POSSIBILITY OF CONTROLING POLLUTION EMISSIONS FROM A JET FLAME BY ACOUSTIC EXCITATION

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Introduction

It has been demonstrated that appropriate external excitation has obvious effects on enhancing fuel-air mixing, flame stability, and even on enhancing unsteady flame extinction, see for examples [1-4]. Recently Chao et al [5] showed that apparent NOx emission reduction can be achieved in a lifted, partially premixed jet flame due to the upstream entrainment associated with the large-scale vortices. Acoustic excitation with proper frequency and amplitude can further enhance turbulent mixing to a condition possibly leading to lean premixed combustion of a lifted jet flame that directly suppresses NOx formation. The results of Chao et al. [6] in an attempt to control NOx emission from a lifted jet flame by acoustic excitation show that cases of the unexcited liftoff flame and flames fundamentally and harmonically excited with low amplitude have significantly low NOx emissions. With strong mixing and large lift-off height in these flames the flame bases are found to be lean with excessive OH radicals and super-equilibrium mechanism may be the dominant NOx formation pathway leading to low NOx emission. On the other hand, it has been extensively investigated that flow and flame interaction strongly affects the formation of NOx in attached turbulent flames such as coflowing (Chen and Driscoll [7]), residence time and Damkhler number (Driscoll et al. [8]), fuel dilution and partial premixing (Turns et al. [9]), and radial air injection (Turns and Brooks [10]). Therefore, further experimental investigation to manipulate the flame/flow interaction in an attached jet flame using external acoustic excitation is warranted to explore the feasibility of further controlling the pollution emissions.

Experimental Setup

The essential features of the current setup and measurement instruments are shown schematically in Fig. 1. The experiments are carried out on a coaxial burner consisted of a 5mm-diameter central nozzle and a 30mm-diameter coaxial air jet. Two large-size high-efficiency loud speakers with good frequency response down to 10 Hz are used for acoustic excitation. The speakers are fixed on the settling-chamber wall of the coaxial burner. The amplitude of the acoustic excitation is monitored using the probe microphone at the exit of the coaxial burner. Two different amplitudes, one at near 75db and the other at near 80db for different excitation frequencies are used to excite the coaxial flow of the flame. Pure propane or propane partially premixed with same amount of air at an equivalent ratio of 24 emerges from the central nozzle to produce either a diffusion or a partially premixed flame for comparison to distinct the effect of partial premixing. The exit Reynolds number based on the central jet diameter is 4800. To look further into the effect of coaxial flow the coaxial air to central jet velocity ratio varies from 0.2 and 0.1, for the cases of diffusion and partially premixed respectively, to a relatively high ratio of 2.5. These effects can be combined into four major flame configurations: one is pure diffusion without coaxial flow (designated as PD), one is partially premixed without coaxial flow (as PP), one is pure fuel with coaxial flow (as CD), the other is partially premixed flame with coaxial flow (as CP). The major apparatus used include, a probe microphone for monitoring the acoustic excitation, the hot-wire anemometer for the spectral characteristics of the excited flow, a R-type thermocouple for temperature, the laser Doppler velocimetry (LDV) system for turbulent velocity and strain rate, gas analyzers for post-flame pollution concentrations, the planar laser induced fluorescence system (PLIF) for mapping the NO and OH concentration profile.

