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Research Article

Investigation of an Iron Particle Behavior in Flame Zones of Dust Combustion

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Abstract: At present study, physics and dynamics of iron particles in combustion chamber crossing the flame zones of (iron-air) suspension is investigated. The effect of Gravity, drag and thermopherotic force are considered on an iron particle. Theoretical estimation for velocity profile in this study has been compared to an experimental study on velocity and concentration profile of iron particles across the flame propagating through the particles cloud.

Keywords: Combustion, gravity force, Iron dust, velocity profile

INTRODUCTION

At the turn of the century it was already known that clouds of organic or metallic dust 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 dust 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.

On of the main problem in the study of heterogeneous dust air mixture is the difficulty in generating a uniform stationary dust 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. The first of this is via the burner-stabilized flame technique in which the dust is convicted 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 study (Sun *et al*., 2001 and 2003).

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 a flame. The concentration change may have an influence on the flammability limit. Some of the measured results of lower flammability limits in the literature are shown in Table 1 (Baker and Tanget, 1991; Zabetakis, 1965; Hertzberg *et al*., 1992).

Table 1: Lean limit equivalence ratio of dusts

Dust	Lean limit equivalence ratio
Adiabic acid	0.28
Lactose	0.22
Poly-methylacrylate	0.17
Poly-ethylene	0.17
Sulfur	0.10
Magnesium	0.14
Titanium	0.19
Aluminum	0.29
Iron	0.35

In this table, concentration is indicated through equivalence ratio (calculated assuming that all combustible solids vaporize). 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.

According to the mass continues law and by having the velocity profile of iron dust in air-dust cloud, we can reach on number density profile of dusts from the edge of the flame edge. These theoretical calculations compare to the experimental results on an iron dust suspension in air. Comparison between theoretical and experimental works on iron particles shows that these calculations on particles in suspension can be done in other fuel suspensions and an earlier conception on concentration of fuel dusts a head of the flame zones will be denoted.

In the present study, a mathematical model for combustion of Iron particle by considering of gravity and thermophoretic forces is studied.

MATHEMATIC MODELING

If the combustion occurs in combustion chamber with the effect of gravity forces as shown in Fig. 1, the velocity profile of a particle must be determined by

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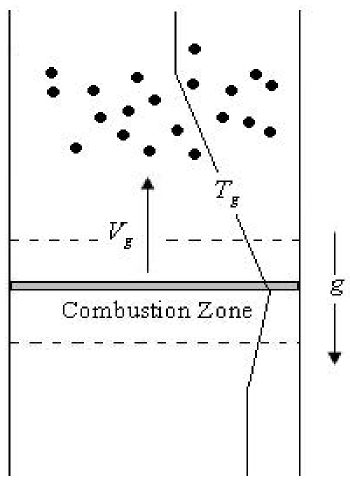

Fig. 1: Flame propagation in iron dust cloud

solving the dynamic equation of a particle in flame zones of combustion.
According to the free body diagram of a particle:

$$(4/3)(\pi r^3 \rho)(d^2 x/dt^2) = 6\pi\mu r(V_g - dx/dt) + F_t + (4/3)\pi r^3(\rho - \rho_g)g \quad (1)$$

To estimating the velocity profile of a particle, the distance traveling by a particle (x) to the time must be derived from the equation. According to the boundary conditions (continues profile for x-t curve in flame zones), constants derived from differential equation will be determined. By solving Eq. (1) we have:

$$x = Ce^{(-9\mu/2r^2\rho)t} + D + [V_g + (F_t/6\pi\mu r) + (2r^2\rho/9\mu)(1-\rho_g/\rho)g]t \quad (2)$$

We assume that there are two profiles for x-t curve; one for 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), then by Considering as the time that a fuel particle reaches the flame edge we have five unknown parameters. By having continues conditions for x-t curve in flame zones we have:

$$\begin{cases} x_1(t_0) = x_2(t_0) \\ dx_1/dt(t \to t_0) = dx_2/dt(t \to t_0) \\ d^2x_1/dt^2(t \to t_0) = d^2x_2/dt^2(t \to t_0) \end{cases} \quad (3)$$

We assume that fuel particles have a constant velocity before entering the preheat zone and after traveling the post-flame zone so by letting ($d^2x/dt^2 = 0$) in Eq. (1) we can obtain Eq. (4) and (5):

$$dx_1/dt(t \to 0) = (2/9)(\rho - \rho_g)rg/\mu_g[zone1] \quad (4)$$

$$dx_2/dt(t \to \infty) = (2/9)(\rho - \rho_g)rg/\mu_g[zone2] \quad (5)$$

By solving the differential equation, velocity profile of a particle passing throw the flame zones will be determined:

$$(1/A^2)\left[B - AV_P - B\ln(B - AV_P)\right] = x + C \quad (6)$$

where, the constant (A, B) are introduced in tree stages of flame zones and C is the differential equation constant.

