

Heat Recirculation Effect on the Structure of Wood Dust Flame Propagation

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ABSTRACT

A model for heat-recirculating micro combustor is developed. It investigates the structure of laminar, one-dimensional and steady state flame propagation in uniformly premixed wood particles with considering the effects of heat recirculation caused by configuration of micro combustor. The flame structure is divided into three regions: a preheat-devolatilization zone where the rate of the gas-phase chemical reaction is small; a narrow reaction zone where convection and the rate of devolatilization of the fuel particles are small; and finally a convection zone where diffusive terms in the conservation equation are small. In this model, it is assumed that the fuel particles vaporize first to yield a gaseous fuel of known chemical structure. The analysis is investigated in the asymptotic limit. The overall investigation of this study leads to a novel non-linear burning velocity correlation that heat recirculation term is considered to calculate it. The results shows that heat recirculation affect the flame structure by different parameters. Burning velocity and flame temperature are the most important of these parameters. Furthermore, as the equivalence ratio increases and the wood particle size decreases, the combustion process in micro combustor can be more stable.

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Nomenclature

A parameter characterizing rate of devolatilization of fuel particles [$\text{kg}/(\text{m}^2 \text{K s})$]
 B frequency factor characterizing rate of gas phase oxidation of the gaseous fuel
 C specific heat capacity of mixture [$\text{J}/(\text{kg K})$]
 C_p specific heat capacity of the gas [$\text{J}/(\text{kg K})$]
 C_s specific heat capacity of a fuel particle [$\text{J}/(\text{kg K})$]
 D molecular diffusion coefficient
 d diameter of micro combustor [m]
 E activation energy characterizing the gas phase reaction [J/mol]
 h_{in} convective heat transfer coefficient between the combustion flow and wall [$\text{W}/(\text{m}^2 \text{K})$]
 k rate constant of the gas-phase reaction
 Nu Nusselt number
 n temperature exponent characterizing rate of devolatilization of fuel particles
 n_s local number density of particles (number of particles per unit volume) [$1/\text{m}^3$]
 Pe Peclet number
 Q heat release per unit mass of gaseous fuel consumed [J/kg]
 Q_v heat associated with devolatilizing unit mass of fuel [J/kg]
 R universal gas constant [$\text{J}/(\text{mol K})$]
 r radius of fuel particle [m]
 T temperature [K]
 v velocity [m/s]
 v_u burning velocity calculated neglecting heat of devolatilization of fuel particles [m/s]

v_v burning velocity calculated including heat of devolatilization of fuel particles [m/s]
 W_F molecular weight of gaseous fuel [kg/mol]
 w_F reaction rate characterizing consumption of gaseous fuel [$\text{kg}/(\text{m}^3 \text{s})$]
 w_v rate of devolatilization of fuel particles [$\text{kg}/(\text{m}^3 \text{s})$]
 x' spatial coordinate [m]
 Y mass fraction
 Z_e Zeldovich number
 z scaled independent variable

Greek letters

θ° value of θ calculated neglecting heat of devolatilization of particles
 λ thermal conductivity [$\text{W}/(\text{m K})$]
 ρ density of the reactant mixture [kg/m^3]
 ϕ_u equivalence ratio based on fuel available in the particles in the ambient reactant stream
 ν stoichiometric coefficient

Subscripts

F gaseous fuel
 f conditions at the reaction zone
 s fuel particles
 u conditions in the ambient reactant stream
 w wall

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1. INTRODUCTION

A sudden rise in using micro-electromechanical-systems (MEMS) encouraged the development of power sources that have higher power density and smaller volume. Vital usages of these power sources are micro gas turbines [1], the micro thermoelectric device [2], the micro thermo-photovoltaic (TPV) system [3], producing propulsive force in pico- and nano-satellites [4], have spurred the investigators to supersede these systems for common electrochemical batteries. The way of electrical power generation from combustion in micro electromechanical systems is such that the heat or radiation which arise from the combustion is converted to electrical energy by thermoelectric or thermo photovoltaic elements.

Hydrocarbon fuels in comparison with lithium-ion batteries (as one of the sources of micro power generation) contain about 100 times more energy per unit mass. Thus, the systems that convert fuel to electrical energy, with the efficiency of more than one percent energy conversion from chemical energy to electrical energy, is better than prevalent electric batteries. In small sizes, heat loss and friction become important and effective phenomena. Hence, design of systems with extremely small sizes, on the basis of systems with common sizes, like internal combustion engines is not possible. So, in these systems, heat recirculation should be used by which transferring heat from combustion products to reactants, the whole enthalpy of reactants (adding heat and chemical enthalpies) is more than the enthalpy of cold reactants. Therefore, combustion can be sustained by heat recirculation under some conditions such as lean mixtures, small heating value fuels, large heat losses and etc that result extinguishment [5].