Results and Conclusion

In the study of the effects of coaxial air and mixing parameters on nitric oxide level in a jet flame, the major conclusions drawn by Chen and Driscoll [7] are: NOx emission index (EINOx) scales with the cube of flame length and coaxial air reduces the flame length and EINOx, deviation from the scaling for methane flame may be due to significant prompt NOx, and flame liftoff does not affect the NOx trend. However, Chao et al. [6] in their study of the partially premixed liftoff flame under acoustic excitation, they found that low Nox emission can be correlated with large liftoff height and intermediate liftoff flame length yielding low NOx emission while short and long liftoff flame lengths generate high NOx emission. Intermediate-length flames are cases of the unexcited liftoff flame and flames fundamentally and harmonically excited with low amplitude that generally have large liftoff height. For the attached propane jet flames in the present study, acoustic excitation is applied at the coaxial jet and the typical resultant flame images for the CD and CPP cases are shown in Fig.2. Obviously, low-frequency excitation, especially at 30 Hz, can reduce the flame length. Flame bulges prevail in the low-frequecy excited flame and the high-frequency excited flame is similar to the diffusion flame. The pollution emissions, in terms of EINOx and EICO, from flames excited at different frequencies and amplitudes for the CD and CPP cases at a coaxial to central jet velocity ratio (U_0 /U_I) of 1 are comparted with the unexcited PD and PP cases in Fig. 3. The effect of coaxial to central jet velocity ratio (U_0 /U_I) for a typical case excited at 30Hz and 75db is shown in Fig. 4. In general, partially premixing has a positive effect on NOx reduction. Reduction of both EINOx and EICO using acoustic excitaion with a suitable combination of frequency and amplitude is possible, for example the CD flame excited 30Hz and 80db with U_0 /U_I=1 and other cases. High-velocity-ratio coaxial flow with suitable acoustic excitation can effectively reduce pollution emissions. The NOx reduction due to acoustic excitation can be related to the flame length reduction. The effective reduction of NOx for the low frequency excitation cases can be related to the enhanced outer vortices, similar the low-frequency buoyant outer vortices in the literature, which generate flame bulges. These outer vortices entrain the coaxial air to the flame surface that effectively cools off the downstream high temperature thermal NOx region. These outer vortices also change the strain characteristics of the downstream flame that affects the polltion formation characteristics. The effect of coaxial flow on NOx reduction can be related to mixing and strain characteristics between the flame and the coaxial flow.

References

1. Chao, Y.C., and Jeng, M.S., *Twenty-Fourth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, 1992, pp. 333-340.
2. Chao, Y.C., Yuan, T., and Jong Y.C., *Exp. in Fluids* 17:381-389 (1994).
3. Egolfopoulos, F.N., *Twenty-Fourth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, 1992, pp.1365-1373.
4. Kistler, J.S., Sung, C.J., Kreutz, T.G., Law, C.K., and Nishioka, M., *Twenty-Sixth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, 1996, pp. 113-120.
5. Chao, Y.C., Yuan, T., and Tseng, C.S., Combust. Sci. Tech. 113-114: 49-65 (1996).
6. Chao, Y.C., Wu, D. C., and Tsai, C.H., “Effects of Acoustic Excitation and Initial Premixing on the Pollution Emission Characteristics of a Jet Flame”, submit to International J. of Transport Phenomena, (1999).

7. Chen, R. H. and Driscoll, J. F., *23rd Symposium (International) on combustion*, The Combustion Institute, Pittsburgh, 1990, pp. 281-288.
8. Driscoll, J. F., Chen, R. H. and Yoon, Y., *Combust. Flame*, Vol. 88, pp. 37-49 (1992).
9. Turns, S. R., Myhr, F. H., Bandaru, R. V. and Maund, E. R., *Combust. Flame*, Vol. 93, pp. 255-269 (1993).
10. Turns S. R. and Brooks, B. K., *Combust. Sci. and Tech.*, Vol. 103, pp. 175-189 (1994).