In zone I:

$$\begin{cases} A_1 = (9/2)(\mu/r^2) \\ B_1 = (9/2)(\mu V_g/r^2) + (3/4)\left[(8/3)(r^2)(\Lambda/\upsilon)(T_{flame} - T_u/\delta_1)\right] \\ \quad -(\rho - \rho_g)g/\rho \end{cases} \quad (7)$$

In zone II:

$$\begin{cases} A_2 = (9/2)(\mu/r^2) \\ B_2 = (9/2)(\mu V_g/r^2) + (3/4)\left[(8/3)(r^2)(\Lambda/\upsilon)(T_{flame} - T_b/\delta_2)\right] \\ \quad -(\rho - \rho_g)g/\rho \end{cases} \quad (8)$$

where, $\upsilon = (8KT/\pi m)^{1/2}$ is an average thermal velocity of the gas atoms? Study on velocity profile of fuel particles in combustion chamber is an important subject to determining the concentration of fuel particles passing through the flame zones. Variation of fuel concentration in dust suspension causes two effects of combustion parameters; flame style propagation (laminar, oscillation and turbulent accelerating flame) and equivalent ratio (ϕ). Preview studies on dust combustion (dust-oxidizer suspension) show that the influence of dust concentration on flame development appears to be weak for most kind of fuel dusts. Second effect of dust concentration which is an important one is to changing the flammability of fuel dust by changing on equivalent ratio and so in this study we use the velocity profile to predict the number density variation along the flame propagation direction.

A control volume moving at the velocity of flame propagation with its abscissa on the leading edge of combustion zone as show in Fig. 2 was used for the evaluation of the number density variation of iron dust suspension.

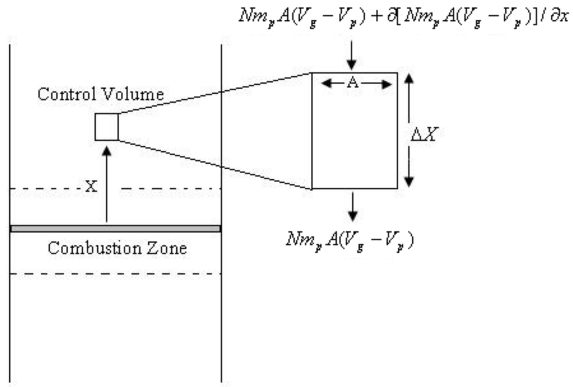

Fig. 2: Control volume of iron dusts ahead of the flame

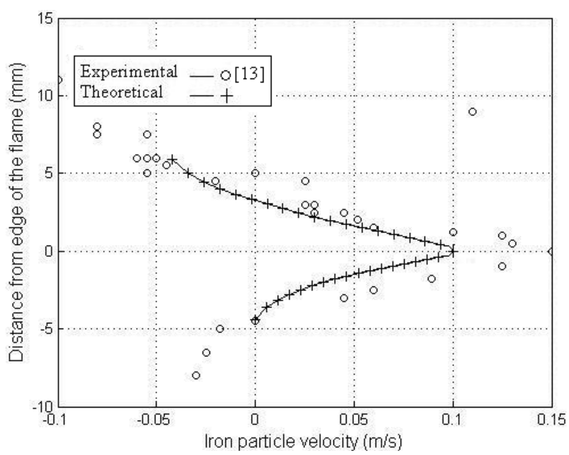

Fig. 3: Variation of iron velocity to distance from edge of the flame

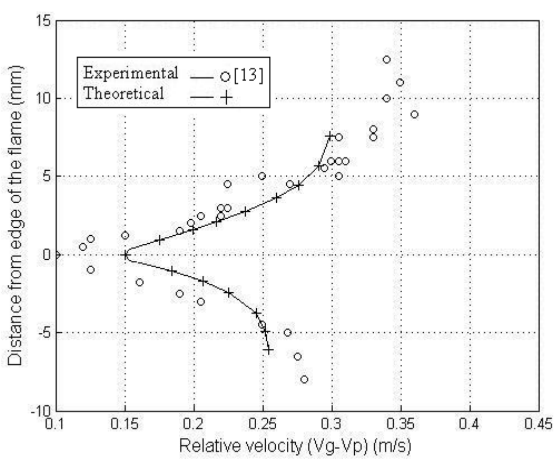

Fig. 4: Variation of relative velocity between gas and iron particles to the distance from edge of the flame

