LABORATORY INVESTIGATION OF FUNDAMENTAL NOISE PRODUCING MECHANISMS IN GASEOUS COMBUSTION

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Introduction

Sound emission from any combustion process stems from a rapid variation in the rate of volume evolution of the combustion products. A variety of mechanisms might contribute to the causes of such variations, the significance of which will depend on the nature and scale of the combustion process. In the case of turbulent combustion it is the variations in the local burning rate in the flame region which is believed to provide the major source of sound and which has been described macroscopically in terms of a distribution of monopole sources (Strahle 1978 and Smith and Kilham 1963). In simple terms small pockets of unburnt fuel and oxident which are formed by the turbulence become heated and ignite in the flame area and so provide a source of sound emission. It is the random nature of the process which accounts for the broad-band sound spectrum characterising this type of combustion.

A model for describing sound generation by these individual elementary sources has been proposed (Thomas and Williams 1961, Hurle et al 1968) where the necessary changing rate of volume evolution comes directly from the changing geometry of the elementary volume as the fuel is consumed. However, a further stage in the process may be reached when the temperature of the as yet unburnt fuel and oxident is raised sufficiently for it to undergo a small thermal explosion and so generate an additional terminating sound pulse. The experimental verification of the Thomas and Williams model used relatively large initial volumes of gas, confined by soap films, which were at room temperature at the moment of ignition. Such conditions might well have caused the sound wave generated in the first stage of the process to overshadow the small non-linear effect at the termination of burning. In a real turbulent flame the pockets would be surrounded in the main by the recirculating combustion products and would, when they commence burning, already be at a relatively high temperature. The critical volume at which the explosive phase occurs could then be significantly larger than for the case of the initially cold gas and it may thus make a contribution to the total sound emission which has been hitherto unrecognised.

The purpose of this paper is to describe the results of laboratory experiments to test a theoretical model of the phenomenon recently reported in the literature (Dalamagas et al 1984).

Theoretical Predictions

The model considers an elementary volume of burning gas as a hydrodynamic system with a steadily decreasing volume and surface area. By considering the conservation equations and the Arrhenius equation, and making certain simplifying assumptions (most important being the wavelength of sound is large compared to the dimensions of the elementary volume) it is possible to obtain the acoustic pressure at a distance d from the small volume of burning fuel.

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The model predicts that in the final stages of burning, when the flame preheat layer is approximately equal to the radius of the volume, the gas will undergo catastrophic collapse in a small thermal explosion. The model also enables an expression for the pressure pulse associated with the thermal explosion to be derived

$$P_{max} = \frac{1}{2} \frac{\nu(\nu+1)}{(\gamma\nu+1)^2} \cdot \frac{\rho}{4d} \cdot U_n^2 \cdot \frac{T_b}{T_o} \cdot \frac{E^*}{RT_o} \cdot L$$

(see table of nomenclature at end).

Experimental Procedure

The purpose of the experiments was to produce in a regular and controllable manner small known volumes of combusting gaseous mixtures which would undergo thermal explosions, and to measure accurately the peak acoustic pressure generated.

The apparatus consisted of a smooth cylindrical burner tube capped by a disc with a small circular orifice to act as the burner port, see Fig.1. When small, premixed laminar flames seated on the port are acoustically excited by a speaker at the base of the burner, the flame shape undergoes cyclical changes, see Fig.2. Initially the flame lengthens into an extended mushroom shape with a long stalk and small head. As the flame front propagates into the unburned mixture, the stalk radius decreases until it disappears in a small thermal explosion. For this thermal explosion the typical dimension, L , in the above equation is that length of the neck which takes part in the explosion. Remaining after the explosion is the "head", a small spherical bubble of combustible mixture with uniform surface burning. The flame front propagates uniformly inwards until the bubble also undergoes a similar thermal explosion. Here L is associated with the radius of the bubble.

