

# Analytical Study over the Lewis number effect on the combustion of biomass particle

Milad Shokouhmand<sup>†</sup>, Mehdi Bidabadi, Payam Asadollahzadeh

[milad.shokouhmand@gmail.com](mailto:milad.shokouhmand@gmail.com)

## Abstract

In this paper, the effect of Lewis number on the structure of one-dimensional flame of biomass combustion is analyzed. This effect can be observed by considering the non-unity Lewis number in the governing equations. The value of the characteristic Zeldovich number is too large and the equivalence ratio is larger than unity  $\phi_u \geq 1$ . The flame structure consists of three different zones which are, a preheat vaporization zone, a reaction zone that consists of gas and Char combustion and a convection zone. The obtained results from the present model declare that the temperature and burning velocity profiles are extremely affected by the various Lewis numbers.

## Physical Modelling

In this process biomass cloud particles ignited right after the vaporization of their moisture and Char material is generated at the same time and react with oxidizer. During the combustion of biomass particles like wood five volatied material such as CO, CO<sub>2</sub>, H<sub>2</sub>, H<sub>2</sub>O and one light hydrocarbon are produced. It is assumed that the rate of gas burning velocity and porous material burning velocities has the same value. The rate of flame propagation is depended on the 1- the rate of the heat exchanged from the flame, 2- thermodynamical equilibrium of gas phase and solid, in the burned zone

## Mathematical Modelling

In the present work, the number and radius of the particles are considered to be known as the primary data and it should also be noticed that all external forces such as gravitational field on earth are neglected in this study. The structure of premixed flames propagation in combustible system, containing uniformly distributed gaseous fuel, char, tar and oxidizing gas mixture, is analyzed.

## Governing Equations

Mass Conservation Equation:

$$\rho V = cte \quad (1)$$

Energy conservation equation:

$$\rho v C \left( \frac{dT}{dx} \right) = \lambda_u \left( \frac{d^2T}{dx^2} \right) + w_F \left( \frac{\rho_u}{\rho} \right) Q - w_v \left( \frac{\rho_u}{\rho} \right) Q_v \quad (2)$$

$$+ w_c \left( \frac{\rho_c}{\rho} \right) Q_c + w_T \left( \frac{\rho_T}{\rho} \right) Q_T - w_{de} \left( \frac{\rho_u}{\rho} \right) Q_{de}$$

Where  $\rho$ ,  $v$ ,  $w_F$ ,  $w_c$ ,  $w_T$  and  $w_v$  are the density, the flow velocity, the reaction rate, the reaction rate of char, the reaction rate of tar and the rate of devolatilization respectively and also  $Y_F$  and  $Y_c$  are the mass fraction of the fuel and the mass fraction of char, respectively.

$\lambda$  is the heat conduction coefficient of both particles and gaseous fuel,  $Q$  is the heat release per unit mass of the particles fuel burned in the reaction,  $Q_v$  is the heat associated with vaporizing unit mass of fuel and  $C$  is the heat capacity of Gaseous and fuel particles combination.

Gaseous fuel conservation equation:

$$\rho v \left( \frac{dY_F}{dx} \right) = \rho_u D_u \left( \frac{d^2Y_F}{dx^2} \right) - w_F \left( \frac{\rho_u}{\rho} \right)$$

$$+ w_v \left( \frac{\rho_u}{\rho} \right) + w_{de} \left( \frac{\rho_u}{\rho} \right) - w_T \left( \frac{\rho_T}{\rho} \right) \quad (3)$$

Where  $Y$  is the mass fraction of particles and  $D$  is the mass diffusion coefficient

Particle mass fraction conservation equation:

$$\rho_s V \left( \frac{dY_s}{dx} \right) = -w_v \left( \frac{\rho_u}{\rho} \right) - w_{de} \left( \frac{\rho_u}{\rho} \right)$$

$$\rho v \left( \frac{dY_c}{dx} \right) = w'_c \left( \frac{\rho_c}{\rho} \right) \quad (4)$$

## Non-dimensional parameters:

$$m = \frac{\rho v}{\rho_u v_u}, \theta = \frac{T - T_u}{T_f - T_u}, y_s = \frac{Y_s}{Y_{FC}} \quad (5)$$

$$z = \frac{\rho_u v_u C}{\lambda_u} x, y_F = \frac{Y_F}{Y_{FC}}, y_C = \frac{Y_C}{Y_{FC}}$$

Solution: By using the differential equations and asymptotical methods for different combustion zones the equations and non-dimensional equations is solved. The reaction rate is calculated by Arrhenius equ.

