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THE DIFFUSIVITY OF NONLINEAR WAVE PROPAGATION IN PIPES.

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Résumé. - Les distributions de vitesse dans le temps et dans l'espace le long de tuyaux de 7.62 cm et 2.54 cm de diamètre et d'une longueur de 64 m produites par des ondes nonlinéaires de pression d'intensités différentes ont été mesurées et comparées avec les résultats théoriques unidimensionnels obtenus par la méthode des caractéristiques avec ou sans le terme de diffusion dans le but de déterminer les caractéristiques d'atténuation de l'onde de propagation. Les données ont été analysées afin d'établir la relation entre le rapport de flux d'énergie et la distance dans le tuyau exprimée en fonction du coefficient d'atténuation α et de la diffusibilité. On a montré que ces paramètres caractéristiques sont fonction de la géométrie du tuyau : diamètre, longueur, et rugosité relative.

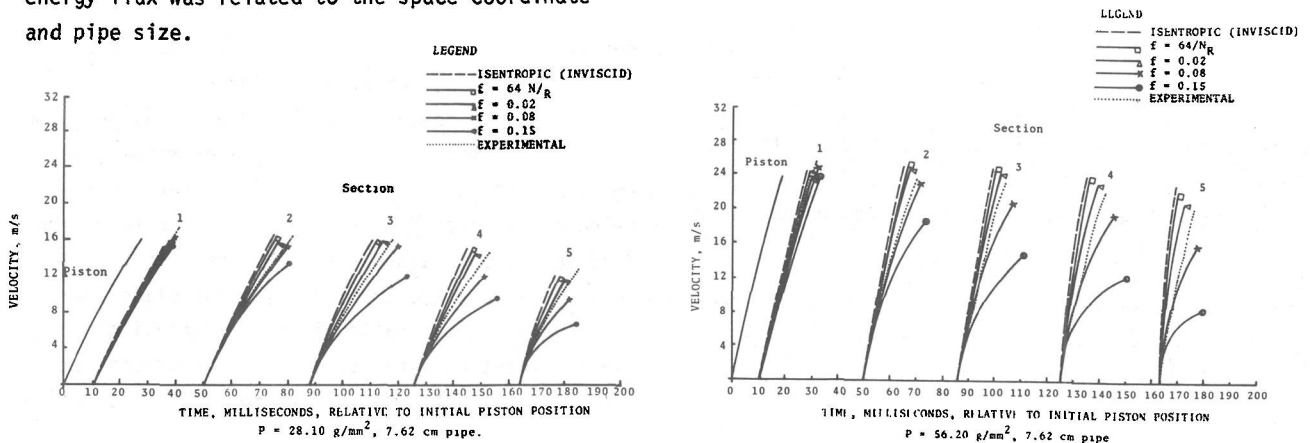
Abstract. - Temporal and spacial velocity distributions along the pipes of 7.62 cm and 2.54 cm in diameter and 64 m in length produced by non-linear pressure waves of various intensities were measured and compared with onedimensional theoretical results obtained by the method of characteristics with and without the diffusion term for the purpose of determining the attenuation characteristics of the wave propagation. Data were analyzed for the relationship between the energy flux ratio and pipe distance in terms of attenuation coefficient α and diffusivity δ . These characteristic parameters are determined to be the function of pipe geometries such as diameter, length and relative roughness.

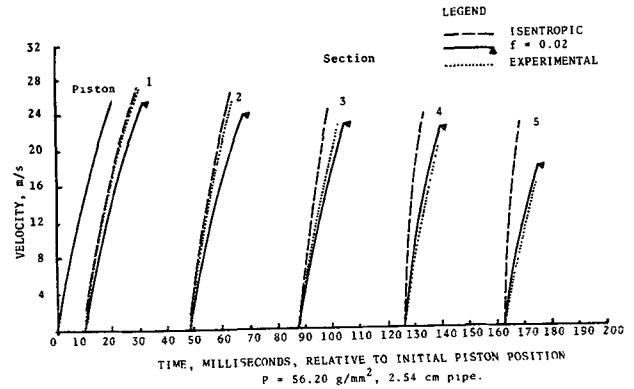
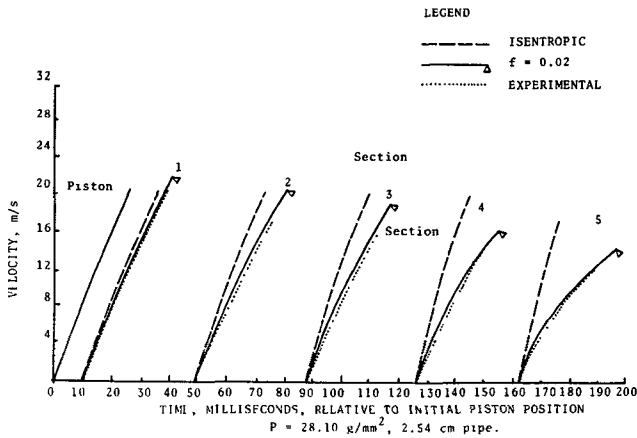
1. INTRODUCTION. - Experimental studies /1/, /2/, /3/ of attenuation characteristics of non-linear pressure waves of progressive type propagating in pipes of 7.62 cm and 2.54 cm in diameters and of various lengths up to 64 m, were measured in temporal and spacial velocity profiles and compared with theoretical results obtained by the method of characteristics with and without the isentropic assumption.

