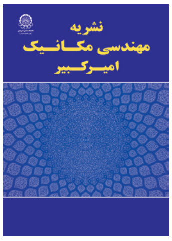

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Frequency Analysis and Parametric Estimation of Bubble Formation in Vertical Column

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ABSTRACT: Frequency analysis is one of the most important methods to estimate parameters of bubble formation in a vertical liquid column. In the present article, the frequency of bubble formation was analysed. Three-dimensional transient two-phase flow was simulated based on the volume of fluid method. Hybrid Reynolds averaged Navier-Stokes/large eddy simulation turbulence methods were used to improve the ability of computational fluid dynamics to capture formation of bubble in the vertical column. The model used for frequency response prediction was modified by applying the compressibility effect that improved the results for the acoustic behaviour. Due to the importance of interface tracking for sound sources recognition in addition to the problems which occur during combining with the large eddy simulation model in the simulation, different interface reconstruction methods have been applied and high-resolution interface capturing scheme was selected. The results were verified by theoretical and empirical data. Furthermore, it was presented that the natural frequency of bubble reduced as the size of the bubbles increased. The compressibility effect improved the results more accurately and the model behaviour was acted more physically.

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1. INTRODUCTION

Measurement and analysis techniques of two-phase flow characteristics have been widely developed by researchers [1]. Among the proposed techniques, acoustic methods have many advantages compared to the common techniques. In short, these advantages include high sensitivity and low delay; low cost; higher reliability, providing more accurate and broader analysis of flow characteristics; and the fact that there is no need to change the system to measure parameters of flow.

In spite of these advantages, however, the demand for a dynamic pressure wave model, employing strong models and theories so as to simulate transient compressible two-phase flows, and analysing the effects of multiple parameters on acoustic waves, are perceived as some of the challenges of this technique [2].

Propagation of waves induced by aerodynamic noises is an instance of passive waves in fluid systems. Noises are induced by the input/output flow, as well as collisions with walls and turbulent flows [3]. Among these sources, the phenomenon of gas penetration into the system is one of the most significant noise sources [4]. The natural bubble-formation frequency is also determined by:

$$\omega_n = \left\{ \frac{1}{4\pi^2 \rho_L R_e^2} \left\{ 3\gamma\left(p_\infty - p_v\right) + 2\left(3\gamma - 1\right)\frac{S}{R_e} \right\} \right\}^{\frac{1}{2}} \qquad (1)$$

where R_e is the equivalent bubble radius and S is the surface tension.

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2. THE SYSTEM EQUATIONS

In view of the nature of turbulent flow and the propagation of acoustic waves through the medium, three-dimensional models provide a better understanding of the flow and the real amplitude of the noise. The bubble shapes generated and valid estimation of the gas mass movement are very important in determining noise centers. The Volume of Fluid (VOF) method is more developed than the others in determining the motion and bubble formation mechanism and interface tracking simulation [5].

The main challenge in extracting acoustic parameters is that the energy induced by sound waves is very low. Large Eddy Simulation (LES) turbulence models were introduced as a way of creating a more detailed picture of turbulent flows with lower computational volumes. In addition, an appropriate acoustic model is used to study the wave propagation through a medium and the noises are detected at the receivers. Ffowcs-Williams and Hawkings (FWH) [6] is an integral method that finds sound sources as an extension of the classical Lighthill aerodynamic acoustics theory.

3. COMPUTATIONAL FIELD AND BOUNDARY CONDITIONS

The system is considered to be three-dimensional, vertical, upward and two-phase at the penetration points and to be single-phase at other points. Mass and heat transfer between the gas and liquid phases are neglected. The model is a cylinder of 100 mm diameter and 200 mm height, in the middle of the end of which there is an x-oriented orifice of 4 mm diameter and 5 mm height. Moreover, in order to sample the pressure fluctuations, a virtual plane is assumed through the flow to extract the flow pressure fluctuations when the bubble formation and separation occur.

Transient Navier–Stokes equations are numerically computed by Ansys Fluent software, by using the Finite Volume Method (FVM). The two-phase VOF method is incorporated into the model to track the interface. The implicit volumetric flux force and volumetric forces are also taken into consideration. Moreover, the pressure-based solvers, the SIMPLE algorithm and the PRESTO pattern are utilized to solve system equations. Hybrid Reynolds Averaged Navier-Stokes (RANS)/LES turbulence methods are used to improve the ability of Computational Fluid Dynamics (CFD) to capture the formation of bubble in the vertical column. The two-equations models such as SST and RNG are the most complete models of RANS. The SST model can be used as a low Reynolds disturbance model. The SST model produces responses similar to those of $k-\varepsilon$, with the difference that it is not sensitive to incoming conditions

4. RESULTS AND DISCUSSION

As the bubbles form, pressure fluctuations are generated through the system. The signals are transmitted through the medium. The signals are generated due to the interaction of the bubbles with the flow, resulting from the pressure difference between the inside and outside of the bubbles. Therefore, the signals generated at the bubble formation and necking time must have the maximum intensity, while after some time the amplitudes of the fluctuations decrease exponentially. The magnitude of fluctuations and signal are normalized to compare the recorded data in different receivers.

