Dynamic Behaviors of Fuel Dusts through the Flame Propagation in Combustion Chamber

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1 Abstract

At present research physics and dynamics of fuel particles according to a particle free body diagram in combustion chamber crossing the flame zones have been studied. Gravity forces, drag force from gas and thermopherotic force are these forces on a fuel particle. By existing of these forces on a particle, acceleration will be inducted to a particle in flame zones. By solving the differential equation of dynamic equation for a particle with continues boundary condition in velocity curve of the fuel dusts versus the distance from the flame, it has been estimated across the flame propagation. Considering the mass continues law in combustion chamber, concentration profile of fuel dusts has been derived across the flame zones. Theoretical estimation of velocity and concentration profiles in this study has been compared to an experimental study on velocity and concentration profiles of iron particles (diameters are distributed from $1\mu m$ to $5\mu m$ and concentration is $1.05 kg/m^3$) across the upward flame propagation through the particles cloud in (Iron-Air) suspensions.

2 Introduction

At the turn of the century it was already known that clouds of metallic or organic dusts cloud generated an explosion. There is an inherent danger of a dust explosion when combustible dusts are handled in industry. Dust explosion occurs in coal mines, in agricultural handling and processing facilities, in wood, sugar, metal, paper, chemical and rubber industries. The interested in dusts explosion is rejuvenated occasionally when a few major explosions occurred over a short time. This occurred in December 1997 when five major agricultural dust explosions occurred in eight days, in the United States.

One of the main problem in the study of heterogeneous dust air mixture is the difficulty in generating a uniform stationary dusts suspension whereby controlled experiment on the propagation of laminar dust flames can be carried out in the bulk of the research effort on dust combustion. This uniform stationary suspension is invariably achieved in one of two ways [1, 2, 3]; The first of this is via the burner-stabilized flame technique in which the dust is convected with the air steams and the flame is anchored on the burner lip. The second method involves a freely propagation flame in a pre-dispersed dust air medium in which a turbulence field maintains the dust suspension which has been studied in this research.

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In this study, the dynamic behaviors of the particles near the flame propagation were examined theoretically. The velocity difference of particles from surrounding gas flow must affect the profile of particle concentration near the flame and this conversion of concentration may have an influence on the flammability limit of the fuel dusts suspension. It is found that the lower limits of combustible dusts are 30 to 50% smaller than those of combustible gases. While the lower flammability limits are of practical importance for prevention of dust and gas explosions, the reason for this characteristic has not been clarified yet.

3 Mathematical Modeling

Velocity profile of a fuel particle can be determined by solving the dynamic equation of a particle in flame zones of combustion through the combustion chamber. According to the free body diagram of a particle the equation becomes:

$$(4/3)(\pi r^3 \rho)(d^2 x/dt^2) = 6\pi \mu r(V_f - dx/dt) + F_t - (4/3)\pi r^3 (\rho - \rho_g) g,$$

where $r, \rho, x, t, \mu, V_f, F_t, \rho_g$ and g are: radius of a fuel particle, fuel particle density, displacement, time, dynamic viscosity, flame speed, thermopherotic force, gas density and gravity acceleration respectively. It is assumed that there are two profiles for x-t curve; one for the position that particles are in preheat zone(1) and another for position that fuel particles reach the edge of the flame and travel to the post-flame zone(2). According to the continues condition of x-t curve, velocity and concentration profiles of the fuel particles related to the edge of the flame, have been derived by combining the x-t and v-t curves:

$$\left\{ \begin{aligned} X_{rel} &= l_u - (X_1(t) - V_f t) \\ V_p &= \frac{dX_1(t)}{dt} \end{aligned} \right\} 0 \le t \le t,$$

$$\left\{ \begin{aligned} X_{rel} &= X_2(t) - V_f t \\ V_p &= \frac{dX_2(t)}{dt} \end{aligned} \right\} t_0 \le t \le t_0',$$

where t_0 and t_0' are: time for traveling preheat and time for traveling post flame zones by a fuel particle respectively and l_u is the preheat length (as shown in Fig 1).

4 Conclusion

Theoretical results in this study have been compared to the experimental results for (Iron – Air) dust suspension (Fig 2) which have done by Jinhua Sun, Ritsu Dobashi and Toshisuke Hirano in 2003 [4]. Results shows that maximum particle velocity has been taken place in the edge of the flame and also particle concentration reaches their maximum value at that position (edge of the flame) as the experimental has been shown. According to these results, dynamic simulation of the fuel particles could be developed for the dusts combustion and concentration profile which is an important value for the combustion parameters could be derived across the flame propagation in other dusts combustion.

