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Direct Numerical Simulations of Multiphase Flows[1]

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Many natural and industrial processes, such as rain and gas exchange between the atmosphere and oceans, boiling heat transfer, atomization and chemical reactions in bubble columns, involve multiphase flows. Often the mixture can be described as a disperse flow where one phase consists of bubbles or drops. Direct numerical simulations (DNS) of disperse flow have recently been used to study the dynamics of multiphase flows with a large number of bubbles and drops, often showing that the collective motion results in relatively simple large-scale structure. Here we review simulations of bubbly flows in vertical channels where the flow direction, as well as the bubble deformability, has profound implications on the flow structure and the total flow rate. Results obtained so far are summarized and open questions identified. The resolution for DNS of multiphase flows is usually determined by a dominant scale, such as the average bubble or drop size, but in many cases much smaller scales are also present. These scales often consist of thin films, threads, or tiny drops appearing during coalescence or breakup, or are due to the presence of additional physical processes that operate on a very different time scale than the fluid flow. The presence of these small-scale features demand excessive resolution for conventional numerical approaches. However, at small flow scales the effects of surface tension are generally strong so the interface geometry is simple and viscous forces dominate the flow and keep it simple also. These are exactly the conditions under which analytical models can be used and we will discuss efforts to combine a semi-analytical description for the small-scale processes with a fully resolved simulation of the rest of the flow. We will, in particular, present an embedded analytical description to capture the mass transfer from bubbles in liquids where the diffusion of mass is much slower than the diffusion of momentum. This results in very thin mass-boundary layers that are difficult to resolve, but the new approach allows us to simulate the mass transfer from many freely evolving bubbles and examine the effect of the interactions of the bubbles with each other and the flow. We will conclude by attempting to summarize the current status of DNS of multiphase flows.

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