ATTENUATION OF ACOUSTIC WAVE IN NON UNIFORM FLOWS CONTAINING SMALL LIQUID DROPLETS AND FLUID-VAPOUR MIXTURE

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Abstract

This research gives a theoretical investigation into the acoustic attenuation of tiny liquid droplets and non uniform fluid-vapour mixtures. To solve the mean quantities necessary for solutions of the acoustic equation, approximate approaches are utilised. The results indicate that the attenuation in acoustic pressure level in a gas-vapour particle mixture with temperature and density gradients may be significantly different than that in a mixture with uniform spatial distribution.

Paper Identification

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Introduction

Propagation of acoustic disturbances in non uniform flows is a subject of great interest in many practical problems, particularly in transport engineering with automotive exhaust systems, etc. Determination of the velocity and attenuation of acoustic waves in a fluid-Vapor mixture has also applications in several important areas such as the analysis of choked flows, the prediction of the onset of instability in parallel boiling channels, etc.

Mixtures of liquid and small gas bubbles occur is many industrial processes (bubble columns and centrifuges in the petrochemical industry, cloud cavitation in hydraulic systems, cooling devices of nuclear - reactor system) and in nature. A lot of attention has been paid to the problem of how to formulate equations of motion for such two-phase flows. The general equations for dispersed two-phase flows in which allowance is made for velocity differences between the phases have been formulated first in heuristic way, but later by applying averaging techniques like time averaging (Ishii 1975), volume averaging (Nigmatulm 1979) and ensemblic averaging to the conservation equations of the separate phases. Lymane et developed a theory to predict the attenuation of a plane acoustic wave propagating in a one-dimensional steady flow of a gas vapour droplet mixture. Condensation on the droplets causes gradients in temperature, density, vapor and droplet concentrations.

Interaction Between The Small Liquid-Particles The Fluid-Vapour Mixture

The system of ordinary differential equations for r, T, T_p, and a are non-dimensionalized by introducing the characteristic length for variation of small liquid particle mass/C_{m0}

$$L = \frac{u\tau_{D0}}{C_{m0}} \quad \text{--(1)}$$

and defining the dimensionless variables $\varepsilon = x/L$ and

$$y_1 = \frac{r}{r_0}, y_2 = \frac{T}{T_0}, y_3 = \frac{T_p}{T_{p0}}, y_4 = \frac{a}{a_0}$$

Since p is assumed constant, $\rho/\rho 0 = 1/y_2$. According to Lewis Equations, it may be written as follows in terms of these variables:

$$\frac{dy_1}{d\varepsilon} = y_1 y_2 y_4 (1 - y_1 r_0)(\frac{1}{\phi} - 1) \quad \text{--(2)}$$

$$\frac{dy_2}{d\varepsilon} = N_{Le} Y_2 Y_4 (Y_3 \theta_0 - y_2) \quad \text{--(3)}$$

$$\frac{dy_3}{d\varepsilon} = -\frac{(c_p/c_l)}{C_{mo} y_3^2}\left[N_{Le}\left(Y_3 - \frac{y_2}{\theta_0}\right) + \frac{h_{Lp}\overline{r_0}}{c_p T_{p0}} y1(\frac{1}{\phi} - 1)\right] \quad \text{--(4)}$$

$$[\frac{dy_4}{d\varepsilon} - \frac{1\overline{r_0}}{3C_{m0}} \frac{y_1}{y_4}(\frac{1}{\phi} - 1)] \quad \text{--(5)}$$

The Lewis number is assumed constant. The supersaturation ratio ϕ is a function of y_1 and y_3, since

$$\phi = \left(\frac{W}{Wv}\right)(\frac{\overline{p}}{\overline{p_s}})\overline{r_0} y_1$$

And $\overline{p_s}$ obtained by integrating the Clausius - Clapeyron equation for constant h_L, is

$$\overline{p_s}(\varepsilon) = \overline{p_s}(0)\exp\left[H_0\left(1 - \frac{1}{y_3}\right)\right] \quad \text{--(6)}$$

