

Note

Flow regime identification in air-water two phase flows based on acoustic impedance

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Air-water two phase flows have been characterized using acoustic measurement and sound processing. Analysis is carried in a mini channel of diameter 1.8 mm. Sound of frequency 21500 Hz is emitted using a sound emitter held over the glass tube. A microphone is kept on the other side of the glass tube and acts as the acoustic electric transducer through which the sound signal is acquired using the microphone and is processed using an open source sound processing software AUDACITY 2.0. Filtering and amplification of sound signal is done using the software to study the two phase flow characteristics. Bubbly, Slug and Annular flow regimes are identified. The method can be used to characterize two phase flows without sophisticated instruments.

Keywords: Two phase flows, Void-fraction measurement, Acoustic measurement, Sound processing.

The study of two phase flow characteristics is an area of intense research in chemical process industries and electronic cooling. Identification of flow regime is important in determining the nature of chemical reactions and heat transfer characteristics in flow through channels. Determination of void fraction is important in studying the cooling rate in the case of electronic cooling and rate of boiling in the case of flow boiling process. Various methods of visualization and characterization of two phase flow patterns have been discussed in the past.

Brown *et al.*¹ studied the properties of various two phase flow regimes such as wave and ripple velocities using a high speed camera. Pike *et al.*² used X ray attenuation technique to measure void fraction and to characterize two phase flows. Chang and Morala³ have used ultrasonic technique to study the interfacial areas in a gas-liquid two phase flow. Zhang and Ishii⁴ used image processing system for droplet size measurement in two phase flows. Reinecke and Mewes⁵ used multi electrode capacitance sensor to

characterize two phase flow pattern. The technique is based on the measurement of effective dielectric constant of the medium inside the tube. Mi *et al.*⁶ used neural network on impedance probe to characterize two phase flow in vertical tube. Fossa⁷ designed and tested the performance of conductance probe for measuring liquid fraction in gas-liquid two phase flows. Kumara *et al.*⁸ developed a LASER Doppler Anemometry (LDA) based technique and compared it with Particle Imaging Velocimetry (PIV). They concluded that LDA is a better alternative for PIV at higher velocities. Muji *et al.*⁹ developed a measurement technique based on optical tomography for study of solid gas flows. The optical two phase measurement techniques are based on principles like varying refractive index of the medium and shift in Doppler frequency. Recently, Shaban and Tavoularis¹⁰ used differential pressure sensor signals to characterize two phase flows.

It can be seen from the above mentioned literature that most of the techniques used for two phase flow characterization technique requires the use of sophisticated instrumentation. Though tremendous advancements have taken place in developing optical and electrical based methods for two phase flows, the area of acoustic measurement is not explored well. In the present work the principle of medium dependency of acoustic impedance is used in developing a cost effective method to characterize two phase flows. The intensity variation of known frequency of sound is found to be different for air and water. This variation in sound intensity is used in identifying the flow patterns for various superficial liquid and gaseous velocities.

Experimental Section

The experimental setup is shown in Fig. 1. The test section consists of a horizontal glass tube 20 cm long of diameter 1.8 mm. Water is pumped using a water pump with a capacity of 1400 LPH and a power rating of 27 W. Air is circulated with the help of an air pump of power rating 3 W with a capacity of 240 LPH. The volumetric flow rates of air and water are measured using air and water rotameters respectively. Water and air mixes thoroughly in a Y section of same diameter which is attached with the glass tube.