Finite sources of fossil fuel and resultant pollution from combustion of these valuable sources was a stimulus for experts who work in energy section of developed countries to replace these sources with renewable energy sources. These new sources of energy are which are compatible with environment. One of the biggest non fossil sources is biomass which from the beginning of the existence of human has played a significant role in its life.

Since biomass usually exists in the solid phase and comes from nature, it is found in different figures and sizes. Thus, it causes a challenge in replacing these sources by fossil sources. One way to solve this problem is breaking it into extremely small sizes and dispersing them in air, in a way that it forms a solid particle-cloud. In such a way, it comes near to a gas mixture of fuel and oxidizer. In these conditions, flame propagation through this particle-cloud is comparable with the flame propagation through a premixed gas reactant.

In previous works, Daou and Matalon [6, 7]

described the effects of heat loss on the structure of premixed flames propagating in channels which the wall of channels were constant-temperature. Chen *et al.* [5] presented a model that is used a perfectly stirred reactor to study non-adiabatic combustion in heat-recirculating combustors in which heat from the post-flame is transferred upstream. This work showed that in microscale, the stream-wise heat conduction is dominant. Leach *et al.* [8] described the similar effects in micro-channels. They have been showed that for determining the performance of micro combustor, axial conduction of heat through the walls has an important effect [9]. Bidabadi *et al.* [10] investigated the role of heat recirculation and non-unity Lewis number on the combustion of organic dust particles. They defined a heat recirculation coefficient and observed that the increase in this coefficient leads to increase the burning velocity and flame temperature.

In this work, the structure of wood dust flame has been studied. The role of heat recirculation has been investigated in order to estimate the change of flame characteristic as burning velocity and flame temperature. The difference between this research and similar works is such that here wood particle-cloud is used as the fuel in a cylindrical micro combustor. Additionally, the effects of heat recirculated and heat loss are studied.

2. APPROACH

As Figure 1 shows, the structure of flame propagation is containing of three zones based on large zelvovich number, and high reaction rate which results in thin reaction zone. In the preheat-devolatilization zone ($-\infty < x < 0^-$), particles heat up to reach to the pyrolysis temperature. In this zone, chemical reaction between the gaseous fuel and oxidizer is neglected. The next zone is reaction zone in which particles are oxidized, and burnt. In this zone ($0^- < x < 0^+$), the convective terms and pyrolysis terms in the conservation equations are presumed to be small in comparison with the reaction term. Another zone is post flame zone ($0^+ < x < \infty$) in which the diffusive terms in the conservation equations are assumed to be small in comparison with others.

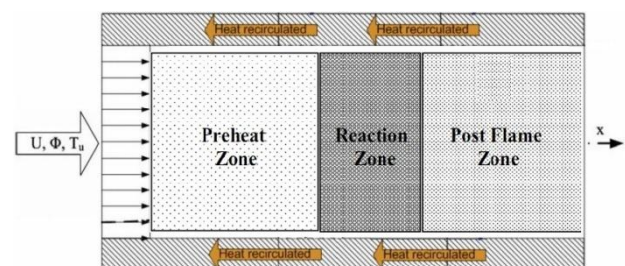


Figure 1. The structure of flame propagation and heat recirculation

According to Figure 1, convective heat from post flame zone transfers to micro combustor wall. Then, this heat recirculates to upstream in preheat-devolatilization zone through wall and after that it transfers to premixed wood dust.

3. GOVERNING EQUATIONS

Much research has been devoted to the theoretical analysis, computational modeling and experimental studies of combustion [11-13]. Wood particles are devolatilized, and the pyrolysis product is assumed to be a known gaseous compound and this compound then oxidized in reaction zone. Many researches focused on the pyrolysis of biomass particles [14,15]. The devolatilization kinetic is assumed to be represented by the following equation [16].

$$w_v = 4A\pi r^2 n_s (T - T_u)^n \quad (1)$$

The constant rate of the overall reaction is written in the arrhenius form $K = B \exp(-E/(RT))$. Also the Zeldovich number, which is presumed to be large, is defined as:

$$Z_e = \frac{E(T_f - T_u)}{RT_f^2} \quad (2)$$

The mass conservation law is:

$$\rho v = \text{Const.} \quad (3)$$

As the thermal conductivity λ is proportional to T , and the diffusion coefficient D is proportional to T^2 , the governing equations in this problem are nonlinear which can be transformed into a linear form by introducing an independent variable x that is related to the spatial coordinate x' as:

$$x = \int_0^{x'} \frac{\rho}{\rho_u} dx' \quad (4)$$

For the combustion of wood particles, the energy equation is derived as:

$$\rho v C \frac{dT}{dx} = \lambda_u \frac{d^2 T}{dx^2} + w_F \frac{\rho_u}{\rho} Q - w_v Q_v \frac{\rho_u}{\rho} - \frac{4h_{in}}{d} (T - T_w) \quad (5)$$