### Burning Velocity Correlation

Using equations (21) and (23), the burning velocity of fuel particles can be obtained as below:

$$v_u^2 = \frac{2(L_e + b)\lambda_u \varepsilon^2 (v_F k_F + v_C k_C + v_T k_T)}{\rho_u C} \quad (6)$$

And if two parameters  $T_f$  and  $b$  are presumed to be known, value  $v_u$  can be calculated. For high value of  $T_f$ , it is reasonable to assume that  $y_{FF} = 0$  which is resulted to  $b = 0$ . Flame temperature ( $T_f$ ) is evaluated by the jump conditions of preheat-vaporization zone and convection zone. The jump condition is written as:

$$\left[ \frac{dy_F}{dz} \right]_{0^-} + \left[ \frac{d\theta^0}{dz} \right]_{0^-} + \left[ \frac{dy_C}{dz} \right]_{0^-} = \left[ \frac{dy_F}{dz} \right]_{0^+} + \left[ \frac{d\theta^0}{dz} \right]_{0^+} + \left[ \frac{dy_C}{dz} \right]_{0^+} \quad (7)$$

## RESULTS

In the combustion of the wood particles, it is presumed that the fuel particles vaporize first to yield the methane structure. The chemical kinetic rate parameters are

$E = 25000 \text{ Cal / mole}$  and  $B = 5.16 \times 10^6 \text{ mol}^{-1} \text{ s}^{-1}$ . Also the kinetic of vaporization of fuel particles are prescribed by these assumptions:

$$A = 3.4 \times 10^{-4} (g)_F / [(cm^2)_s ks], n = 1.33. \quad (29)$$

The constant parameters are presumed are

$$\lambda_u = 3 \times 10^{-4} (cal / cm.s.k), \rho_u = 1.13 \times 10^{-3} (g / cm^3)$$

$$\rho_s = 0.72 \times 10^{-3} (g / cm^3), T_u = 300K, q = 0.01$$

It is shown that for  $\varphi_u \geq 1$  the equivalence ratio based on the fuel available in the fuel particles ( $\varphi_u$ ) are formulated by  $\varphi_u = 17.18 Y_{Fu} / (1 - Y_{Fu})$ . Also the effective equivalence ratio in the reaction zone ( $\varphi_g$ ) is calculated by  $\varphi_g = 17.18 Y_{FC} / (1 - Y_{FC})$ .

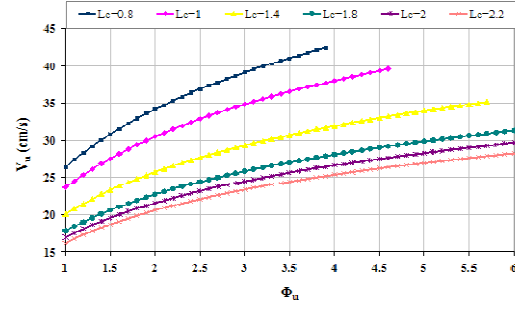


Fig. 5. The variation of burning velocity, neglecting the heat of vaporization, as a function of equivalence ratio for different Lewis numbers at  $R = 20 \mu m$

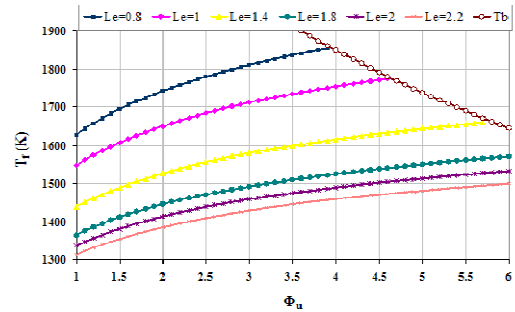


Fig. 7. The variation of flame temperature as a function of equivalence ratio for different Lewis numbers at  $R = 20 \mu m$

