Gas Hold-Up Profiles Measurement Using Ultrasonic Sensor

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***Abstract*—In this letter, we present a work carried out to measure gas hold-up profiles in a liquid column using a pair of ultrasonic sensors. The gas hold-up profiles from 1.85 to 7.7 mm in diameter are of interest in this investigation. The measurement setup consists of a pair of ultrasonic sensors, an experimental column, a signal conditioning circuit, and a digital storage oscilloscope. The experiment was conducted using several gas hold-up profiles, and the relationship between the ultrasonic signal and the profile were deduced. This letter explains how one could use an ultrasonic sensor to estimate gas hold-up profiles.**

***Index Terms*—Gas hold-ups, ultrasonic measurement, ultrasonic sensor.**

I. Introduction

WHEN an acoustic wave travels through a medium, its energy decreases exponentially with the distance travelled and the energy lost from the radiation appearing as heat; this is known as attenuation. In orther words, attenuation is the loss of acoustic energy from a sound beam. Attenuation can be divided into two parts: an absorption mechanism that convert acoustic energy into thermal energy and other mechanisms that deflect or scatter acoustic energy out of the beam [1].

The pressure of ultrasonic wave propagating in the medium decreases exponentially along the path as shown in Fig. 1 and expressed mathematically in

$$P = P_o \exp\left(-\int_L f(x,y)dP\right) \tag{1}$$

where P is the measured sound pressure (dB), P_o is the initial sound pressure (dB), L is the path length in the object field (m), and $f(x,y)$ is the attenuation function of the object field (dB/m). Because pressure is proportional to the voltage measured by the transducer [2], (1) can be written as

$$v_{Rx} = v_{Tx}e^{-\alpha L} \tag{2}$$

where v_{Rx} is the ultrasonic receiver voltage (V), v_{Tx} is the ultrasonic transmitted voltage (V), and α is the attenuation coefficient of the object field (Np/m).

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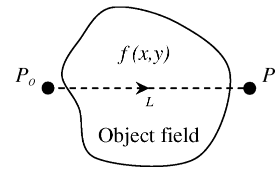

Fig. 1. Ultrasonic attenuation model.

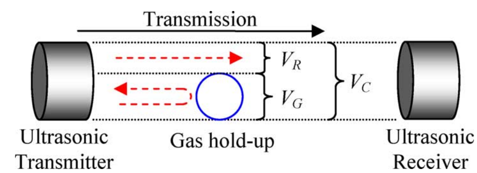

Fig. 2. Simplified ultrasonic transmission model.

II. Scattering Effects

It is obvious that the greater the difference in acoustic impedance at the interface, the greater the amount of energy reflected will be [3]. For the case of water and gas interface, about 99.94% ultrasonic energy will be reflected [4]. However, in some cases, scattering occurs on small gas hold-ups. "Small" was defined as a sphere with a radius of a where the circumference of the sphere $2\pi a$, divided by the wavelength λ is much less than 1, i.e., $ka = 2\pi a/\lambda \ll 1$, where k is the wavenumber $= 2\pi f/c$ [5].

If ultrasonic waves propagate in a bubbly air/water with a wavelength much shorter than the gas radius a, i.e., $ka \gg 1$, the diffraction can be ignored and these hold-ups will act as many acoustics opacities [6]. This is because, when $ka \gg 1$, the surface of the sphere appears as a flat surface with respect to the wavelength and the scattering becomes the same as reflection from a flat surface.

The motivation of this study is to be able to describe the gas hold-up profile (diameter) from the receiving ultrasonic amplitude. The relationship of the simplified ultrasonic transmission model is shown graphically in Fig. 2. and is depicted in

$$V_G = V_C - V_R \tag{3}$$

where V_G is the sensor loss voltage due to the gas opacity, V_C is the calibration voltage, and V_R is the receiving voltage. In order to estimate the gas hold-up profiles, the parameter V_G is to be resolved.

III. Experiments and Results

The experimental setup for evaluating gas hold-up profiles and the ultrasonic receiving signal is shown in Fig. 3.

