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The effect of Lewis number on radiative extinction and flamelet modeling

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Abstract

This study investigates the influence of Lewis number on radiative extinction and flamelet modeling. The interaction of Lewis number with different transient effects, such as fluctuating reactant concentrations, fluctuating reactant temperatures, and variable partial premixing, are considered. The results underscore the importance of including the effect of non-unity Lewis numbers and their interaction with chemistry and unsteadiness in improving the predictive capability of flamelet combustion modeling approach, and in precise determination of radiation-induced extinction limits. An increase of Lewis pushes the radiation-induced extinction limit, which occurs at low strain rates, toward higher values of strain rates. © 2002 Published by Elsevier Science Ltd.

1. Introduction

Lewis number, which relates the rates of heat and mass diffusion of various species, is an important parameter in combustion studies. Despite the early recognition of the importance of unequal rates of diffusion on the flame's structure and stability [1], the assumption of unity Lewis number has been common in many combustion modeling approaches. It is a convenient, and in many cases a reasonable, assumption that provides ease in obtaining analytical and numerical solutions and helps simplifying the experimental data interpretations. However, in some applications, this assumption may lead to significantly erroneous conclusions. In turbulent flames, for example, the effect of non-unity Lewis number may be responsible for the discrepancies between the measured and the predicted mass fraction of combustion intermediates [2]. This effect has been reported to influence the flame's thermal structure and extinction mechanism of premixed flames [3,4] and of diffusion flames [5–8]. Non-unity Lewis number effect is also shown to influence the NO_x emission levels [9], and induce temperature oscillations in diffusion flame [10,11]. In turbulent jet diffusion flames, the effects are noted in both low and high Reynolds number flames [12].

Non-unity Lewis number results when there is preferential mass diffusion (due to unequal rates of mass diffusion of various species), or when the rates of heat and mass diffusion are unequal even in the absence of preferential diffusion. The preferential diffusion effect becomes important when there is a large disparity of diffusion rates of various species present. For example, in a hydrogen–air jet diffusion flame, Katta et al. [10] found that the preferential diffusion affects both the temperature and species concentrations. It also complicates the flame stretching phenomenon. However, Sanders and Gokalp [13] showed that the inclusion of preferential diffusion effects might not always give better predictions of temperature and species concentrations. Using turbulent hydrogen–air diffusion flames, they found that suppression of the differential effects (by considering unity Lewis number) in the far field improves the prediction of NO mass fractions. However, the suppression of these effects in the near field results in underestimation of NO.

Lewis number also strongly influences the flame structure [5]. Cuenot and Poinsot studied the influence of non-unity Lewis number resulting from both preferential diffusion and thermo-diffusive effect. Their

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Nomenclature

a_P	Planck's mean absorption coefficient
A	pre-exponential factor, amplitude
c_p	constant pressure specific heat of the mixture
D_i	coefficient of diffusivity of species
E	activation energy
f	frequency, pressure gradient in radial direction
g	pressure gradient in axial direction
h	enthalpy
$h^0_{\mathrm{f},i}$	enthalpy of formation of species i
Le	Lewis number
MW_i	molecular weight of species i
P	pressure
Q_R	radiant heat flux vector
r	spatial coordinate
R	universal gas constant
T	temperature
t	time
u, u_r	tangential or radial velocity
v, u_z	axial velocity
Y_i	mass fraction of species
z	spatial coordinate

Greek symbols

α	thermal diffusivity
ε	strain rate
η	similarity transformation variable
λ	thermal conductivity of the mixture
μ	dynamic viscosity of the mixture
ν	mass based stoichiometric ratio
ρ	mass density
σ	Stefan–Boltzmann constant
ψ	similarity transformation variable
ω	mass production rate
ω_i	mass production rate of species i

results show that when the two (oxidizer and fuel) Lewis numbers are equal and lower than unity, higher diffusion rates of the reactants enhance the straining effects and the flame is quenched at a lower dissipation rate. And when the Lewis numbers are greater than unity, critical dissipation rate is found to be higher than the reference value. However, when the Lewis numbers are different, critical dissipation rate can take any value, depending on reactant temperatures and stoichiometric ratio. The effect of Lewis number on the flame quenching (extinction) is also studied by Abdel-Gayed et al. [14]. Their results show that non-unity Lewis numbers are responsible for greater quenching effects on the lean hydrocarbon and richer hydrogen mixtures.

The present study is motivated by realizing that the quantitative predictive understanding of many combustion phenomena can significantly be improved by incorporating the influence of non-unity Lewis number. The main focus of the study is on the interaction of non-unity Lewis number with the coupled effect of radiation, chemistry and unsteadiness. The investigation of such an interaction, which has not been *explicitly* studied, will improve inter alia the flamelet approach of turbulent combustion modeling and specification of radiation-induced extinction limits of diffusion flames.

