BRITISH ACOUSTICAL SOCIETY

Meeting on Thursday, 4th January, 1973
at Chelsea College, London, S.W.3.

'APPLIANCE NOISE'

Paper No. 73/06

BROAD BAND NOISE IN COMBUSTION SYSTEMS

C. HUGHES, MIDLANDS RESEARCH STATION
BRITISH GAS CORPORATION

The combustion of any fuel, whether it be solid, liquid or gas must necessarily produce some noise. In this paper, particular attention is paid to the combustion noise from nozzle mixing package burners, ignoring other sources such as the air intake and fan blades. This category of burner produces a turbulent diffusion flame and is important for the firing of industrial heating plant.

There is ample evidence to suggest that the noise from a premix flame can be represented as a distribution of monopole sources[1,2,3,4,5,6] caused by fluctuations in the local rate of combustion. It has been suggested,[2,6] that this model can be extended to cover the turbulent diffusion flame, although it is not clear which other parameters will have to be introduced.

In order to explore this proposal, the noise from a variety of practical packaged burners has been studied by measuring sound power levels, under controlled conditions, in a reverberant room. The noise from the burners, operating without a combustion chamber, was monitored at different air and gas flow rates extending over the useful operating range.

In performing these tests two fuels were used, town gas and natural gas, but the trends in results were the same for both fuels.

RESULTS

Empirical correlations between sound power levels and various parameters related to the combustion process were made. A power law relationship, involving the most important parameters, was sought of the form:

$$\pi = K(E-1)^{w} Q_g^{\,x} U_T^{\,y} S^{z} \qquad \text{..... (1)}$$

The relative importance of these parameters was assessed by plotting the sound power output against gas flow rate, the combined air and gas flow rates and finally the total velocity ($U_T = U_g + U_a$), at a series of different excess air levels. At each excess air level the expansion ratio (E) and the burning velocity (S) will remain constant so that for a given fuel the relationship in (1) simplifies to:

$$\pi = K_1 Q_g^{\,x} U_T^{\,y} \qquad \text{..... (2)}$$

Since for constant excess air level the air/gas ratio is constant, it can be shown that:

Sound Power Level $PWL = 10(x + y) \log_{10} Q_g + K_4$ ..... (3)

For a given gas type the following relationships were examined

1. The effect of gas flow rate

For all the burners tested this resulted in a series of near parallel lines (see Fig. 1) for a range of excess air levels between 20-100%. At first inspection, it would seem that sound power has a strong dependency on heat input. However, each point represents not only an increase in gas rate, but also a corresponding increase in air flow rate and both air and gas velocities. Furthermore, as excess air level increases for a fixed gas rate the sound power output increases. This is attributed to the increased air flow rate and associated air velocity.

The increase in noise is unexpected, since both the expansion ratio and the burning velocity fall sharply with increasing excess air, and contrasts with results for premix burners. This observation might be explained by inhomogeneous mixing in a nozzle mixing burner such that burning velocity changes are not fully realised or, alternatively, that the dependency of noise on burning velocity is less important with diffusion flames. The former explanation would presume that pockets of air and gas are formed in the flame and some of the air is not involved in the reaction; the increase in aeration merely affects the turbulence, which strengthens the monopole sources and increases the noise.

It is also interesting to note, that the rate of change of sound power output with gas rate is constant irrespective of excess air level, and hence expansion ratio and burning velocity. This would again seem to suggest that these latter parameters are less important with diffusion flames.

2. The effect of total air and gas flow

Plots of sound power output against total gas and air flow rates, for a range of excess air levels, show that the sound power output increases with total air and gas throughput. For a fixed cross-sectional area this is equivalent to an increase in exit velocity. It is clear (from Fig. 2) that there is only a weak dependence on excess air level, and hence expansion ratio and burning velocity. In this case, increase in excess air does produce slightly lower noise levels.

3. The effect of total velocity

For burners with the mixing head enclosed in a tunnel, accurate values can be given to the velocities U_a and U_g. This velocity term is an attempt to obtain a parameter which governs the turbulence in the reaction zone. Plots of sound power output against total velocity for constant fuel flow rates gave the straight line relationship Fig. 3. At different fuel flow rates all points fell on the same line irrespective of excess air level. This indicated a strong dependence on total velocity and underlined the weak dependence on expansion ratio and burning velocity.

As a result of the above studies, the most useful relationship for practical purposes is

$$\pi \propto U_T \quad \text{i.e. } \pi \propto (U_a + U_g) \qquad \ldots\ldots (7)$$

DISCUSSION

It was noticed that head design has had a large effect on the noise from the burner; whether the simple velocity considerations explain this completely is debateable. Most of the work on premixed flame noise has ignored the effects of burner geometry and the effects of burner construction on the combustion process and the noise. Further, the scaling factors have been calculated using the wrinkled laminar flame model of the reaction zone [1,4,5,6] or the distributed reaction zone model[4]. Neither of these models seems to apply to a practical packaged burner flame, and, as suggested by Strahle[4] a combination of these models would be more accurate and bring in terms involving turbulence in the flame. However, at the moment, the theories of combustion noise for premixed flames cannot be extended to practical flames.

