TRANSACTIONS B: Applications Vol. 29, No. 2, (February 2016) 246-254

International Journal of Engineering

Journal Homepage: www.ije.ir

Laminar Flame Speed Prediction in Lean Mixture of Aluminum Dust Clouds by Considering the Effect of Random Distribution of Particles in Two-dimension

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PAPER INFO

Paper history:
Received 29 October 2014
Received in revised form 19 April 2015
Accepted 26 January 2016

Keywords:
Random Distribution
Aluminum Particles
Flame Temperature
Burning Velocity

ABSTRACT

In the present study, the effect of random distribution of reactants and products on laminar, 2D and steady-state flame propagation in aluminum particles has been investigated. The flame structure is assumed to consist of a preheat zone, a reaction zone and a post flame zone. It is presumed that in the preheat zone particles are heated and reaction does not exist. Energy conservation equations of laminar flame had been solved two-dimensionally for different zones and algebraic equations of flame speed are obtained. Finally, gas temperature distribution in different flame zones in the channel and also flame speed changes in terms of particles diameter, equivalence ratio, and channel width in random media are compared with previous experimental and theoretical results. The results show a reasonable compatibility with this theory and experimental data.

***doi**: 10.5829/idosi.ije.2016.29.02b.14*

NOMENCLATURE

B	mass concentration of fuel (kg/m^3)	x,y	spatial coordinates (m)
B_{st}	stoichiometric dust concentration (kg/m$^{3)}$	h	convective heat transfer coefficient (W/m^2.K)
d_p	particle diameter (μm)	A	heat transfer area of the surface (m^2)
d	width of the channel (m)	**Greek Symbols**	
T	temperature (k)	Φ	equivalence ratio
Nu	Nusselt number	α	heat transfer coefficient between gas and flat channel (W/K)
m_s	mass of the particle (kg)	λ	thermal conductivity of gas (W/m K)
C	concentration (kg/m^3)	τ_c	total combustion time (s)
D	diffusion coefficient of oxygen (m^2/s)	ρ	density(kg/m^3)
W_f	reaction rate characterizing cons. of fuel	ν	velocity (m/s)
q	heat of reaction per unit mass of fuel (J/kg)	**Subscripts**	
T_{si}	heat of reaction per unit mass of fuel (J/kg)	u	unburned
C_p	specific heat of gas at constant pressure (J/kgK)	1	preheat zone
C_s	specific heat of particle (J/kg K)	2	flame zone
q	heat transfer between each particle and surrounding gas (j)	3	post flame zone
r	particle radius (m)	s	Solid particle
		si	solid particle at the beginning of burning

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Please cite this article as: M. Bidabadi, B. Akhoondian, M. Harati, Laminar Flame Speed Prediction in Lean Mixture of Aluminum Dust Clouds by Considering the Effect of Random Distribution of Particles in Two-dimension, International Journal of Engineering (IJE), TRANSACTIONS B: Applications Vol. 29, No. 2, (February 2016) 246-254

1. INTRODUCTION

Due to their applicability in various industrial processes and energy conversion systems, reacting two-phase flow of gas/solid mixtures attract researcher's attention [1-4]. Aluminum is a common additive to propellants and high explosives. In solid rocket motor (SRM) applications, aluminum increases the specific impulse of the propellant by lowering the molecular weight of the products and increasing combustion temperatures. The aluminum particles in the propellant pass un-reacted through the primary flame zone and then react with the product gases, that consist primarily of CO_2, H_2O, and HCl at temperatures of approximately 2600–3000 K and pressures of 40–100 atm. [5].

Dust explosion is a sort of phenomena in which flame propagates through dust clouds in air with an increasing degree of subdivision of any combustible solid particles. Research on combustion of Aluminum has been actively embarked on over the last five decades and a large body of experimental findings has been obtained. Many studies have been published on combustion of aluminum dust particles in the last few years. In their study, flame propagation speed and maximum flame temperature of the mixture in a random media of aluminum particles were analyzed [6].

Particle diameter is a one of main factors in determining the relevant combustion mechanisms by affecting the characteristic transport diffusion time proportionate to the chemical kinetics time. A large diameter particle at high pressure may burn under diffusion controlled conditions, whereas a small particle at low pressure may burn under kinetically controlled conditions [7, 8].

