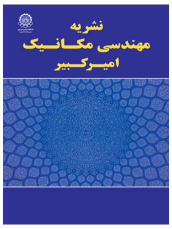

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Analytical model for the non-premixed combustion of the titanium dust cloud in counter-flow geometry

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ABSTRACT: Today, the issue of achieving high-efficiency energy is important in various industries. The study of metal particle combustion is very important due to its increasing applications. Among these applications, it is possible to produce particle oxides with various applications, high energy density as a result of the increase in temperature due to combustion, medical applications, etc. In this paper, the analytical model of titanium dust particle combustion in the counter-flow configuration with a multi-zone approach was investigated. The governing equations, consist of mass and energy conservation was expressed and became dimensionless using dimensionless parameters and solved by using appropriate boundary and jump conditions in Matlab and Mathematica software. After solving the equations, the distribution of temperature and mass fraction of the components was presented and the effect of some important parameters such as Lewis number and mass particle concentration was investigated. It was observed that with increasing Lewis number from 0.6 to 1.4 at 300 g/m3, the flame temperature decreased from 3600 K to 3050 K, also the reduction of mass diffusion caused the flame position to be transferred to the oxidizer nozzle. Also with an increasing particle diameter of fuel from 2µm to 200µm, the temperature and position of the flame were shifted from 3600 K and -1.8 mm to 3400 K and -1 mm, respectively.

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1- Introduction

Combustion of titanium particles is used in various fields. In this area, various works have been done that can be classified from different aspects. Molodetsky and Vicenzi [1] investigated combustion phases, particle burning time and temperature of combustion of titanium particles in the air. Karasev et al. [2] investigated the formation of metal oxide nanoparticles in the combustion of titanium and aluminum droplets. Cairns et al. [3] investigated the effect of oxygen concentration on the combustion of titanium particles.

According to a review of resources in this area, it was observed that the combustion of the titanium particles has been studied experimentally and numerically. In this paper, an analytical study of non-premixed combustion of the titanium dust particle in the counter-flow configuration with a multi-zone approach has been carried out. After presenting the governing equations, including the equations of energy conservation and mass conservation of components and non-dimensionalization, mass fraction distribution of components and temperature in the solution domain presented and then the effect of some important parameters such as Lewis number, particle diameter size and mass particle concentration investigated.

2- Methodology

According to Fig. 1, three-zone are considered. The first zone is $X=-\infty$ to $X=X_f$, the second zone is $X=X_f$ to $X=X_{melt}$ and the third zone is $X=X_{melt}$ to $X=+\infty$. The velocity field is considered to be $u=-aX$ in the x-direction and a expresses the strain rate.

The governing equations include energy and mass conservation. The energy conservation equation is [4]:

$$-aX\frac{dT}{dX}=D_T\frac{d^2T}{dX^2}+\omega_S\frac{Q}{\rho C}-\omega_{melt}\frac{Q_{melt}}{C} \tag{1}$$

where D_T, Q and Q_{melt} are thermal diffusion coefficient, the heat released per unit mass of fuel consumed and the latent heat of melting of fuel particles, respectively.

The mass conservation equation of solid fuel particles is also expressed in the form of Eq. (2) [4]:

$$-aX\frac{dY_S}{dX}=-\frac{\omega_S}{\rho} \tag{2}$$

The mass conservation equation of products in the liquid phase is [4]:

$$-aX\left(\frac{dY_m}{dX}\right)=D_m\left(\frac{d^2Y_m}{dX^2}\right)+\omega_{melt} \tag{3}$$

where Y_m and D_m express the mass fraction of liquid products and the mass diffusion coefficient of liquid products respectively.

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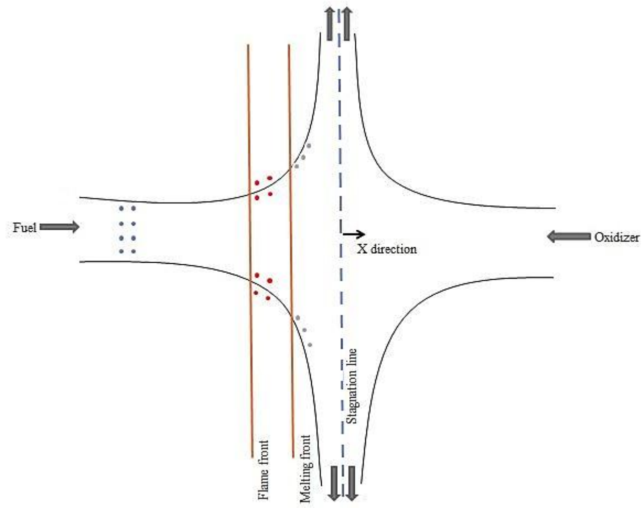

