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Turbulence Effect on Clustering in Bubble Swarms using DNS and Front-Tracking

BURLLOT Alan¹, RAMIREZ Gabriel^{1,2}, RISSO Frédéric²,

BOIS Guillaume¹ and ZAMANSKY Rémi²

[1] Université Paris-Saclay, CEA, Service de Thermo-hydraulique et de Mécanique des Fluides, 91191, Gif-sur-Yvette, France.

[2] Institut de Mécanique des Fluides de Toulouse (IMFT), Université de Toulouse-CNRS, 31400 Toulouse, France.

alan.burlot@cea.fr

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Abstract

We investigate cluster's formation in bubbles' swarms using direct numerical simulations and the Front-Tracking method for bubbles' motions. Void fractions of 3 % and 6 % are simulated with and without a background forcing turbulence. The bubbles' concentration is measured using Voronoi volumes computed from the bubbles' mass centres. We show a clear effect of turbulence on the probability density function of Voronoi volumes as it increases the probability of extreme values. Common scalings based on standard deviation and analytical functions are investigated and show only a partial fit with our data suggesting a different cluster mechanism.

Introduction

The dynamics of a bubbles' swarm is still of interest as bubbles show a non-trivial collective behaviour when moving in a liquid. Numerous two-phase flow models are derived from the dynamics of a single bubble, such as the lift force or turbulence dispersion in the Eulerian-Eulerian approach of dispersed flows. However, they rarely account for the modification induced by collective effects. A typical collective effect that isolated bubbles cannot by definition predict is the formation of clusters. As bubbles interact, they tend to accumulate in certain regions. One aspect that could help models is the identification of a length scale related to these clusters to account for this collective effect.

This work takes place in an extensive effort made for several decades to identify clustering effects in two-phase flows, as reported in the review of Monchaux et al. (2012) and Brandt & Coletti (2022). A large part of the literature is focused on the concentration of particles, neutrally or actively buoyant. The originality of the current work is to consider numerical simulation of resolved bubble ten times larger than the Kolmogorov length scale. Our objective is to identify the effect of turbulence on a swarm dynamics where turbulence and the Bubble-Induced Agitation (BIA) share common length scales, as suggested by Risso (2018).

We propose to investigate this question using direct numerical simulation of bubble swarms with an interface tracking method. A supplementary effect is added to the inquiry with the addition of an external forcing that mimics a *single-phase* turbulence. We will thus try to identify the effect of turbulence on the cluster formation. The main results from the literature on clustering is evaluated on our case.

Numerical Methods

Four numerical simulations of bubble swarms are made using the in-house open-source code TrioCFD using a Front-Tracking method. Two sets of simulation are produced: the first one only simulates a bubble swarm, the second one simulates a swarm with an additional forcing. Two void fraction values are tested, $\alpha = 3\%$ and $\alpha = 6\%$, with a bubble diameter $D_b = 1$ mm. In each simulation, three mesh levels are simulated. No fragmentation is permitted in our simulations and an anti-collision force is set to avoid coalescence. We ensure that this extra force has no impact on the flow statistics.

The physical conditions are close to the one presented in the work of Du Cluzeau et al. (2022). The box simulated is a cube with a size of 3.17 cm. The number of bubbles is 1825 for $\alpha = 3\%$ and 3650 for $\alpha = 6\%$. The bubble Reynolds number is close to 470. The forcing of turbulence is obtained using a stochastic approach described in Eswaran & Pope (1988) and Chouippe & Uhlmann (2015). The lambda Reynolds number associated with our forcing without bubble is close to 150. Its intensity was calibrated to be of the same order of magnitude than the BIA-only energy. The densities are 1171.3 kg.m^{-3} for the liquid and 87.5 kg.m^{-3} for the vapour. The liquid and vapour viscosities are equal and set at $3.73 \times 10^{-4} \text{ kg.m}^{-1}.\text{s}^{-1}$. The surface tension is equal to $1.8055 \times 10^{-2} \text{ N.m}^{-1}$. This is close to Freon R12 conditions at 70 bars.