However, a small number of studies show that the flame characterization of an Aluminum dust cloud is much more complex than the flame characterization of a single particle. Cassel [9] conducted an experimental test that investigated the flame propagation in Aluminum dust–air mixtures using a Bunsen-type and a flat dust flame burner. Ballal [10] examined the burning velocity of a flat flame in an aluminum–air dust cloud in a microgravity environment by using a freely falling tube. In all these pioneering studies of Cassel [9] and Ballal [10], the lean dust mixtures are investigated.

Furthermore, it is found that the burning velocities increase with dust concentrations. Recently, Goroshin et al. [11] measured the quenching distance and the flame speed of Aluminum dust during the laminar stage of flame propagation in various oxidizer environments in a vertical Pyrex tube over a wide range of dust concentrations of 0.13–0.60 kg/m^3. As a result, three different stages of flame propagation are observed: laminar flame, oscillation flame, and turbulent accelerating flame, and at last, a theoretical model is proposed. Goroshin et al. [10] also established an experimental apparatus that is capable of producing Bunsen-type premixed dust flames of rich Aluminum mixtures. The dust mass concentration covered a range from 0.25 to 0.60 kg/m^3, corresponding to the equivalence ratio φ of 0.81–1.9. In both experiments [11, 12], the burning velocity was shown to be a weak function of dust concentration for fuel-rich mixtures, a phenomenon that can be attributed to the weak dependence of particle burning rate on the flame temperature in the diffusive regime.

In particle combustion field, Bidabadi et al. [13], investigated the structure of moist lycopodium dust flame and their results indicate that the moisture resists against flame propagation, thus increase in particle moisture content yields to decrease in flame temperature and burning velocity.

Recently, Huang et al. [14, 15] theoretically studied the combustion of Aluminum particle dust in a laminar airflow under fuel–lean conditions. A wide range of particle sizes of nano and micron scales are explored. The flame speed and temperature distribution are obtained by solving the energy equation numerically in the flame zone. Also, the particle-burning rate is modeled as a function of the particle diameter and ambient temperature. By decreasing the particle diameter from the micron to the nano range, the flame speed increased and the combustion transited from a diffusion-controlled to a kinetically controlled mode. They concluded that no universal law of the flame speed existed for any range of particle sizes [15].

In the previous theoretical models [11, 12, 14, 15], the effect of burning time and ignition temperature, which are different for various particles in dust cloud, is neglected. Moreover, the reaction rate is constant during the reaction. In their research, the ignition point of each particle in terms of the particle size distribution is determined and by considering the burning time of this particle, the new reaction rate is obtained. The science of the combustion of fine solid particles needs to be developed both experimentally and analytically.

While the combustion of volatile, polydispersity sprays has been numerically investigated in several works, flame propagation in a non-volatile, multi-size dust suspension has not received much attention. This can be because of the complexities involved in the combustion of non-volatile particles including the simulation of laboratory conditions, such as uniformly distributing suspended particles in the presence of gravity force [16, 17], and complexity and unexpected changes of the flame behavior and quantities related to the type and even size of the particles [18].

2. GOVERNING EQUATIONS

The present study follows the work of Bidabadi et al. [19]. They solved partial differential equations (PDEs)

under lean mixture conditions and their study takes the initiative in presenting an analytical 2D model of Aluminum dust cloud combustion in a channel. In this study, the current combustion zones divided in many subzones and the particles are distributed randomly. While for any subzone the 2D expression is correct. Such that model [19], the heat loss term to wall is obtained by $(-\lambda(\partial T/\partial y))$, as the boundary condition, whereas in the 1D model it was entered into the energy equation. In this way α(T-Tu), and a heat transfer coefficient between gas and flat channel was computed in the following way: $\alpha = Nu\lambda / d^2$ [19].

For the purpose of the present work, i.e. the analysis of flame propagation in narrow channels, the radiative heat transfer from the flame to the preheat zone will be neglected. The radiation emitted by the flame front and post-flame zone, which passes the preheat flame zone almost without extinction and is absorbed almost entirely by the channel walls [11], is also neglected. The analytical model described below is based on a 2D approximation of the flame with conductive heat losses. The major assumptions and approximations are [11, 12, 14, 20]:

(a) the dust cloud consists of a mixture of gaseous oxidizer and randomly distributed, equal-sized Aluminum particles;

(b) the gravitational effects are neglected, although they may play important roles in flame propagation;

(c) the particle velocity is equal to the gas velocity in the laminar, steady and uniform flow;

(d) the Biot number for the particle is very small, which implies that the temperature of each particle is uniform.

