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Review of Bubble Column Reactors with Vibration

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ABSTRACT: Vibrating a bubble column reactor can increase the gas holdup (void fraction), as well the mass-transfer rate. Since the seminal work in the 1960s, there has been minimal effort focused on this topic until the early 2000s. Currently there are several groups studying this problem making advancements in our fundamental understanding of the process with detailed experiments, theoretical analyses, and physics-based models. However, throughout the literature, there are inconsistencies with both experimental results and proposed scaling of the fundamental properties, as well as minimal data spanning the parameter space. This review serves as an overview of key works from the 1960s and the 2000s, as well as to identify these inconsistencies between key studies. Recommendations for how to proceed with future work is provided with an emphasis on defining the parameter space in terms of the Reynolds number and the Froude number.

1. INTRODUCTION

1.1. Motivation. Numerous real-world systems involve multiphase flow, which produce complex flow patterns that are dependent on the balance of forces and phase distribution. The control of these flows for engineered systems, such as piping networks for the petroleum industry, require a complete understanding of the phase interactions with the boundary conditions and the other phase(s). However, for many of these flow fields, there is a relative velocity between phases and nonhomogeneous distributions that prevent the governing equations from being solved as a mixture with average fluid properties. Consequently, each phase must be solved individually, which requires an understanding of the mass, force, and energy interaction terms between the phases. Currently, these relationships are unknown, which forces researchers to form heuristic models for a specific flow pattern.[1] For this reason, the study of multiphase flows are typically confined to specific flow configurations and rely heavily on experimental data and empirical modeling. The current review focuses on a bubble column reactor (BCR) with vibration, which involves two phases interacting with each other to dissolve the dispersed phase (gas) into the continuous phase (liquid mixture).

BCRs are widely used throughout the chemical, biochemical, and petrochemical industries, because of their simple design, low cost, compactness, ease of operation, and high heat-/mass-transfer rates. Some BCR applications include wastewater treatment, aeration of organic organisms in bioreactors, solvent gasification for chemical reactions, and hydrogenation of coal slurries to produce synthetic fuels. The last example has gained significant attention recently, because several military and civilian aircraft have been qualified to fly with synthetic fuel blends, which are produced using the Fischer−Tropsch process. United Airlines ran the first flight demonstration of a commercial airliner in the United States using synthetic fuel blends with an Airbus A319 in April of 2010.[2] Currently, several United States Air Force fighters and aircraft (e.g., A-10, C-17, KC-135 and F-22) have been approved to fly with synthetic fuel.[3−6] This example, as well as numerous others related to chemical processing, highlight the ever-increasing use and application of BCRs in our society. Thus, there is also an increasing interest in the ability to control the physical processes within the reactor. While the primary limiting factor in the Fischer−Tropsch process example is not the mass-transfer rate,[7] mass-transfer rate and gas holdup are critical parameters for any BCR application.

It was discovered in the early 1960s that vibrating a BCR could increase the mass-transfer rate and gas holdup. While some additional research expanded the theory, minimal research effort focused on this phenomena until the early 2000s. A summary of the primary studies spanning this range is provided in Table 1, along with the primary measurements from each study.[8−23] Recent research has gone so far as to develop theoretical, physics-based models to predict mass transfer and void fraction in these systems. While there is a nontrivial body of work on vibrating BCRs, to date, the parameter space has been explored in a rather haphazard fashion. With numerous studies available, there is a need for a systematic, dimensionally reasoned analysis of the available data to identify specific flow regimes and the flow physics that dominate the given range of conditions. The available models have been tested against limited data, but there are inconsistencies with both experimental results as well as the proposed scaling of the fundamental properties. In addition, the large gap in time between studies provides motivation to re-examine these past studies, because of the significant advancements in experimental and computational tools. This review will provide a broad overview of previous studies, identify key findings that have established our current knowledge, and note inconsistencies in the literature that need further examination.

1.2. Background. It is beneficial to first review some basic physical properties and common definitions used to study vibrating BCRs. From an industrial point of view, the chemical reaction rate is typically the most important property. It is often assumed to be proportional to the volumetric mass-transfer

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