The equation of gaseous fuel conservation is:

$$\rho v \frac{dY_F}{dx} = \rho_u D_u \frac{d^2 Y_F}{dx^2} + w_v \frac{\rho_u}{\rho} - w_F \frac{\rho_u}{\rho} \quad (6)$$

The equation governing the mass fraction of the particles neglecting diffusion can be written as:

$$\rho v \frac{dY_S}{dx} = -w_v \frac{\rho_u}{\rho} \quad (7)$$

The equation of state is:

$$\rho T = \text{Const.} \quad (8)$$

The heat capacity in Equation (5) is the sum of heat capacity of the gas C_p , and heat capacity of the particles C_s , and can be calculated from the following equation:

$$C = C_p + \frac{4\pi r^3 C_s \rho_s n_s}{3\rho} \quad (9)$$

3.1. Nondimensionalization of equations The nondimensional parameters are described as:

$$D_f = \frac{T_f - T_w}{T_f - T_u}, \quad \theta = \frac{T - T_u}{T_f - T_u}, \quad y_s = \frac{Y_s}{Y_{FC}}, \quad z = \frac{\rho_u v_u C}{\lambda_u} x, \quad (10)$$

$$y_F = \frac{Y_F}{Y_{FC}}, \quad m = \frac{\rho v}{\rho_u v_u}, \quad \theta' = \frac{T - T_w}{T_f - T_w}, \quad D_f' = \frac{T - T_u}{T - T_w},$$

where, v_u is the burning velocity.

The quantity Y_{FC} is as follow:

$$Y_{FC} Q = C(T_f - T_u) \quad (11)$$

For simplicity it is assumed that the Lewis number $\lambda/(\rho CD) = 1$. By using the introduced parameter the nondimensional equations are obtained as:

$$m \frac{d\theta}{dz} = \frac{d^2 \theta}{dz^2} + \omega \frac{\rho_u}{\rho} - q\gamma y_s^{2/3} \theta^n - \frac{4Nu.Pe^{-2}}{D_f'} \theta \quad (12)$$

$$m \frac{dy_F}{dz} = \frac{d^2 y_F}{dz^2} - \omega \frac{\rho_u}{\rho} + \gamma y_s^{2/3} \theta^n \quad (13)$$

$$m \frac{dy_S}{dz} = -\gamma y_s^{2/3} \theta^n \quad (14)$$

in which m is constant and y_s is described as:

$$y_s = \frac{4\pi r^3 n_s \rho_s}{3\rho Y_{FC}} \quad (15)$$

$$\omega = \frac{\lambda_u w_F}{(\rho_u v_u)^2 C Y_{FC}}, \quad \gamma = \frac{4.836 A n_u^{1/3} \lambda_u (T_f - T_u)^n}{v_u^2 \rho_u^{4/3} C Y_{FC}^{1/3} \rho_s^{2/3}}$$

Some another parameters are defined as:

$$q = \frac{Q_v}{Q}, \quad Nu = \frac{h_{in} d}{\lambda_u}, \quad Pe = \frac{\rho_u v_u C d}{\lambda_u}$$

Since the quantity q , the ratio of required energy for pyrolysis of fuel particles to the overall heat release by the flame, is too small, it is vanished in the above equation. θ^0 represents the dimensionless temperature, for $q=0$. Also the quantity m presumed to be unity, so the governing equations rewritten as:

$$\frac{d\theta^0}{dz} = \frac{d^2 \theta^0}{dz^2} + \omega \frac{\rho_u}{\rho} - \frac{4Nu.Pe^{-2}}{D_f'} \theta^0 \quad (16)$$

$$\frac{dy_F}{dz} = \frac{d^2 y_F}{dz^2} - \omega \frac{\rho_u}{\rho} + \gamma y_s^{2/3} (\theta^0)^n \quad (17)$$

$$\frac{dy_s}{dz} = -\gamma y_s^{\frac{2}{3}} (\theta^0)^n \quad (18)$$

In order to obtain the solution of these differential equations, the asymptotic approach is utilized based on the thin reaction zone.

