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SOUND EMISSION FROM FLAMES EXCITED BY A MODULATED ELECTRIC FIELD

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Introduction

The possibility of using electrically induced pressure oscillations within a flame plasma to control and diagnose acoustic combustion instabilities, in industrial burners, has focused attention on the mechanisms involved in acoustic emission from flames subjected to alternating electrical fields. Sound generation by this process has been investigated by a number of workers (1-6). Further study of this phenomenon has been prompted by the need for more detailed information concerning the sound emission characteristics and its dependence on various parameters to help in establishing a satisfactory model.

This paper presents the results of recent experimental investigations of the dependence of sound generated by an electrically excited flame on gas mixture, frequency of excitation, input power and electrode spacing. The measurements were made in the power range similar to those previously reported in the literature so that comparisons could be made, but the intension is to extend the investigation to higher input powers where there may be changes in the nature of the emission process.

Experimental

The essential features of the experimental arrangement are shown in Fig.1. The electrical signal was derived from an audio frequency oscillator and a low output impedance thermionic valve amplifier. The signal was fed to the flame through a stainless steel electrode placed over the flame and another of carbon placed just above the flame front. The alternating current through and the potential across the flame were measured using AC meters with the resistance arrangement shown. Sound measurements were taken using a 1" capacitor microphone placed close to the flame and a digital frequency analyser. Fuel and air to the flame were monitored either by calibrated Rotameters or by a Rayleigh interferometer when greater accuracy was required. An electrical discharge over a potassium hydroxide solution contained within the air line was used for seeding the flame when necessary.

The types of flame examined were a) an unseeded Bunsen flame with high potential across the electrodes and drawing low current, and b) a seeded flame from a Meker burner under conditions of continuous discharge between the electrodes.

Readings and Results

Fig. 2 shows typical relationships between the sound level from and current through the unseeded flame against mixture strength, the maxima occuring at a fuel-air mixture slightly richer than stoichiometric. The sound output power was found to be approximately proportional to the square of the input AC electrical power in this case.

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Fig. 3 indicates the manner in which sound output power contained in the fundamental varies with the alternating electrical power fed to the seeded flame. Although the points show some scatter they lie about a line of slope 10dB/decade. Similar relationships were found for other frequencies within the range 250 Hz to 16 kHz.

Fig. 4 gives a typical frequency spectrum for constant AC electrical input. This plot was obtained from the constant current characteristics (which was the most convenient to obtain with the apparatus), assuming the linear relationship between electrical and audio power indicated above. The same general shape of spectrum, albeit at slightly different levels, was found for both natural gas and propane, and also for different electrode spacings between 20 mm and 80 mm. The slope of SPL vs frequency is very close to 6dB/octave over most of the spectrum but falls to a lower value at higher frequencies.

Discussion

The results of these experiments suggest the following:
a) When the flame is unseeded the ions existing in the combustion products provide the main source of conduction. When the fuel-air mixture is slightly on the rich side of stoichiometric the ion density is a maximum as are AC current through the flame and sound output power. The ion density is relatively low in this region and the electric field would be little affected by it.

b) With seeding and constant voltage input the current through the flame increases with a consequent increase in sound output. When a continuous discharge occurs the main source of ions would seem to be thermionic secondary emission from the electrodes. It was found that changes in the fuel-air ratio and external seeding had little influence on the sound output under these conditions. External seeding was maintained throughout the experimental measurements as it had a steadying influence on the flame, however high sound outputs could be obtained for a short time after the flame had been extinguished while a residual arc discharge remained.

c) The linear dependence of sound output power from the flame on input AC electrical power means that other energy dissipating processes do not change significantly within the energy range studied.

d) The 6dB/octave frequency spectrum obtained with constant AC power input is as would be expected if the flame were acting as a simple sound source of constant displacement amplitude. In fact the small variation in sound output with electrode separation would suggest a point source possibly at or near the carbon electrode. The fall in slope at high frequencies is probably due to the flame's electrical impedance becoming reactive. This was not taken into account in the energy calculations.

Models which have been proposed for the sound emission process have been based either on Joulean heating (3) and (4) or on an electric wind mechanism (5) and (6). The results presented in this paper do suggest that for the two cases studied essentially different mechanisms predominate. The experimentally observed frequency spectrum of Babcock and Baker given in (3) (assumed to be relating to a discharge flame) shows a slope near to 6dB/octave, although the accompanying analysis predicted a slope of only 3dB/octave. The model proposed in (4) predicts that sound output should be inversely proportional to the frequency of the applied electrical signal, which is difficult to reconsile with experimental observations.

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Summary

Sound emission from electrically excited flames has been investigated experimentally. The results indicate essentially different mechanisms of sound production from the two cases observed, viz low current high voltage and high current continuous discharge. In the former sound output depends on the ion density already existing in the flame and is approximately proportional to the square of the input electrical power. In the latter, sound output is proportional to input electrical power and proportional to the square of the frequency.

With discharge, the efficiency of conversion and linear dependence of input AC electrical power on output acoustical power gives rise to the hope that this process may be used to obtain sufficiently high acoustical power to be of use in controlling and diagnosing acoustic instabilities in high intensity combustion chambers.

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