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THE ACOUSTICS OF A HIGH INTENSITY LOW VOLUME COMBUSTION CHAMBER

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1. INTRODUCTION

The acoustic behaviour of a high intensity low volume combustion chamber was investigated in order to illuminate the causes of unacceptably high operational noise levels. Knowledge of the precise operating conditions of the device were limited, however it was understood that the device was a liquid fuelled direct steam generator driving a turbine.

Simulation of the combustion noise produced was achieved by replacing the liquid fuel with a natural gas/air mixture. Acoustic measurements were taken of the noise produced by the burner alone and that produced by the complete combustion system. The acoustic impedance of the complete combustion system was also measured as a function of frequency using a passive standing wave technique.

The dimensions of the cylindrical combustion chamber were approximately 200mm long by 80mm diameter which was small enough for the acoustic measurements to be conveniently carried out under "ideal" laboratory conditions. The anechoic room of the Polytechnic of the South Bank was employed for the combustion noise measurements; the other relevant measurements being made in the adjacent laboratories.

2. EXPERIMENTAL PROCEDURE

The investigation had three separate lines of enquiry:

(1) Examination of the noise generated by the burner alone when fuelled by a natural gas/air mixture and its dependence on the various input fuel parameters, e.g. mixture ratio and nozzle velocity.

(2) Measurement of the noise spectrum of the gas fuelled burner with combustion chamber and exhaust tube attached.

(3) Measurements of the variation with frequency of the acoustical impedance of the chamber and exhaust tube.

2.1 Flame Noise and Fuel Flow Rate

Under normal operating conditions the liquid fuel (or liquid fuel and additional oxidant) enters the combustion chamber through a small spring loaded non return valve. This valve is similar to an internal combustion engine poppet valve and has a tapered seat, the pressure difference set up across this annular jet opening is much higher for the liquid fuel than anything which could be supplied by the substitute natural gas/air fuelling arrangement. Therefore, the original valve spring had to be replaced, this was done by inserting a number of shims to hold the valve open and allow a range of nozzle velocities to be investigated. The air and gas flow rates were measured separately using an arrangement of rotameters (GEC-Elliot Process Instruments, type 7X for natural gas and type 18 for air). From these flow rates and nozzle area measurements the mean nozzle velocity could be calculated. The fuel gases were then passed separately to a 'Y' piece (filled with wire wool) where they were mixed prior to combustion in the burner. Acoustic measurements were taken using a Bruel and Kjaer capacitor microphone (type 4145), Digital frequency analyster (type 2131) and level recorder (type 2307).

Depending on the mixture ratio (primary air:gas) and flow rate, three distinct flame types could be seen:

i) a quiet laminar flame seated on the burner nozzle;
ii) as (i) but with a turbulent "brush" (noisy);
iii) a lifted turbulent flame (noisy).

Third octave noise spectra were recorded for a range of gas/air flow rates, the significance of which will be discussed in the next section.

2.2 Noise Spectra with the Chamber and Exhaust Tube

When the system was fully assembled, burner, combustion chamber and exhaust tube, it proved very difficult to sustain a flame. This was of course due to the relative low reactivity of natural gas/air mixtures, when compared to the fuel used in practice.

Various methods of ignition were tried including a small pilot flame but the most satisfactory method proved to be a continuous electrical spark discharge onto the valve head from an internal electrode (a type of continuous spark plug). This method of ignition produced noise of its own, however this was shown to make a significant contribution to the sound power level only at frequencies well above those of interest (Figure 1).

Despite the difficulties encountered in sustaining flames within the chamber, worthwhile conclusions could be drawn from the results obtained.

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Figure 1(a) Flame with spark ignition, inside chamber

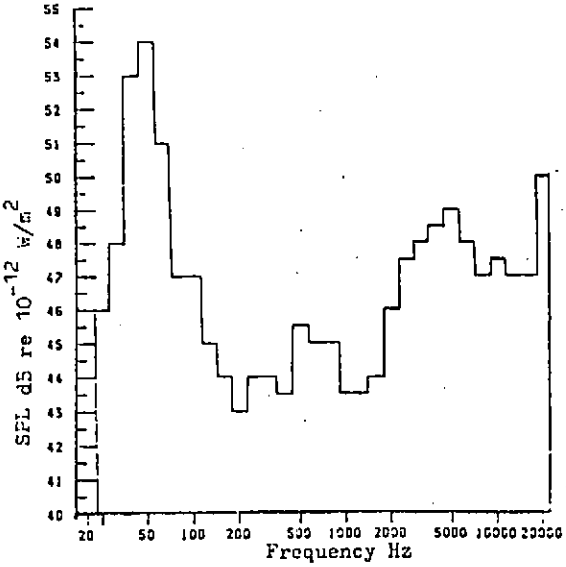
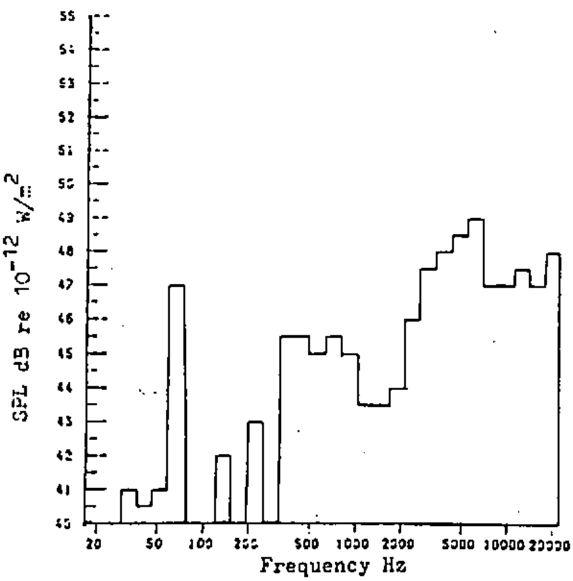