Preheat-devolatilization zone ($-\infty < x < 0^-$) The Z_e , based on the gas-phase oxidation of the gaseous fuel is considered to be large, so chemical reaction between the gaseous fuel and oxidizer is neglected. Consider $K = 4NuPe^{-2}/D'_T$, dimensionless temperature equation and the required boundary condition in the preheat zone according to the above assumptions are extracted as:

$$\frac{d\theta^0}{dz} = \frac{d^2\theta^0}{dz^2} - K\theta^0, \quad (19)$$

$$z = 0 \rightarrow \theta^0 = 1, \quad z = -\infty \rightarrow \theta^0 = 0$$

The above simplified differential equation is solved as follow:

$$\theta^0 = \exp(k'z) \quad (20)$$

where,

$$k' = \frac{1 + \sqrt{1 + 4K}}{2} \quad (21)$$

In order to determine the mass fraction of the wood particles, the obtained dimensionless temperature correlation is substituted into the Equation (18). Thus Equation (18) and its boundary condition are rewritten as:

$$\frac{dy_s}{dz} = -\gamma y_s^{\frac{2}{3}} \exp(nk'z), \quad (22)$$

$$z = -\infty \rightarrow y_s = \frac{Y_{Fu}}{Y_{FC}} = \alpha$$

Thus, the correlation for mass fraction of wood particles is followed by:

$$y_s = \left[\alpha^{\frac{1}{3}} - a \exp(nk'z) \right]^3 \quad (23)$$

where,

$$a = \frac{\gamma}{3nk'} \quad (24)$$

Replacing the above achieved correlations, for the dimensionless temperature, and wood mass fraction into the gaseous fuel mass fraction yields to:

$$\frac{dy_F}{dz} = \frac{d^2y_F}{dz^2} + \gamma \left[\alpha^{\frac{1}{3}} - a \exp(nk'z) \right]^2 \exp(nk'z), \quad (25)$$

$$z = -\infty \rightarrow y_F = \frac{dy_F}{dz}, \quad z = 0 \rightarrow y_F = y_{Ff}$$

Integrating the above differential equations using the boundary conditions culminates in:

$$-\left[\frac{dy_F}{dz} \right]_{0^-} = 3a\alpha^{2/3} - 3a^2\alpha^{1/3} + a^3 - y_{Ff} \quad (26)$$

Post flame zone ($0+ < x < +\infty$) Before we verify the reaction zone, we analyze the post flame zone because we need the matching conditions between the reaction zone and the post flame zone.

In post flame zone, the diffusive terms in the conservation equations are assumed to be small in comparison with other terms, thus the basic Equations (16-18) are obtained as:

$$\frac{d\theta^0}{dz} = -K\theta^0 \Rightarrow \left[\frac{d\theta^0}{dz} \right]_{0^+} = -K \quad (27)$$

$$\frac{dy_F}{dz} = 0 \Rightarrow \left[\frac{dy_F}{dz} \right]_{0^+} = 0 \quad (28)$$

$$\frac{dy_s}{dz} = 0 \rightarrow y_s \cong cte \quad (29)$$

Reaction zone ($0- < x < 0+$) In this zone, the convective terms and devolatilization terms in the conservation equations are presumed to be small in comparison with the diffusive terms and reactive terms. Thus, the governing equations are as follows:

$$\frac{d^2\theta^0}{dz^2} = \omega \frac{\rho_u}{\rho} \quad (30)$$

$$\frac{d^2y_F}{dz^2} = \omega \frac{\rho_u}{\rho} \quad (31)$$

$$\frac{dy_s}{dz} = 0 \rightarrow y_s = cte \quad (32)$$

The gaseous fuel reaction rate appearing in the governing equation are evaluated as:

$$w_F = v_F W_F k_F C_F \quad (33)$$

For analyzing the structure of this region, the following expansions are introduced.

$$y_F = \varepsilon(b + y), \quad \eta = \frac{z}{\varepsilon}, \quad t = \frac{1 - \theta^0}{\varepsilon} \quad (34)$$

where, $b = y_{Ff}/\varepsilon$ and $\varepsilon = l/Z_e$. The quantities t and b are assumed to be of order unity. The Equations (30) and (31) are extracted using Equations (15), (33) and (34) as:

$$\frac{d^2t}{d\eta^2} = \Lambda(b + y) \exp(-t) \quad (35)$$

$$\frac{d^2(t - y)}{d\eta^2} = 0 \quad (36)$$

where, quantity Λ assumed to be of order unity defined as:

$$\Lambda = \frac{v_f \lambda_u B \varepsilon^2}{\rho_u v_u^2 C} \exp\left(\frac{-E}{RT_f}\right) \quad (37)$$

