A light attenuation technique for void fraction measurement of microbubbles

D. M. Leppinen, S. B. Dalziel

Abstract A non-intrusive technique to measure the two-dimensional distribution of line averaged void fraction in a two-phase flow is discussed. A CCD camera is used to measure the attenuation of light as it passes through a bubbly flow, and this attenuation is related to the bubble concentration. The technique is appropriate for microbubbly flows where the bubble size is much smaller than the area imaged by a single pixel and where there are many bubbles attenuating light within each pixel. The measurement system is calibrated by using a two-dimensional line source microbubble plume as a reference.

1 Introduction

Bubbly two-phase flows are important to numerous applications in nuclear, chemical, and petroleum engineering, and a key parameter when modelling these flows is the void fraction which is defined as the ratio of the volume of the dispersed gas phase to the total volume of the two phases. Various optical, electrical, and acoustical techniques have been employed to measure the void fraction both globally and locally and many reviews are available (e.g. Vagle and Farmer 1998; Ceccio and George 1996; Cheremisinoff 1986; Hetronsoni 1982; Jones and Delhaye 1976). With some of these techniques it is possible to measure the local void fraction at a given point, while with others it is possible to measure the global void fraction of a flow and even the size distribution of the bubbles. Tomographic techniques are available to measure the spatial distribution of void fraction, but these techniques can only be used at relatively large void fractions and the spatial resolution is relatively low. This paper describes a high resolution technique which has been developed to measure void fraction distributions in bubbly flows over length scales which are much larger than the size of individual bubbles. The technique is appropriate for situations where the bubble number density is so high that the measured void fraction is insensitive to the presence or absence of individual bubbles (i.e., the measured void fraction represents the average over a volume containing many bubbles). The technique is based on light attenuation: when a bubbly flow is lit from the back and viewed from the front, regions of high concentration appear darker than regions of low concentration. The technique described in this paper is similar to the light extinction technique discussed in the recent paper by Shamoun et al. (1999). The current technique is appropriate when the bubble number density is so large that individual bubbles do not need to be resolved, while the technique of Shamoun et al. (1999) is only appropriate when the bubble number density is so low that individual bubbles must be resolved.

The motivation for developing the current technique is to examine the hydraulics of a dissolved air flotation tank. Dissolved air flotation is a gravity-assisted separation process in which microscopic air bubbles are used to remove suspended solids from a liquid, and it is noted that flotation is rapidly becoming the process of choice for drinking water purification (Edzwald 1995). As discussed by Leppinen, Dalziel & Linden (2000), a knowledge of the void fraction distribution in the tank is necessary in order to model the hydraulics of the flotation process. While the number concentration of bubbles in a dissolved air flotation tank can be very high (on the order of $10^5$ bubbles/cm$^3$), the local void fraction due to microbubbles is very low (typically on the order of 0.001). The light attenuation technique described in this paper is thought to be the first of its kind capable of resolving the two-dimensional distribution of void fraction at such low values of the void fraction.

2 Experimental apparatus

The experiments were performed in a 243 cm x 15.1 cm x 55 cm (deep) tank which has a clear front and back walls made of Perspex. Diffuse backlighting was obtained by placing an array of seven fluorescent tubes 30 cm to the rear of the tank (see Fig. 1). The fluorescent tubes and the rear of the tank were covered with layers of tracing film to increase the uniformity of the backlighting. Images were acquired using a monochrome CCD camera (COHU Model 4912) with a Cosmican 8–48 mm TV zoom lens which was located 460 cm to the front of the tank. The camera output was digitized using a Data Translation DT2862 frame grabber card and the images were analyzed using the DigImage (Dalziel 1993) image processing system running on a 120 MHz Pentium

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PC. The digitized images consisted of an array of 512 × 512 (horizontal by vertical) pixel intensities of which only the central 512 × 192 pixels imaged the experimental tank, and these pixel intensities were saved to hard disk. The COHU Model 4912 is an interlaced video camera operating at 25 frames per second. Due to the limitations in transferring data from the frame grabber card to the hard disk, images were only acquired at approximately 7.6 frames per second. At the magnification employed during the calibration experiments, one pixel corresponded to an area of 3.81 mm (horizontal) × 2.58 mm (vertical).

Microbubbles were generated via the electrolysis of a dilute aqueous solution of sodium nitrate (8 g/l) across platinum electrodes producing predominantly hydrogen and oxygen gas from the negative and positive electrodes, respectively. The electrodes were 145-cm long segments of 0.125-mm diameter platinum wire which were threaded in a serpentine configuration along a 15 cm × 4.5 cm Perspex wire holder in such a way that the electrodes did not touch. The electrical current was supplied by an IsoTech DC power supply (Model IPS 303D) and the platinum electrodes were connected to the power supply via tinned copper electrical lead wires. The size of the bubbles generated was controlled by the addition of isopropyl alcohol. In the absence of isopropyl alcohol the gas bubbles were typically on the order of 1–2 mm in diameter, however, the size of the bubbles decreased dramatically by adding isopropyl alcohol. At the concentration of 15 ml of isopropyl alcohol per litre of water used during the calibration experiments, the bubbles were estimated using microphotography to primarily range from 35–50 μm in diameter. However, even with the addition of the isopropyl alcohol, there was still a small number fraction of macro bubbles generated with diameters on the order of 1–2 mm. The total volumetric production rate of gas was solely a function of the electrical current for fixed temperature, isopropyl alcohol, and sodium nitrate concentrations. For all of the experiments discussed in this paper, the total volumetric production rate of gas was 0.52 cm³/s, as measured using a gas collection technique.

3 Measurement technique
Figure 2 shows a schematic of a microbubble plume rising from a source at the bottom of a tank and then spreading along the free surface. The void fraction measurement technique discussed in this paper is based on the observation that microbubbles attenuate light. When the tank is lit from the back and viewed from the front, regions containing microbubbles appear darker than they would if no microbubbles were present because the microbubbles act as light scatterers. Light from the light source to the rear of the tank is partially reflected and partially refracted.

Fig. 1. Schematic of the experimental layout

Fig. 2. Schematic of a microbubble plume rising from a bubble source at the bottom of the tank and spreading along the free surface with inset showing a magnification of an area corresponding to one pixel of the CCD camera. Note that the bubbles are much smaller than the pixel size and that there are a large number of bubbles within each pixel.