The 1D flame with fuel-lean mixtures is assumed to consist of three zones: preheat, flame, and post-flame regimes, as illustrated in Figure 1 [19].

The reaction rate in the preheat zone (zone1, $-\infty \prec x \prec 0$) is negligibly small and the gas is heated by conduction from the flame zone. Particles are heated by the surrounding gas until their temperature reaches its ignition point. The difference in temperature between the dust particles and the gas progressively increases due to inertia in the heat exchange. The transient period from ignition to a stable diffusive combustion is much less than the total combustion time τ_c [11, 14, 20-22]. In the flame zone, particles are ignited and totally consumed (zone 2, $0 \prec x \prec \upsilon_u \tau_c$). When combustion is completed, the gas temperature gradually returns to the initial value T_u because of heat loss in the post-flame zone (zone 3, $\upsilon_u \tau_c \prec x \prec +\infty$). The particle burning rate dm_s/dt in the diffusive regime of particle combustion is in proportional relation with the local particle radius r, the local carbondioxide concentration CO_2, and the diffusion coefficient of oxygen D [11]:

$$\frac{dm_s}{dt} \approx D(\bar{T}) r C_{o_2} \tag{1}$$

Because of the excess of oxygen in a lean mixture and the weak dependence of oxygen diffusivity on ambient gas temperature, the total particle burning time in a flame front is close to the burning time of a single particle τ_c [11, 14, 20, 22]. Thus, using the average burning rate of Aluminum particle (m_s/τ_c), the heat source term can be written for the flame zone as follows [11, 20, 22]:

$$W_f = \frac{B_u}{\tau_c} Q \tag{2}$$

Goroshin et al. [11] (other examples include [22] , [20], [14] references) also assumed that the particle temperature at the moment of ignition (x = 0) is close to the auto ignition temperature of a single particle T_{si} (the ignition temperature in a gas media of constant temperature) and can be found from the equation describing inert particle heating in the preheat zone:

$$\upsilon_u m_s C_s \frac{dT_s}{dx} = \frac{\lambda_u}{r}(4\pi r^2)(T_s - T) \tag{3}$$

The gas phase governing equations for mass and energy conservation in 1D approximation can be written as follows:

$$\rho \upsilon = \rho_u \upsilon_u \tag{4}$$

$$\upsilon_u \rho_u C_p \frac{dT}{dx} = \lambda_u \frac{d^2T}{dx^2} + W_f \frac{\rho_u}{\rho} - \alpha \frac{\rho_u}{\rho}(T - T_u) \tag{5}$$

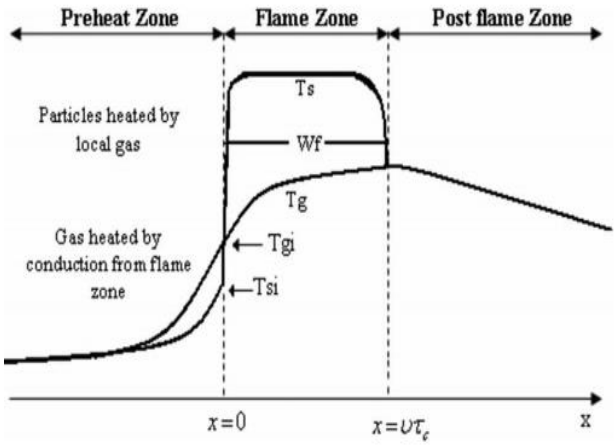


Figure 1. 1D flame structure in fuel-lean mixture

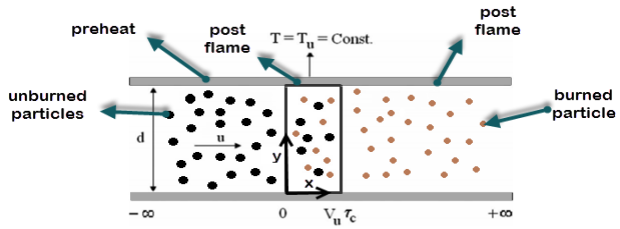


Figure 2. The schematic diagram of combustion in a channel with randomly distributed particles and the constant surface temperature under fuel-lean condition

The third term on the right-hand side of Equation (5) indicates that the heat loss to the wall is linearly proportional to the temperature difference between the gas and the wall. By solving the energy equation in each zone and matching the temperature and heat flux at the interfacial boundaries, an algebraic equation for the flame speed in a fuel-lean mixture can be found. With this assumption, Goroshin et al. [11] could measure quenching distance, lean flammability limit, and flame speed, but their results did not correspond to the experimental data.