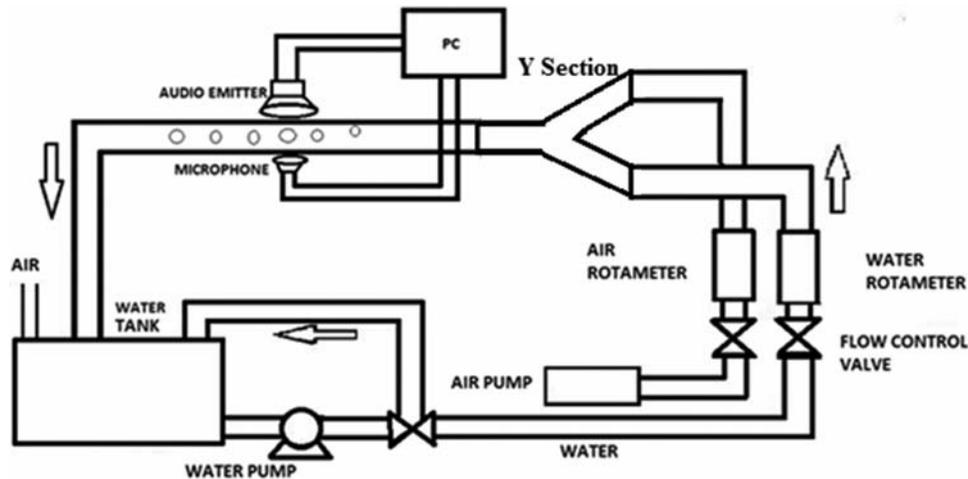


Fig. 1 — Experimental setup

Water pumped from the open tank has a TDS concentration of 440 ppm and is at a temperature of 27°C. Air is pumped slightly above the atmospheric pressure. Air and water velocities are controlled using Flow control valves. The sound transmission section consists of an audio emitter Sony MDR-XB30EX stereo headphones with a frequency range of 4–24000 Hz and a sensitivity of 105 dB, impedance of 16 ohm and a peripheral diameter of 1.4 mm. Sound wave of frequency 21500 Hz is generated using AUDACITY 2.0 open source sound processing software. The generated wave is passed out of the emitter through the glass tube. Microphone is the key element of the sound reception section connected to the PC via USB. The microphone is a Sennheiser MKE 2 and has a sensitivity of 5 mV/Pa \pm 3 dB and the frequency response is observed in the range 20-24000 Hz. The sound signal is received in the PC using a recording interface provided by AUDACITY 2.0. Since the emitted sound is of frequency $>$ 21000 Hz, high pass filter is used to remove frequencies less than 21000 Hz. The sound is amplified 100 times and the processing is done on the resulting waveform. AUDACITY uses relative intensity to characterize the sound signals. The relative intensity is measured with reference to intensity at 0 dB. So the intensity is always negative. Sound with less negative (dB) value indicates more intensity. The flow pattern identified is validated using a Basler CMOS high speed camera Model No: acA2000 monochrome, with a zooming lens (Navitar Zoom 18-108 mm).

Results and Discussion

The relative intensity of sound is the ratio of absolute intensity to the reference intensity of sound

in air at a frequency of 1000 Hz. The intensity of sound depends on the medium of propagation. Acoustic impedance of medium is defined as the product of density of the medium and velocity of sound in the medium. The specific acoustic impedance of water (1.5 Mpa s m^{-3}) is higher than that of air ($0.02 \text{ Mpa s m}^{-3}$). It can be stated that as the velocity of sound is higher in water when compared to air, the intensity of sound passing through water medium is lower compared to that of air medium. Initially experiment is done with water and air flow separately to record the intensity of the sound for single phase flow. The amplified sound is recorded using AUDACITY 2.0 and is processed. Figure 2 shows the variation in sound obtained for single phase air and water flow. It is found that with increase in flow rate of air and water, there is a change in frequency of sound with negligible change in the intensity of sound.

The sound intensity in the present work is quantified with the help of relative intensity of sound measured in decibels. The average relative intensity in the case of water is found to be -17 dB and air is found to be -10 dB. This value is because of higher acoustic impedance of water when compared to air. So these values are taken as the reference values for water and air flow respectively for single phase ($I_w = -17 \text{ dB}$ and $I_a = -10 \text{ dB}$). The values in between indicate the presence of air-water mixture in the medium for propagation of sound. Analysis is done with superficial liquid velocities in the range 0.2 to 2.4 m/s and gaseous velocities from 1 to 20 m/s. A rise in intensity value is seen as air passes through the test section filled with water. The variation in

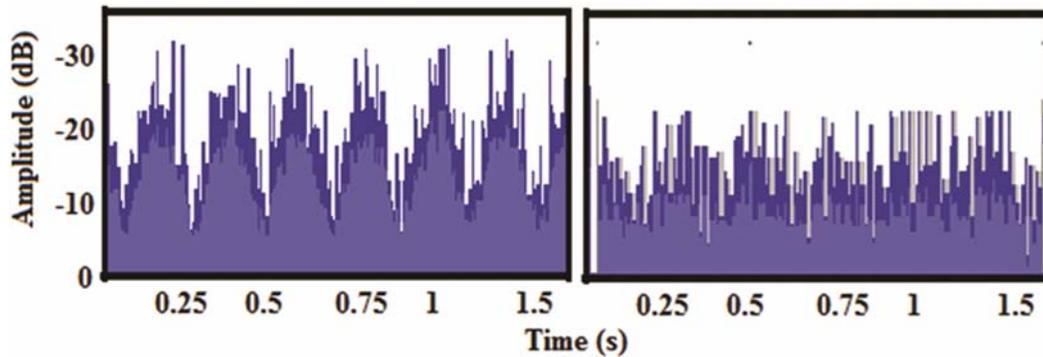


Fig. 2 — Intensity variation of sound in single phase air and water

intensity with time is shown in the form of a graph. The identified flow regime using the Acoustic sensor output is validated by direct visualization of the flow regime using high speed video camera. The high speed videograph is acquired using Streampix software and the flow regime is identified using a frame by frame analysis. The identified flow regimes and the corresponding sensor outputs are discussed in the following sections. Images for the identified flow regime are shown with the sensor output.

Bubbly Flow

Bubbly flow is characterized by movement of spherical and non-spherical bubbles having a lower void fraction when compared to water. They occur at moderate liquid and gaseous velocities. As the bubble passes across the emitter-receiver arrangement, the rise in amplitude is observed as shown in Fig. 3. The amplitude at the peak is around -10 dB which corresponds to air flow. The width of the peak is less when compared to the width of the signal below -16 dB. This indicates the low void fraction compared to the fraction of water. This characterizes a bubbly flow.

