

Measurement of Laminar Flame Speed of DME-Air Diluted CO₂/N₂ Mixtures at Elevated Temperatures

Akram Mohammad^{1,*}, Abdul Naseer Mohammed¹, Khalid A. Juhany¹, Sudarshan Kumar², Ratna Kishore V³,

¹*Department of Aeronautical Engineering, King Abdulaziz University, Jeddah, Saudi Arabia*

²*Department of Aerospace Engineering, Indian Institute of Technology Bombay, Powai, Mumbai, India*

³*Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, Amrita University, India.*

Abstract:

The laminar flame speed of CO₂/N₂ diluted dimethyl ether (DME)air mixtures is determined experimentally at atmospheric pressure and elevated mixture temperatures over a range of mixture equivalence ratio ($0.8 \leq \Phi \leq 1.3$) using a mesoscale high aspect-ratio diverging channel. In this method, planar flames at different initial temperatures were stabilized inside the channel using an external electric heater. The magnitude of burning velocities was acquired by measuring the flame position and initial temperature. The mass conservation of the mixture entering the inlet and the stationary planar flame front is applied to obtain the flame speed. The laminar flame speed at different initial mixture temperatures is plotted with temperature ratio for the diluted mixtures where a reference temperature of 300 K is used. Enhancement in the laminar flame speed is observed with mixture temperature for DME-air mixtures with CO₂ and N₂ dilutions. A significant decrement in the flame speed is observed with the increase in dilution with a marginal increment in temperature exponent with dilution. The addition of CO₂ has profound influence when compared to N₂ addition on both flame speed and temperature exponent.

1. Introduction:

Growing concern over global warming and environmental pollution due to the increasing amount of exhaust emission particularly CO and NO_x emission have intensified the search for high-efficient, low emission alternative fuel for the automobile industry in recent years. One such fuel which received considerable attention as an alternative fuel is Dimethyl ether (DME)[1–7]. The presence of high oxygen content (about 35% by mass) reduces the particulate formation which contributes to almost smokeless (clean) combustion [1]. However exhaust gas recirculation (EGR) or mixture dilution techniques are been widely used presently to further reduce the NO_x emission and the combustion temperature, DME, in particular, has a high tolerance to EGR [4].

One of the important fundamental combustion characteristics of a fuel is the laminar flame speed as it illustrates the information on reactivity, diffusivity and heat release rate of the combustible mixture and also helps in development and validation of chemical kinetics' mechanism and in predicting the dynamic instabilities, flame flash back and blown off limits [2,8]. The accurate knowledge of flame speed helps in understanding the combustion characteristics of various fuel-air mixtures. Considering the importance of this parameter, various methods have been established in past for the flame speed measurement [9–13], the measurement of laminar flame speed for DME-air mixtures have been determined experimentally over past few years [1–4,8,14,15]. Daly et al.[1] used the spherical vessel method to report the flame speed of DME-air mixture at ambient conditions whereas Zhao et al.[2] Used the stagnation flame method to report the

flame speed, however, the predicted flame speed by Zhao et al.[2] is comparatively higher than Daly et al.[1]

2. Experimental method:

A high aspect ratio diverging channel method has been used for the measurement of laminar flame speed as shown in Fig 1. The details of the method can be found elsewhere [16]. The CO₂/N₂ diluted DME-air mixture was supplied to channel through electric mass flow controllers (MFCs). The unburned mixture gets ignited near the exit of the channel where the temperature reaches its auto-ignition temperature. The flame front moves upstream and stabilizes at a location where the mixture velocity equals to the flame speed at that particular temperature. The one-dimensional stabilize flame front position was captured by using a digital camera. The wall temperature measurement of the stabilize flame location was carried out by using the K-type thermocouple.

