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AERODYNAMIC NOISE SOURCES IN INDUSTRY

NOISE SOURCES IN OIL AND GAS COMBUSTION PROCESSES

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1. Oil Combustion Noise. (1) (2) The characteristics of a pressure jet oil burner, based on a Shell Combustion Head, were investigated with the flame firing into the open. Further studies with an enclosed flame are currently in progress. If it is assumed that oil droplets act as monopole sources as they vapourise and burn, then

$$p(t) = \rho(E-1)/4\pi d \left(dQ/dt\right)_{t-\tau} \quad \ldots\ldots(1)$$

where $p(t)$ is the instantaneous magnitude of the pressure pulse at a distance d from the source, Q is the volume rate of fuel consumption in the flame, ρ is the density of the surrounding medium and τ is the time taken by the sound to reach the measuring point.

A subsidiary experiment showed that the ionisation current (I) for the whole flame was proportional to the flow rate of fuel to the flame. A high concentration of electrons, indicating a region of preferred combustion, results in a high ionisation current. Hence, the time differential of ionisation current is proportional to the time differential of volume rate of fuel consumption i.e. $dI/dt \propto dQ/dt$ and determination of the spatial distribution of dI/dt within the flame leads to the distribution of noise sources. The ionisation current was measured using stainless steel disk electrodes 5×10^{-3}m in diameter and 10^{-2}m apart which were scanned in a horizontal plane bisecting the flame. A typical set of results using a nozzle which produced a droplet distribution with a high axial concentration is shown in Fig. 1, whilst a nozzle producing an annular spray pattern showed low axial ionisation current with off-axis peaks. The distribution of noise sources within a flame may be significant in determining the acoustic coupling of an enclosed flame with its combustion chamber.

The sound field at a point near the flame is, however, produced by the total of all noise sources in the flame and a correlation analysis was made between the differential of ionisation current for the whole flame and the noise. The ionisation current was monitored by a large pair of flat electrodes which completely contained the flame whilst the microphone was at approximately 0.6m from the flame. Fig. 2 shows the cross-correlogram of $p(t)$ and dI/dt obtained in this way for the 125 Hz octave band. The principal peak is displaced 2ms from the origin, corresponding to the path difference, and a periodic component with a period of about 8ms, corresponding to the filter frequency, is evident.

2. Gas Combustion Noise. (3) (4) The simplest source of gas combustion noise is the ignition of single spheres of combustible mixture. It may be shown that the magnitude of the pressure from this monopole source is given by

$$p(t) = \rho(E-1)/4\pi d \left\{ 8\pi r V_b^2 + 4\pi r^2 \frac{dV_b}{dt} \right\} \quad \ldots\ldots(2)$$

where r is the radius of the sphere and V_b the flame speed. The terms involving V_b are equivalent to dQ/dt in Equ.(1). If the flame speed is assumed to be constant, the sound pressure level at 1 metre distance from a bubble of radius 0.01m with flame speed of 0.5m/s is about 60 dB. The spheres of combustible mixture could be considered as approximated by turbulent eddies in a gas-air jet which ignite instantaneously over their entire surface as they penetrate the flame front.

Other possible sources of noise are fluctuations in flow velocity and fluctuations in flame speed of the mixture. Considering fluctuations in flow velocity it may be shown that the pressure pulse dp produced at the flame front is given approximately by

$$dP/P_1-P_2 \approx c^2/25 \cdot dU/U^3$$

where P_1-P_2 is the pressure drop across the flame front, dU is the fluctuation in flow velocity, U, and c is the velocity of sound. For dU = 1 m/s, U = 10 m/s, c = 1000 m/s at the flame temperature and $P_1-P_2 = 50N/m^2$ we obtain dp = 160 dB.