Following the previous 1D works [11, 12, 14, 15, 20, 22, 23] and in order to obtain flame speed and temperature distributions, in the present study, flame structure is divided into the three preheat, flame, and post flame zones. The schematic representation of this structure is presented in Figure 2. The x axis in the figure has the same direction as that of flame's movement in the channel, and the y axis shows the width of the channel. By solving the PDE of energy equation in two dimensional condition and by using the separation of variables method in all the three zones and satisfying the boundary conditions, an algebraic equation for the flame speed as a function of equivalence ratio can be found. Also, the lean flammability limit and gas phase temperature distribution can be found. The experimental data show that the quenching plate temperature does not exceed and is almost equal to that of the initial or the unburned mixture temperature [11, 24]. Therefore, this temperature is assumed to be constant $T=T_u$. The thermal conductivity of gas, λ, which usually varies with temperature, is taken to be constant for the sake of simplicity [14, 20]. With these assumptions, the gas phase governing heat diffusivity equation and the boundary conditions for the problem illustrated in Figure 2 can be obtained [19].

Preheat zone:

$$\frac{\partial^2\theta_1}{\partial x^2}+\frac{\partial^2\theta_1}{\partial y^2}-2s\frac{\partial\theta_1}{\partial x}=0 \tag{6}$$

Flame zone:

$$\frac{\partial^2\theta_2}{\partial x^2}+\frac{\partial^2\theta_2}{\partial y^2}-2s\frac{\partial\theta_2}{\partial x}=-R\phi \tag{7}$$

Post-flame zone:

$$\frac{\partial^2\theta_3}{\partial x^2}+\frac{\partial^2\theta_3}{\partial y^2}-2s\frac{\partial\theta_3}{\partial x}=0 \tag{8}$$

The parameters, s, R, θ, ϕ in the above equations are defined as:

$$s=\frac{\rho_u \upsilon_u C_p}{2\lambda}$$
$$R=\frac{B_{st}Q}{\lambda\tau_c},\quad \theta=T-T_u,\quad \phi=\frac{B}{B_{st}} \tag{9}$$

Boundary conditions:

$$\theta_1(-\infty,y)=0,\ \theta_1(x,0)=0,\ \theta_1(x,d)=0$$
$$\theta_1(0^-,y)=\theta_2(0^+,y)$$
$$\frac{\partial\theta_1}{\partial x}(0^-,y)=\frac{\partial\theta_2}{\partial x}(0^+,y)$$
$$\theta_2(x,0)=0,\ \theta_2(x,d)=0$$
$$\theta_2(\upsilon_u\tau_c,y)=\theta_3(\upsilon_u\tau_c,y) \tag{10}$$
$$\frac{\partial\theta_2}{\partial x}(\upsilon_u\tau_c,y)=\frac{\partial\theta_3}{\partial x}(\upsilon_u\tau_c,y),$$
$$\theta_3(x,0)=0$$
$$\theta_3(x,d)=0,\ \theta_3(+\infty,y)=0$$

By solving the above equations the following solutions are obtained:

$$\theta_1(x,y)=\sum_{n=1}^{\infty}A_n\exp\left[\left(s+\sqrt{s^2+\mu_n^2}\right)x\right]\sin(\mu_n y) \tag{11}$$

$$\theta_2(x,y)=\frac{1}{2}R\varphi y(d-y)+\sum_{n=1}^{\infty}B_n\times\left(\frac{(\sqrt{s^2+\mu_n^2}-s)\exp((s-\sqrt{s^2+\mu_n^2})\upsilon_u\tau_c)}{(\sqrt{s^2+\mu_n^2}+s)\exp((s-\sqrt{s^2+\mu_n^2})\upsilon_u\tau_c)}\times\exp\left(\left(s+\sqrt{s^2+\mu_n^2}\right)x\right)\right.$$
$$\left.+\exp\left(\left(s-\sqrt{s^2+\mu_n^2}\right)x\right)\right)\sin(\mu_n y)+\sum_{n=1}^{\infty}C_n\left(\frac{\sqrt{s^2+\mu_n^2}-s}{\sqrt{s^2+\mu_n^2}+s}\times\exp\left(\left(s+\sqrt{s^2+\mu_n^2}\right)x\right)+\left(\left(s-\sqrt{s^2+\mu_n^2}\right)x\right)\right)\sin(\mu_n y) \tag{12}$$

