Title: **Investigation on the Flame Extinction Limit of Fuel Blends**

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Objectives:

The objective of this project is to understand the flame extinction behavior of fuel blends. However, the current study concentrates on generating flammability (flame extinction limit) maps of different compositions of methane-propane and methane ethane fuel blends with varying stoichiometry. This particular fuel combinations were selected because they are the primary constitutes of the natural gas and the extinction behavior of natural gas is the primary focus of the present study. The influence of mixture composition and flame stretch rate on flame extinction behavior of hydrocarbon fuel blends was studied. Since most of the fuel blends have peculiar behavior at the limit, the present study measured only the lean extinction of blended fuel flames. Based on experimental measurements, a generalized empirical model was sought for the flame extinction behavior of methane-propane and methane-ethane fuel blends. Validity of the currently practiced flame extinction limit rule (Le Chatelier approximation) for fuel blends was also investigated.

Accomplishments To Date:

Lean flame extinction limits of binary fuel mixtures of methane (CH_4), propane (C_3H_8), and ethane (C_2H_6) were measured using a twin-flame counter-flow burner (Figure 1). Experiments were conducted to generate an extinction equivalence ratio vs. global stretch rate plot and an extrapolation method was used to calculate the equivalence ratio corresponding to an experimentally unattainable zero-stretch condition. The details of the experimental setup and methodologies are presented elsewhere[1]. Figure 2 shows twin flames of methane 80-20% CH_4-C_3H_8 mixture from inception to extinction.

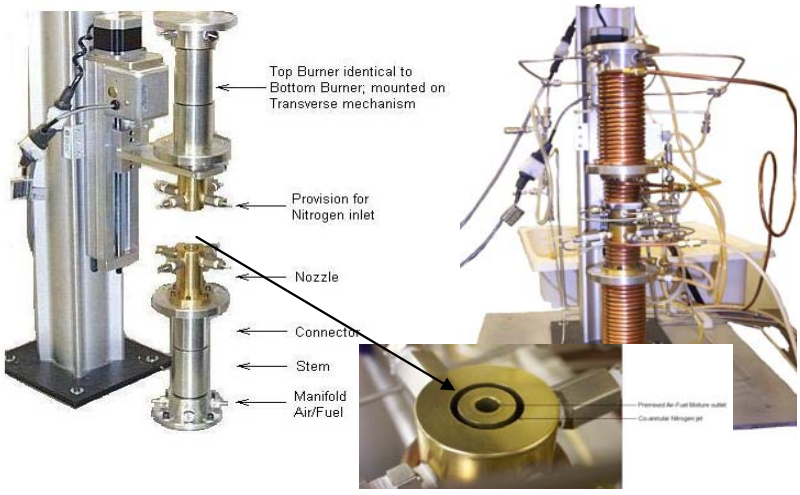

Figure 1. Twin-Flame Counter-Flow Burner Setup

To validate the experimental setup and methodology, the flame extinction limit of pure fuels at zero stretch conditions were also estimated and compared with published values. The lean flame

extinction limits of methane (f_{ext} = 4.6%) and propane (f_{ext} = 2.25 %) flames measured in the present study agreed with the values reported in the literature. It was observed that the flame extinction limit of fuel blends have a polynomial relation with the concentration of component fuels in the mixture. This behavior contradicts with the commonly used linear Le Chatelier's approximation. The experimentally determined polynomial relations between the flame extinction limits of fuel blends (i.e. methane-propane and methane-ethane) and methane concentration are as follows:

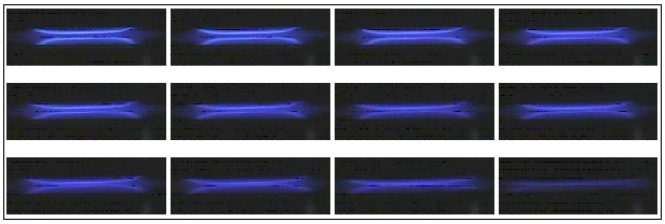

Figure 2: Twin-flame images of 80% CH_4 – 20% C_3H_8 fuel blend, from formation to just before extinction at a flame-stretch ~ 800 sec^{-1}

Methane-Propane

$$\%\, f_{ext} = \left(1.05\times10^{-9}\right) f^5 - \left(1.3644\times10^{-7}\right) f^4 + \left(6.40299\times10^{-6}\right) f^3 - \left(1.2108459\times10^{-4}\right) f^2 + \left(2.87305329\times10^{-3}\right) f + 2.2483$$

Methane-Ethane

$$\%\, f_{ext} = (2.1\times10^{-9}) f^5 - (3.5752\times10^{-7}) f^4 + (2.095425\times10^{-5}) f^3 - (5.037353\times10^{-4}) f^2 + 6.08980409\, f + 2.8923$$

Where f_{ext} is the extinction limits of methane-propane and methane-ethane fuel blends, and f is the concentration (% volume) of methane in the fuel mixture. The relations were obtained by fitting fifth order curve (polynomial regression) to experimentally measured extinction limits at different mixture conditions. To extend the study to a commercial fuel, the flame extinction limit for Birmingham natural gas (a blend of 95% methane, 5% ethane and 5% nitrogen) was experimentally determined and was found to be 3.62% fuel in the air-fuel mixture.

List of Paper Published:

[1] Franco, R., Subramanya, M., and Choudhuri, A., "Investigation on the Flame Extinction Limits of Fuel Blends," AIAA 2005-3586.
[2] Subramanya, M. and Choudhuri, A., "Experimental Investigation on the Flame Extinction Limits of Fuel Blends," AIAA 2005-0374.

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[1] Choudhuri, A. R., Investigation on the Flame Extinction Limit of Fuel Blends, Final Technical Report, Department of Energy Grant DE-FG26-03NT41917, January 2005