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OPTO-ACOUSTIC STUDIES OF WELDING-TORCH FLAMES AND COLD JET MIXTURES

S-L. HALL

SCHOOL OF MECHANICAL ENGINEERING

N.S.W. INSTITUTE OF TECHNOLOGY, SYDNEY, N.S.W. 2007 AUSTRALIA

SUMMARY In order to understand combustion noise in high-temperature flames, acoustical studies of welding-torch flames have been performed. Due to large values of sound-directivity angle and maximum frequency, with respect to flames using air as the oxidant, additional optical studies have been performed.

1 INTRODUCTION

A commercial welding torch with a tip having an internal exit diameter of 2.6 mm was used for all experiments. Oxygen and liquified petroleum gas (LPG) were supplied from commercial cylinders and metered by mercury manometers and calibrated rotameters. The premixed cold-flow velocity of O_2/LPG mixture was varied in four test cases from 15 to 75 m sec^{-1}. Initially the flames/cold jets were kept in a *horizontal* position. Acoustic measurements were taken first with a stationary microphone position and rotatable torch, and secondly with the torch in a fixed position and the microphone position moved through various azimuth angles. Far-field sound measurements were obtained at 0.26 (minimum far-field distance = 100 burner diameters), 1.0 and 2.0 metre distances from the burner tip. In 1982, the torch position was changed to produce *vertical* flames/cold jets. Hemi-spherical acoustic measurements were taken at a 0.26 metre radius. Sound-pressure level was measured in dB(A), dB(UN) and in one-octave bands. Identical readings were taken at a distance of 1.0 metre in the plane of the burner tip.

A conventional Z-type schlieren system was used to study ignited and unignited mixtures in both the horizontal and vertical planes. A 16 mm HYCAM camera was run at 5,000 frames per second for all schlieren films.

2 ACOUSTIC MEASUREMENTS

When the flames/cold jets were in a horizontal position, sound-pressure levels were measured in overall and dB(A) weightings, as well as 1/1 and 1/3 octave bands. Frequency spectra were obtained in one octave, one-third octave and 6% bandwidths. Figure 1 shows that peak sound frequencies were in the 2 to 7 kHz range; unignited mixtures all peaked at 14 kHz. Although the preferred direction of acoustic emission from hydrocarbon/air flames is in the range of 40 to 60 degrees from the flame axis, the maximum directivity angle for all *horizontal* cases tested occurred between 75 and 82 degrees from the flame axis while the *vertical* flames had maximum directivity at 62 to 76 degrees from the flame axis. Figure 2 illustrates an isobaric plot which is typical of all four test cases. Ribner (1964) found that temperature gradients refract the acoustic radiation in jets and produce the same heart-shaped isobaric pattern. Strahle (1972) commented that sound directionality due to the behaviour of acoustic sources were minor and was most likely caused "by other phenomena such as refraction at temperature discontinuities". Large temperature gradients and/or fluctuations can also be responsible for these large values of peak frequency and directivity angle. Yoshido and Tsuji (1979) found, from instantaneous temperature measurements, that high-frequency temperature fluctuations in the kilohertz range were predominant in their turbulent premixed flames.

One and one-third octave analysis showed that less than 2dB variation in directivity was measured up to 1 kHz for flow velocities below 60 m sec^{-1} and up to 500 Hz for flow velocities above 60 m sec^{-1}. The directivity shifted to approximately 75 degrees from the flame axis above the 500 or 1,000 Hz levels. At 31.5kHz, a variation of 14 to 17 dB relative to azimuth angle was obtained.

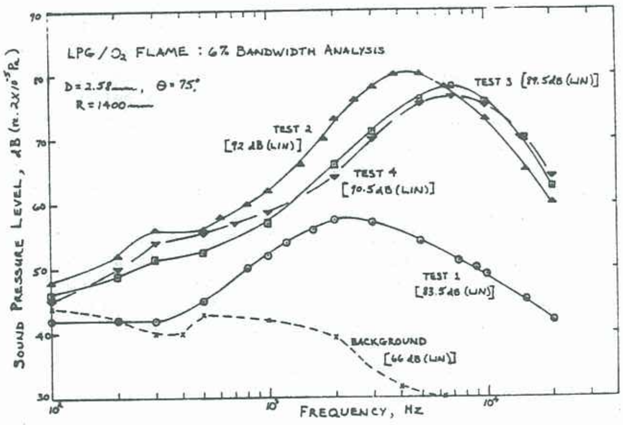

Figure 1 Frequency spectra with 6% bandwidth filter

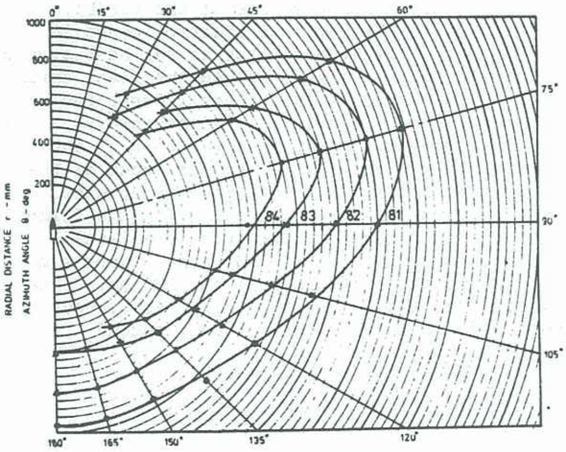

Figure 2 Isobaric plot of Test 1

3 SCHLIEREN STUDIES

Schlieren photographs show all flames to be initially laminar. With the exception of the flame with the lowest cold-flow mixture velocity, all other flame settings produced turbulent globules in the post-flame region. Ballal (1981) attributes the globules "to the mixing and instability of the lighter post-flame burnt gases which are spreading into the nonreactive ambient surroundings". The transition point occurs where the outer flame brush or secondary combustion begins. Although the fuel and oxidant are mixed 100 diameters upstream of the burner exit, the visual appearance of the flame varies from totally diffusion-controlled to totally premixed as flow velocity is increased. In fact, the schlierens obtained in this study look very similar to the hydrogen and acetylene diffusion flames of Takeno (1978).

