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A new turbulence-induced theoretical breakage kernel in the context of the population balance equation

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Abstract

The current paper develops a new breakage kernel for use in the population balance equation. The study properly accounts for the direction of the relative velocity of the eddy and determines the size of the daughter bubble from the angle at which the eddy hits the parent bubble and its orientation at the point of impact. The breakup kernel considers both the capillary pressure of the parent bubble and the surface energy increase of the daughter bubbles in its formulation. The model predictions agree very well with the experimental data available in the literature. A parametric study of the breakage kernel further analyzes its behavior over a range of flow conditions. The parameterization also leads to a simplified breakage kernel.

1 Introduction

Numerous critical equipment in various industries depend on bubbly flows for enhanced heat and mass transfer. A detailed understanding of these flows is imperative for understanding and optimizing the performance of such equipment. Bubbly flows encounter complex phenomena like coalescence and breakage of bubbles. It is obvious that an accurate prediction tool should be capable of handling these physics. Recent advances in computational resources have led researchers to rely on computer simulations to understand the complicated details of multiphase flows. This spawns the need for accurate, fundamentals-based computer models. The current research on developing a breakage model is an attempt in this direction. The focus is to develop a breakage kernel in the population balance equation framework. However, the solution of the equation with breakage and coalescence kernels for a multiphase flow problem is outside the scope of the present study. The paper caters to the development of a new breakage kernel and the examination of its behavior in different flow conditions.

The population balance equation is given by

$$\frac{\partial \mathcal{N}\left(\vec{x},V,t\right)}{\partial t} + \nabla \cdot \left(\vec{u}\,\mathcal{N}\left(\vec{x},V,t\right)\right) = C_+ - C_- + B_+ - B_- \tag{1}$$

where $\mathcal{N}\left(\vec{x},V,t\right)$ is the number density function of the bubbles, $\vec{x}$ is the space vector, t is the time, $\vec{u}$ is the velocity vector, V is the bubble volume, C_+ and C_- are the birth and death terms due to coalescence and B_+ and B_- are the birth and death terms due to breakage. The last two terms in the above equation is the subject of the paper. These are given by

$$\begin{aligned} B_+ &= \int_V^{\infty} p_c b(V^{'})\beta\left(V|V^{'}\right)\mathcal{N}\left(\vec{x},V^{'},t\right)\mathrm{d}V^{'} \\ B_- &= b\left(V\right)\mathcal{N}\left(\vec{x},V,t\right) \end{aligned} \tag{2}$$