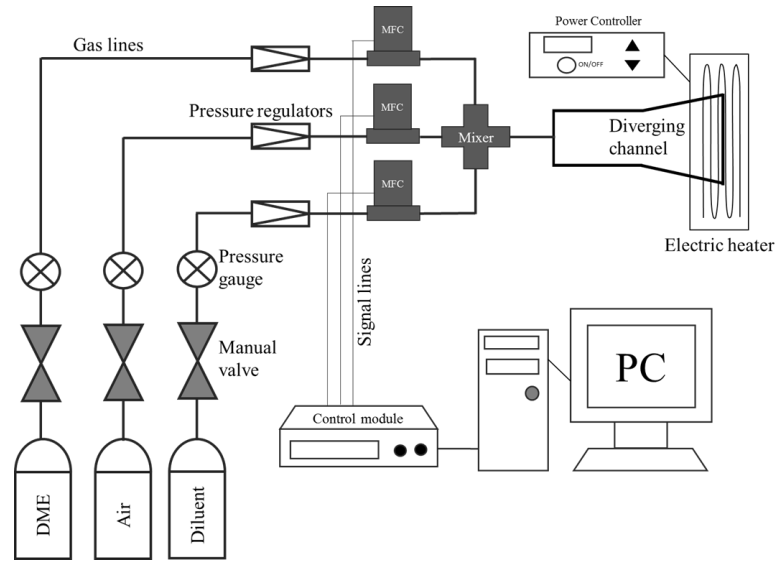


Figure 1: Schematic of the experimental setup

The stabilized planar flame at a different location for different mixture velocities was used in extracting the flame speed. The position of the stationary stabilize planar flame inside the diverging channel is captured by means of a digital camera and the exact flame (A_f) area was calculated. It is to be assumed that the temperature attained by the mixture is equal to the wall temperature (T_u) of the channel. The flame speed is obtained by using the following conservation of mass equation.

$$S_l = U_{inlet} (A_{inlet} / A_f) (T_u / T_o) \quad (1)$$

3. Result and Discussion:

The present work emphasizes on the effect of inert gas dilution on laminar flame speed. The magnitude of diluted CO₂/N₂ DME-air mixtures for the range of equivalence ratios ($\Phi=0.8-1.3$) and different elevated temperatures (300-600K) have been determined experimentally. The dilution ratio is expressed in terms of percentage of the volume added to the fuel stream, for instance, if 10% CO₂ is added, the fuel stream consists of 10% CO₂ and 90%DME. The percentage dilution (ϕ_d) is calculated in terms of the volume of

diluent added to the fuel to the total volume of the fuel that is (fuel + diluent). The initial temperature and pressure for the entire experiment were maintained at 300K and 1atm respectively. The variation of flame speed S_l was plotted against the ratio of mixture temperature and initial temperature by applying the power law correlation as follows.

$$S_l = S_o \times (T_u/T_o)^\alpha \quad (2)$$

The laminar flame speed for both dilutions increases with the increase in mixture temperature at any mixture equivalence ratio. The measured flame speed was compared with the computational results of Zhao et al. mechanism [17]. Which are close with the experimental results at higher mixture temperature. The measured flame speed is extrapolated at different mixture temperature by using the magnitude and temperature exponent obtained at ambient conditions for all the cases.

3.1. Influence of CO₂ dilution:

Figure 2 shows the variation of the laminar flame speed of lean ($\Phi=0.8$) and rich ($\Phi=1.3$) mixtures. The continuous line was obtained by applying the power law trend line, while the error bar shows the uncertainty in measurement. The obtained magnitudes are in close agreement with the computational results for higher mixture temperatures.

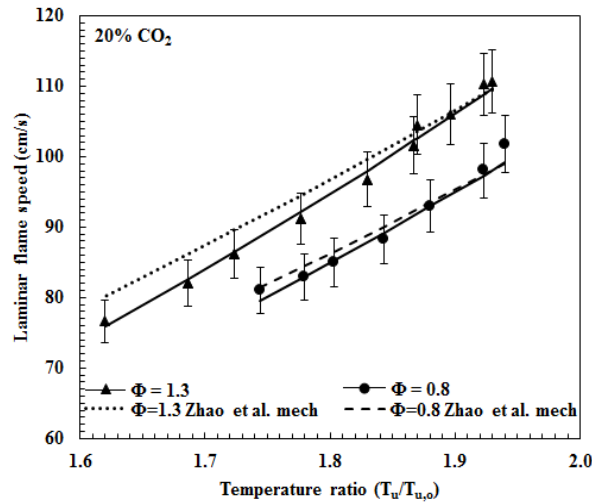


Figure 2: Laminar flame speed of 20% CO₂ diluted DME-air mixtures at elevated temperatures

Figure 3a shows the variation of laminar flame speed against the equivalence ratio for CO₂ diluted DME-air mixtures. The magnitude of laminar flame speed decreases with the increase in dilution ratio for all equivalence ratios. The peak flame speed was obtained at slightly rich mixture for all the dilution cases.