Fig.3 demonstrates a typical record of the acoustic pressure waveform as a result of the two explosions described above. By varying the frequency and amplitude of the applied acoustic signal, it was possible to vary the length of the neck prior to the first thermal explosion, generally the higher the applied frequency the shorter the neck length. Similarly the diameter of the bubble ejected from the neck may be varied, though always as a result of some change in the behaviour of the neck. By changing the fuel gas used and the primary air/gas ratio it was possible to vary other parameters contained in the above equation.

A stroboscopic Schlieren technique is used to visualise the flame geometry at any instant of the cycle, Fig. 4. A slotted disc interrupts the light beam and a photo-sensitive diode detects the passage of each slot, sending a signal to a 'sine-wave tracker' which converts the input square wave to a sine-wave with adjustable amplitude and phase. The sine-wave is fed to the speaker in the base of the burner and by suitable adjustment of the phase, the flame geometry at any point in the cycle may be 'frozen' and examined.

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Results and Conclusions

The experimental findings are in good qualitative agreement with the theoretical predictions. Fig. 5 shows the peak pressure measured as a function of neck length for natural gas with different primary air/gas ratios. The data sets generally approximate closely to straight line fits which pass through the origin, as predicted by the theoretical model.

Difficulties arise, however, in quantifying the comparison between model and measurements due to the lack of precision in determining the values of T_B and U_n which vary with air/fuel gas ratio. The value of peak pressure corresponding to stoichiometric ratio is calculated as $75\ Pa/m$. This will be the theoretical maximum value it is possible to obtain, and the measured values should approach this as the combusting mixture nears stoichiometric. In the experimental arrangement, the primary air/fuel gas ratio was varied from fuel-rich towards fuel-lean and at specific points the peak acoustic pressure generated by the exploding neck measured. These are shown in Fig.4, and it is clear that the slope of the plots increases as the combustible mixture ratio approaches stoichiometric, the peak value being some 90 at a primary air/fuel gas ratio of 9:1.

Further work is now required to refine the measurement of peak slope and to extend the measurement procedure to include the bubbles of combusting mixture ejected from the thermal explosion of the neck.

Nomenclature

ρ -	density of ambient air	1.2 kg/m^3
T_B -	steady flame temperature	2250 K
T_o -	temperature of air/gas supply (cold)	300 K
U_n -	constant normal burning velocity	0.44 m/s
γ -	specific heat ratio	1.4
ν -	symmetry parameter, 2 for neck, 3 for sphere	
d -	microphone distance from thermal explosion	0.08 m
R -	gas constant	8.3 J/mole. K
E^* -	effective mean activation energy	170 kJ/mole.
L -	effective dimension, length of neck	m

References

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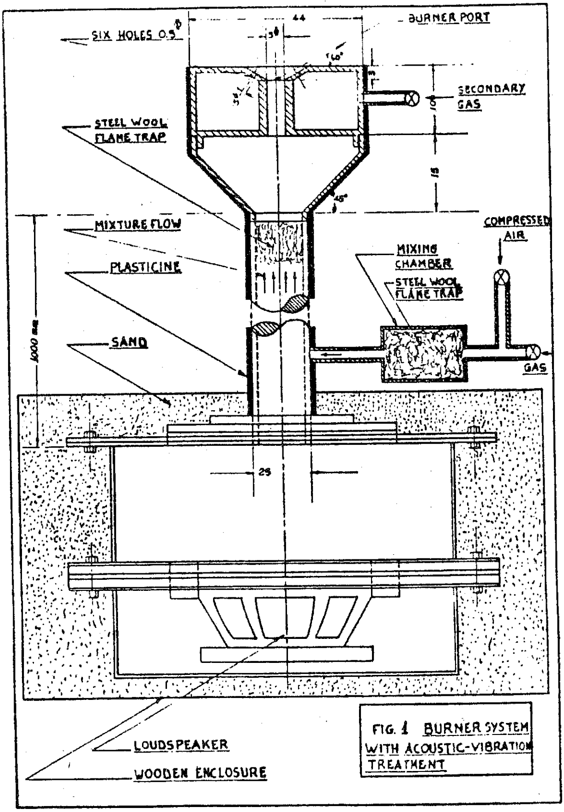