The first point in recording the pressure fluctuation data is recording fluctuations with the same pattern at the receivers located through the flow. The impact of the non-physical phenomena generated by boundaries causes the patterns to undergo some changes at the receivers. Acoustic data yielding bubble formation noises are recorded in various receivers. Comparisons between the results are shown in Figs. 1 and 2.

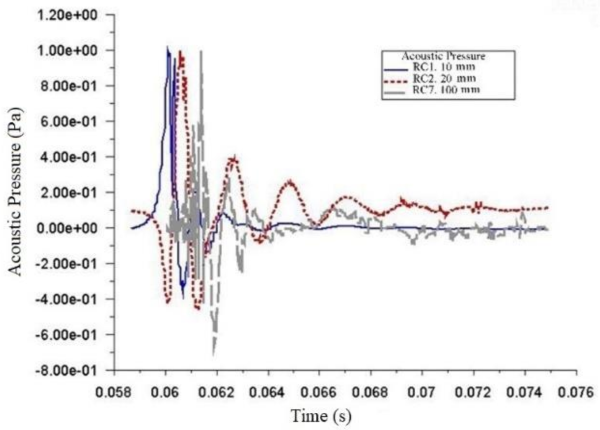

Fig. 1. Acoustic pressure of various receivers

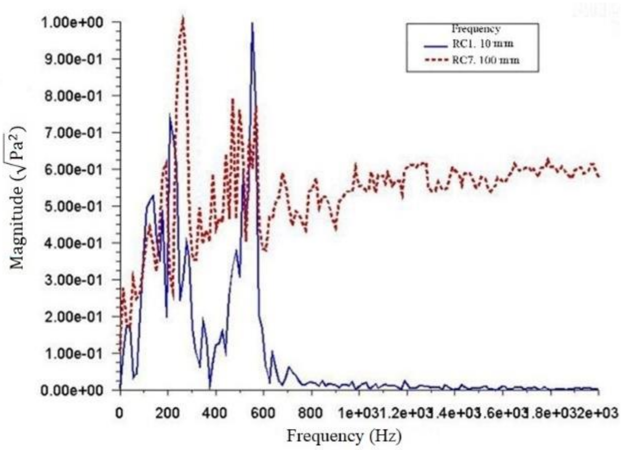

Fig. 2. Recording non-physical effects at distant receivers

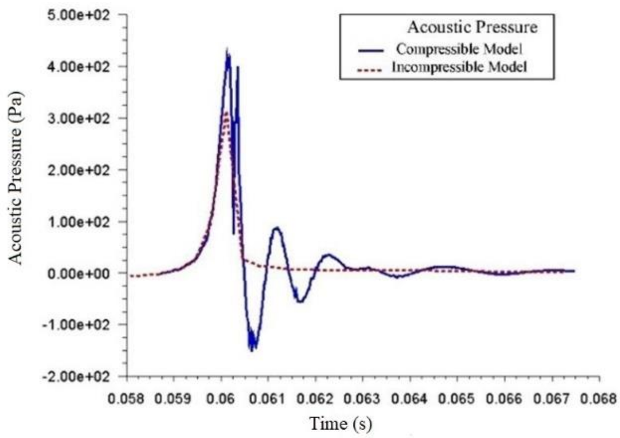

Fig. 3. Compressibility effect in the recording acoustic pressure

The compressibility effects should be considered in the model equations. Fig. 3 show the comparison of the compressible and incompressible model for a flow rate of 10 cm^3/s. As can be seen, the compressible model shows all the fluctuation associated with the separation of the bubble and noises generated from other sources around it.

5. CONCLUSION

Based on the study carried out, it is shown that pressure oscillations are generated during the bubble necking time, with the largest one occurring in the smallest-bubble necking time. Moreover, a better understanding of the peaks, as well as exponential reduction of the amplitudes and the correct frequency pattern, result from sampling the oscillations at the virtual plane parallel to the flow. The compressibility effect is applied to the model and increases the accuracy of the physical behaviour of the phenomena. Transforming the data to the frequency domain, the bubble separation and formation frequencies are compared with the experimental data. The comparison of the results is encouraging. The results show that the tracked frequency increases as the flow rate decreases and the bubble sizes reduce.

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