Fig. 1. General schematic of non-premixed combustion of titanium dust particles in the counter-flow configuration

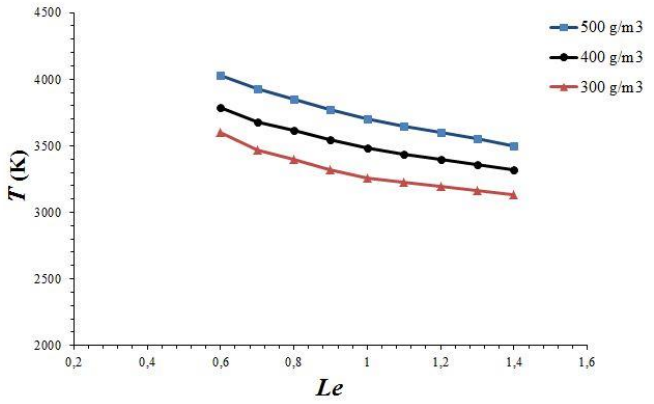

Fig. 3. Temperature versus position

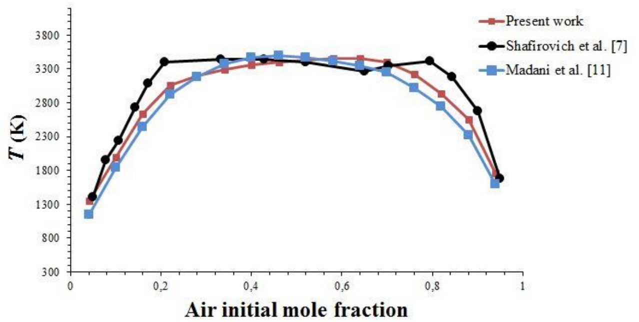

Fig. 2. The flame temperature in terms of air initial mole fraction and comparison with previous works

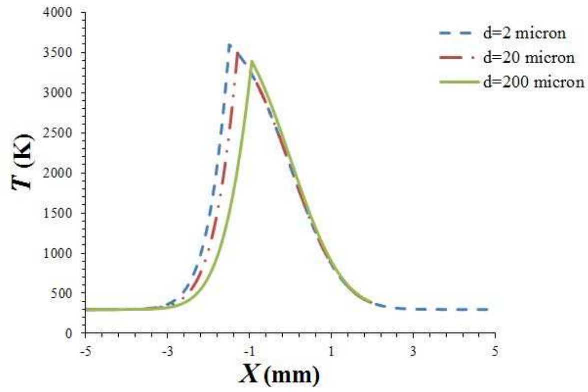

Fig. 4. Flame temperature versus Lewis number with considering mass particle concentration effect

Eq. (4) expresses the conservation of the oxidizer mass fraction [4]:

$$-aX\,\frac{dY_O}{dX} = D_O\,\frac{d^2Y_O}{dX^2} - \vartheta\frac{\omega_S}{\rho} \tag{4}$$

In the above equation, D_O and ϑ are oxidizer mass diffusion coefficient and oxidizer stoichiometric mass ratio to fuel, respectively.

3- Results and Discussion

Fig. 2 represents the results of the flame temperature value in terms of the initial mole fraction of air and a comparison with previous works for validation.

In Fig. 3 the temperature distribution diagram versus position with different diameters is plotted. The maximum temperature is obtained in the flame region, which is approximately at X=-1.8 mm and is equal to 3600 K for 2 μm diameter.

In Fig. 4 the effect of Lewis number on the flame temperature is investigated by considering the effect of mass particle concentration. By increasing the Lewis number, which means a decrease in the mass diffusion, the flame temperature has decreased. Also, with increasing the concentration of fuel particles, the flame temperature has increased.

4- Conclusions

Due to the many applications of metal particle combustion, this paper investigates the non-premixed combustion of titanium dust particles in the counter-flow configuration. In this multi-zone modeling by using boundary and jump conditions are presented, governing equations in the combustion process in a dimensionless form including energy and species conservation were solved and the temperature distribution and mass fraction of the components were presented.

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