Temperature exponent (α) is a strong function of equivalence ratio. The magnitude of the temperature exponent increases with the dilution. The temperature exponent of the diluted mixture varies just as the laminar flame speed. The variation of temperature exponent for the CO₂ diluted case is shown in Fig. 3b, which is reported to be slightly higher than the N₂ dilution. The reported temperature exponent has a minimum value at slightly rich mixture which is opposite to the flame speed magnitude at slightly higher mixture

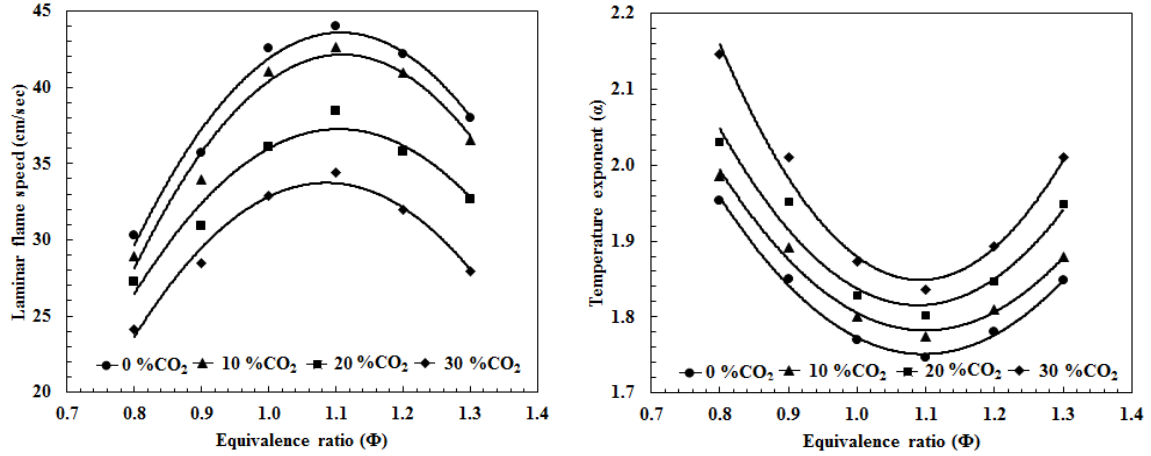


Figure 3: (a) Laminar flame speed and (b) temperature exponent of CO₂ diluted DME-air mixtures at ambient conditions

4.2 Influence of N₂ dilution:

Figure 4 shows the variation of the laminar flame speed of lean ($\Phi=0.9$) and rich ($\Phi=1.1$) mixtures with the continuous line shows the power law trend line, while the error bar shows the uncertainty. The laminar flame speed for the N₂ dilution case increase with the increase in mixture temperature but has a less pronounced effect on laminar flame speed as compared to CO₂ dilution. The obtained magnitudes are compared with the computational results symbolize with the dashed lines are reported to be under the uncertainty range for higher mixture temperatures.

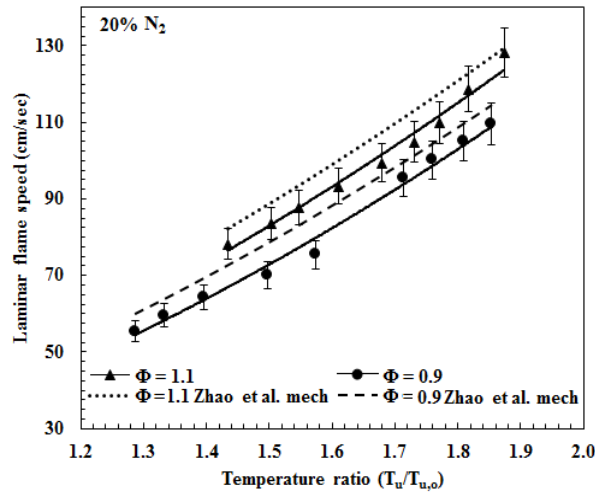


Figure 4: Laminar flame speed of 20% N₂ diluted DME-air mixtures at elevated temperatures

Figure 5a shows the variation of laminar flame speed against the equivalence ratio for N₂ diluted DME-air mixtures. The decreases in the magnitudes of laminar flame speed are almost linear with the increase in dilution ratio. The reduction in the magnitudes of laminar flame speed is less compared to the magnitudes of CO₂ dilution