Now the matching conditions with the solution in the preheat zone ($\eta \rightarrow -\infty$), and with the post flame zone ($\eta \rightarrow +\infty$) are used, for determine the flame characteristics in this zone. Matching with the post flame zone results in:

$$\left[\frac{dt}{d\eta}\right]_{\eta \rightarrow +\infty} = -\left[\frac{d\theta^0}{dz}\right]_{z \rightarrow 0^+} = K \quad (38)$$

$$\left[\frac{dy}{d\eta}\right]_{\eta \rightarrow +\infty} = \left[\frac{dy_f}{dz}\right]_{z \rightarrow 0^+} = 0 \quad (39)$$

Matching with the preheat zone:

$$\left[\frac{dt}{d\eta}\right]_{\eta \rightarrow -\infty} = -\left[\frac{d\theta^0}{dz}\right]_{z \rightarrow 0^-} = -k' \quad (40)$$

Solution of the Equation (35) and using boundary conditions mentioned above result in:

$$2\Lambda(b+1) = k'^2 \quad (41)$$

3.2. Burning velocity Introducing Equation (41) into Equation (37) yields to the burning velocity as:

$$v_u^2 = \frac{2(b+1)v_f \lambda_u B \varepsilon^2}{k'^2 \rho_u c} \exp\left(\frac{-E}{RT_f}\right) \quad (42)$$

If T_f and b are known, the above equation can be used to calculate the burning velocity. For sufficiently high values of T_f , it is reasonable to set $y_{Ff}=0$ which implies that $b=0$. The matching conditions across the reaction zone are used to evaluate another expression for determination of T_f :

$$\left[\frac{d\theta^0}{dz}\right]_{0^-} + \left[\frac{dy_f}{dz}\right]_{0^-} = \left[\frac{dy_f}{dz}\right]_{0^+} + \left[\frac{d\theta^0}{dz}\right]_{0^+} \quad (43)$$

then,

$$3a\alpha^{2/3} - 3a^2\alpha^{1/3} + a^3 - k' - K = 0 \quad (44)$$

If the heat of devolatilization is considered, then the equation of burning velocity can be written:

$$v_v = v_u \exp\left(-\frac{qZ_e}{2}\right) \quad (45)$$

4. RESULTS AND DISCUSSIONS

In this work heat recirculation effect on the flame structure and combustion characteristics of the wood dust in a micro combustor has been investigated. A standard code is used to analyze the combustion model.

The flame temperature as a function of equivalence ratio is compared with the results of Ref. [10], for validation of the model. As seen in Figure 2, a reasonable agreement is obtained.

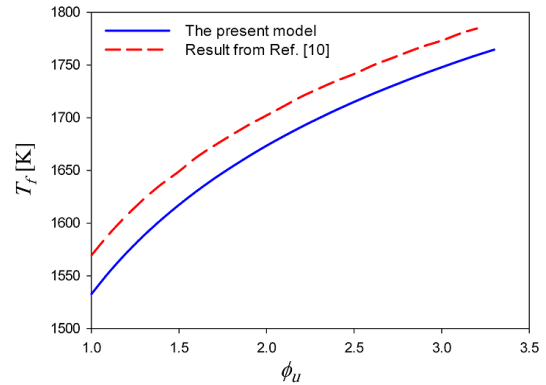


Figure 2. The variation of flame temperature as a function of equivalence ratio ($r_u=10 \mu\text{m}$, $K=0.1$)

The variation of the burning velocity as a function of equivalence ratio, for different values of particle radius is plotted in Figure 3. As observed, by increasing the equivalence ratio, the burning velocity increases, and when particle radius increases, the burning velocity goes down. This phenomenon occurs because with an increase in radius of the particle, the ratio of the particle surface to its volume decreases. So, for a given mass of the particles, there is less surface for oxidizer to react with particle. Hence, the time of reaction increases and as a result, burning velocity decreases.

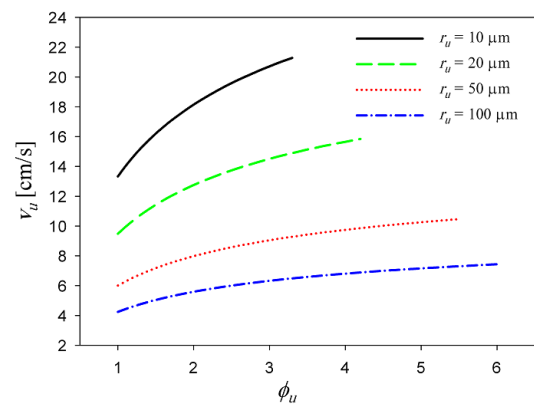


Figure 3. The variation of burning velocity as a function of equivalence ratio for different values of particle radius

Figure 4 illustrates the variation of flame temperature as a function of equivalence ratio, for different values of particle radius. As shown, with an increase in equivalence ratio, the flame temperature increases. Also, at the constant equivalence ratio, a decrease in

particle radius results in increasing the flame temperature. This is to be expected, because for any given equivalence ratio as particle size becomes smaller, both the number of particles and the total particle surface area increase. As perceived in this figure, the flame temperature increases with an increase in equivalence ratio due to the fact that higher equivalence ratio leads to higher heat of reaction. Therefore, the rate of the chemical reaction speeds up, and the flame temperature increases.

