Blowout Limits of Diluted Jet Flames

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INTRODUCTION

For several decades, the stabilization mechanisms and blowout limits of a jet diffusion flame were studied and discussed in detail. Various models and physical mechanisms have been proposed to delineate the liftoff behaviors and blowout limits. Models used to predict blowout velocities are in general in good agreement with experimental data for various types of fuels, especially those proposed by Kalghatgi [1] and Broadwell et al. [2]. However, some of the predictions were found to deviate from the experimental data for diluted flames, such as CO_2-CH_4, air-CH_4, CO_2-C_3H_8 [2], and air-H_2 flames [3]. Briefly, blow out velocity can be estimated simply base on the properties of the fuel stream at jet exit. Nevertheless, there has not been any complete experimental verification of blowout velocity of diluted jet diffusion flames. This motivates the current experimental investigation of blowout velocity of various gaseous jet flames of H_2, CH_4, and C_3H_8 diluted with different inert gases, such as He, Ar, N_2, and CO_2. All results are compared with models proposed by Kalghatgi and Broadwell, and modifications are also proposed.

EXPERIMENTAL SETUP

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The jet burners was a 500mm long tube with 5mm in diameter for diluted propane and methane flames, and 2.5mm in diameter for diluted hydrogen flame respectively. High purity fuels (methane, propane, and hydrogen) and diluents (Helium, Argon, Nitrogen, and Carbon Dioxide) were used and supplied from cylinder. Fuels and diluents were metered by rotameters and electronic flow meters. Readings of rotameters and electric flow meters were recorded to calculate the experimental blowout velocity that defined as the bulk fuel stream velocity when the flame blows out.

RESULTS

For diffusion flames, He-, Ar-, N_2, and CO_2-diluted methane, propane and hydrogen mixtures were used and burnt in still air. The blowout velocity calculated based on the total volume flow rate including fuel and inert, and the volume fractions of inert were increased step by step. To verify the accuracy the current results, blowout velocity data of methane and propane diluted with carbon dioxide by Kalghatgi [1], blowout velocity estimation based on by Broadwell's model [2], and current results are compared in Fig. 1. Current results with extended inert dilution level agreed very well with Kaghatgi's results [1]. This implies that the current experiment can accurately reproduce Kalghatgi's data and the mixtures were tested under a condition similar to Kalghatgi' s work. However, the Broadwell's blowout prediction [2] was found to deviate from experimental results.

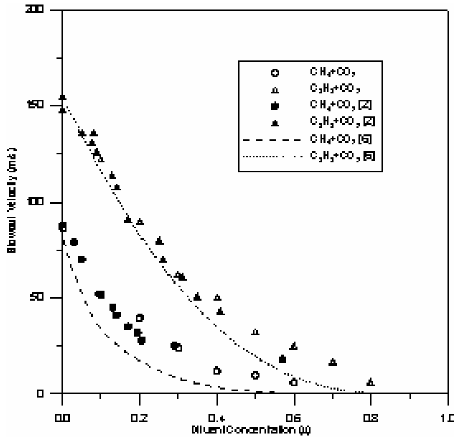

Fig. 1

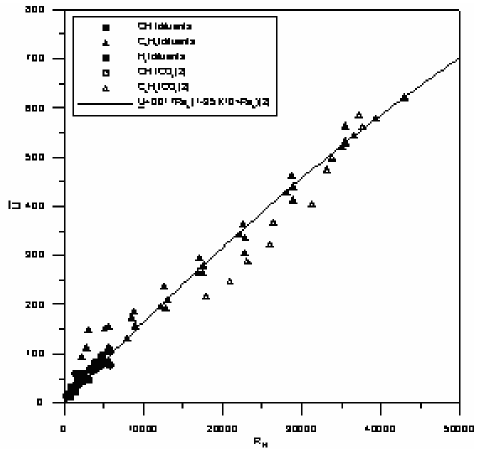

Fig. 2

Having obtained experimentally the blowout velocities of the inert-diluted cases and in order to compare with the "Universal Formula" proposed by Kalghatgi [1], was calculated. The relationship between U and R_H was obeyed despite the fuels were diluted with different levels of diluents and shown in Fig. 2 . Thus, it can be seen that the blowout velocity of fuels and fuel/diluents mixture can be estimated by the universal formula.