The two first meshes are made of 216^3 cells and 432^3 cells. A third level with 864^3 cells will be shown in the final presentation.

The analysis of the clustering effect is performed using a Voronoi method as described by Ferenc & Néda (2007).

We use the centre of mass of bubbles as a seed for the Voronoi volumes evaluation. The Voronoi method of the SciPy Python package is used to calculate the vertices of the Voronoi regions. The volume is then evaluated using the ConvexHull method of the same SciPy package. Additional results on the time evolution of the statistics are available, but omitted here for concision.

Results and Discussion

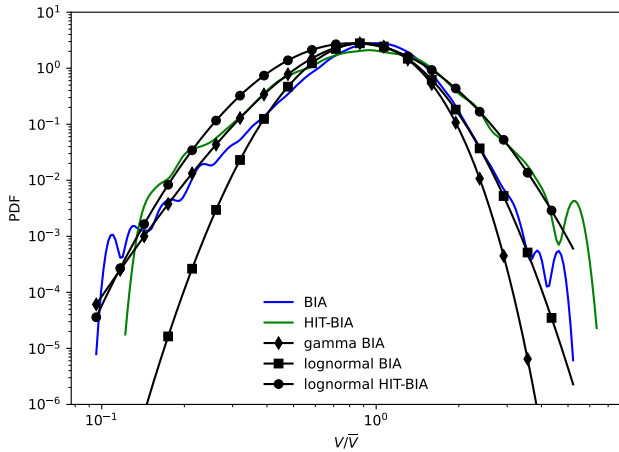


Figure 1: Probability density function of the swarm-only flow (BIA, blue) and the swarm+forcing flow (HIT-BIA, green) for the $\alpha = 6\%$ case. Three plots are added: a gamma function (diamonds) using the standard deviation of the BIA-blue curve, and two log-normal distributions taking the standard deviation of both flows (square for BIA, circle for HIT-BIA).

On Figure 1, we show the density distribution of Voronoi volumes for a void fraction of 6 % for a swarm of bubbles without forcing (in blue, hereafter referred to as BIA) and a swarm with a forcing (in green, hereafter referred to as HIT-BIA). We compare those distributions to a gamma function, as suggested by Tagawa et al. (2012), and with log-normal distributions as suggested by Monchaux et al. (2012).

First, we can observe the effect of the turbulence as it broadens the distribution of Voronoi volumes. Smaller and larger Voronoi volumes are observed in the HIT-BIA flow. Voronoi volumes are inversely correlated to the concentration of bubbles. These results are thus suggesting that there is a higher probability of finding clustered bubbles in the flow with a background turbulence.

Finding a useful number to characterize the clustering effect is of a primary importance to improve modelling. The standard deviation of the distribution is usually taken as a seed for analytic functions. Here we compare our results with gamma and lognormal distributions. The small volumes are better captured than the high volumes. For both BIA and HIT-BIA PDFs, the large volumes are well captured by a log-normal distribution.

Further results will be presented on, first, averaged statistics related to the Voronoi volumes distribution and, second,

the link between bubbles' concentration and other quantities, as enstrophy (Tagawa et al. 2012). The void fraction effect using the $\alpha = 3\%$ simulations will also be presented.

Conclusion

We performed numerical simulations of bubbles' swarm with and without an external forcing to investigate the effect of turbulence on bubbles clusters' formation. The bubble dynamics is captured using a Front-Tracking method. The bubbles' diameter is ten times greater than the Kolmogorov length scale, resulting in a strong interaction between bubbles and turbulence. The clustering effect is investigated with a Voronoi method. We show a clear effect of the turbulence on the Voronoi volumes PDF as the extreme values of both small and large volumes are enhanced by the presence of turbulence. Common scalings from the literature are investigated such as the gamma and lognormal distributions are compared. We show a partial fit for both as they tend to capture one part of the probability distribution function only.

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