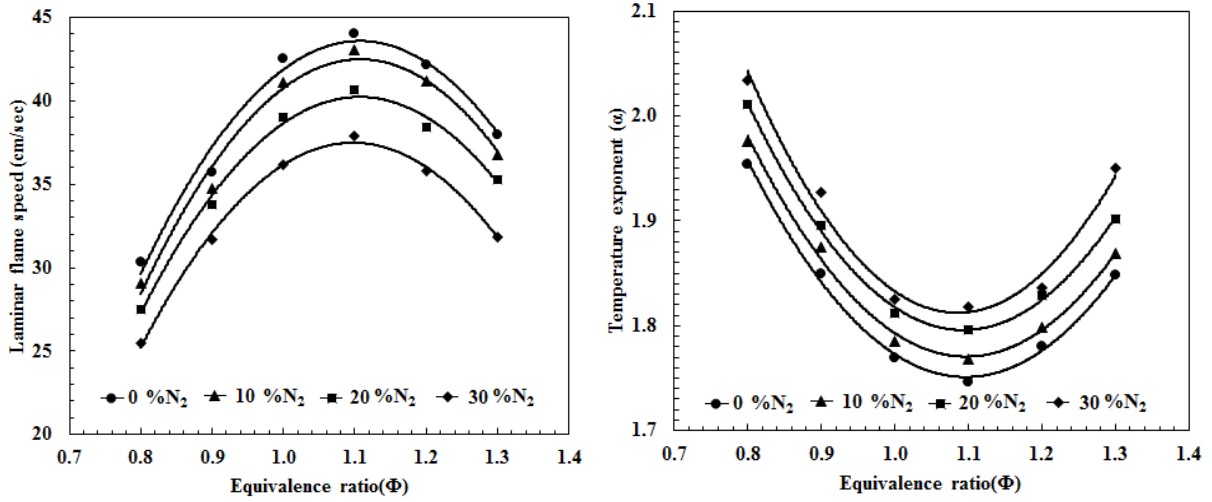


Figure 5: (a) Laminar flame speed and (b) temperature exponent of N_2 diluted DME-air mixtures at ambient conditions.

The magnitude of the temperature exponent for N_2 dilution case increases linearly with the dilution but the variation of temperature exponent has less effect compared to CO_2 diluted case as shown in Fig.5b.

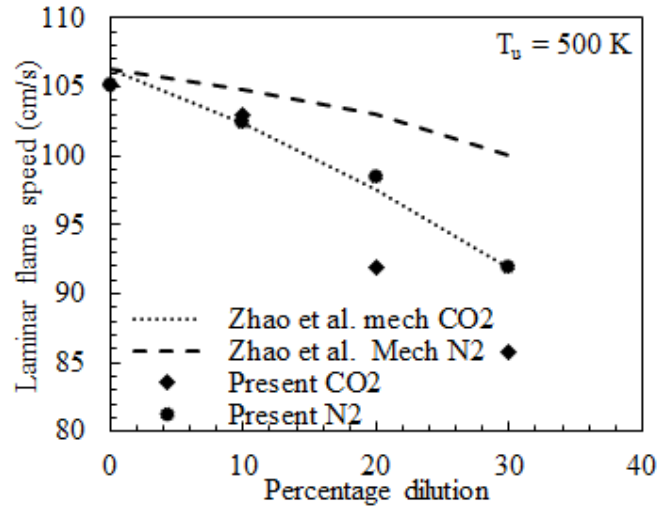


Figure 6: Comparison of present experimental and computational laminar flame speed of stoichiometric DME-air mixture with different CO_2 and N_2 dilutions at 500 K

Figure 6 shows the comparison of laminar flame speed of stoichiometric DME-air mixture obtained present experiments and computational predictions of Zhao et al. mech at 500 K for both CO_2 and N_2 at different percentage dilutions. Mechanism compares well for pure DME-air mixtures at all temperatures. However, it consistently over-predicts the flame speed for all dilution cases. A similar under-prediction is observed for temperature exponent with inert gases percentage dilution.

4. Conclusion:

It can be concluded from the present study that laminar flame speed of DME-air mixture increases with temperature and reduces with dilution of inert gases. Zhao et al. mechanism predicts both laminar flame speed and temperature exponent for pure DME-air mixtures. However, mechanism over-predicts the flame speed and under-predicts the temperature exponent.

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