For burners of similar geometry but different size, the sound power levels generated at equivalent fuel and air flow rates can differ by up to 12 dB, the larger burners being the quieter. Thus, there could be some reduction in combustion noise if larger burners, with lower air supply pressures leading to reduced air velocities, were used.

A change in fuel type, with this type of burner does not merely entail a simple substitution of fuels. Differences of calorific value, flame speed and air/fuel ratio usually means that alteration to the burner is required to effectively burn the fuel. One way of achieving this is to alter the configuration of the burner head. Thus a basic design alteration is made which directly affects velocities and flow pattern at the head and which results in a completely different definition of the reaction zone. Thus direct comparison of two fuels using converted burners is not possible. Alternatively, if no alteration to the burner head were required to obtain satisfactory combustion on fuel changeover, then direct substitution of fuel type could be made, but if flow rates and velocities were maintained, the differences in energy input, air/fuel ratio and flame speed would affect the flame configuration and direct comparison between the two fuels would again not be possible.

From the theories of premixed flame noise, a change from a high flame speed fuel to a low flame speed fuel, all other things remaining equal, should result in less noise, although a change in frequency content is to be expected.

REFERENCES

1. Cummings A., Turbulent Combustion Noise, Midlands Research Station, Gas Council, Publication 205.

2. Strahle W.C., Some results in Combustion Generated Noise, AIAA 10th Aerospace Science Meeting, San Diego, California U.S.A., Jan 17-19, 1972.

3. Smith T.J.B. Kilham J.K., Noise Generation by Open Turbulent Flames, J.A.S.A., Vol. 35 No. 5, 715-724, May 1963

4. Strahle W.C. On Combustion Generated Noise, J.Fluid Mech. G.B. (1971) Vol. 49, Part 2 pp 399-414

5. Hurle I.R., Price R.B., Sugden T.M. Thomas A., Sound Emission from Open Turbulent Premixed Flames, Proc.Roy.Soc. A.303, 409-427 (1968)

6. Price R.B., Hurle I.R., Sugden T.M., Optical Studies of the Generation of Noise in Turbulent Flames, 12th Symposium (International) on Combustion, 1093-1102 (1968)

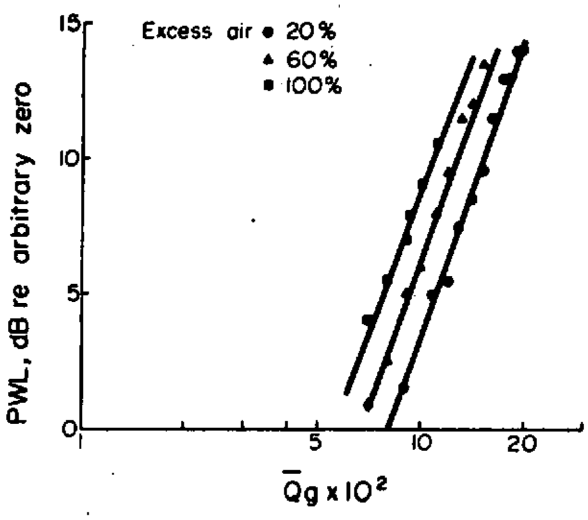

Fig. 1 Sound power level vs gas flow rate

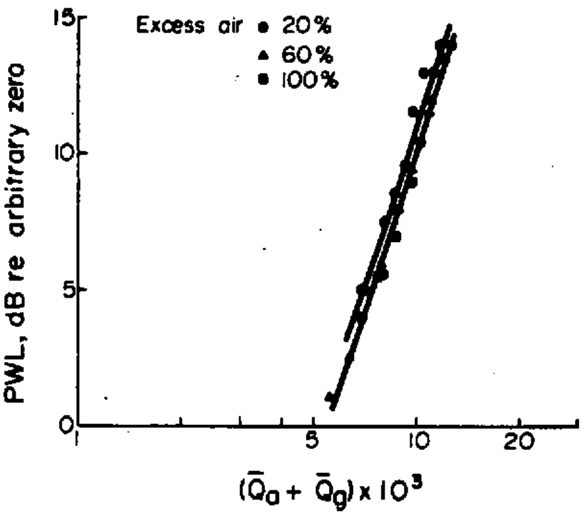

Fig.2 Sound power level vs total air and gas flow rate

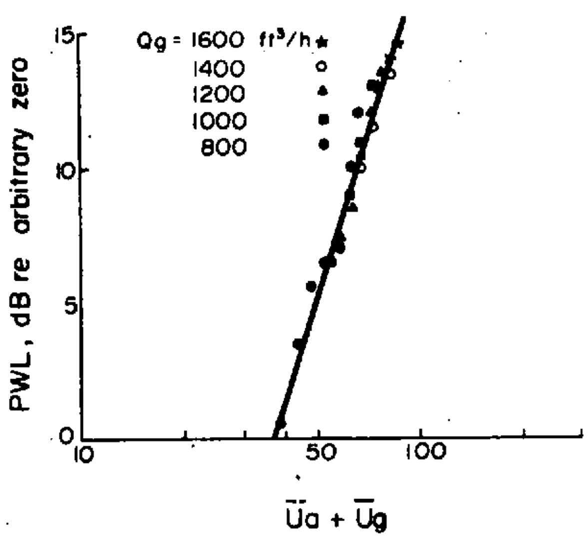

Fig.3 Sound power level vs total velocity