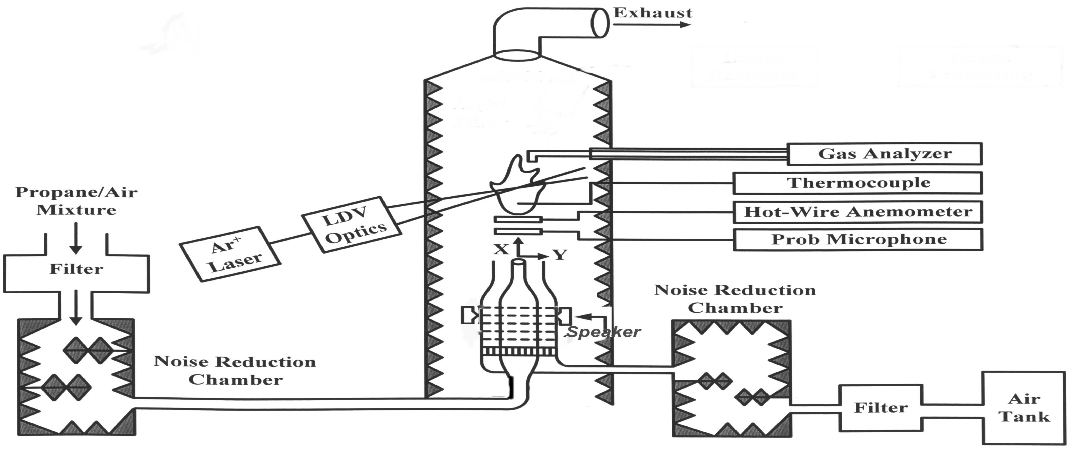
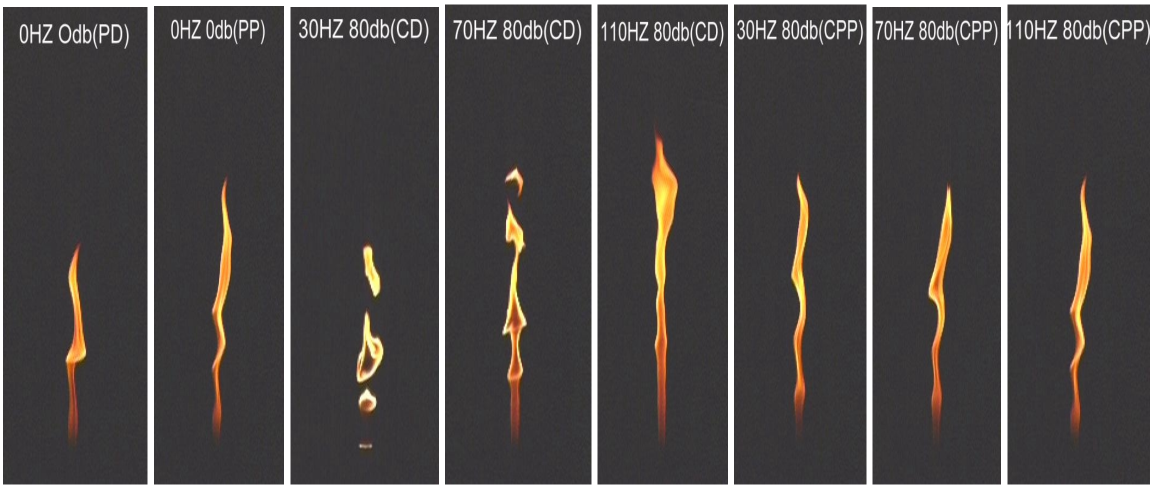


Fig.1 Schematic of the experimental setup and instrumentation



(a) (b) (c) (d) (e) (f) (g) (h)

Fig.2 Typical flames images of excitation conditions of: (a)0Hz 0db PD (b)0Hz 0db PP (c)30Hz 80db CD (d)70Hz 80db CD (e)110Hz 80db CD (f)30Hz 80db CPP (g)70Hz 80db CPP (h)110Hz 80db CPP