FIG. 1 BURNER SYSTEM WITH ACOUSTIC-VIBRATION TREATMENT

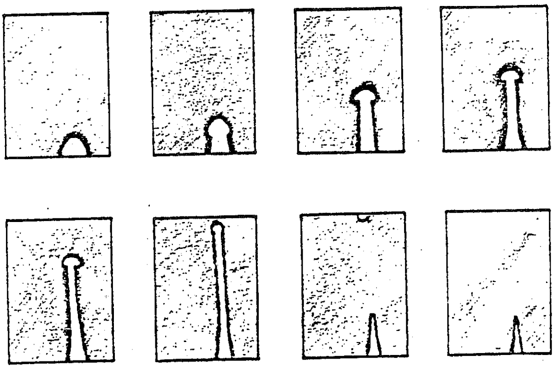

Fig. 2 Schematic of neck / bubble oscillation

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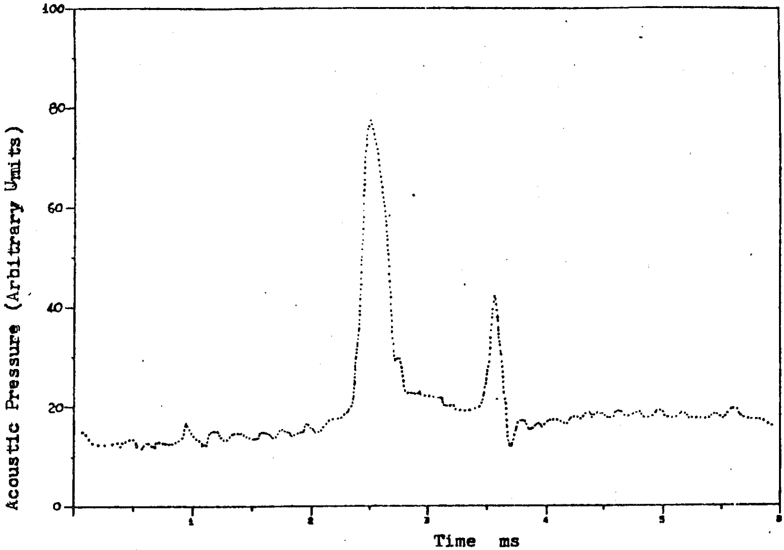