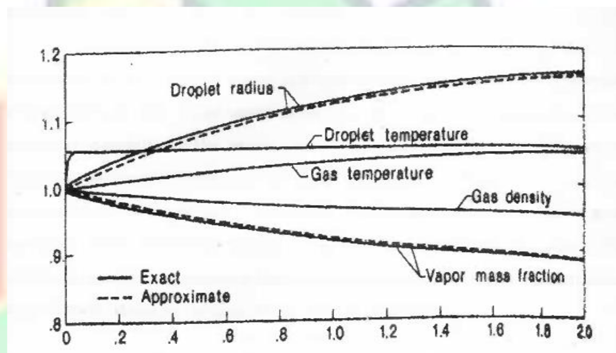
Equations (2), (5) were solved numerically by the fourth-order

Runge - Kutta method for the initial conditions $y_j(0) = 1(j, \ldots\ldots, 4)$. Typical results for an air-water vapour mixture containing droplets are shown by the solid curves in Fig.1. The initial vapour mass fraction r_0 was taken as 0.05,

which is larger than the saturation value of 0.0174 corresponding to the assumed initial temperature of the air-water vapor mixture (23.1°C) and 1 atm. The initial temperatures of the droplets and the air-vapour mixture were assumed to be equal in this case. At first the small liquid particle temperature increases rapidly as the influx of latent heat from the condensing vapour is utilized to raise the

vapour pressure of the liquid in an attempt to bring it into equilibrium with the vapor. This occurs in a time of order T_T, or distance $\varepsilon \sim O(C_m)$. Thereafter the small liquid particle remains essentially constant as energy released in

condensation is transferred from the small liquid particle to the gas-vapor



$$\varepsilon = xC_m(0)/\bar{u}\tau_D(0)$$

Fig.1. Conditions in non uniform medium due to condensation of an initially supersaturated air-water vapour mixture.

mixture, causing the temperature of the latter to rise. This process requires a much longer time, of order T_D/C_m , or distance $\varepsilon \sim O(1)$.

The numerical results indicate that the temperature to which the small liquid particle rapidly adjust is slightly above the saturation temperature corresponding to the initial vapor mass fraction. Since the change in droplet temperature depends on the initial vapour mass fraction, the initial temperature difference between the small liquid particle and gas, which is in reality unknown. It is not of great importance in the present problem. Considerable simplification results if the small liquid particle temperature is assumed constant and equal to its final value, which is determined by setting $\frac{dy_3}{d\varepsilon} = 0$ in equation 4

$$y_3 = \frac{1}{\theta_0}\left[y_2 - \frac{h_L \overline{r_0}}{c_p \overline{T_0} N_{Le}} y_1\left(\frac{1}{\phi} - 1\right)\right]$$

--(7)

Since y_1 and y_2 do not differ much from their initial values when y_3 has completed its rapid adjustment, a close approximation to the final small liquid particle temperature can be obtained from this equation by taking $y_1 = y_2 = 1$. Equation 7 is solved for y_3 by iteration because ϕ depends on y_3.

From equations 2, 3 and 7

$$y_2 = 1 + \frac{h_L}{c_p \overline{T_0}} \, In\left(\frac{1 - y_1 \overline{r_0}}{1 - \overline{r_0}}\right)$$

--(8)

which provides a simple relation between the temperature rise of the gas and the liquid particle mass fraction. The following relation between the small liquid particle radius and gas temperature is obtained from equation 3 ,5 & 7

$$y_4 = \left(1 + \frac{c_p \overline{T_0}}{h_L c_{m0}} \, Iny_2\right)^{\frac{1}{3}}$$

--(9)

Substitution of equation 9 into equation 3 leads to a single

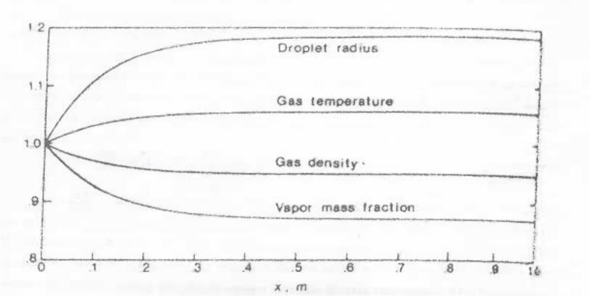


Fig. 2 . Variation of mean quantities with actual distance x.

First - order differential equation in y_2 which is solved numerically. The dashed curves in Fig. 1 correspond to the solutions obtained in this manner. The approximate results are in excellent agreement with the exact solutions of equations 2 to 5, in fact, the curves for the gas temperature and density are coincident. Therefore, the simpler approximate method was used to calculate the mean quantities needed for solution of the acoustics equations. These mean quantities are replotted as functions of the actual distance x in Fig. 2.

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