Schlieren photographs show the primary reaction zone of the flames to be remarkably clear of any density gradients in the streamwise direction, although the inner cone is well defined. The transition to the turbulent post-flame region occurs at 15 burner diameters or less for all flames with flow velocities over 30 m sec^{-1}. From frame-by-frame examination of the schlieren films, the highest 'point' velocities along the outer profile of the flame occur just after the transition point. The velocity along the schlieren profile decreases to half its peak value at approximately 75 diameters from the burner exit. After the transition to the turbulent post-flame region, the eddys become several orders-of-magnitude larger in scale than those of the unignited gases.

The small-scale, high-frequency structure of all unignited mixtures was identical to those of cold jets, but quite different from the equivalent burning gas mixtures. All unignited jets were turbulent while all flames were laminar. In the unignited mixtures, the laminar core is 5 to 8 diameters long and the turbulent portion makes a 10-degree angle with the jet centreline. On the high-speed schlieren films, the unignited laminar jet core pulsated in a similar manner to the flickering motion of the flame inner cone. The centreline velocity for the unignited jets decayed to 20% of its burner-exit value in 20 to 40 diameters. In the flames, the mean centreline velocity of the turbulent products has no decay over 75 diameters but up to 50% fluctuation in the "point" velocity were measured from the films.

Another 2.6 mm torch tip was used to produce a vertical lifted flame. The only physical differences between the two tips were the rounding of the burner lip and roughness of the internal surface. The lifted portion, which was invisible to the naked eye, was approximately 20 diameters long; the visible blue flame was approximately 200 diameters high. The flame was quite noisy and the base of the visible flame fluctuated in its vertical position about 10 diameters. A very light-blue ring at the base of the visible flame slowly precessed around the flame axis. A schlieren film of this lifted flame illustrated several features, see Figure 3. The invisible unignited gases were injected into the core of the visible flame approximately the same distance as the height the flame was lifted above the burner exit. The enlargement of the structural scale in the flame (about 100 to 1,000 times) of the very small-scale high-frequency structure of the unignited gases almost totally stabilized the fluctuating gas motion. The flame was seen as a slowly fluctuating, continuous laminar surface in the 5,000 frames-per-second schlieren film.

4 CONCLUSIONS

Acoustic measurements show the LPG/O_2 welding-torch flames to be very noisy (with a sound power of approximately 100 dB) and to have large measured values of peak frequency and of sound-directivity angle. Large temperature gradients and/or fluctuations in the kilohertz range are most likely to be responsible for large values of directivity angle and peak frequency. With increasing flow velocity, flame noise increases while the transition to turbulence and the flame luminosity decrease.

Schlieren films of all unignited gas mixtures showed small-scale, high-frequency structure very similar to nonreacting cold jets. In ignited gas mixtures, the increase in kinematic viscosity by several orders-of-magnitude has a remarkable stabilizing or smoothing effect on the instability waves of the cold jet. The ejected small-scale, high-frequency "pipe flow" fluctuations are enclosed within the flame surface (illustrated by the lifted-flame schlieren) which eventually constitute a layer of high-viscosity burnt gases. These viscous gases produce a growth in the low-frequency component of large-scale eddy motion. The transition point from the laminar primary-reaction zone to the turbulent secondary-reaction zone has a major role in the structure and stability of the flame. The distance from the burner exit to this transition point decreases as the cold-flow velocity and Reynolds number increase.

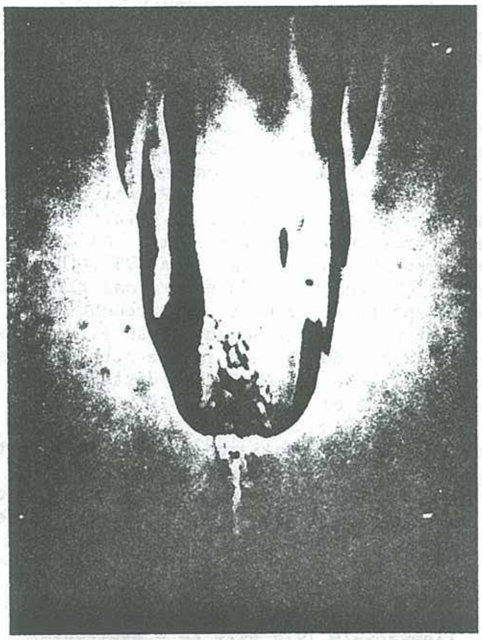

Figure 3 Schlieren photo of lifted LPG/O_2 flame

5 REFERENCES

BALLAL, D.R. (1981) Private communication.

RIBNER, H.S. (1964) The Generation of Sound by Turbulent Jets. Advances in Applied Mechanics, 8, pp.103-182.

STRAHLE, W.C. (1972) Some Results in Combustion Noise, J. Sound and Vibration, 23, pp.113-125.

TAKENO, T. and KOTANI, Y. (1978) Transition and Structure of Turbulent Diffusion Flames. Progress in Astronautics and Aeronautics, 58, pp.19-35.

YOSHIDA, A. and TSUJI, H. (1979) Measurements of Fluctuating Temperature and Velocity in a Turbulent Premixed Flame. Seventeenth Symp. (Int'l) on Combustion, pp.945-955.