Fig. 3 Schematic Time / Pressure Waveform

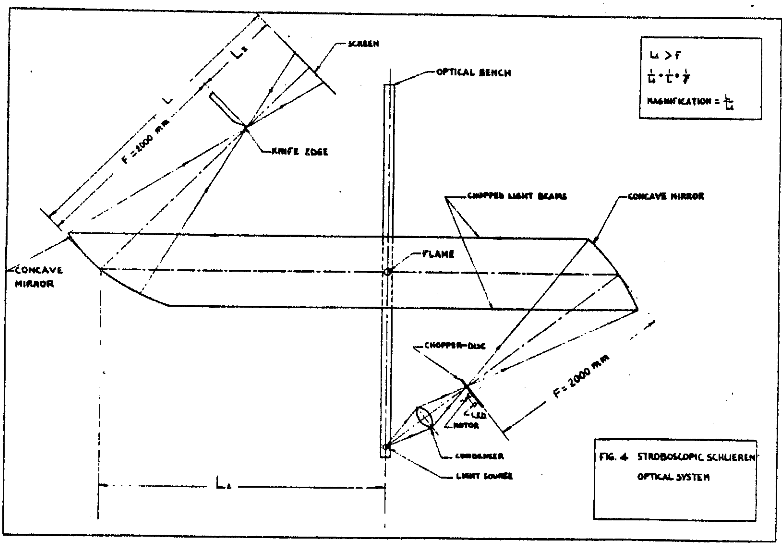

FIG. 4 STROBOSCOPIC SCHLIEREN OPTICAL SYSTEM

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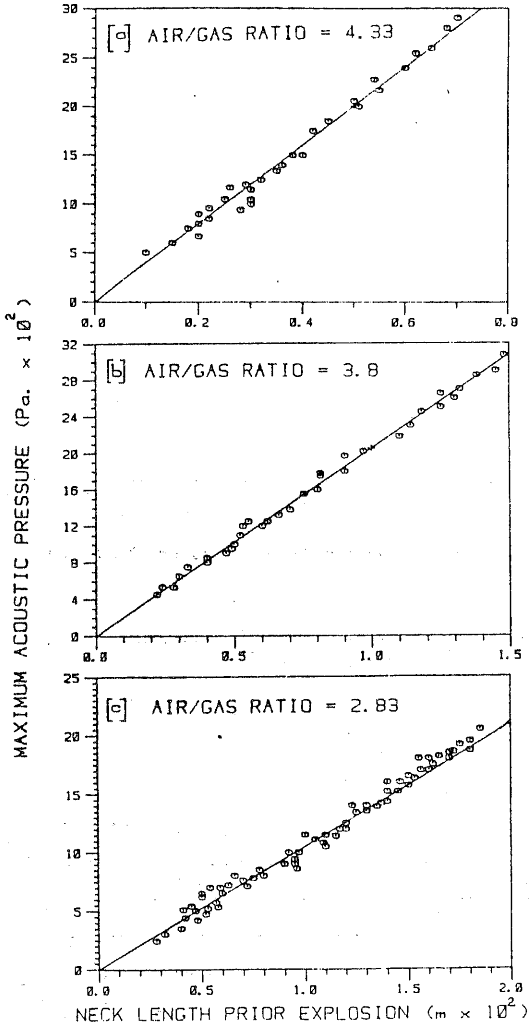

Fig.5 Peak Acoustic Pressure vs neck length for various primary air/gas ratios of natural gas.

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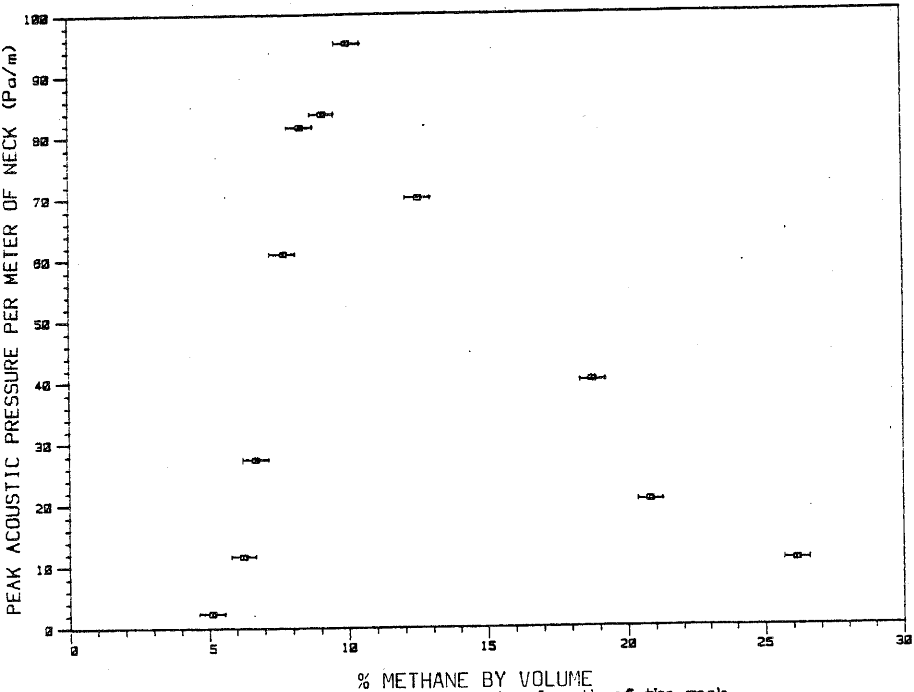

Fig. 6 Acoustic Pressure per meter length of the neck just prior its explosion versus % Methane.