The particle mass flux through a cross sectional area of the control volume is:

$$Nm_p A(V_g - V_p) \quad (9)$$

Considering ∂A/∂x = 0, mass continues of iron dusts leads to the following equation.

$$Nm_p (V_g - V_p) = const. \quad (10)$$

So by having the relative velocity profile for iron dust suspension, we can estimate the variation of number density along the flame zones.

RESULTS

An experimental work on dynamic and kinetic behavior of an iron-air suspension in cylindrical combustion chamber with up ward flame propagation has been donning by Sun *et al*. (2003). By comparing these theoretical solutions for velocity profile of an iron particle to the experimental work done in that research on an iron particle, as shown in Fig. 3, we reach on a good agreement between theoretical and experimental results.

The purity of the used iron particles was 99.5% and the concentration of the iron particle cloud was set to be 1.05Kg/m^3 in that study. The diameters of most iron particles were distributed from 1 m to 5 m, most of the iron particles suspended in air were agglomerated and most of the diameters of iron agglomerates were larger than 10 m. Flame propagation through an iron particle cloud was observed as a propagation of a combustion zone of 3 to 5 nm in width, which consists of luminous particles without gas phase flame (Sun *et al*., 1999) and behind the leading edge of the combustion zone, particles start to burn, emit strong thermal radiation and their velocities decrease (Sun *et al*., 1998a, b) .

It could be seen from the high-speed photomicrographs, the propagating velocity of the combustion zone was almost constant 25cm/s and the propagating phenomena could be considered as steady state.

Figure 3 shows the variation of distance from the edge of the combustion zone (*x*) and velocity of iron particles with diameter of 10 μm (agglomerated). Maximum calculated velocity in experimental work (Sun *et al*., 2003) was almost and it occurs on the edge of the combustion zone in this study we calculated the maximum velocity on the edge of the combustion zone and its value has been calculated about.

Variation of relative velocity between iron particles and gas via distance has been shown in Fig. 4. Comparison between theoretical and experimental work shows a difference value about in relative velocity in the edge of combustion zone (maximum particle velocity).

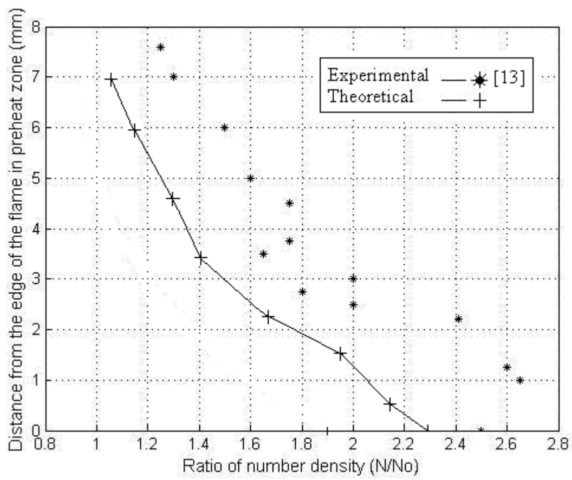

Fig. 5: Variation of number density ratio (N/N_0) along the preheat zone

By using Eq. (9) and having relative velocity profile of iron particles and air variation of N/N_0 (N_0 is initial number density) along the flame zones will be determined as shown in Fig. 5.

NOMENCLATURE

ρ	:	iron density (kg/m^3)
x	:	distance traveling by particle (m)
t	:	t is time (s)
r	:	the radius of an iron particle(m)
V	:	The velocity of flame propagation (m/s)
F_t	:	The thermophoretic force
r	:	Radius of particle
v	:	Average thermal velocity
m	:	Mass of gas atoms
T	:	Gas temperature
K	:	Boltzmann constant
Λ	:	Coefficient of heat conductivity (W/mK)
u	:	Referred to unburned temperature
b	:	Referred to burned temperature
φ	:	Equivalence ratio
N	:	Number density of iron dust (1/m^3)
m_p	:	Iron mass (*Kg*)
A	:	Cross sectional area (m^2)
V_g-V_p	:	Relative velocity (m/s)
δ_1	:	Lengths of zone 1
δ_2	:	Lengths of zone 2
μ	:	Viscosity of gas

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