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SOME COMBUSTION NOISE PROBLEMS AND COUNTERMEASURES

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INTRODUCTION

A stable laminar flame, whether a diffusion or a premixed flame, is not an original source of sound.

In the absence of a flame a turbulent flow is a source of broadband aerodynamic noise. Interrellated fluctuations in velocity, pressure and density act in free flow as quadrupole sources of sound. For free jet flows, the peak wavelength is about 7 times the jet nozzle diameter often with peak frequency in the range 1000 - 4000 Hz in practice.

A turbulent flame emits broadband noise which peaks at a wavelength about 50 times the burner nozzle diameter usually with a peak frequency of 200 - 800 Hz in practice.

In a furnace, a flame is one element of a system comprised of the combustion chamber, fuel and air supply lines, the burner, and the flue gas duct. Fluctuations of pressure in the combustion chamber can vary the fuel or air supply rate. When the corresponding variation in the heat release rate possesses a component in phase with the chamber pressure then an oscillation can be sustained in accord with Lord Rayleigh's dictum. Reported system oscillations [1,2,3] have a specific low frequency often in the range 4 - 70 Hz and sometimes a factor of up to 10 times less than the natural acoustic frequencies of the combustion chamber at the hot gas temperature. In addition, the natural frequencies of the ducts and chambers are liable to excitation by broadband noise.

These phenomena and the combinations of interactions between them provide a rich variety of sound producing phenomena which are often difficult to diagnose and to remedy owing to the wavelength variation in atmospheric air from about 17 m at 20 Hz to about 34 mm at 10 kHz which encompasses plant dimensions.

Sound is a form of energy which once produced can only be removed by conversion into thermal energy by viscous dissipation in fluids or internal friction in solids. When a source of noise is identified there are two basic approaches to deal with it:

(a) reduce or eliminate the source itself,

(b) insulate the source from its environs and absorb the sound energy produced.

COMBUSTION NOISE

Mechanism

Noise emitted from turbulent combustion arises from fluctuations in the dilatation of elements of fluid. The release of heat and change of mols between reactants and products in the combustion reaction causes dilatation. The fluctuation can result from:

(a) turbulence originating either from shear as fuel and air flow into a relatively static environment or present in the fuel and air supply, or
(b) a fundamental instability of the combustion wave front.

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The chemical physics of turbulent combustion is insufficiently developed to predict the detail of combustion noise. A crude dimensional analysis [4] predicts the efficiency of conversion of thermal to acoustic energy to be,

$$\eta \approx \frac{(\alpha-1)^2}{4\pi} \beta M \frac{V^2}{H} \quad (1)$$

A noise level of 90 dB corresponds to an energy flux of only 10^{-3} W/m^2 so that very low efficiencies of conversion to sound energy typically 10^{-8} can produce significant sound levels. Equation (1) fails to relate sound production to the details of the turbulence but it picks out a number of variables under the control of the designer and whose effect is confirmed to some extent by experiment.

Flow Velocity
For low pressure gas/air burners, [5,6,7] acoustic energy production is roughly proportional to the square of the velocity as per Equation (1) and therefore to the pressure drop across the burner so doubling the velocity increases the noise level by 6 dB. Even increasing the air flow rate with constant fuel rate gives nearly the same effect.

Air-Fuel Ratio
This affects the combustion expansion ratio, k, and the Mach Number of the laminar flame speed, M, both of which are at a maximum close to stoichiometric combustion where conversion to acoustic energy is highest for a given velocity. Reductions of about 10 dB in noise from premixed flames can be obtained by using larger burner ports and off-stoichiometric mixtures [5,6] which for fuel rich mixtures necessitates two stage combustion.

In turbulent mixing flames these effects can be obtained by reduction of velocities and by recycling combustion products mixed with the air supply. This is, however, at the expense of an increase in flame volume reducing combustion intensity.

Natural versus Forced Draught
Where buoyancy is used to move combustion gases as in some vertical cylindrical process heaters, noise readily escapes through the air inlet ports. This noise can be controlled by building an enclosure at the base of the furnace with a silenced air intake. [8,9]. In the long term, the use of forced draught is preferable [10]. The major noise problem then becomes the air intake which needs to be silenced to reduce the fan and burner noise. The remaining noise escape paths are the stack, and transmission through furnace walls where, if a problem, thermal and sound insulation may be combined wrapped in lead sheeting or substitute with a mass of about 5 kg/m^2.

Turbulence in a Supply Line
For premixed flames increased turbulence in the supply line amplifies combustion noise over all its spectrum. [5].

Interactions of Flame with Sound
It is a well known curiosity, demonstrated with a microphone in an aerated bar burner, that laminar premixed flames are able to amplify sound in the sub-kilohertz range. On the other hand, aerodynamic noise in a supply line tends to suppress low frequency combustion roar yet itself be amplified at frequencies greater than 1000 Hz [5]. Apart from excessive velocity noise may be traced to valves and other fittings. It may be reduced by internal acoustic lagging of a

section of pipe or more conveniently of a windbox or plenum. In cases where gas is supplied through an orifice with a high pressure ratio, an in-line silencer may be necessary, which conducts the gas through several changes of direction with an acoustically absorbing lining.

