Acoustic Emission for monitoring two-phase flow

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Abstract

This paper presents an investigation into single bubble dynamics detection in a liquid-filled column with AE, and, correlations of Gas Void Fractions in two phase gas-liquid flow with Acoustic Emission (AE). Furthermore, this paper demonstrates the feasibility of employing AE technology as on-line process monitoring tool for bubble detection in two phase gas-liquid flow.

Introduction

Employing the acoustic technology for observing the dynamics of bubbles in a liquid started in 1933 [1]. Most research has involved measuring sound generated from entrained gas (cavitation/bubble) in liquid using hydrophones (<20 kHz). The opportunity for on-line monitoring in multi-phase flow with AE offers a complementary technology to industry. Such an application would offer significantly reduced installation time as it can be fitted directly onto a steel pipe without any requirement for modifying the existing pipe infrastructure; in addition, the cost of the AE technology is considerably less than existing systems.

Acoustic Emission (AE) is defined as transient elastic waves within a material or by a process resulting in the spontaneous release of elastic energy [2]. The frequency of the elastic wave is usually beyond human hearing threshold (25 kHz) and AE transducer can typically measure frequencies that are above 25 kHz and less than 1 MHz. AE instruments and systems have been developed for monitoring and non-destructive testing of the structural integrity, manufacturing processes, and etc [3]. For example, AE technology has been employed in machine tool industry for detecting tool wear in turning process [3]; in process industrial equipment particularly gears and bearings for detecting defects such as pitting and crack [4, 5]; in rail industry for assessing surface integrity of rail-track [6]; and in liquid-pump process industry AE technology has been employed for detecting cavitation and determining Best Efficiency Pump (BEP) in centrifugal pump [7, 8, 9].

The application of AE technology as a monitoring tool in two phase gas-liquid flow is considerable new and it is now gaining attention because of the advantages of the AE technology over the other measuring techniques. A passive AE technology offers an alternative to the intrusive ultrasonic methods.

Detection of bubble formation and burst at free surface

The apparatus employed for AE detection is shown in figures 1. The rig consists of a column filled with a tap water and salt water for the comparison of the effect of viscosity on the AE bubble released upon its formation and burst. A single bubble in the column was produced with a syringe. Three AE sensors were used; sensor-1 was positioned at the bottom near to the nozzle, sensor-3 was positioned near to the water free surface. While sensor-2 was positioned in between sensors 1 and 3. Three broadband piezoelectric transducers (Physical Acoustic Corporation type WD) were fitted in the liquid column with the active sensor face in the fluid. The transducers had an operating frequency of 100-750 kHz and a pre-amplification at 60 dB was applied. The
sampling rate for acquisition of AE waveforms was set at 2 MHz. A trigger level of 24 dB was set above the electronic background noise of the acquisition system.

Experimental results

It was observed that as the bubble detached from the nozzle, an AE event was captured by the nearest AE sensor-1. A waveform associated with a single bubble formation (pinched off from nozzle) data output from AE sensor-1 is shown in figure 2 (top). A corresponding time-frequency plot (Gabor wavelet) was generated by the AGU-Vallen software tool [11], see figure 2 (bottom) which showed the intensity of frequency over the time duration of the signal captured during bubble formation.

![Fig. 1. Schematic diagram of experiment layout](image)

![Fig. 2. Typical waveform (top) and wavelet (bottom) associated with bubble formation (nozzle size 8.4 mm in water (1 cP))](image)
Correspondingly the bubble burst at the free surface is presented in figure 3. The time-frequency content plot associated with this particular bubble activity is shown in figure 3 (bottom). Both figure 2 and 3 show that the bubble inception or burst is accompanied by high frequencies of upto 750 kHz at the start of the AE wave.

The results show the sensitivity of AE sensors to detect single bubble activities; formation at a nozzle and burst at free surface. The magnitude of AE energy from bubble burst was dependent on liquid properties; surface tension and viscosity, as well as the bubble size, see figure 4.

Monitoring gas void fraction (GVF) in two-phase flow with AE

Having established that AE could be measured during single bubble dynamics, the next phase of this investigation was to assess if AE could be correlated to Gas Void Fraction (GVF). GVF is defined as the ratio of the volumetric of the gas to the total volumetric flow-rate. In multiphase flow Superficial Liquid Velocity (VSL) is defined as the volumetric flow rate of liquid phase divided by the cross-sectional area of the pipe. Whilst, Superficial Gas Velocity (VSG) is defined
as the volumetric flow rate of gas phase divided by the cross-sectional area of the pipe. For the experiments in this investigation liquid superficial velocity (VSL) ranged from 0.3 m/s to 2.0 m/s at increments of 0.1 m/s, and the gas superficial velocity (VSG) ranged from 0.1 m/s to 1.4 m/s at increments of 0.2 m/s. At each VSL value all ranges of VSG’s were investigated. Conductivity rings (commercially available GVF measuring devices) were installed and used as reference for gas void fraction (GVF) measurements (see fig 5 and 6) which can be determined numerically from equation (1).

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GVF = \frac{V_{gs}}{V_{gs} + V_{lg}}
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EQ (1)

Fig. 5. Experimental setup for two-phase GVF measurement

In this experiment, a WD AE sensor was used for correlating AE absolute energy to GVF. AE energy levels were acquired at a sampling rate of 2 MHz. The gas-liquid phase fractions were achieved by injecting known liquid volumes using an air compressor.

Fig. 6. Test section: AE sensor, preamplifier and conductivity sensor
Experimental results and discussion

Results from this test rig show that AE absolute energy gradually increased with the increase of VSG at all VSL velocities (see figure 7).

It was also observed that under slug flow regimes, signal fluctuation were seen with increasing and decaying AE levels which could be correlated with the slug head and tail respectively, see figure 8. The time-frequency plot is shown in figure 9 with frequencies of upto 500 kHz. These high frequencies were also noted for bubble inception and burst.

Fig. 7. AE absolute Energy level for varying VSG and VSL

Fig. 8. Typical AE Signal from fully developed slug flow
A time-frequency plot (see figure 9) of an AE waveform associated with the slug showed frequencies at up to 500 kHz at the earliest part of the AE slug wave.

Figure 10 presents the measured GVF, calculated GVF and absolute energy level of AE signal acquired at varying $V_{SG}$ and a fixed $V_{SL}$ of 2.0 ms$^{-1}$. Observations showed that any increase in GVF resulted in an increase in AE absolute energy. A Pearson’s correlation factor $(r)$ [12] was used to quantitatively access the degree of correlation between the results presented.

Fig. 9. Waveform (top) and time-frequency plot (bottom) associated with slug flow

Fig. 10. GVF and AE absolute energy levels at $V_{SL}$=2.0 m/s for Ch1
Conclusions

It has been demonstrated that the AE technology is capable of detecting single bubble formation and burst at the free surface. The result also shown AE level associated with bubble burst at the free surface increases as the viscosity of liquid increased. These findings formed the basis for assessing the applicability of AE to monitoring gas content in multi-phase flow.

Results from preliminary investigations on the application of AE technology for measuring GVF in two-phase air/water under different flow regimes, particularly slug flow conditions, was successful. It is evident that the main source of AE is directly correlated with the dynamics of bubbles; its formation, coalescence and destruction. This work has introduced a new passive and non-invasive GVF measuring technique utilising AE technology.

References