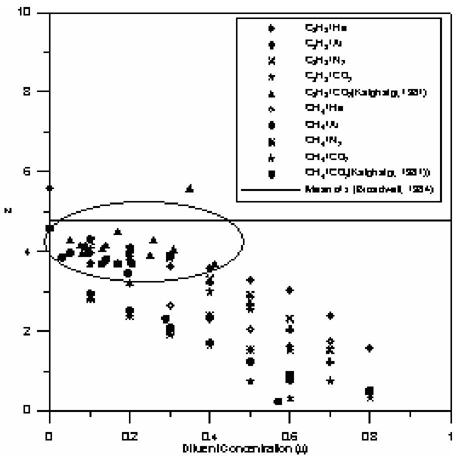

Fig. 3

The foundation of Broadwell's theory [2] is the competition between vortical mass transport rate and chemical reaction rate. The blowout parameters were calculated. To look into the relation between *e* and diluents concentration, *e* of each kind of fuel/diluents including results calculated based on the blowout velocity obtained by Kalghatgi[1] are plotted against diluents concentration in Fig. 3. Obviously, *e* is not a constant especially in the case of highly diluted fuel, it decreases with increasing diluents concentration. However, most of ε's based on blowout velocities obtained by Kalghatgi[1] of limited dilution distribute in a rather flat region as marked in Fig.3, and the deviation is rather unimportant when they used Kalghatgi's data[1] to verify their formula. In order to explorer the effect of mixing remained in a turbulent blowout jet,

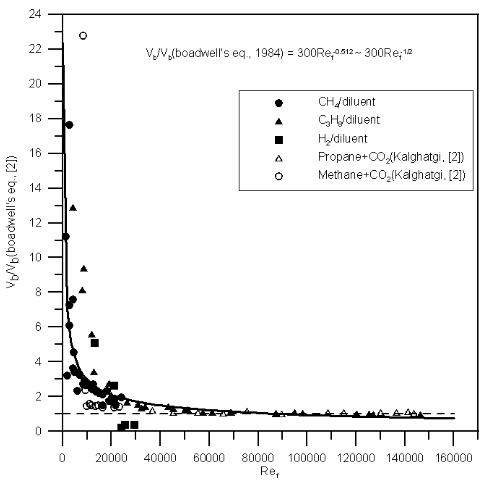

Fig. 4

blowout velocity normalized by blowout velocity estimated by Broadwell's model against fuel Reynolds number was plotted in Fig. 4. In Fig. 4, all resultant data can be collapsed on a linear line very well. An empirical formula, defined as U_e/U_{em}(based on Boadwell's eq.,[2]) =

$300Re_f^{-0.512} \sim 300Re_f^{-1/2}$, can be obtained from curve fitting. The exponent of Re_f is approximate to 0.5. Furthermore, the ratio of U_{em} to U'_{em} is equal to unity when Re_f is larger than 30,000. In other words, blowout estimation based on large scale model can be applied with good accuracy when Re_f is larger than 30,000.

CONCLUSION

Examination and verification of blowout limits estimated by premixed model and large-scale model in inert-diluted flames were performed experimentally. Inert-diluted including helium, argon, nitrogen, and carbon dioxide, methane, propane, and hydrogen flames were tested. Based on current results, most of the cases tested can fairly collapse into the universal formula proposed by Kalghatgi [1]. On the other hand, the ratio of experimental blowout velocity to blowout velocity based on Broadwell's theory approximated to unity when fuel Reynolds number larger than 30,000. However, blowout estimations based on large scale vortex model can do as well after proper modification by including the Reynolds number effect Re_f.

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