$$\theta_3(x,y)=\sum_{n=1}^{\infty}E_n\left[\left(s-\sqrt{s^2+\mu_n^2}\right)x\right]\sin(\mu_n y) \tag{13}$$

where:

$$\mu_n=\frac{n\pi}{d},\ n=1,2,3,... \tag{14}$$

The first term on the right-hand side of Equation (12) can be expanded as:

$$\frac{1}{2}R\phi y(d-y)=\sum_{n=1}^{\infty}F_n\sin(\mu_n y) \tag{15}$$

To find parameters A_n, B_n, C_n, and E_n, boundary conditions described in Equation (10) are used, which are in the interfacial boundaries of three zones [19],

$$A_n=\frac{\alpha_n}{1+\alpha_n}F_n(1-\gamma_n\beta_n),\ B_n=\frac{-F_n}{1+\alpha_n}(\gamma_n+\frac{1-\gamma_n}{1-\beta_n})$$
$$C_n=\frac{F_n}{1+\alpha_n}\frac{1-\gamma_n}{1/\beta_n-1},\ E_n=\frac{F_n}{1+\alpha_n}(\gamma_n-1) \tag{16}$$

where:

$$F_n=\frac{2R\phi d^2}{(n\pi)^3}(1-\cos n\pi),$$
$$\alpha_n=\frac{\sqrt{s^2+\mu_n^2}-s}{\sqrt{s^2+\mu_n^2}+s}$$
$$\beta_n=\frac{\exp\left[(s-\sqrt{s^2+\mu_n^2})\upsilon_u\tau_c\right]}{\exp\left[(s+\sqrt{s^2+\mu_n^2})\upsilon_u\tau_c\right]}, \tag{17}$$
$$\gamma_n=\frac{1}{\exp\left[(s-\sqrt{s^2+\mu_n^2})\upsilon_u\tau_c\right]}$$

The heat transfer between each particle and surrounding gas is given by [14, 20]:

$$q=hA(T-T_s)=\frac{Nu\lambda}{2r}4\pi r^2(T-T_s)=4\pi r\lambda(T-T_s) \tag{18}$$

where h is convective heat transfer coefficient and A the area of heat transfer, and the Nusselt number is taken as a constant equal to 2.

It is assumed that the particle temperature varies in x direction, so the energy conservation equation for the solid phase is [11, 14, 20, 22]:

$$\frac{\partial\theta_s}{\partial x}=\zeta(\theta_1-\theta_s) \tag{19}$$

where:

$$\zeta=\frac{3\lambda}{r^2\rho_s C_s\upsilon_u},\ \theta_s=T_s-T_u \tag{20}$$

Boundary condition for Equation (19) is:

$$x\to-\infty,\ \theta_s=0 \tag{21}$$

By solving Equation (19) and using the boundary condition (21), also for lean mixture:

$$\theta_s(x,y)=\sum_{n=1}^{\infty}\frac{A_n\zeta}{(s+\sqrt{s^2+\mu_n^2})+\zeta}$$
$$\times\exp\left[\left(s+\sqrt{s^2+\mu_n^2}\right)x\right]\sin(\mu_n y) \tag{22}$$

Also, since the particle temperature in x = 0 equals the ignition temperature, T_{si}, then:

$$\theta_s(0,y)=\sum_{n=1}^{\infty}\frac{A_n\zeta}{(s+\sqrt{s^2+\mu_n^2})+\zeta}\sin(\mu_n y) \tag{23}$$

where:

$$\theta_{si}=T_{si}-T_u \tag{24}$$

θ_{si} is expanded as:

$$\theta_{si}=\sum_{n=1}^{\infty}Z_n\sin(\mu_n y) \tag{25}$$

where (utilizing orthogonality of functions [25]):

$$Z_n=\frac{2\theta_{si}}{n\pi}(1-\cos n\pi) \tag{26}$$

In addition (Equations (23) and (25)):