Flamelet modeling is a popular approach used in turbulent combustion. In this approach, the local structure of the reaction zone is considered to be composed of a series of quasi-steady strained laminar flame elements. The validity of the steady state assumption has been challenged in some recent studies [15–17] by showing that the transient effects are also important. Consequently, there has been a growing interest in the study of time-dependent effects on flamelet combustion [2,15–23]. The majority of these studies are on the effect of time varying strain rates, but the effects of the other parameters, such as reactant concentration and reactant temperature fluctuations, and unsteady partial premixing, have also been studied [21–23]. The results of these studies demonstrate that the quasi-steady model may not always correctly predict the flame response to time-dependent changes. Our recent work on variable reactant concentration [23] clearly shows the existence of a regime where the quasi-steady assumption does not hold, and its use will lead to erroneous conclusions. Similar results were found by Egolfopoulos and Campbell [21] for flames subjected to different unsteady fluctuations. The results of these studies suggest modification of the flamelet modeling by including the transient effects. However, none of the previous studies investigates the improvement of flamelet modeling by including the influence of Lewis number and its interaction with transient fluctuations. Consideration of the effect of non-linear coupling between unsteadiness, radiation, chemistry and non-unity Lewis number is very important in developing any recipe for improving the flamelet modeling approach.

The specification of radiation-induced extinction is another motivation for the present study. Radiative extinction becomes important for flames at low strain rates or under microgravity conditions. In microgravity environment, due to the absence of buoyancy effect, the combustion products are accumulated in the flame zone that enhances the effect of flame radiation. The radiation-induced extinction was first analyzed by Bonne [24], who used a numerical study to show that the radiative extinguishment occurs in a zero gravity environment. After the pioneer work of Bonne, this area, with the exception of T'ien's work [25], has largely remained unexplored until recently. The reason for this lack of interest was that the radiation-induced extinction does not occur at moderate to high strain regimes, which were of interest to most studies. At low strain rates, however, the relative effect of radiation becomes important which may even lead to extinction [26]. With the current interest in microgravity conditions, low strain regimes and subsequently radiation-induced extinction have begun to attract the attention of many researchers [26–31]. However, with the exception of Maruta et al. [29], and Mills and Matalon [31], these studies do not include the influence of non-unity Lewis number on radiative extinction. The need for including the effect of Lewis number in estimating the radiation-induced extinction limits has been clearly demonstrated by Mills and Matalon [31] in their theoretical study on a spherical flame configuration. Hence, the findings of the previous studies that do not consider non-unity Lewis number are specific to their flame conditions and may not be generalized.

The present study is an attempt to fill the existing gap in the literature. It investigates the influence of non-unity Lewis number due to thermo-diffusive effects (i.e., unequal rates of heat and mass diffusion) on turbulent flames. The effects of non-unity Lewis number with transient fluctuations are studied by simulating flames subjected to time-dependent fluctuations in reactant concentrations, reactant temperatures, and partial premixing. The influence of Lewis number on radiation-induced extinction is investigated by selecting low strain flames since radiative losses are more prominent for these flames.

2. Formulation of the problem

The problem was formulated by considering a counterflow diffusion flame stabilized near the stagnation plane of two laminar flows as shown in Fig. 1. In this figure, r and z denote the independent spatial coordinates in the tangential and the axial directions, respectively. This configuration was modeled by an unsteady, axisymmetric, stagnation point-flow model, with negligible body forces, viscous dissipation and Dufour effect. The resulting governing equations were simplified by using the following similarity transformations:

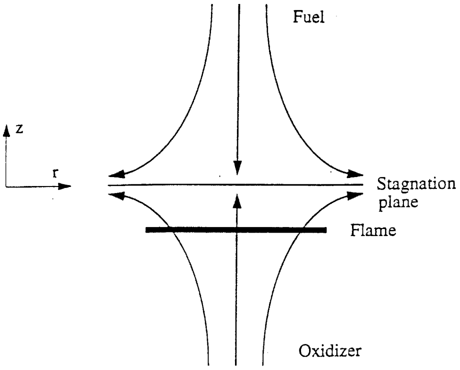

Fig. 1. Schematic of a counterflow diffusion flame.

$$u_r = \varepsilon(t) r\psi(z,t), \quad u_z = v(z,t),$$
$$\partial p/\partial r = f(r,t), \quad \partial p/\partial z = g(z,t),$$
$$h = h(z,t), \quad Y_i = Y_i(z,t),$$
$$\rho = \rho(z,t), \quad \lambda = \lambda(z,t),$$
$$\mu = \mu(z,t), \quad c_p = c_p(z,t).$$

Using the above transformations, and neglecting the temporal variations of pressure, the final forms of governing equations are as follows:

$$\frac{\partial\rho}{\partial t} + 2\rho\varepsilon\psi + \partial\frac{(\rho v)}{\partial z} = 0, \tag{1}$$

$$\rho\frac{\partial\psi}{\partial t} + \rho v\frac{\partial\psi}{\partial z} - \frac{\partial}{\partial z}\left(\mu\frac{\partial\psi}{\partial z}\right) + \rho\varepsilon\left(\psi^2 - \frac{\rho_\infty}{\rho}\right) + \frac{\rho}{\varepsilon}\frac{d\varepsilon}{dt}\left(\psi - \frac{\rho_\infty}{\rho}\right) = 0, \tag{2}$$

$$\rho\frac{\partial h}{\partial t} + \rho v\frac{\partial h}{\partial z} - \frac{\partial}{\partial z}\left(\frac{\lambda}{c_p}\right) + \nabla Q_R = -\sum_{i=1}^{N}\omega_i\Delta h^0_{f,i}, \tag{3}$$

$$\rho\frac{\partial Y_i}{\partial t} + \rho v\frac{\partial Y_i}{\partial z} - \frac{\partial}{\partial z}\left(\rho D_i\frac{\partial Y_i}{\partial z}\right) = \omega_i. \tag{4}$$