Figure 1(b) Spark alone, inside chamber



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2.3 Impedance Measurements

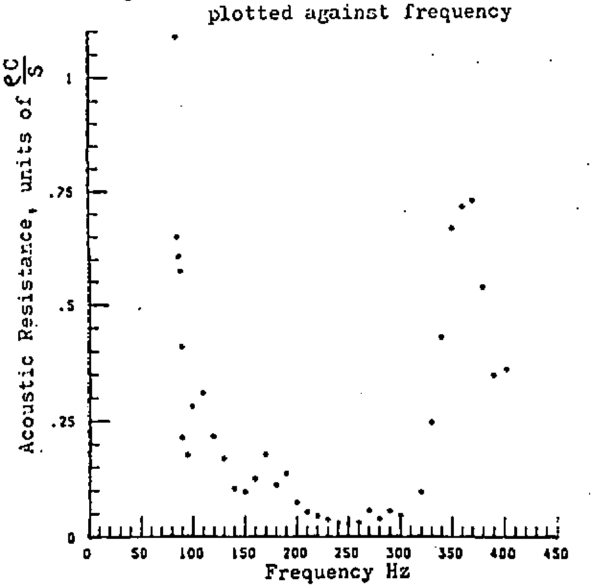
Essentially in this series of measurements the combustion chamber formed the passive end of a standing wave tube with the inlet port set at the zero position of the probe microphone. The measurements taken were the magnitude of the sound pressure level maxima and minima and also the position of the first minimum in relation to the zero position. This was completed for a range of frequencies. From these measurements the acoustic impedance of the combustion chamber was calculated.[1]

3. DISCUSSION

The precise operating conditions of the device were unknown, however it was understood that the undesirable sound spectrum was broad band, the shape and intensity of which was governed by the nature of the oxidation process used in the combustion. Under normal operating conditions the spectrum was centered around 100 Hz and did not extend above 175 Hz with any significant intensity. However, with additional oxidant in the fuel the overall sound pressure level increased markedly and a noticeable shift to higher frequencies was observed.

The acoustic impedance measurements (Figure 2) indicated a clear minimum at about 215 Hz at 20°C however the temperature inside the working chamber would be much greater. The available information suggested a frequency scaling factor of 2, therefore any resonance effect due to standing waves in the working chamber should occur at frequencies above 400 Hz and consequently outside the range of concern.

Figure 2 Real part of acoustic impedance plotted against frequency



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The sound spectra measured with the combustion chamber and exhaust tube attached with combustion taking place showed a typical Helmholtz resonance at about 75 Hz (Figure 1). Whilst the frequency of the peak would appear to occur within the band of interest (allowing for temperature effects) it does not show itself prominantly in the measured spectrum of the working unit. As the sound spectrum of concern is broad band it appears unlikely that any form of combustion driven oscillation is the source of sound generation of concern.

Combustion "roar" however has no specific frequency but a broad band of noise, in this respect, has the same characteristic as the unwanted sound. The noise generated is normally a function of the flow and chemical parameters, typically input flow, velocity and flame speed.[2] There appears to be uncertainty in the literature as regards the precise effect of flame speed on the frequency of the combustion noise, but it is generally agreed that flame speed gives increased noise levels and in the working unit there is indeed an increase in noise with a more reactive oxidant/fuel mixture.

All the spectra were of a similar shape and so the peak SPL value may be taken as a measure of the overall sound intensity.

The two main types of flame investigated behaved very differently with regard to changes in the nozzle velocity. Figures 3 and 4 show the variation of sound level with changes in nozzle velocity for constant total flow. The sound output of lifted flames is highly dependent on velocity but relatively insensitive to total flow (Figure 3). However, the major criterion governing the sound output appears to be the total flow at any particular valve opening for both sealed and turbulent flames (Figure 5).