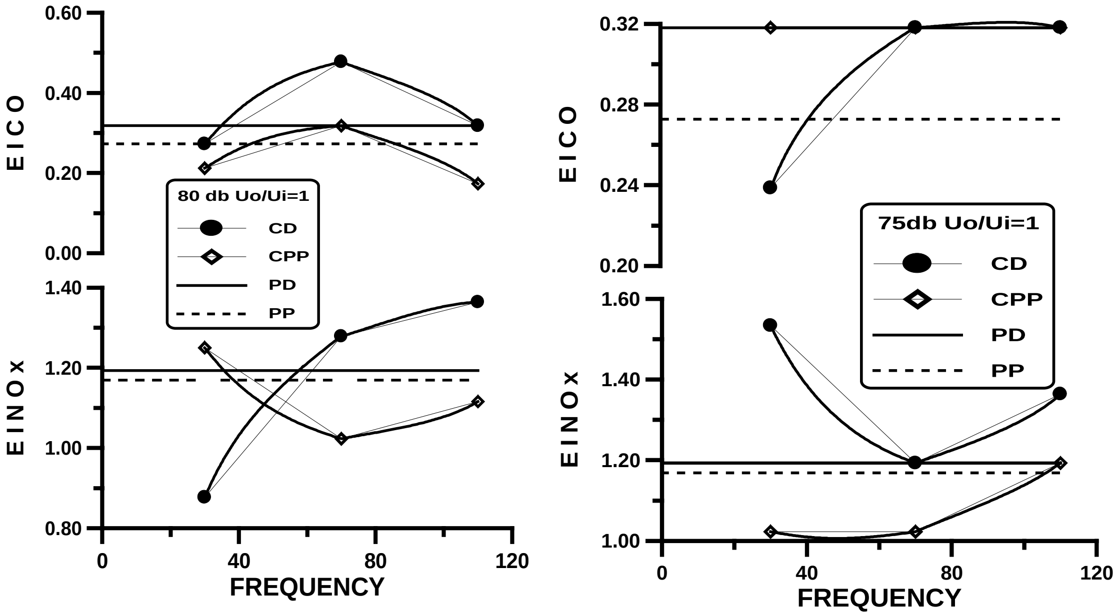


Fig.3 The effects of acoustic excitation for different flame configurations at the coaxial to central jet velocity ratio of Uo/Ui=1 on the pollution emission indices of NOx and CO

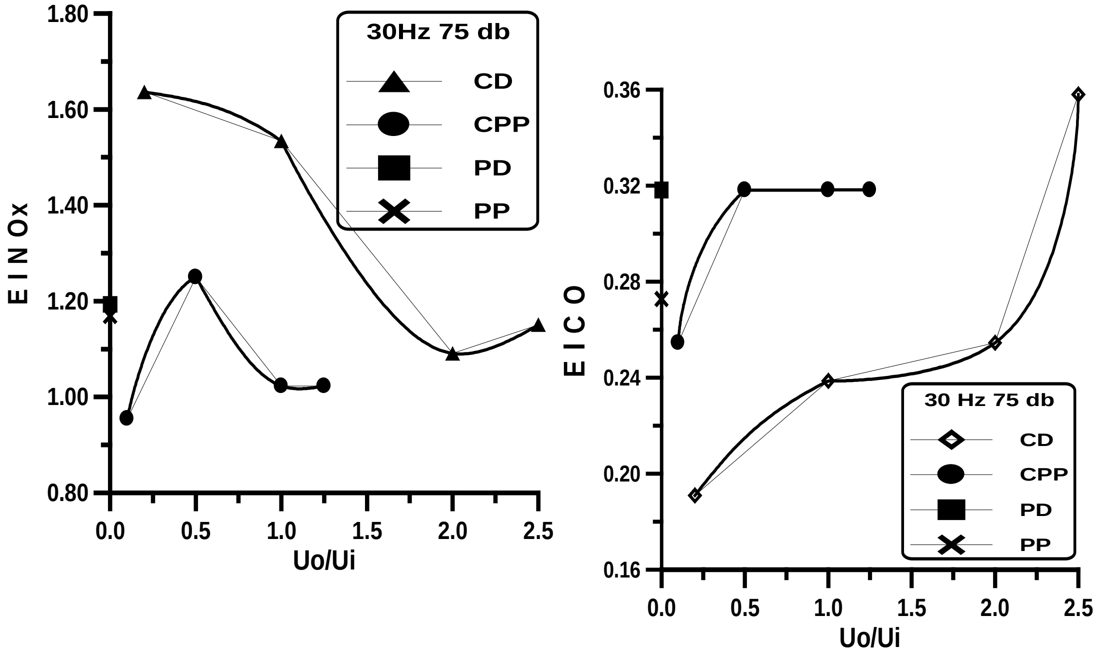


Fig.4 The effect of the coaxial to central jet velocity ratio on the NOx and CO pollution emission indices.