The above equations are closed by the following ideal gas relations:

$$\rho = \frac{p}{RT}\frac{1}{\sum_{i=1}^{N}(Y_i/\mathrm{MW}_i)} \quad \text{and} \quad dh = c_p\,dT. \tag{5}$$

The symbols used in the above equations are defined in the nomenclature. Note that in the present form the equations do not depend on the radial direction. In this study, the radiative heat flux is modeled by assuming that the flame gases are optically thin and all the radiation emitted by the flame leaves without absorption or scattering. The validity of this assumption for flamelet calculations has been shown by Chan et al. [32]. The main contributors to radiative losses are assumed to be gaseous combustion products CO_2 and H_2O for the methane-air flame studied in the present work. For this relatively less sooty flame, the radiation emitted from soot particles is neglected. Hence, the radiative heat flux may be written as: $\nabla Q_R = 4\sigma T^4(a_{P,CO_2} + a_{P,H_2O})$; where σ is the Stefan–Boltzmann constant, and a_{P,CO_2}, a_{P,H_2O} are the Planck mean absorption coefficients for CO_2 and H_2O, respectively. The values of absorption coefficients were obtained from [33], and their accuracy was checked by using Grosshandler's narrow band model [34].

The chemical reaction was modeled by considering a single step overall reaction which may be written as follows:

$$[F] + v[O_2] \rightarrow (1+v)[P]$$

Here, v is the mass-based stoichiometric coefficient. Using second-order Arrhenius kinetics, the reaction rate was defined as $\omega = A\rho^2 Y_F Y_O \exp(-E/RT)$. The reaction rates for fuel, oxidizer, and product may then be written as $\omega_F = -\omega$; $\omega_O = -v\omega$; and $\omega_P = (1+v)\omega$. For the calculations presented here, the values of various constants and properties were taken from [30].

The governing equations were solved by specifying the following initial conditions:

$$\psi(z,0) = \psi_0(z), \quad h(z,0) = h_0(z),$$
$$Y_i(z,0) = Y_{i,0}(z)$$
$$[n \text{ conditions or } (n-1) \text{ conditions} + \rho(z,0)],$$
$$v(z,0) = v(z).$$

Here the subscript 0 represents the initial steady profiles. These initial steady profiles were obtained in two different manners. For the study of radiation-induced extinction, these steady profiles were obtained from the analytical solution of a non-radiating flame with some additional assumptions. And for the study of dynamic response, these functions were numerically obtained and represent the initial steady state conditions of flames.

The boundary conditions were specified by defining the origin of the coordinate system at the initial stagnation plane, and are described as follows:

$$\psi(\infty,t) = 1, \quad \psi(-\infty,t) = (\rho_\infty/\rho_{-\infty})^{1/2},$$
$$h(\infty,t) = h_{up}, \quad h(-\infty,t) = h_{low},$$
$$Y_i(\infty,t) = Y_{i,up}, \quad Y_i(-\infty,t) = Y_{i,low},$$
$$v(\infty,t) = v_\infty.$$

In addition to the boundary conditions, the strain rate ε is also specified. For the study of unsteady effects on flamelets, the transient effects were simulated by imposing time-dependent (sinusoidal) fluctuations in reactant concentration, reactant temperatures and partial premixing. This was done by multiplying the boundary value of either fuel or oxidizer concentration or their temperatures by $[1 + A\sin(2\pi ft)]$ for sinusoidal variations.

The governing equations were solved by using the numerical method of lines. A second-order three-point central difference formula was used to spatially discretize the equations and an implicit backward differentiation formula (BDF) was used to integrate in the temporal direction. In order to carry out the numerical integration, infinity was approximated by a finite length on the order of the length scale of the problem (i.e., $(D/\varepsilon)^{1/2}$). This was confirmed by checking the gradients of all the variables, which must vanish at the boundaries (except the gradient of the fluctuating boundary parameter in the study of the dynamic response of flamelet). Based on a grid sensitivity analysis, a uniform grid with a mesh size of 0.16 mm (which is much less than the length scale of the problem) and a variable time step of the order of 1 μs (which is also smaller than the smallest time scale of the problem) was used in this study. The code was validated by comparing the numerical results with both the analytical solution of a simplified case, and the results of Atreya and Agrawal [30]. The details of code validation are given elsewhere [22].

3. Results and discussion

The results were obtained by assuming constant specific heat ($c_p = 1.3 \times 10^3$ J/kg K), equal diffusion coefficients for all gases and $\rho^2 D =$ constant (with $D_\infty = 2.26 \times 10^{-5}$ m^2/s). The influence of Lewis number and its interaction with unsteadiness can be better understood by first studying the effect of Lewis number on flame temperature and radiation characteristics under steady state conditions. Fig. 2 shows the temperature and radiative heat loss profiles of flames subjected to a strain rate of 10 s^{-1} with different Lewis numbers. The results show that the peak flame temperature decreases and the reaction zone thickness increases with an increase of Lewis number. The flame temperature is decreased due to an increase of the thermal diffusivity, which increases the heat removal rate from the high temperature zone. This decrease of temperature is nearly exponential as shown in the inset of Fig. 2(a). In this inset, the temperature is normalized by the peak flame temperature corresponding to a unity Lewis number.