$$Z_n=\frac{A_n\zeta}{(s+\sqrt{s^2+\mu_n^2})+\zeta} \tag{27}$$

By equating the above two equations (Equations (26) and (27)) and after simplifying, the key equation of flame speed as a function of equivalence ratio is obtained for the 2D condition, which is accurate for each quantity of n [19]:

$$\frac{A_n\zeta}{(s+\sqrt{s^2+\mu_n^2})+\zeta}=Z_n=\frac{2\theta_{si}}{n\pi}(1-\cos n\pi)$$
$$\Rightarrow\frac{2\mu_n^2\theta_{si}(\sqrt{s^2+\mu_n^2})(s+\sqrt{s^2+\mu_n^2}+\zeta)}{R\zeta(\sqrt{s^2+\mu_n^2}-s)}=\phi \tag{28}$$
$$(1-\left\{1/\exp\left[\left(s+\sqrt{s^2+\mu_n^2}\right)\upsilon_u\tau_c\right]\right\})$$

The velocity obtained from Equation (28) by try an error procedure, next the value of velocity substituted in Equations (11) to (13), then temperature value can be find from Equations (11)-(13). In this model, we distributed the value of dust concentration randomly in the range of concentration of experimental values. Then,

results have been plotted and compared with nonrandom experimental values.

The main goal of the present paper is to validate the capabilities of the random model for analytical simulation of inorganic dust particle combustion like Aluminum in comparison with the other combustion models. In this study, flame propagation speed, the effects of particle diameter and random distribution of dust concentration have been studied theoretically. Equations in random zones have been divided into many subzones; by applying equations on subzones we can find random results.

3. RESULTS AND DISCUSSIONS

In this study an analytical model for the combustion of mono-size Aluminum particles with air presented and the effect of random media on the combustion properties were investigated via 2D analytical equations. In order to model the random media of the combustion, dust concentration distribution in the reaction zone was considered randomly.

In reality, the preparation conditions for different particles are not the same. So, the combustion properties such as burning velocity, flame temperature and the amount of released energy which are functions of these preparation conditions would vary -along the flame front since these preparation condition for different fuel particles are random and different. In other words, the combustion process is not uniform.

Temperature distribution for the combustion of Aluminum particles with diameter of d_p=5.4 μm in air and the equivalence ratio of φ=0.8 are obtained. Channel width is 5 cm and the surface temperature (in y = 0, y = 0.05 m) is equal to the surrounding temperature, as it had been assumed (T =T_u).

In Figure 3, random and nonrandom calculations are compared with the experimental data obtained from [12, 23]. It is seen that random results show a better compatibility with the experimental results.

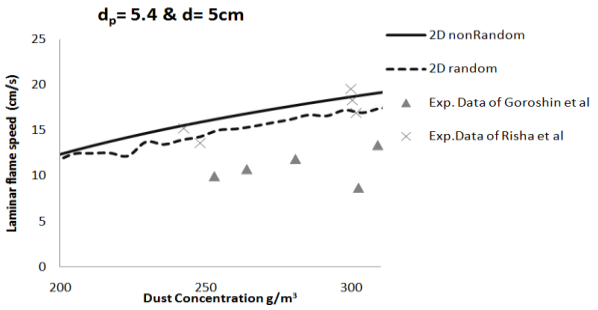


Figure 3. Comparison between random and nonrandom for flame speed with experimental data as a function of dust concentration

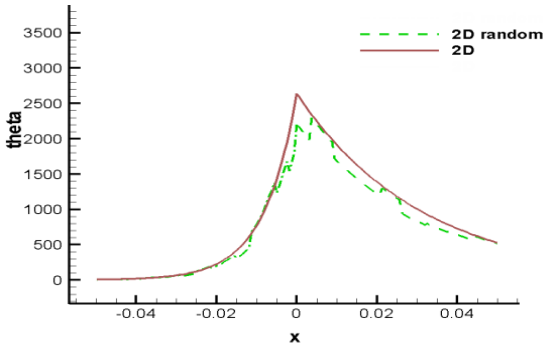


Figure 4. Temperature profile in the middle of channel(y=d/2).

