Summary

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Title: Study on Behaviors of Gas–Liquid Two–Phase Flow in Slope Conditions

In a long history of study on the gas–liquid two–phase flow for several decades, many studies on the two–phase flow with slope conditions have been completed in physics and engineering fields. Most physics studies have been performed with quiescent fluids while engineering studies have been completed with various flow conditions. This means that there are large gaps between the two studies, although both studies commonly share the slope conditions. This is not a critical issue for engineering fields. However, no one can deny that it is best to do the design of engineering with an understanding of physics due to many advantages such as the improvement of devices and the safety of engineering. The following question can be derived from this point: "Why could not the physics of the two-phase flow with the slope conditions in engineering have been understood?". There are two main reasons. One is because of the very complicated mechanisms of the two–phase flow with slope conditions in engineering, and the other is due to the difficulty of measuring the two–phase flow in engineering. For the first reason, the buoyancy contributes to the one-dimensional motion of bubbles in horizontal and vertical conditions. It induces wall-perpendicular and -normal motion of bubbles in the horizontal and vertical conditions, respectively. On the contrary, the buoyancy is decomposed into two components in the slope conditions resulting in the multi-dimensional motion of the bubbles. Thus, the behaviors of the bubbles in the slope conditions are much more complicated than those of horizontal and vertical conditions. However, the complicated mechanism can be clarified if a lot of informative data are obtained from a good measurement technique, and this is strongly related to the second reason. Although optical measurement is most widely used in experimental fluid mechanics, it entails several troubles in analyzing the bubble behavior such as a lens flare and unfocused bubbles. An influential alternative to optical measurement is ultrasound measurement because it can provide the interface information of bubble and liquid velocity profiles without the troubles due to the independence of light sources. Nevertheless, ultrasound measurement has not been also vigorously utilized in the two–phase flow measurement because of fatal problems. For example, only a single velocity vector can be obtained from the ultrasound measurement. In other words, the ultrasound measurement can play an important key in elucidating the gas–liquid two–phase flow in the inclined conditions if it is possible to overcome the problems. The motivation for this thesis comes from the abovementioned reasons, and there are three objectives: i) Supplying useful ultrasound measurement methods to engineering fields, ii) Understanding the physics of two–phase flow with slope conditions in engineering based on the proposed ultrasound measurement, and iii) Suggesting useful numerical models which can be used in engineering.

This thesis consists of 7 chapters, and the summary of each chapter is as follows:

Chapter 1 summarizes the literature reviews and objectives of this study.

Chapter 2 proposes a novel technique for the instantaneous velocity vector profiling method using

conventional ultrasonic transducers. A problem when using the conventional transducers for the velocity vector profiling is introduced, and the principle of a new equation and a configuration of the transducers is explained to overcome the problem. The developed system accurately measures the velocity vector within 5% error. In demonstrations, the good performance of the developed method is verified in the measurement of two unsteady flows.

Chapter 3 describes the motions of bubbles sliding beneath the towed model ship. The boundary layers, which are varied by inclination, are visualized to estimate the base flow. The behaviors of sliding bubbles beneath the towed model ship are observed by optical measurement, and the measurement results confirm that the behaviors are governed by buoyancy at low towed speeds while the inertia of liquid flow is dominant to the bubbles. Finally, correlation models of the drag coefficient and velocity of bubbles sliding inside the boundary layers on the tilt plate are proposed using the measured variables.

Chapter 4 describes the behaviors of the bubble sliding inside turbulent boundary layers in an inclinable channel investigated by an optoacoustic measurement. The qualitative visualization confirms a periodic deformation of the sliding bubbles, and the optoacoustic measurement quantifies the deformation. The lift coefficient of the bubble is estimated using a force balance equation among the lift, buoyancy, and surface tension to further analyze the interface force inducing the deformation. The numerical model of the lift coefficient is proposed using Weber and Bond numbers.

Chapter 5 describes the characteristics of the wall-sliding bubbles in the inclinable turbulent channel flow are clarified using optoacoustic measurement with a wide range of inclination. The variation of bubble shape and velocity are measured by optoacoustic measurement. A constitutive equation of ellipticity is established based on the measurement results that the ellipticity is linearly reduced with the increase of inclination. The drag coefficient is estimated to further analyze the variation of bubble shape and velocity, and the numerical model for the drag coefficient is suggested.

Chapter 6 describes a challenging study to understand the two–phase flow with slope conditions in engineering based on the physics of the two–phase flow and ultrasound measurement understood in previous chapters. A new method of ultrasound measurement to identify the large bubbles rising with high velocity in an inclinable pipe is suggested. Several problems when using the ultrasound measurement for the slug flow with the high superficial velocity of gas–phase are introduced with corresponding solutions. The maximum absolute average relative error in the chord length-frequency is 2.4 Hz compared to the optical measurement in validation. In extensive applications using the method, the velocity of large bubble and slug-passing frequency are measured in an airlift pump.

Chapter 7 summarize the notable finding and future works.