## REFERENCES

- Backreedy, R.I., J.M. Jones, M. Pourkashanian and A. Williams, "Modeling the reaction of oxygen with coal and biomass chars," Proceedings of the Combustion Institute, 29, 415–422 (2002).
- Bidabadi, M., and A. Rahbari, "Modeling combustion of lycopodium particles by considering the temperature difference between the gas and the particles," Combustion Explosion and Shockwaves, 45, 49-57 (2009).



### Abstract

In this paper, the effect of Lewis number on the structure of one-dimensional flame of biomass combustion is analyzed. This effect can be observed by considering the non-unity Lewis number in the governing equations. The value of the characteristic Zeldovich number is too large and the equivalence ratio is larger than unity. The flame structure consists of three different zones which are, a preheat vaporization zone a reaction zone that consists of gas and Char combustion and a convection zone. The obtained results from the present model declare that the temperature and burning velocity profiles are extremely affected by the various Lewis numbers.

### Physical Modelling

In this process biomass cloud particles ignited right after the vaporization of their moisture and Char material is generated at the same time and react with oxidizer. During the combustion of biomass particles like wood five volatile material such as CO, CO<sub>2</sub>, H<sub>2</sub>, H<sub>2</sub>O and one light hydrocarbon are produced. It is assumed that the rate of gas burning velocity and porous material burning velocities has the same value. The rate of flame propagation is depended on the 1- the rate of the heat exchanged from the flame, 2- thermodynamical equilibrium of gas phase and solid, in the burned zone

### Mathematical Modelling

In the present work, the number and radius of the particles are considered to be known as the primary data and it should also be noticed that all external forces such as gravitational field on earth are neglected in this study. The structure of premixed flames propagation in combustible system, containing uniformly distributed gaseous fuel, char, tar and oxidizing gas mixture, is analyzed.

### Governing Equations

#### 1-Mass Conservation

$$\rho V = cte$$

#### 2-Energy Conservation

$$\rho v C \left( \frac{dT}{dx} \right) = \lambda \left( \frac{dT}{dx^2} \right) + w_r \left( \frac{\rho_r}{\rho} \right) Q - w_o \left( \frac{\rho_o}{\rho} \right) Q + w_c \left( \frac{\rho_c}{\rho} \right) Q + w_s \left( \frac{\rho_s}{\rho} \right) Q - w_a \left( \frac{\rho_a}{\rho} \right) Q$$

#### 3-Gaseous Fuel Conservation

$$\rho v \left( \frac{dY_r}{dx} \right) = \rho D \left( \frac{d^2 Y_r}{dx^2} \right) - w_r \left( \frac{\rho_r}{\rho} \right) + w_o \left( \frac{\rho_o}{\rho} \right) + w_c \left( \frac{\rho_c}{\rho} \right) - w_s \left( \frac{\rho_s}{\rho} \right)$$

#### 4-Particle Mass Fraction Conservation

$$\rho_s V \left( \frac{dY_s}{dx} \right) = -w_r \left( \frac{\rho_r}{\rho} \right) - w_o \left( \frac{\rho_o}{\rho} \right)$$

$$\rho V \left( \frac{dY_c}{dx} \right) = w_c \left( \frac{\rho_c}{\rho} \right)$$