Ultrasonic sound waves directed across the base of a turbulent jet diffusion flame with a transition Reynolds Number reduce combustion noise [11] probably by altering the development of turbulence.

Flame Stability

In turbulent diffusion flames in combustion chambers, the fuel and air are mixed with recirculated hot combustion product gas to bring them to a temperature at which the turbulent flame speed is sufficient to give a stable flame. Noise emission is greatly increased when stability is not assured and the flame jumps between various positions. In an oxy-fuel burner this behaviour was cured by modifying burner geometry [12]. For unreactive fuels such as pulverised anthracite and lignite, the temperature and quantity of recirculation products can be increased by design and the use of insulating refractories.

Similar stability problems arise when a burner is operated close to a blow-off limit either by increasing throughput or altering the fuel-air ratio. Measurements of static pressure in a tunnel burner running noisily close to blow off [13] show transitions in the flow between that for combustion and that for partial or no combustion. In this cycle, fuel/air mixture fails to be ignited on entry, this increases the recirculation and ignition is re-established. The frequency of ∿ 20 Hz is unrelated to the natural acoustic frequencies of the tunnel.

SYSTEM OSCILLATIONS

Helmholtz Type

The boom on ignition sometimes experienced with a central heating boiler can be composed of damped pressure oscillations of about 40 Hz with 0.5 second duration [14]. Stable oscillations in the range 5 - 50 Hz are well known in oil-fired boilers and gas-fired [1,2,3] hot metal holding vessels. They are interpreted as Helmholtz oscillations in which the gas in the chamber acts a spring and the gas in the flue or supply ducts as a mass [1]. Fluctuations in heat release in phase with chamber pressure provide a driving force and friction in the flue a damping force. Oscillations can be suppressed

(a) by weakening the energy feedback mechanism, e.g. by increasing the pressure drop across the burner register,

(b) introducing additional damping by increasing the length of the waste gas flue, by placing baffles in the combustion chamber, or by a hole in the wall connected to a soft walled enclosure or a hard walled one with an acoustic lining,

(c) detuning the system by connecting a closed end quarterwave tube into the wall of the combustion chamber near a point of maximum pressure amplitude. The tube diameter should be a significant proportion of the combustion chamber diameter. This method is impractical at low frequencies owing to the great length of the tube required. Another example of detuning is to move the burner slightly off-centre in an axisymmetric chamber [1].

The frequency and damping of a furnace system can be measured by either the detonation or piston methods [3]. Considering the whole system of chambers and ducts there is no discontinuity between acoustic and these non-acoustic types of oscillation [3] though they can be up to 10 times lower than the natural frequencies of the chamber.

Excitation of Natural Frequencies

Because it is broadband, combustion excites the natural acoustic frequencies of a combustion system and given a mechanism this can lead to resonance. An example is the tunnel burner where a combustion excited standing wave in the tunnel can couple with and feed energy to standing waves in the supply pipe to give intense screaming [15]. Rules to avoid this specify the lengths of pipe between bends and fittings to avoid acoustic coupling.

Quarter wave damping tubes fitted to a burner tunnel can detune specific frequencies [12]. The tubes need to be tuned by adjustable pistons and at these higher frequencies are themselves reasonably short. The provision of damping by multihole Helmholtz resonators in the wall of the burner also reduces noise [3].

The excitation of natural frequencies by a flame may extend beyond the furnace for example to feed standing waves in a workshop. A standing wave is most effectively driven when the noise source is at a position of maximum pressure amplitude. Moving a small furnace away from a wall can improve a noise problem if care is taken not to move it into the antinode of a higher mode of oscillation.

AERODYNAMIC NOISE

The acoustic power of a free subsonic jet due to shear flow alone is given by [16].

$$P = 6 \times 10^{-5} \quad \rho U^8 D^2/c^5 \qquad (2)$$

As the pressure of either the air or gaseous fuel supply is raised beyond about 0.3 bar g, aerodynamic noise becomes significant. A burner used in process heaters uses fuel gas at 0.7 - 2 bar g to inspirate the air. Noise from the combustion and from the jet give a spectrum with two broad peaks typically at 250 Hz and 2500 Hz respectively. The human ear is more sensitive in the 1000 - 4000 Hz range so that the aerodynamic noise (hiss) is often of equal importance and in extreme cases dominant. The use of lined shields around open air inlets, and the lining of ductwork can substantially reduce noise levels for the operators.

CONCLUSION

This survey is complementary to one by Strahle [17] who discusses combustion noise theory, noise in flares, and internal combustion engines, and indirect combustion noise from inhomogeneous gases discharging through large pressure gradients as in gas turbines and rocket engines. There are still many other phenomena in furnaces, for example, the tones in shaft furnaces.

NOMENCLATURE

c	velocity of sound	m/s
D	nozzle diameter	m
H	calorific value	J/kg
M	laminar flame speed Mach Number	-
P	sound power	W
U	velocity in nozzle	m/s
V	flow velocity	m/s
α	volume expansion ratio for combustion	-

β	mass ratio of air to fuel	-
η	thermo-acoustic fractional efficiency	-
ρ	density	kg/m^3

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