The radiative heat loss, shown in Fig. 2(b), follows a similar trend as temperature. The total amount of heat release per unit area (obtained by integrating over the whole domain) remains, however, unchanged for all flames (since the same amount of enthalpy is supplied for all flames). The radiative heat losses are maximum at low Lewis number, which is due to corresponding high flame temperatures, and decrease with an increase of Lewis number. For the calculations presented here, the radiative heat losses are 11.3% of the total heat release for a flame with a unity Lewis number. These losses increase to 13.5% for the flame with Lewis number of 0.5 and decrease to 8.2% for the flame with Lewis number of 2.

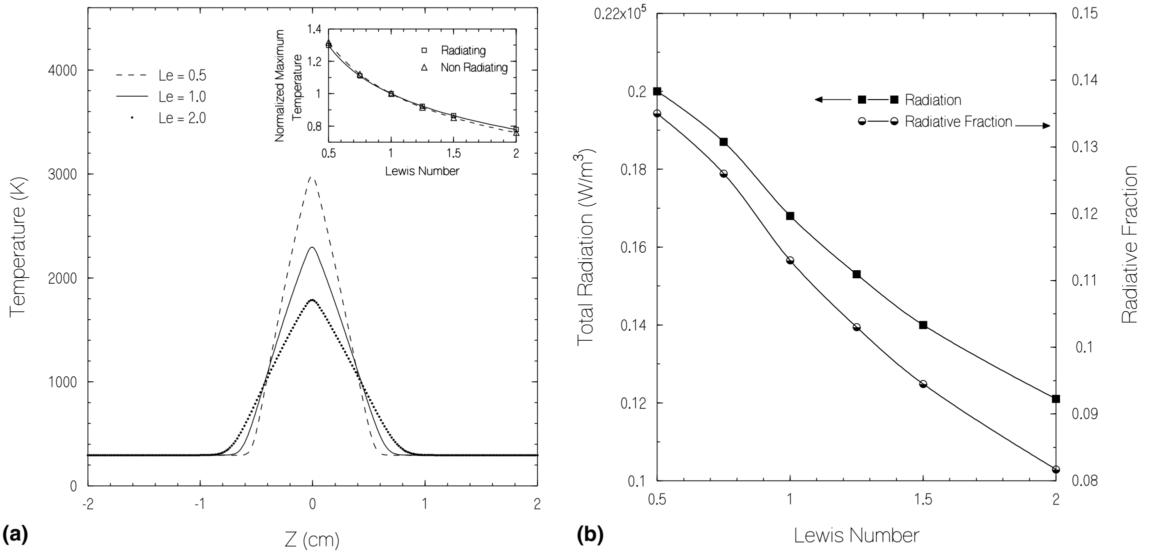

Fig. 2. Effect of Lewis number on: (a) flame temperature; (b) radiative heat loss and radiative fraction (strain rate = 10 s^{-1}; boundary temperature = 295 K; reactant mass fractions = 12.5% CH_4 + 87.5% N_2 on the fuel side and 50% O_2 + 50% N_2 on the oxidizer side).

3.1. Unsteady effects on flamelet

As described earlier, the unsteady effects are simulated by considering flames subjected to time-dependent fluctuations in reactant concentrations, reactant temperatures, and partial premixing. The influence of Lewis number and its interaction with the unsteadiness and radiation is described below.

3.1.1. Effect on reactant concentration fluctuations

These results were obtained by considering initially steady flames that were later subjected to sinusoidal variations in one of the reactants (either fuel or oxidizer). Results reported in this paper are only for fuel concentration fluctuations but are applicable to both reactants since similar findings were obtained for oxidizer fluctuations. Fig. 3(a) shows the variation of the

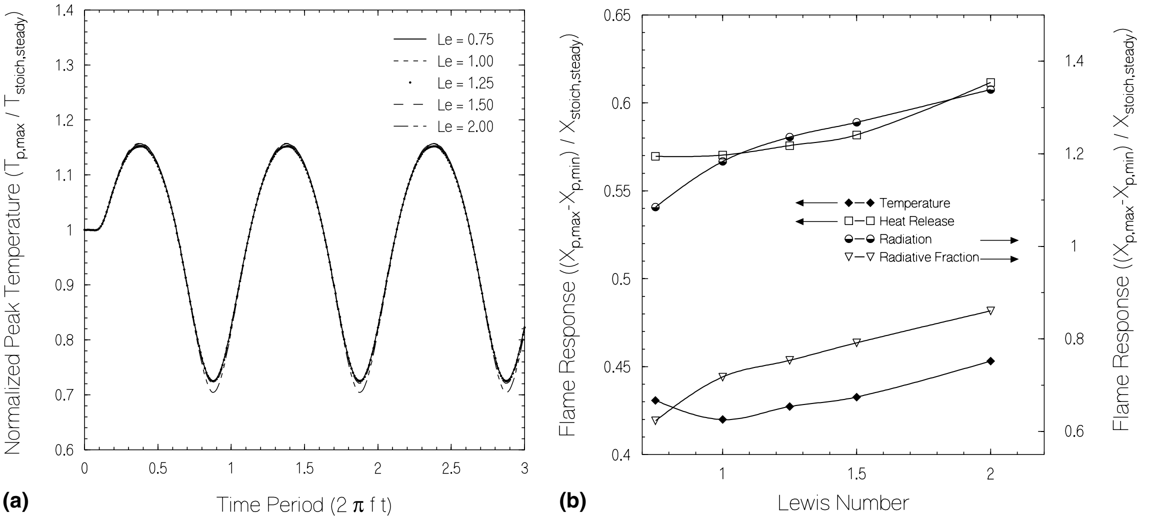

Fig. 3. Flame response to sinusoidal fluctuations in reactant concentrations: (a) variation of the normalized maximum flame temperature; (b) relative changes of the peak flame temperature, heat release rate, radiative loss, and radiative fraction (amplitude = 50%; frequency = 1 Hz; strain rate = 10 s^{-1}; time period = $2\pi ft$).