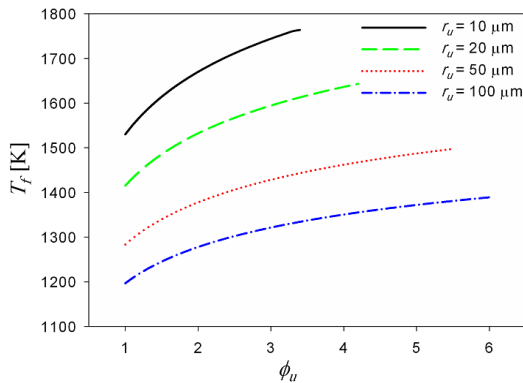


Figure 4. The variation of flame temperature as a function of equivalence ratio for different values of particle radius

The temperature profile of gas in the length of micro combustor for adiabatic and non-adiabatic states is shown in Figure 5. Combustion products are at high temperatures in the post-flame zone and so their temperature is higher than walls. Therefore, the last term of Equation (5) takes a negative value which causes the temperature drop in this area. This heat is transferred through the wall into the preheat zone and the heat flow takes place. In preheat zone, heat diffusion and heat recirculation are the effective terms of increasing temperature, as denoted in Equation (19). In post-flame zone, heat loss term is the only effective term of decreasing temperature.

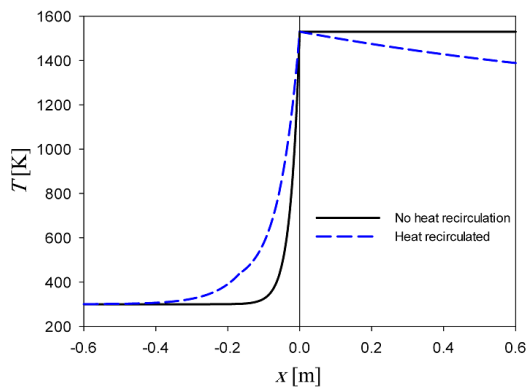


Figure 5. The variation of temperature profile of gas in the length of micro combustor for adiabatic and non-adiabatic states

The variation of $D'T$ in the length of micro combustor is plotted in Figure 6. The Equation (10) justifies the unfamiliar trend of this parameter. The asymptotic line is somewhere that gas temperature reaches to the wall temperature.

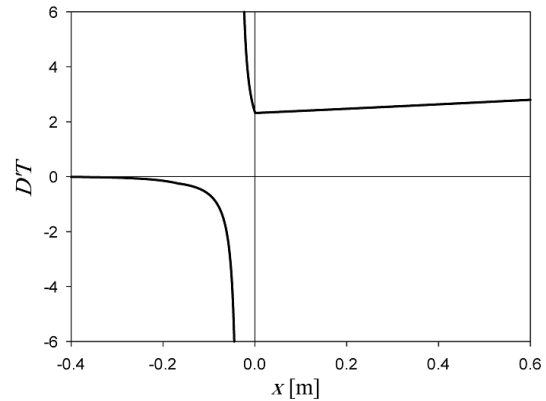


Figure 6. The variation of $D'T$ in the length of micro combustor

The power density of a micro combustor is defined as $\dot{w}_D = \dot{W}/V$, where \dot{W} is the power generated by the combustion process and V is the volume of the combustor in which the chemical energy is released.

The variation of power density of the micro combustor as a function of equivalence ratio is plotted in Figure 7. As seen in this figure, by increasing the equivalence ratio, power density of micro combustor also increases. These results may be explained as follows: in Figure 4, we saw that the flame temperature is increased with an increase in equivalence ratio. An increase in the flame temperature is equivalent to an increase in the heat transfer rate and thus power generated by the combustion process also increases. The power density of a micro combustor is in direct proportion to the generated power and so it increases.

