measures of mixing and segregation (Kresta et al., 2009) which is important for applications like laminar mixing where the thickness of striations determines the state of mixedness or solid-liquid, liquid-liquid and gas-liquid mixing where the size of the particles, drops and bubbles, respectively determines the mass transfer rates or where achieving a specific size is the main objective of the operation. In order to quantify the mixing progress for these processes, it is essential to measure the scale of segregation. This contribution shows several evaluation techniques of the scale of segregation in realistic data sets from mixing applications. The data available from industrial mixing processes suitable for the scale of segregation evaluation come in the form of full field measurements or CFD simulations. Techniques will be presented to show calculations using 2D planes of data; however, the extension to 3D analysis is straightforward. The data sets needed for this kind of analysis should contain the locations of particles, drops, or bubbles or can be images of particles, drops, bubbles and species concentrations in the region of interest. In this paper several options for quantifying the scale of segregation are compared. The first set of measures comes from early mixing literature which appeared at a time when realistic data sets could not meet the demands of the analysis. These measures will be compared with methods from spatial statistics: the distribution of scales of segregation, the point nearest neighbor analysis, and the variogram, which is closely related to the autocorrelation function.

Two types of data were used. The first data type is locations of particles coming from CFD simulations (Aubin et al., 2005). The scale of segregation for particle location data can be measured by evaluating the maximum striation thickness on a transect through cross-sectional planes, which is defined based on a minimum interparticle distance, or point adjacency limit. As mixing progresses, the injected particles are dispersed across the cross-section which is nicely indicated by decreasing maximum striation thickness (Kukuková et al., 2008). Another approach to measuring the scales of segregation in particle data is to calculate point-to-nearest neighbour (PNN) distributions. This method measures the distances from node points on a regular hexahedral sampling grid to the nearest tracking particle. As mixing progresses, the distributions evolve from clustered

through a random distribution and finally towards a regular homogeneous particle distribution.

The second data type is concentration maps. Two data sets of this type were studied. The first is a set of greyscale photographs of smoke being distributed by a jet in cross flow (Watson, 2007), where the pixel intensity in photographs corresponds to the smoke concentration. The last data set are concentration maps of a glycerin-water mixture in a scaled down industrial reactor. Species concentration data coming from photographs or concentration maps do not provide us with sharp interfaces due to the effects of molecular diffusion, so the evaluation of striation thickness evaluation is based on a minimum concentration threshold, typically 1% of the mean concentration. Point-to-nearest neighbour analysis cannot be used at all. Instead, spatial statistics techniques such as the variogram are used to evaluate the spatial variability of the concentration. Figure 1 shows how variogram analysis can be useful for this kind of data. Oscillations in the vertical variogram indicate periodicity in the data and indeed, there are periodic striations in the photograph when looking at vertical cross-sections. On the other hand, no periodicity can be observed in horizontal direction, which is confirmed by the variogram. Peaks in the variogram can also be used as indicators of mean striation thickness on several scales of data.

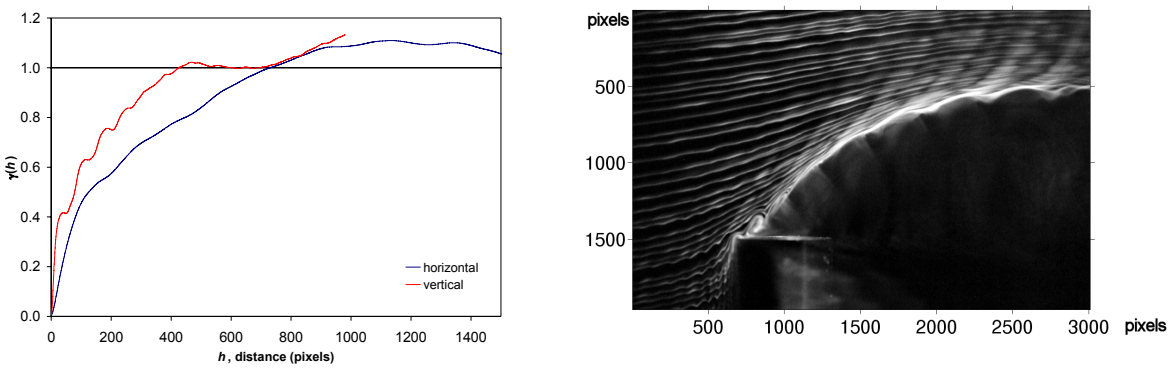

Fig. 1. Example of a horizontal and vertical semivariogram of the smoke concentration data.

keywords: mixing, scale of segregation, striation thickness, spatial statistics, variogram, coefficient of correlation, nearest neighbour analysis, spatial randomness, homogeneous distribution

References

Aubin, J., Fletcher, D. F., Xuereb, C. (2005). Design of micromixers using CFD modelling. Chem. Eng. Sci.. 60(8 9), 2503-2516.

Kresta S. M., Kukukova A. and Aubin J. (2009). Measurement of Mixing Using Three Dimensions of Segregation, Proceedings of the 13th European Conference on Mixing, London, April 2009.

Kukuková, A., Noël, B., Kresta, S. M., Aubin, J. (2008). Impact of sampling method and scale on the measurement of mixing and the coefficient of variance. AIChE J. 54(12), 3068-3083.

Watson, M. G. G. (2007). The structure and the controlled relaminarization of low momentum elevated jets in crossflow. Dept. of Mech. Eng., Edmonton, University of Alberta. MSc. Thesis.

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