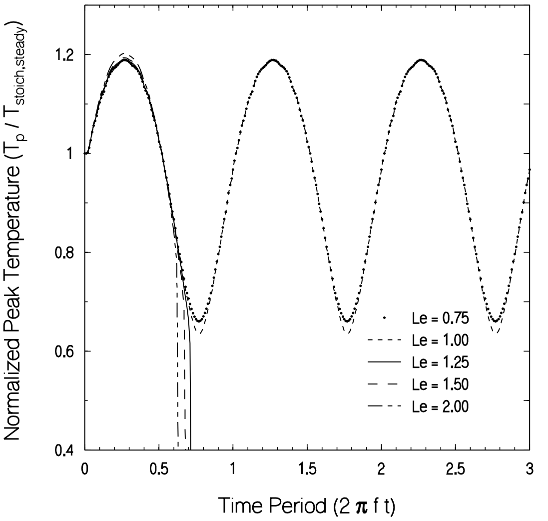

Fig. 4. Flame response to sinusoidal fluctuations in reactant concentrations: variation of the normalized maximum flame temperature. Results show extinction for flames with Lewis number greater than unity (amplitude = 50%; frequency = 1 Hz; strain rate = 100 s^{-1}; time period = $2\pi ft$).

maximum flame temperature (normalized with the steady state value) as a function of time period for flames with different Lewis numbers. These flames were subjected to a strain rate of 10 s^{-1} with the fuel concentration varied sinusoidally at 1 Hz and 50% amplitude. The results show that the flame temperature responds sinusoidally to sinusoidal fluctuations. The normalized flame response is not affected by Lewis number. The phase lag, asymmetry of the response and the normalized amplitude of the response remain unchanged for values of Lewis numbers ranging from 0.75 to 2. It must be mentioned here that for the present values of strain rate and perturbation frequency, the flame responds quasi-steadily to any modulation in reactant concentrations. Fig. 3(b) shows that, for flames with Lewis numbers less than unity, the effect of Lewis number is stronger on changes of radiative heat losses and radiative fraction than that on the heat release.

As mentioned in the previous section, the peak flame temperature is reduced with an increase of Lewis number. Furthermore, the amplitude of the flame response to the imposed fluctuations is large at high strain rate [22]. Hence, at high strain rates with large Lewis number, the imposed fluctuations may cause extinction. Such extinction at a strain rate of 100 s^{-1} is shown in Fig. 4. These flames were subjected to sinusoidal fuel concentration fluctuations of 1 Hz and 50% amplitude. The figure depicts that at this relatively higher strain rate, the flames, with Lewis number greater than unity, are not able to survive the imposed fluctuations and suffer extinction. This result clearly shows the significance of including the influence of Lewis number in flamelet modeling.

3.1.2. *Effect on reactant temperature fluctuations*

These results were obtained by considering initially steady flames, which were later subjected to sinusoidal variations in reactant boundary temperatures. The boundary temperatures of both oxidizer and fuel were

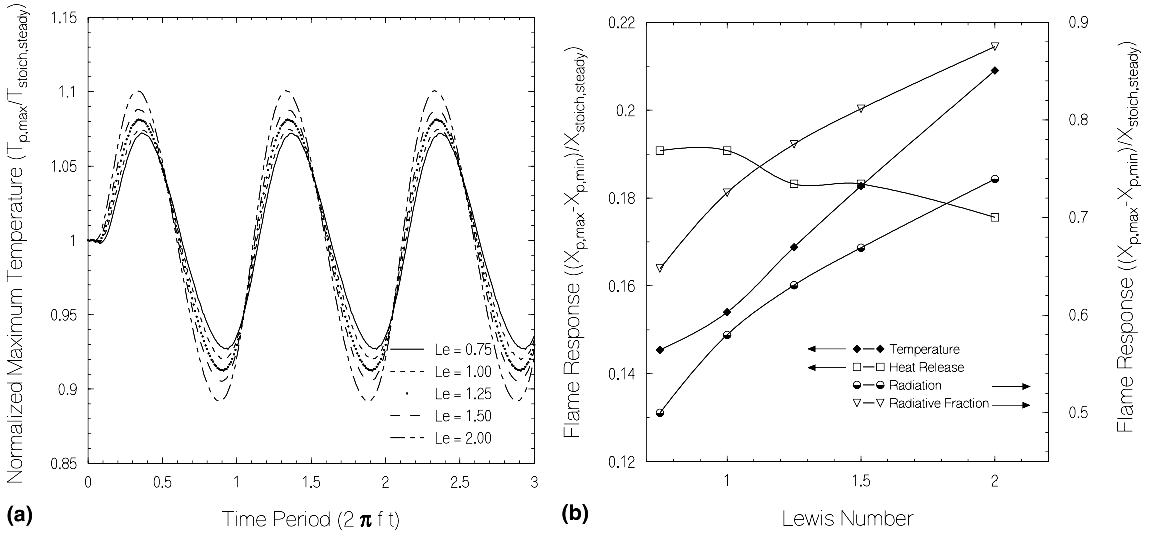

Fig. 5. Flame response to sinusoidal fluctuations in reactant boundary temperatures: (a) variation of the normalized maximum flame temperature; (b) relative changes of the peak flame temperature, heat release rate, radiative loss, and radiative fraction (amplitude = 50%; frequency = 1 Hz; strain rate = 10 s^{-1}; time period = $2\pi ft$).