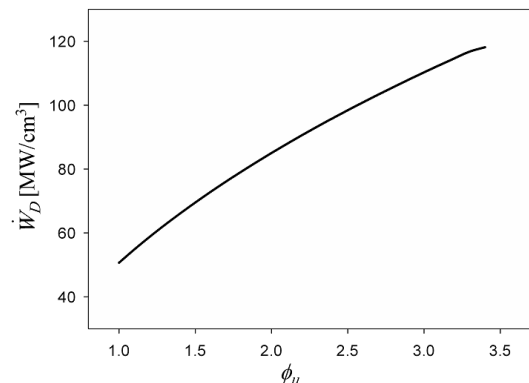


Figure 7. The variation of power density of the micro combustor as a function of equivalence ratio

Figure 8 shows the variation of the dimensionless mass fraction of gaseous fuel and wood particles in preheat zone. It is evident that a decrease in mass fraction of the particles results in an increase in mass fraction of the gaseous fuel. Indeed, the role of mass diffusion term in the mass conservation equation becomes more prominent with the approaching the flame zone. Therefore, the conversion rate of wood particles to gaseous fuel increases.

As shown in Figure 9, the variation of heat capacity of the gas is small when the variation of equivalence ratio is great. Therefore, its variation is similar to wide range of gases.

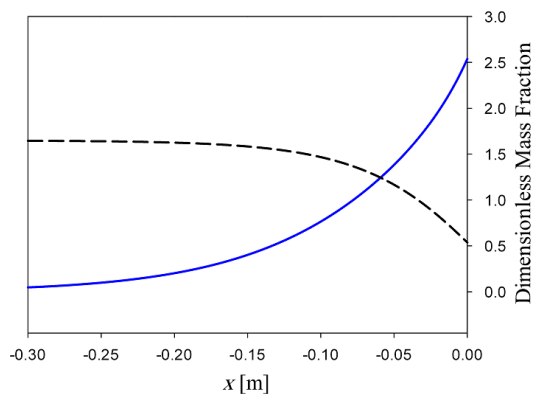


Figure 8. The variation of the dimensionless mass fraction of gaseous fuel and wood particles in preheat zone

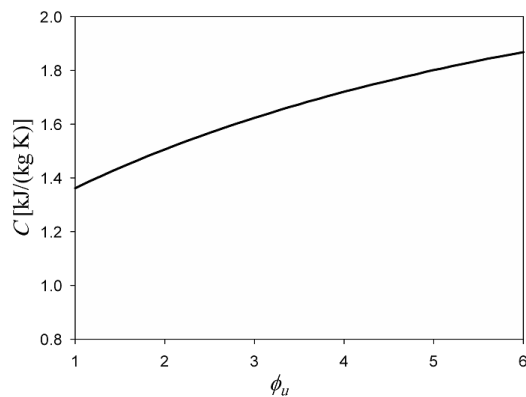


Figure 9. The variation of heat capacity of the gas as a function of equivalence ratio

5. CONCLUSION

If many combustible dusts dispersed as a cloud in air and ignited, it will allow a flame to propagate through the cloud in a manner similar to the propagation of flames in premixed fuel oxidant gases. The violence of explosion on particle size strongly depends on the interplay of phenomena controlling the combustion/heating of the solid material, such as

pyrolysis, gas-phase mixing, gas-phase combustion, and the dispersion of the dust particles in air.

Heat recirculation as an important parameter in the wood dust flame propagation is investigated. In the steady analysis, dust flame is separated to three zones: broad preheat-devolatilization zone, thin reaction zone, and finally the post-flame zone. Heat is circulated from the exhaust flow in post flame zone into the preheat zone.

Result shows that with an increase in the equivalence ratio, the burning velocity, the flame temperature and the power density of micro combustor increase. As it is reported, gas temperature in preheat zone increase when heat recirculation is considered. It means that heat recirculation is a process which results in advantages of high temperature combustion. Moreover, combustion process in micro combustor will remain more stable due to an increase in the equivalence ratio and a decrease in the wood particle size.