### Burning Velocity Correlation

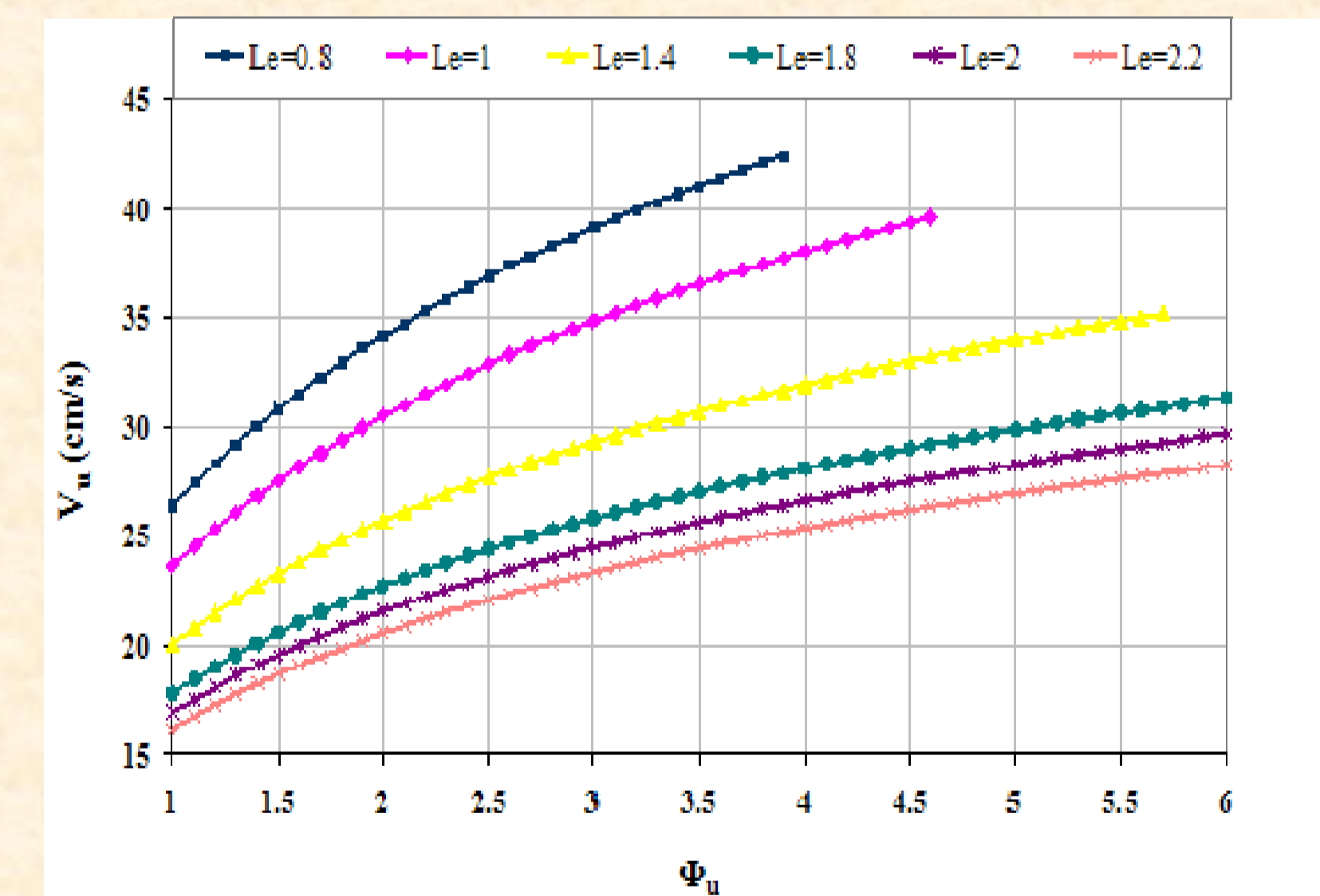
$$v_u^2 = \frac{2(L_e + b)\lambda_u \varepsilon^2 (v_F k_F + v_C k_C + v_T k_T)}{\rho_u C}$$

### RESULTS

In the combustion of the wood particles, it is presumed that the fuel particles vaporize first to yield the methane structure. The chemical kinetic rate parameters

$$E = 25000 \text{ Cal / mole} \quad B = 5.16 \times 10^6 \text{ mol}^{-1} \text{ s}^{-1}$$

$$A = 3.4 \times 10^{-1} \text{ (g)}_r / [(cm^2)_s \text{ ks}] \quad n = 1.33$$



The variation of burning velocity, neglecting the heat of vaporization, as a function of equivalence ratio for different Lewis numbers at  $R = 20 \mu m$