The transducer has an active area of 7.1 mm in diameter and radiates 1 MHz. A pulser was used to provide the ultrasonic pulse tone to the receiver. Both the transmitter and receiver

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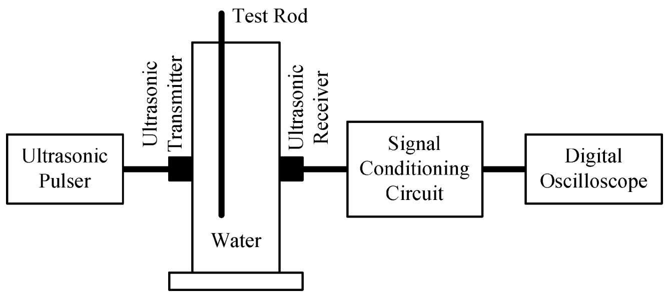

Fig. 3. Experimental setup for measuring the gas hold-up profiles.

were clamped on a vertical acrylic column of 100-mm diameter and filled with water. Before clamping the transducers, a small amount of gel was apply on the surface of the transducers to provide acoustic coupling. The signal conditioning is used to process the receiving signal and the signal amplitude was observed and measured using a digital oscilloscope.

There were five samples (test rod) used in the experiment with several diameters namely, 1.85, 3.3, 4.27, 6.27, and 7.7 mm. The test rods are hollow and were closed at one end and this will act as gas hold-up which is acoustically opaque. The test rods material is plastic with thickness of 0.1 mm. Before each measurement, a calibration was made by sending a pulse tone to the receiver with empty profile in the column and the receiving signal amplitude was measured. The calibration amplitude will act as initial amplitude.

When the sample is placed in the center of the column, the receiving amplitude decreases proportionally to the sample profiles. The larger the profile, the smaller receiver amplitude obtained. Fig. 4 shows the sensor loss obtained when all of the profiles were evaluated.

When a 7.7-mm profile was placed in the column, the receiving amplitude was zero because the profile size is larger than the transducer active diameter (7.1 mm) and all ultrasonic energy was reflected. Thus, the sensor loss voltage is 3.64 V, which is the same as calibration voltage. However, for a 1.85-mm profile, the sensor loss measured was small because small ultrasonic energy was reflected at the gas surface [according to (3)].

The relationship between the sensor loss voltage V_G and the gas hold-up profiles can now be deduced. Using statistical software, the linear regression (red line, online version) obtained is

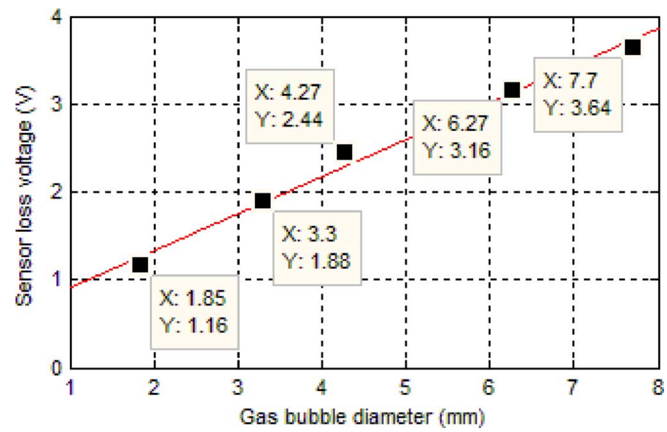

Fig. 4. Sensor loss voltage when several gas hold-up profiles were placed in the experimental column.

$y = 0.4217x + 0.4831$ with R^2 equal to 0.9887. Thus, the gas hold-up diameter G_D can be estimated using

$$G_D = \frac{V_C - V_R - 0.4831}{0.4217}. \tag{4}$$

Throughout the experiments, (4) is valid for $G_D \geq 1.85$ mm or $ka \geq 3.87$. The R^2 error could be improved if more measurement of samples were made. If smaller profiles were used (i.e., $ka \ll 1$), the amplitude of scattering has a strong dependence on the size of the profiles. Scattering in this case is approximately omni-directional and is known as Rayleigh scattering. Thus, the direction of scattering could not be identified. In some applications where smaller gas profiles are required, a higher ultrasonic frequency could be used.

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