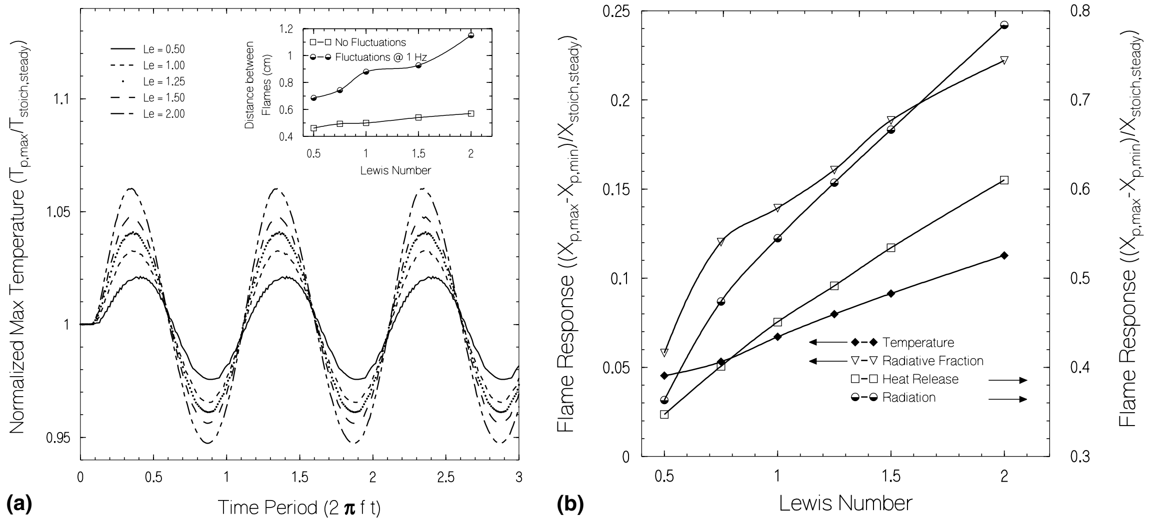

Fig. 6. Flame response to sinusoidal fluctuations in partial premixing: (a) variation of the normalized maximum flame temperature; (b) relative changes of the peak flame temperature, heat release rate, radiative loss, and radiative fraction (amplitude = ±5% O_2; frequency = 1 Hz; strain rate = 10 s^{-1}; time period = $2\pi ft$).

varied at the same rate. Fig. 5(a) shows the variation of the maximum flame temperature (normalized with the steady state value) as a function of time period for flames with different Lewis numbers. The flames were subjected to a strain rate of 10 s^{-1} with the reactant boundary temperatures varied sinusoidally about the mean temperature of 600 K at 1 Hz and 50% amplitude. The imposed fluctuations bring about sinusoidal flame temperature response as shown in this figure. The flame response is nearly symmetric for all Lewis numbers and its amplitude increases with an increase of Lewis number. The response phase lag shows a slight decrease with an increase of Lewis number, which is due to an increase of the thermal diffusivity. The flame radiation characteristics, such as the variation in radiative heat losses, exhibit trends similar to those of peak temperature (Fig. 5(b)). As expected, the variations in heat release rates remain nearly unaffected.

3.1.3. *Effect on time-dependent partial premixing*

These simulations were carried out by considering initially a steady partially premixed flame (a double flame configuration which is obtained by mixing a small quantity of oxidizer on the fuel side or a small quantity of fuel on the oxidizer side) which was later subjected to sinusoidal fluctuations in partial premixing. Fig. 6(a) shows the variation of the maximum diffusion flame temperature (normalized with the steady state value) as a function of time period for flames with different Lewis numbers subjected to time-dependent partial premixing. The results shown are for flames subjected to a strain rate of 10 s^{-1} with 5% oxidizer partially premixed on the fuel side. The concentration of the premixed oxidizer was varied sinusoidally at 1 Hz and 100% amplitude (i.e., ±5% O_2). The imposed fluctuations in partial premixing also bring about sinusoidal flame response. The results show that the amplitude of the flame temperature response increases with an increase of Lewis number, i.e., the effect of fluctuations in partial premixing is

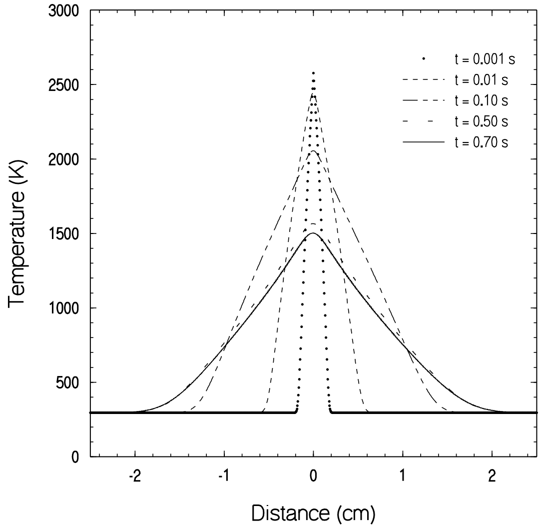

Fig. 7. Effect of radiative heat loss on flame temperature (strain rate = 0.5 s^{-1}; boundary temperature = 295 K; 12.5% CH_4 + 87.5% N_2 on the fuel side and 50% O_2 + 50% N_2 on the oxidizer side; Lewis number = 1).