Considering fluctuations in flame speed alone it may be shown that for a fluctuation of dV_b in V_b the pressure pulse at the flame front is given approximately by

$$dP/P_1-P_2 \approx 6c^2\, dV_b/U^3$$

For a fluctuation in flame speed of about 10%, dV_b = 0.05 m/s for natural gas, giving a pressure pulse of about 145 dB at the flame front.

The various mechanisms were investigated as follows. Gas and air were premixed and the flow smoothed before the jet emerged from the orifice(Fig.3). The flame was held at various distances above the orifice by means of retaining flames. If the mechanism of sound production is by the combustion of turbulent eddies as spheres of gas, then the peak frequency of the spectrum of the flame noise should be dependent on the flame speed of the mixture (Equ.2). However, changing from natural gas to town gas did not alter the frequency of the spectrum peak although the turbulence eddies were of similar size. Also, cross-correlation of the differential of ionisation current for the whole flame with flame noise did not show any significant peak.

The effect of flow velocity fluctuation was determined by direct monitoring of flow fluctuations close to the heel of the flame and comparison of these with flame noise. The flame noise and velocity fluctuations peaked in the same octave frequency band, varying from 250 Hz when the flame was seated at eight port diameters downstream to 32.5 Hz when 20 port diameters downstream. Cross-correlation of flame noise and flow velocity fluctuations gave a normalised coefficient of 0.25, indicating that velocity fluctuations are an important contribution to flame noise.

Similar measurements were carried out on a number of commercial package burners. All three noise sources could be present because of the highly turbulent and inhomogeneous mixture. However, cross-correlation of flame noise with differential of ionisation current gave no discernible peak, indicating that there was no noise contribution from turbulent eddies acting as spheres of gas, whilst cross-correlation of flame noise and velocity fluctuations gave a significant peak as shown in Fig. 4. The spectra of noise and velocity fluctuations (Fig.5) compare well up to 500 Hz whilst the difference at higher frequencies indicates the presence of another noise producing mechanism, probably fluctuations in flame speed.

<u>References.</u> (1) C.G. Palmer, Ph.D. thesis, University of London,1971
(2) C.G. Palmer and H.G. Leventhall - Nature (Physical Science) November 1st 1971. (3) I.R. Hurle et al Proc. Roy. Soc.409-427,1968
(4) J.P. Roberts, Ph.D. thesis, University of London, 1971.

