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An Experimental Investigation of the Behavior of Droplets in Axial Acoustic Fields

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This paper describes an experimental investigation of the behavior of water droplets in axial acoustic fields. It was motivated by the increasing interest in the use of pulsations to improve the performance of energy intensive, industrial processes. The presence of an acoustic field is believed to enhance heat and mass transfer to and from the droplets, probably because of the relative motion between the droplets and the gas phase. This relative motion is characterized by the ratio of the amplitude of the oscillatory droplet velocity to that of the acoustic velocity (entrainment factor), and by the phase between the droplet and gas phase oscillations. An experimental set-up was developed to investigate the effect of acoustic oscillations on the motion of individual droplets. In these experiments a droplet produced by a piezo-ceramic droplet generator is allowed to fall through a transparent test section in which an acoustic field has been set up using a pair of acoustic drivers. Images of the droplets in the test section acquired at consecutive instants using a high speed, intensified imaging system were used to determine the time dependent droplet trajectory and velocity. The acoustic velocity was calculated from measured acoustic pressure distributions. The entrainment factor and the phase difference were then determined from these data. The results show how the entrainment factor decreases and the phase difference increases with increasing droplet diameter and frequency, indicating that larger diameters and higher frequencies reduce the "ability" of the droplets to follow the gas phase oscillations. The measured data are in excellent agreement with the prediction of the Hjelmfelt and Mockros model. Both theoretical predictions and measured data were correlated with the Stokes number, which accounts for the effects of droplet diameter and frequency. It was also shown that acoustic oscillations decrease the mean terminal velocity of the droplets.

Introduction

This paper describes an experimental investigation of the behavior of water droplets in axial acoustic fields. The study is motivated by the increasing interest in the use of sound waves to improve the performance of energy intensive industrial processes such as spray drying and calcining. In such processes, the rate controlling mechanisms are the heat and mass transfer between the gas phase and the droplets. For instance, the performance of a spray dryer depends upon the rate of heat transfer from the hot gas to the spray droplets and the rate of mass (i.e., moisture) transfer from the droplets to the gas. If these rates can be increased by, for example, acoustic oscillations, the time required to dry a typical droplet will decrease. This, in turn, will permit pumping more material through an existing dryer, thus increasing the dryer productivity. Alternately, the reduced drying time will reduce the required size of a new dryer, which will reduce capital investment costs. Furthermore, increasing the rate of heat transfer from the gas to the droplets will increase the fraction of input energy that will be transferred to the wet material, resulting in fuel and operating costs savings. Finally, reducing the fuel consumption will reduce emissions such as CO_2 and NO_x, which may help combat global warming.

The realization that the performance of energy intensive processes could be improved if means for increasing the rates of mass, momentum, (i.e., mixing) and heat transfer within these processes could be found has stimulated interest in developing practical means for enhancing these transport processes. The possibility of using sound or vibrations to increase convective heat transfer rates has recently received increased attention. It has been shown that pulsations (which, for example, can be established in industrial processes using pulse combustors) increase the heat and mass transfer from stationary objects (Bayley et al., 1961; and Richardson, 1967) where relative motions between the gas phase oscillations and the objects exist. These findings suggest that pulsations could also increase the rates of transport processes between gases and small particles when relative motions exist between the two phases. This conjecture is supported by additional studies (Richardson, 1967; Al Taweel and Landau, 1976; Lyman, 1977; and Padmanabha and Ramachandran, 1970) showing that pulsations increase the rates of heat and mass transfer to or from solid spheres or droplets.

In order to understand the effect of pulsations on sprays, it is important to understand their effect on individual droplets. This would require quantitative determination of the ranges of particle sizes and pulsation amplitudes and frequencies for which relative oscillatory motions can be established and whether such relative motions increase the rates of transport processes between the two phases.

A number of related studies of the effect of axial acoustic oscillations on droplets and particles can be found in the literature. The equation describing the unsteady motion of a rigid particle was developed by Basset (1961) assuming creeping flow (i.e., Re < 0.01, where Re is based on the relative velocity of the droplet with respect to the gas phase and the droplet diameter). Here, the drag on the droplet is linear and is given by the Stokes drag. An analytical solution for this equation was obtained by Hjelmfelt and Mockros (Hjelmfelt and Mockros, 1966; Clift et al. 1978).

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