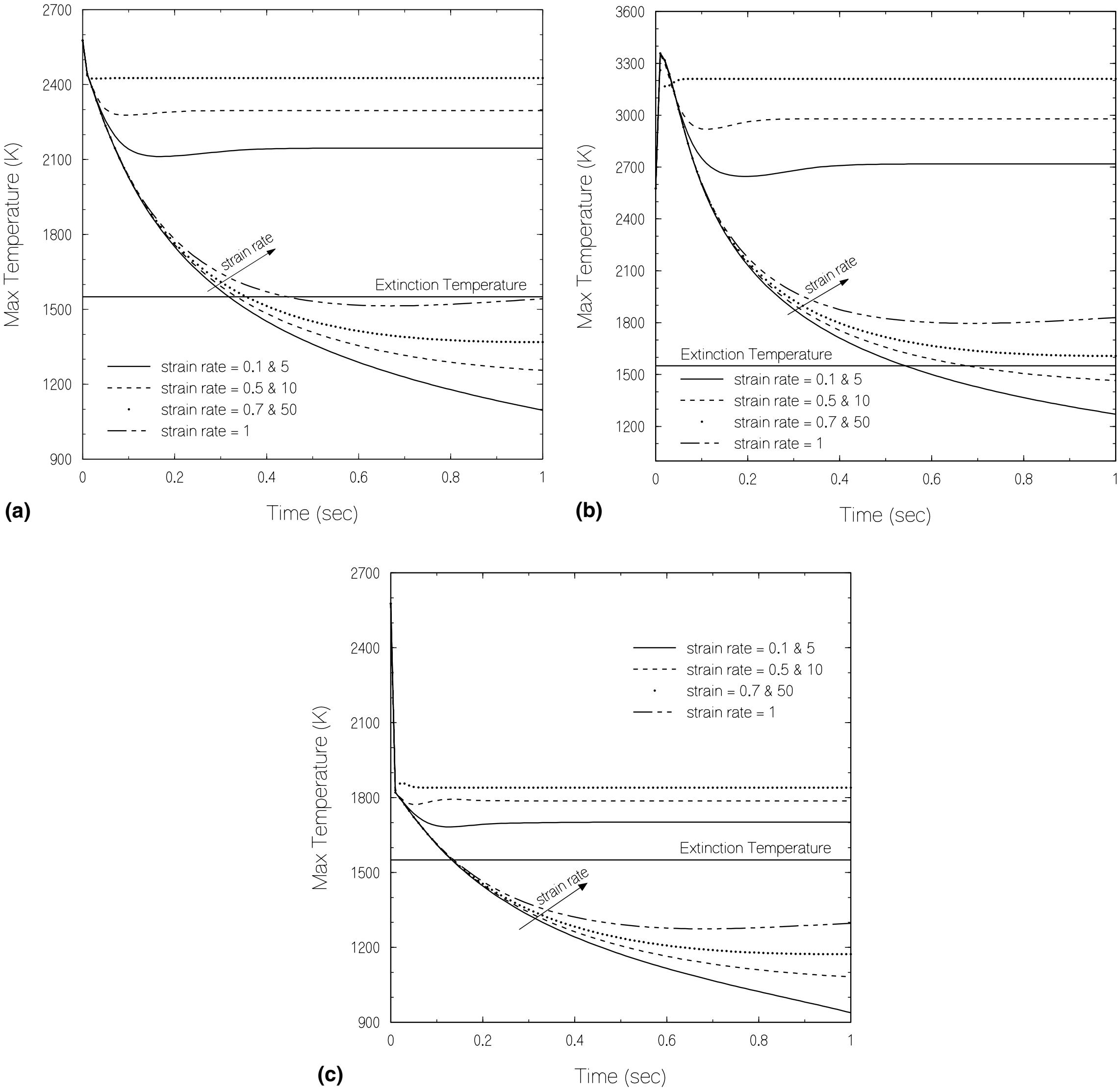

Fig. 8. Effect of Lewis number on radiative extinction: variation of the peak flame temperature due to radiation for various strain rates (boundary temperature = 295 K; 12.5% CH_4 + 87.5% N_2 on the fuel side and 50% O_2 + 50% N_2 on the oxidizer side): (a) Lewis number = 1; (b) Lewis number = 0.5; (c) Lewis number = 2.

greater on flames with large Lewis number. This may be explained by considering that with an increase of Lewis number, the diffusion flame becomes weaker and thus may be more extensively influenced by changes of partial premixing. The results indicate that Lewis number has no effect on the phase lag and the asymmetry of the flame response. The distance between the premixed and the diffusion flames is found to increase with an increase of Lewis number (as shown in the inset of Fig. 6(a)).