Because the random distribution of particles is closer to reality, so result of random model is better matched to experimental and velocity profile is adapted to the experimental results. In Figure 4 the gas temperature distribution in preheat, reaction, and post-flame zones for the mixture are given, which are obtained from Equations (11) to (13) by considering both random and nonrandom distribution for fuel concentration. Temperature profile in the middle of the channel is in agreement with the temperature curves of the previous 1D and 2D models [14, 20]. As shown in Figure 4, random and nonrandom results are approximately matched for preheat zone but they are completely different for the reaction and post flame zone. Since it is assumed that in the preheat zone the particles are just heated and no reaction occurs, the random consideration for the distribution of the fuel concentration does not have a significant effect on temperature rise of the particles. However, in the reaction zone, as a rate of released energy during the reaction is highly dependent on the fuel concentration, the random results are different from the nonrandom calculations.

Figure 5 indicates the calculated 2D laminar flame speed for random and nonrandom combustion as a function of dust concentration for different particle diameters of aluminium–air mixture under fuel-lean conditions (d= 5 cm). The flame speeds increase as particle size decreases. This is due to reduction in the surface of the particle as the volume of particle increases which means that the available fuel on the surface of the particle would decrease, and this would lead to lower flame temperature and burning velocity. It is also seen that for the dust concentrations lower than 200gr/m^3, random and nonrandom calculations are approximately matched. Also, for a constant value of dust concentration, as the particle diameter increases, random calculations become more and more close to nonrandom calculations. This is because the number of particles decrease by increasing the particle diameter in a constant dust concentration, hence the probability of large variation for the distribution of fuel concentration in the reaction zone decrease. This means that the

combustion situation matches with the uniform situation.

The solution of Equation (28) gives two values for the flame speed for the same set of dust parameters. However, it can be shown that the solution with the lower value of the flame speed is unstable, so this solution in Figures 5 and 6 is neglected. With the increase of particle diameter, the lean flammability limit increases; a result that is reasonable and accords with the experimental results [11]. In Figure 6, the key relation of speed in terms of concentration for fuel-lean mixture can be drawn. It is observed that the 2D new random model in comparison with the 2D old model proposed by Bidabadi et al. [19] is closer to the experimental results and a little better than the previous works, a finding that can indicate the effect of random solution. In this figure, the channel width varies and particle diameter is 5.4μm, and the lean limit has a good agreement with Goroshin's results for the same diameter. In this figure, a lean limit of about 150 g/m^3 has been obtained.

By reducing the channel width, and because of the increase of heat transfer rate between the flame and the wall, or in fact the increase of heat loss to the wall, the lean flammability limit increases. With the increase of channel width, flame speed increases a little as well.

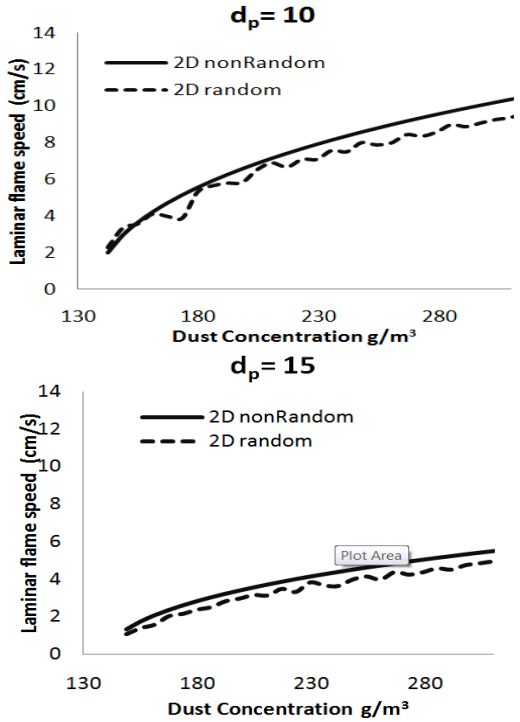
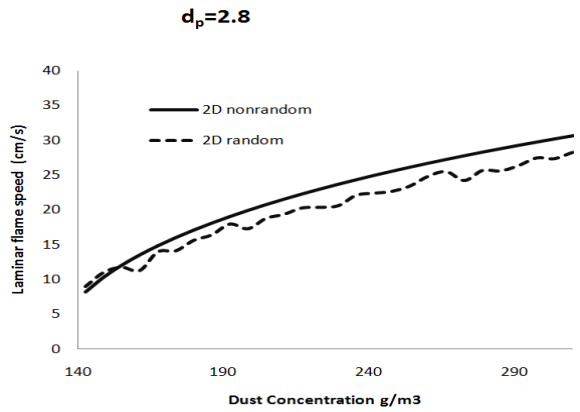
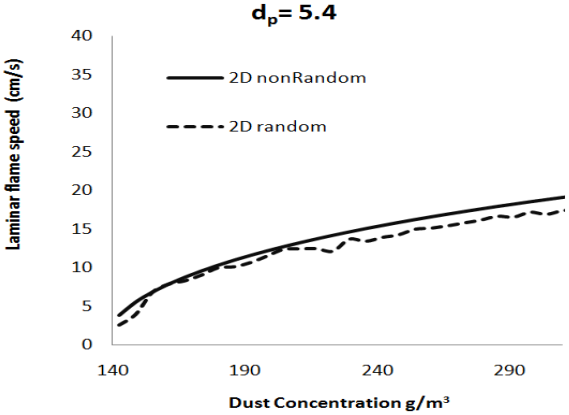