6. REFERENCES

1. Spadaccini, C. M., Peck, J. and Waitz, I. A., "Catalytic Combustion Systems for Microscale Gas Turbine Engines", *Journal of Engineering for Gas Turbines and Power*, Vol. 129, (2007), 49–60.
2. Cho, J. H., Lin, C. S., Richards, C. D., Richards, R. F., Ahn, J. and Ronney, P. D., "Demonstration of an external combustion micro-heat engine", *Proceedings of the Combustion Institute*, Vol. 32, (2009), 3099–3105.
3. Chou, S. K., Yang, W. M., Li, J. and Li, Z. W., "Porous media combustion for micro thermophotovoltaic system applications", *Applied Energy*, Vol. 87, (2010), 2862–2867.
4. Fernandez-Pello, A. C., "Micropower Generation Using Combustion: Issues and Approaches", *Twenty-Ninth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, (2002), 883–899.
5. Chen, C. H. and Ronney, P. D., "Three-dimensional effects in counterflow heat-recirculating combustors", *Proceedings of the Combustion Institute*, Vol. 33, (2011), 3285–3291.
6. Daou, J. and Matalon, M., "Influence of conductive heat losses on the propagation of premixed flames in channels", *Combustion and Flame*, Vol. 128, (2002), 321–339.
7. Daou, J. and Matalon, M., "Flame propagation in channels: differential diffusion effects", *3rd Joint Meeting of the US Sections of the Combustion Institute*, Chicago, Illinois, USA, (2003).
8. Leach, T. T., Cadou, C. P. and Jackson, G. S., "Effect of structural heat conduction and heat loss on combustion in micro-channels", *Combustion Theory and Modeling*, Vol. 10, (2006), 85–103.
9. Leach, T. T. and Cadou, C. P., "The role of structural heat exchange and heat loss in the design of efficient silicon micro-combustors", *Proceedings of the Combustion Institute*, Vol. 30, (2005), 2437–2444.
10. Bidabadi, M., Fanaee, A. and Rahbari, A., "Investigation over the recirculation influence on the combustion of micro organic dust particles", *Applied Mathematics and Mechanics (English Edition)*, Vol. 31, (2010), 685–696.
11. Abbasi Khazaei, K., Hamidi, A. A. and Rahimi, M., "Numerical modeling and simulation of highly preheated and diluted air combustion furnaces", *International Journal of Engineering*,

- Vol. 22, (2009), 107-118.
12. Bidabadi, M., Fereidooni, J. and Rahbari, A., "Theoretical Model of Flame Propagation Through Dry Biomass Particles in a Fixed Bed", *World Applied Sciences Journal*, Vol. 13, No. 3, (2011), 531-536.
 13. Shahriarian, S. and Heidarinejad, G., "Simulation of premixed combustion flow around circular cylinder using hybrid random vortex", *International Journal of Engineering*, Vol. 24, (2011), 269-278.
 14. Babu, B. V. and Chaurasia, A. S., "Heat transfer and kinetics in the pyrolysis of shrinking biomass particle", *Chemical Engineering Science*, Vol. 59, (2004), 1999-2012.
 15. Tasaka, K., Furusawa, T. and Tsutsumi, A., "Biomass gasification in fluidized bed reactor with Co catalyst", *Chemical Engineering Science*, Vol. 62, (2007), 5558-5563.
 16. Bidabadi, M., Abedinejad, M. S. and Fereidooni, J., "Modeling of the propagation of a reaction front in fixed bed combustion of wood particles", *Journal of Mechanics*, Vol. 27, No. 3, (2011), 453-35.

TECHNICAL NOTE

Heat Recirculation Effect on the Structure of Wood Dust Flame Propagation

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مدلی تحلیلی برای یک محفظه ی احتراق بسیار کوچک همراه با گردش حرارتی در آن، توسعه داده شد. در این مقاله، ساختار شعله ای آرام، یک بعدی و پایا که در پیش مخلوط همگنی از ذرات چوب منتشر می گردد، با در نظر گرفتن اثرات گردش حرارتی که از طریق ساختار محفظه ی احتراق اعمال می گردد، بررسی می شود. ساختار شعله به سه ناحیه تقسیم می شود: یک ناحیه ی پیشگرم-تبخیر که در آن نرخ واکنش شیمیایی فاز گازی کوچک است، یک ناحیه ی واکنش بسیار باریک که در آن جایجایی و نرخ تبخیر ذرات سوخت کوچک است، و در آخر یک ناحیه ی جایجایی که در آن جمله های مربوط به نفوذ در معادلات بقا کوچک هستند. در این مدل فرض می شود که ذرات سوخت ابتدا تبخیر می شوند و تشکیل یک ساختار شیمیایی مشخص را می دهند. تحلیلی که در این مقاله انجام شده است، به صورت حد مجانبی می باشد. بررسی کلی این مطالعه منجر به عبارت نوینی برای سرعت سوزش غیر خطی می گردد که در آن گردش حرارتی مد نظر قرار گرفته است. نتایج نشان دادند که گردش حرارتی توسط پارامترهای مختلف بر ساختار شعله تاثیر می گذارد. دمای شعله و سرعت سوزش مهمترین این پارامترها هستند. همچنین افزایش نسبت هم ارزی و ریزتر کردن ذرات چوب به بهتر شدن و پایدار ماندن فرایند احتراق در میکروکامبستور کمک می کند.

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