Non-linear attenuation of the pressure waves were presented in terms of attenuation coefficient α and diffusivity δ , based on the experimental results. The energy flux was determined from the velocity profiles measured at various sections along the pipes, and the decay of the total energy flux was related to the space coordinate and pipe size.

Experimental Data Presentation. - Experimental data of velocity profiles were measured at the center of each of five sections located 3.60 ; 16.62 ; 29.45 ; 45.44 ; 55.40 m from the pipe inlet, respectively, in the pipes of 7.62 and 2.54 cm in diameter. Two pressure waves of progressive type applied to each pipe for the time-dependent measurement of velocity profiles with hot-wire anemometers were presented for comparison in this paper.

Figures 1 to 4 shows time-dependent velocity profiles measured at the five pipe sections in the 7.62 cm (3-in.) and 2.54 cm (1-in.) pipes for two pressure waves produced with nominal burst pressures of 28.10 and 56.20 g/mm². Also presented are





Figures 1 - 4 : Comparison of Numerical Calculations With Experimental Data for Burst Pressure.

piston velocity profile at the pipe inlet, theoretical results of wave propagation analyzed in terms of velocity profiles for isentropic process and frictional processes with four assumed values of frictional coefficient in each of the figures.

Specific comparison made between the two pipes is the relationship among attenuation coefficients α , pipe distance χ and the energy diffusion expressed in terms of energy flux ratio, E/E_0 as shown in Figure 5. E denotes the energy flux on a time average contained in the pressure wave in propagation process and E_0 is the energy flux on a time average contained in the progressive wave at the origin of propagation.

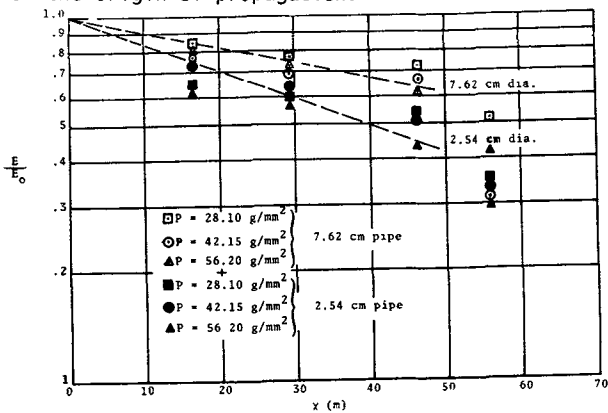


Figure 5 : Energy Flux Ratio Vs. Pipe Length.

The energy flux ratio may be approximated by

$$\frac{E}{E_0} = \frac{\frac{1}{T} \int_0^T v^2 dt}{\frac{1}{T} \int_0^T v_0^2 dt} \quad (1)$$

as a function of χ . Values of E/E_0 were calculated from velocity profile data as functions of time in Figures 1 to 4 using Equation (1). Slopes of the lines averaged through plotted points in Figure 5 yield varied attenuation coefficients, α for the two pipes. The average values of α for 7.62 and 2.54 cm pipes are respectively 0.0102 m^{-1} and 0.0173 m^{-1} for the first 40 m of the pipes. However, α appears to be the function of χ , signifying that the attenuation is non-linear.

Comparison and Discussion of Data. - Since the energy flux ratio is suggested /4/ to be

$$\frac{E}{E_0} = e^{-\alpha \chi} \quad (2)$$

and

$$\alpha = \frac{\omega^2 \delta}{a^3} \quad (3)$$

where ω is the angular or radian frequency, δ the diffusivity. Values of δ calculated from Equation (3) with $\omega = 78.5 \text{ rad/sec}$ and $a = 350.52 \text{ m/sec}$ are noted to be $71.29 \text{ m}^2/\text{sec}$ for 7.52 cm pipe and $121.11 \text{ m}^2/\text{sec}$ for 2.54 cm pipe.

Figure 5 reveals that the theory may be valid in a significant portion of the pipe except the section next to the pipe exit. The experimental evidence seems to demonstrate that the attenuation tend to increase along the pipe. The theoretical analysis was developed simply for the plane progressive wave propagating in a one-dimensional plane without consideration of the frictional effect along the pipe wall. Therefore, any prediction

of the effects of pipe size and wall friction was not possible.

However, the experimental analysis evidently shows, through graphical presentation, that the effects of pipe geometry are pronounced on the attenuation characteristics for the type of wave propagation in the pipes studied.

The values of α and δ are considered rather high due to high humidity of about 80 % relative in the atmosphere at the time of experimentation. But this factor of nature cannot be easily controlled, so is the temperature of the atmosphere. However, it might be deduced that the attenuation coefficient as well as diffusivity may not be a constant value in the process of non-linear wave propagation, and the exponential decay of energy flux in the wave seems to exhibit some non-linearity.

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