Slug Flow

Slug flow generally occurs at low liquid and a wide range of gaseous velocities. It is characterized by higher void fraction compared to bubbles. The slug flow observed and its time scope is shown in Fig. 4. The width of the peak at -10 dB corresponding to air is more when compared to the width of the signal below -16 dB corresponding to water. This indicates a slug type of flow.

Annular Flow

Figure 5 shows the annular flow observed in the tube and its time scope. Lengthy Slugs with higher velocities collide with each other to form annular flow

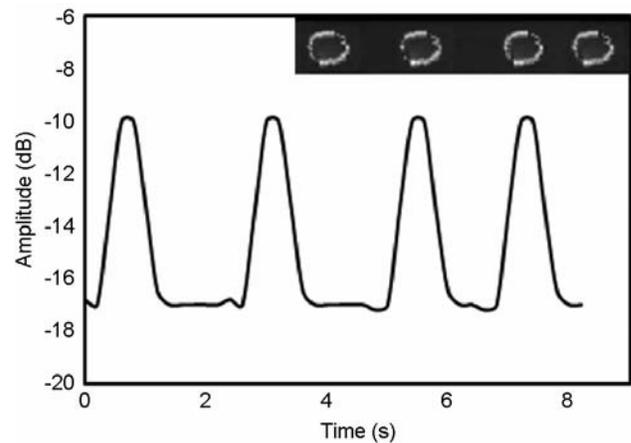


Fig. 3 — Time scope and high speed photograph for bubbly flow $U_g = 1.6$ m/s and $U_l = 0.4$ m/s

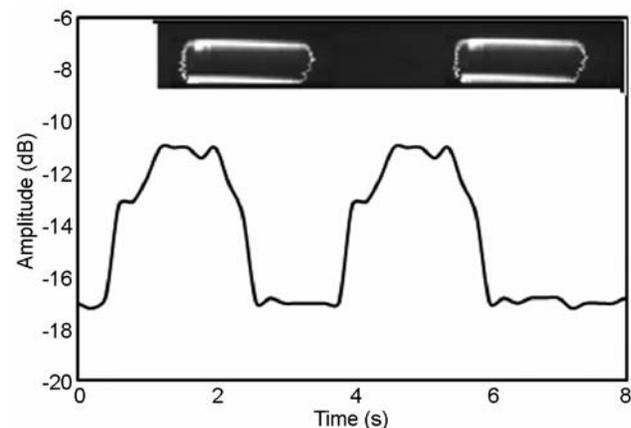


Fig. 4 — Time scope and high speed photograph for slug flow $U_g = 4.1$ m/s and $U_l = 0.72$ m/s

pattern. In certain cases, annular flow move with smaller waves at the surface of the liquid film. The amplitude is found to be in -12 dB (close to -10 dB but less than -17 dB) which indicates that the air is predominant in the flow with thin liquid films. The

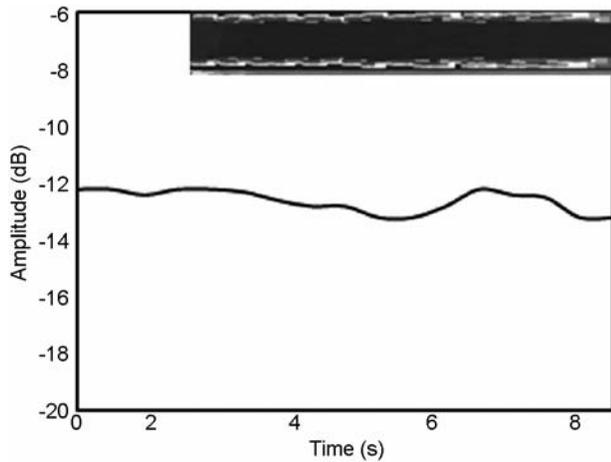


Fig. 5 — Time scope and high speed photograph for annular flow $U_g = 18.4$ m/s and $U_l = 0.22$ m/s

drop in amplitude indicates the presence of waves in the annular flows.

Conclusion

In the present work, acoustic measurement and sound processing is used to characterize air – liquid two phase flow pattern in a horizontal tube of diameter 1.8 mm. The variation in sound intensity for single phase air (-10 dB) and water is studied (-17 dB). The intensities pertaining to single phase flow is taken as the reference and the two phase flow patterns are characterized on the basis of the reference values. Two phase flow patterns like bubble, slug and annular flow patterns are identified using acoustic measurement. The flow patterns are validated with the photographs taken using High speed camera. The

technique is a simple one using open source software and without any complex procedures. It is well known that sound waves are mechanical waves and the developed technique can be well applied in both transparent and non-transparent tubes of any shape with simple calibrations. The technique can be applied for multiphase fluids having considerable difference in acoustic impedance values.

Acknowledgement

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