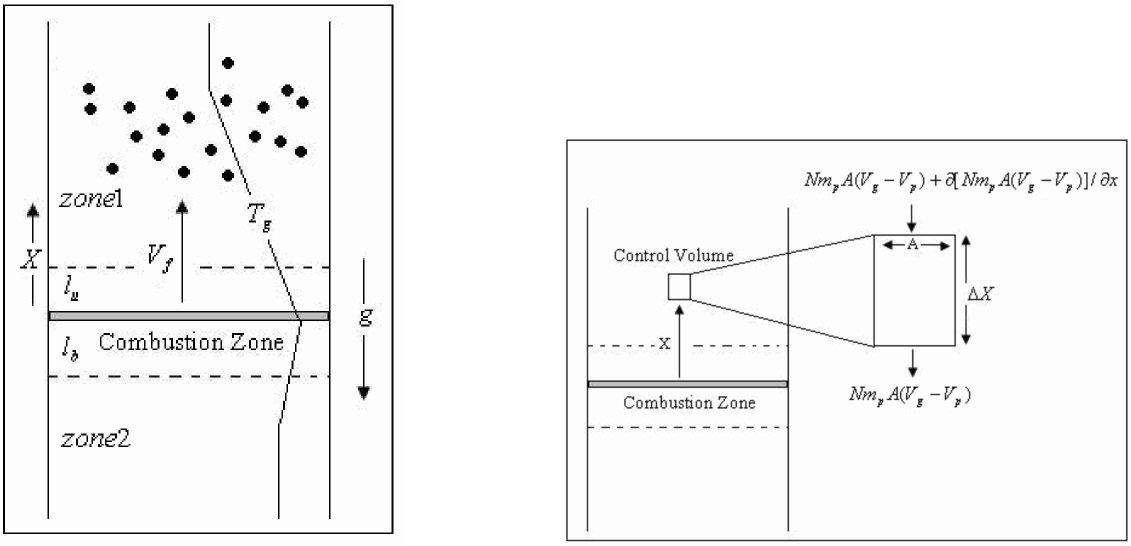

Figure 1. Flame propagation in dust suspension. Left: position of the fuel particles passing throw the flame zones with temperature gradient. Right: Control volume in front of the flame edge.

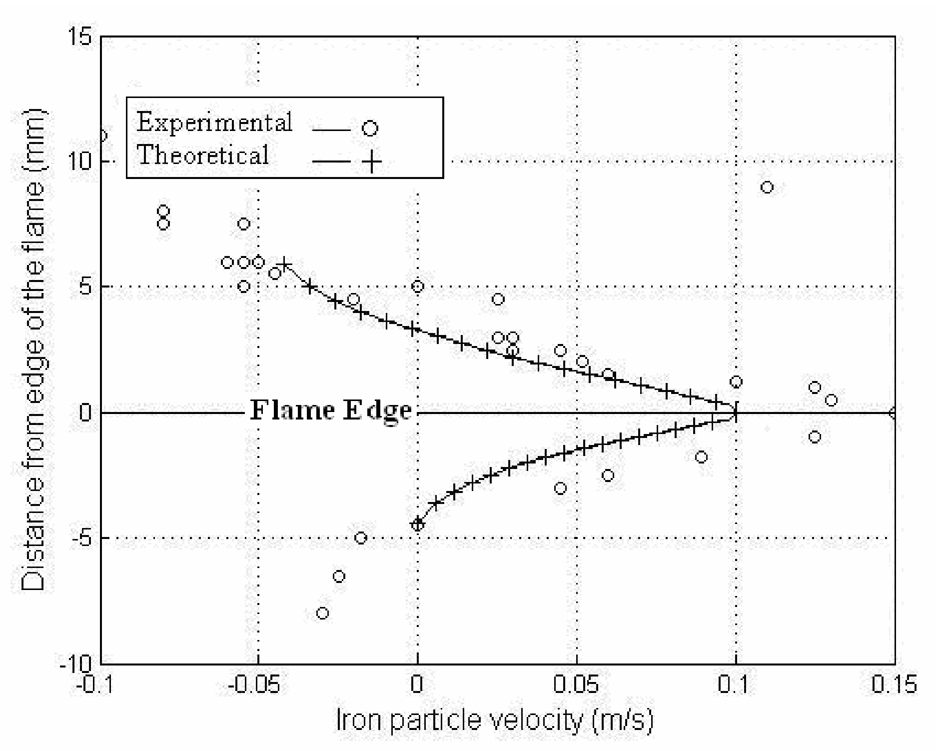

Figure 2. Velocity profile of iron particles versus the distance from edge of the flame in (Iron – Air) combustion with upward flame propagation.

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