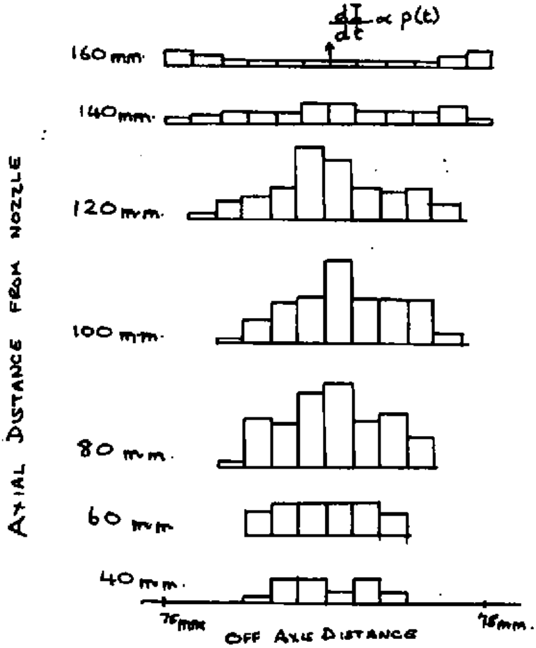

FIG 1. DISTRIBUTION OF NOISE SOURCES WITHIN FLAME

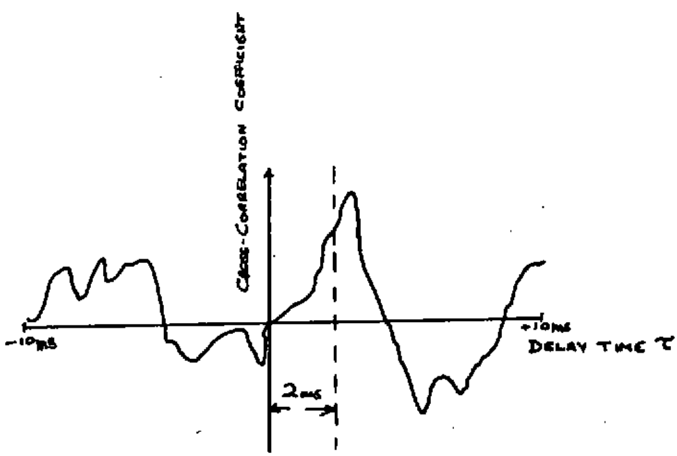

FIG 2 CROSS-CORRELATION OF $\frac{dI}{dt}$ AND p(t) FOR THE 125 Hz OCTAVE BAND.

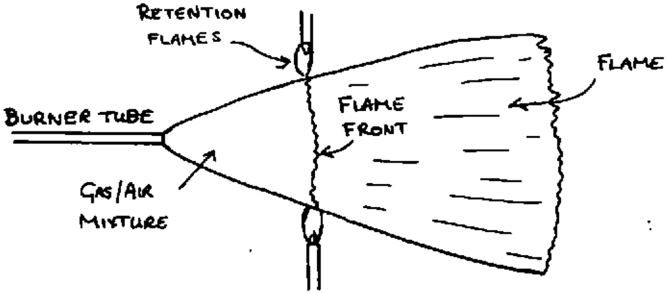

FIG 3. EXPERIMENTAL BURNER

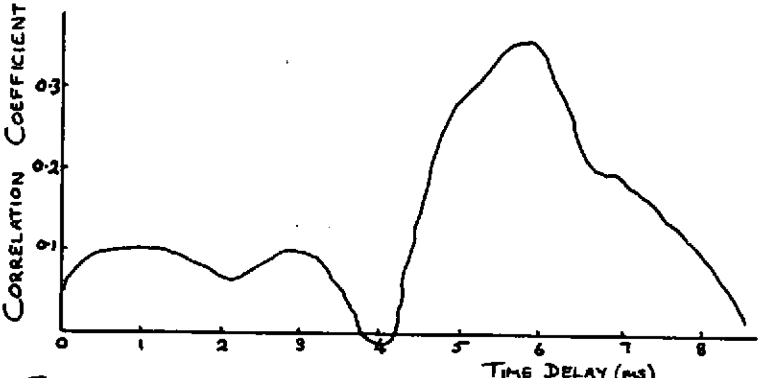

FIG 4. CROSS-CORRELOGRAM OF FLAME NOISE AND FLOW VELOCITY FLUCTUATIONS FOR PACKAGED BURNER

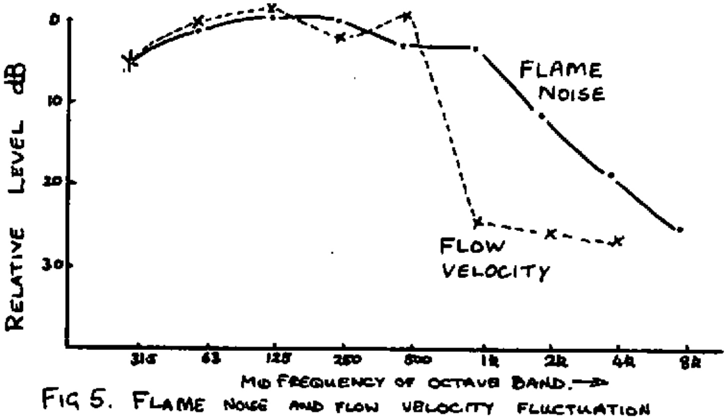

FIG 5. FLAME NOISE AND FLOW VELOCITY FLUCTUATION SPECTRA FOR PACKAGED BURNER.