The effect of Lewis number on radiative losses, heat release rate, and radiative fraction is shown in Fig. 6(b). The radiative losses, as expected, follow trends similar to that of temperature. Contrary to the cases of fluctuations of fuel concentration, or reactant temperatures (which are pure diffusion flames), changes of heat release rate in this case increase with an increase in the Lewis number. The results, not plotted here, also show that the average heat release rate increases with an increase of Lewis number. Since the same amount of enthalpy is supplied to flames having different Lewis numbers, the enhancement of the heat release indicates improved burning. Furthermore, pure diffusion flames show a much smaller increase in the heat release with an increase of Lewis number. This suggests that an increase in the Lewis number in partially premixed combustion improve the incomplete burning of the premixed flame.

4. Radiation-induced extinction

The existence of radiation-induced extinction is depicted in Fig. 7, which shows the temperature profiles of a flame subjected to a strain rate of 0.5 s^{-1}. The results were obtained by utilizing the analytical solutions of non-radiating flames as the initial conditions. The radiative losses from the major combustion products were considered. The results show a reduction in the maximum flame temperature due to radiative losses. The effect of radiation for this flame is found to be sufficient to cause extinction (which is defined as disappearance of chemiluminescence $\approx$ 1550 K [24]) in approximately 0.3 s. The effect of radiation, however, decreases with the increase in strain rate as shown in Fig. 8(a), which depicts the drop of the peak flame temperature due to gas radiation as a function of time for various values of strain rates. The results show a reduction in flame temperature for all strain rates. However, the temperature reduction is significant at low strain rates, which eventually leads to extinction. Recall that at low strain rates, the flame has a low heat release rate (due to slow burning rate) and hence its stability is greatly affected by the temperature drop due to radiation. These results are for flames with unity Lewis number.

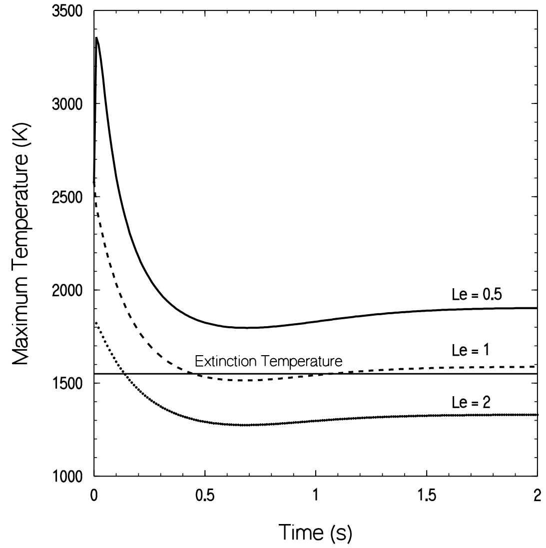

Fig. 9. Effect of Lewis number on radiative extinction: variation of the peak flame temperature due to radiation (strain rate = 1 s^{-1}; boundary temperature = 295 K; 12.5% CH_4 + 87.5% N_2 on the fuel side and 50% O_2 + 50% N_2 on the oxidizer side).

The effect of Lewis number on the radiation-induced extinction is demonstrated by plotting the results of flames with Lewis numbers of 0.5, and 2 (Fig. 8(b) and (c)). The results show that with an increase of Lewis number, flames become relatively "weak" and are more susceptible to radiative losses. For example, the flame at strain rate of 1 s^{-1} escapes radiative extinction for Lewis numbers of 0.5 and 1.0 but not for 2 (Fig. 9). Hence, keeping all conditions similar, an increase of Lewis number pushes the radiative extinction limit toward higher values of strain rate.

5. Conclusions

In this paper, the effect of non-unity Lewis number (due to unequal mass and thermal diffusion rates) on radiative extinction and flamelet modeling has been investigated. The results lead to the following conclusions:

- The steady flame temperature decreases with an increase of Lewis number. This decrease is due to an increase of the thermal diffusivity, and thereby an increase of the heat removal rates from the high temperature zone. Thus at large Lewis number, the radiative heat losses are reduced (due to decrease in flame temperature), but the relative effect of radiative losses is enhanced. The variation of Lewis number has no effect on the total amount of heat released per unit area.
- Lewis number significantly influences the flame response to unsteadiness. A large value of Lewis number with high strain rates may cause extinction of flames subjected to unsteady changes. The effect of Lewis number differs for different types of imposed changes. For flames subjected to reactant concentration fluctuations at low strain rates, the normalized flame response is unaffected by Lewis number. Whereas, a large Lewis number increases the normalized flame response for flames subjected to reactant boundary temperature fluctuations (which is due to an increase of thermal diffusion rate). The increase of Lewis number also increases the influence of partial premixing fluctuations. This is due to weakening of the diffusion flame at large Lewis numbers so that it is more susceptible to fluctuations in partial premixing. Furthermore, the results indicate that an increase in the Lewis number in partial premixing improves the incomplete burning of the premixed flame.
- Lewis number also has major influence on radiation-induced extinction. With an increase of Lewis number, flames become relatively weak and hence become more susceptible to radiative heat losses. Thus, large Lewis number pushes the radiation-induced extinction limit, which occurs at low strain rates, toward higher values of strain rate.

Acknowledgements

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