Figure 3 Sound power level plotted against nozzle velocity for lifted flames

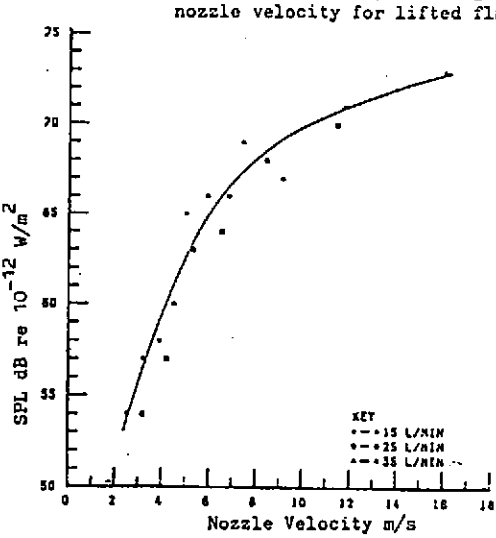

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Figure 4 Sound power level plotted against nozzle velocity for seated and turbulent flames

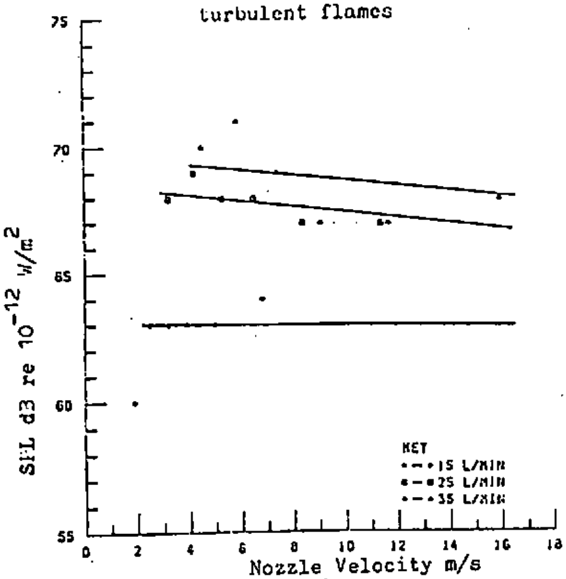
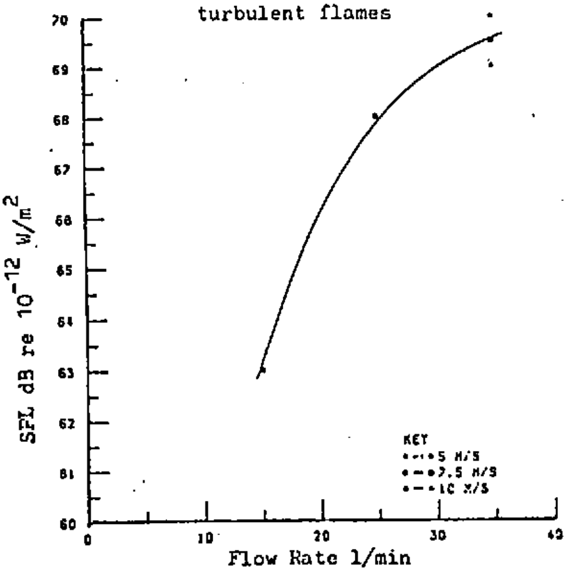


Figure 5 Sound power level plotted against total flow rate for seated and turbulent flames



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An analysis of the operation of the spring loaded burner valve [3] reveals that due to the variation in free area the flow velocity through the nozzle is proportional to the cube root of the volume flow rate and therefore resulting changes in velocity would be small for changes in flow rate. Thus the nozzle velocity under operating conditions may be taken to be essentially constant and any noise produced by a "lifted type" flame in the device would also be relatively constant. The lifted flames in the experiments were generally gas rich (3.8 : 1 mean air to gas ratio). It would appear unlikely that this type of "lifted" flame best simulates the actual operation of the burner with fuel/oxidant mixtures.

Seated and turbulent flames did however give increased noise levels with increased intensity of combustion (Figure 5) (increased flow rate at the same nozzle velocity) and the flows are generally closer to stoichiometric (5.3 : 1 mean air to gas volume ratio).

From the results it may be concluded that the unacceptably high noise levels are the result of combustion roar and as such can be simulated in the laboratory using different fuels.

Thus it should be possible for additional tests to be carried out in the laboratory to attempt to determine a fuel/oxidant mixture capable of producing the required power output but with reduced noise levels.

REFERENCES

[1] Kinsler and Frey, "Fundamentals of Acoustics", Wiley.

[2] A. A. Putnam, "Noise Control Engineering", July-Aug 1976.

[3] R. Turner, "MSc Dissertation", Polytechnic of the South Bank, 1984.