Figure 5. Flame speed as a function of particle diameter in fuel-lean mixture of Aluminum particle dust and air for channel width of 5cm.





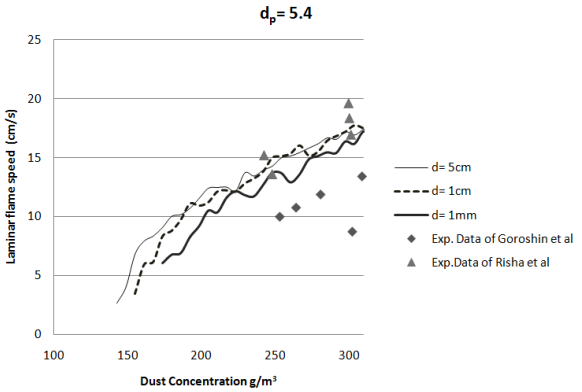


Figure 6. Effect of channel width on flame speed, (d_p=5.4 μm).

4. CONCLUSIONS

This work presented a method for randomization that focuses on all zones. In this method, the preheat zone randomly divides into some zones, and dust concentration distribute in these zones. In this work, random combustion characteristics of Aluminum dust particles and the effect of particle diameter and channel width on the characteristics of combustion of Aluminum in 2D- dimension have been investigated.

The present study shows following conclusions:

- Flame speed in random model compared with the continuous model with change of particle diameter

and showed that by increasing the particle diameter, the value of burning velocity decreases and the values of burning velocity for random method are less than the same case with same values for continuous model.

- The calculated flame temperature from the present model, both in random and nonrandom mode is comparable with the experimental data. It was also shown that the random calculations have a better agreement with the experimental data than nonrandom calculations.
- By reducing the channel width, and because of the increase of heat transfer rate between the flame and the wall, or in fact the increase of heat loss to the wall, the lean flammability limit increases. Also, with the increase of channel width, flame speed decreases in comparison with 2D continuous model.

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Laminar Flame Speed Prediction in Lean Mixture of Aluminum Dust Clouds by Considering the Effect of Random Distribution of Particles in Two-dimension

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P A P E R I N F O

Paper history:
Received 29 October 2014
Received in revised form 19 April 2015
Accepted 26 January 2016

Keywords:
Random Distribution
Aluminum Particles
Flame Temperature
Burning Velocity

چکیده

در این تحقیق گسترش شعله آرام در محیط ذرات آلومینیوم با درنظر گرفتن تاثیر پخش ذرات به صورت تصادفی بررسی شده است. ساختار کلی شعله از سه محدوده پیش‌گرمایش، واکنش و پس از شعله تشکیل شده است. فرضیات مسئله بدین صورت است که در ناحیه پیش‌گرمایش واکنشی رخ نخواهد داد. معادله دوبعدی بقای انرژی برای هر یک از محدوده‌های شعله حل شده و نهایتاً سرعت شعله به دست آمده است. برای مطالعه اثر تصادفی، تغییر پارامترهایی از قبیل قطر ذرات، نسبت اکووالانسی و عرض کانال آنالیز، و همچنین مشاهده نتایج توزیع دما و سرعت شعله و مقایسه آن با نتایج تجربی و تئوری‌های گذشته انجام پذیرفته است. مقایسه نتایج بیانگر این است که تصادفی کردن توزیع ذرات سبب بهتر شدن نتایج و نزدیک شدن به نتایج تجربی شده است.

***doi**: 10.5829/idosi.ije.2016.29.02b.14*