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STORMFLOW: a STOchastic geometRical model for Multiphase FLOW characterization

Léo Théodon, Kassem Dia, Johan Debayle, Fabrice Lamadie

CEA, DES, ISEC, DMRC, Univ Montpellier,

F-30207 Bagnols-sur-Cèze Cedex, France

MINES Saint-Etienne, CNRS, UMR 5307 LGF, Centre SPIN, 158 cours Fauriel

42023 Saint-Etienne Cedex 2, France

fabrice.lamadie@cea.fr

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Abstract

Due to its simplicity, but also to its performances, one of the most used techniques to characterize gas-liquid flows is direct imaging. However, the efficiency of direct imaging methods is strongly linked to the image processing algorithm used. In this communication, we present an image processing algorithm based on 2D stochastic image modeling that allows to retrieve the main geometrical parameters of bubbles in gas-liquid flows, including complex flows for which deterministic algorithms are less efficient.

Context

Bubble columns are common contactors widely used in the chemical and biochemical industries. They have been, and are still today the aim of an abundant literature, describing either experimental or numerical studies (see e.g. (Bello et al. 1985; Shimizu et al. 2016; Buffo et al. 2017)). Thanks to this extensive research, the characterization of the flow field in a bubble column, including shape and velocity of the bubbles as well as their interaction with surrounding liquid, has led to numerous developments of instrumental techniques, particularly in direct imaging and image processing.

The various imaging techniques that can be used to characterize 2D images of bubbly flows can be classified in two main categories. Deterministic methods mainly rely on segmentation, pattern recognition, geometrical methods and, more recently, on machine learning to characterize the images (Cerqueira et al. 2018; Fu et al. 2018; de Langlard et al. 2018). They are usually fast but are less efficient for more complex flows (higher particle densities, larger clusters, more complex shapes). The second family, based on stochastic methods, uses models capable of generating large numbers of numerical images. Thanks to a cost function used to compare their characteristics with the real images, a best set of parameter values for the stochastic model can be found resulting in a measurement of the bubbles geometrical features (Kracht et al. 2013; de Langlard et al. 2018).

In this paper, we present a new image processing algorithm based on 2D stochastic image modeling, called STORMFLOW (STOchastic geometRical model for Multiphase FLOW characterization), that allows to retrieve quickly and efficiently the main geometrical parameters of

bubbles (equivalent diameter, ellipticity, etc.) within complex flows (swarm, plume, etc.) forming clusters of particles.

Main workflow of the STORMFLOW algorithm

The overall principle of the image processing algorithm is based on the training of a stochastic germ-grain model of ellipses like shape particles. It is structured around the following steps:

- (i) From a deterministic ellipse detection algorithm (de Langlard et al. 2018), extraction of one geometrical characteristic from the images, the major axis - eccentricity correlation, considering a number of variable hydrodynamic parameters, here two different gas injection rates. About 1000 ellipses detected are sufficient to achieve a representative statistic.
- (ii) Optimization of the stochastic model parameters (μ the mean number of particles and t an interpolation factor of the major axis - eccentricity correlation) using a simple cost function combining the global area and perimeter measurements of the random set of ellipses.
- (iii) Fitting of a polynomial function between the parameters of the stochastic model (μ, t) and the variables under consideration (gas flow rates).

Once trained, the model is able to generate, for a given set of variables, as many images as required with average characteristics (equivalent diameter, eccentricity, size distribution, etc.) fully representative of the real acquisition. The model can therefore predict all geometrical variations in bubble size or shape induced by a change in flow parameters.

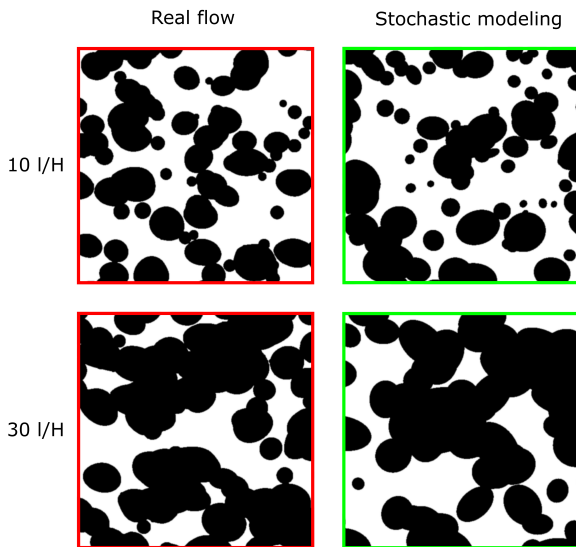


Figure 1: Comparison between the acquisitions and the realizations of the trained model for two gas injection flow rates.

Results and Discussion

The method was experimentally validated on a plume-like flow generated by a porous sintered glass in a static water tank of about 1.5 L volume. The gas is injected with a flow rate adjustable to a precision of 0.05 L/h in a range between 2.5 L/h and 40.0 L/h. The experimental optical imaging setup used to capture the images runs in backlight illumination setup, in which the light source and an imaging sensor are placed on either side of the flow. The images are captured using a bi-telecentric lens and collimated light to avoid perspective effects. Based on this setup, the stochastic model was trained on the two extreme flow rates and then used to "predict" images at 7 other intermediate flow rates (5, 10, 15, 20, 25, 30 and 35 L/h). Fig. 1 shows a comparison between the acquisitions and the modeling results for two different intermediate flow rates (10 L/h and 30 L/h). The agreement between both images is very good and proves the ability of the model to reproduce the images for any gas flow. The Fig. 2 compares quantitatively three mean parameters, eccentricity, equivalent diameter and flattening, with the results of a deterministic ellipse detection algorithm (Zou et al. 2018) not used when training the model. The results are consistent for all three parameters whatever the gas flow considered while the image processing time decreases by several orders of magnitude.

Conclusion

In this study, we have demonstrated that image processing using stochastic modeling is a relevant alternative for characterizing complex bubbly flows. Compared to deterministic algorithms based on pattern recognition, such an approach allows to retrieve easily and quickly the average geometrical characteristics of the dispersed phase in images even considering complex flows. Future work will address other more complex shapes such as caps or wobbling bubbles.

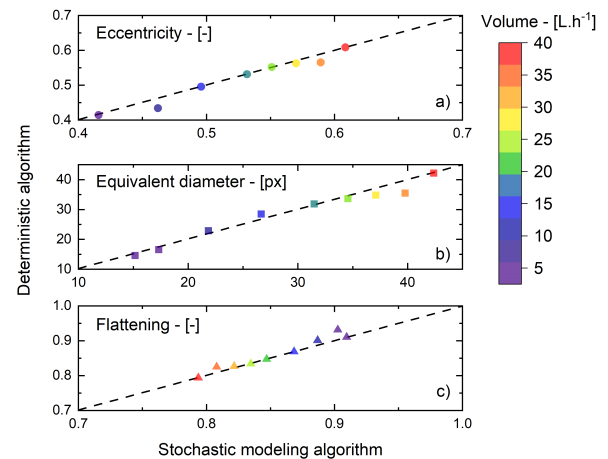


Figure 2: Quantitative comparison between the mean parameters determined using STORMFLOW and the deterministic algorithm proposed by Zou et al. for a) the eccentricity, b) the equivalent diameter, c) the flattening.

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