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Analytical Modeling of a Counterflow Diffusion Flame of a Dust Cloud

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1- Introduction

Due to the importance of investigation of flame features of combustion dust cloud, many studies have been performed analytically, numerically and experimental to model the phenomenon of combustion of dust particles with the oxidizer.

In the concept of modeling of counerflow combustion, Daou et al. studied counteflow combustion of premixed gaseous flames with the consideration of heat losses. In the presented two-dimensional model, a first order Arrhenius model was considered and the influences of heat losses and strain rate on premixed flame were studied. Also, Fashadi et al. studied counterflow combustion of premixed organic flames. In his research, two three-zone and four-zone combustion models in counterflow combustion of premixed flame were investigated. Linan studied counterflow diffusion flames. In his research, two streams of fuel and oxidizer from opposite sides that react chemically at a certain location were investigated. Also, Seshadri et al. studied the structure of counterflow diffusion flames at high values of activation energy. They presented their results for small ratios of mass of gaseous fuel to that of oxygen. Greenberg et al. investigated counterflow combustion for the spray of gaseous fuel from nozzles. In this research, they studied the effects of change of Lewis numbers of the fuel on the maximum adiabatic temperature where fuels were being sprayed form nozzles. Witchman and Yang also analytically investigated modeling of a counterflow diffusion flame consisting of fuel and oxidizers spraying from nozzles in a counterflow system. With regards to numerous investigations on the concept of counterflow combustion of diffusion flames, counterflow combustion of diffusion flame of dust particles is presented with a novel approach in the present research study. In this model, it is assumed that with vaporization of organic dust cloud, gaseous fuel will be obtained which will undergo reaction with the oxidizer. As the fuel and oxidizer streams flow towards the stagnation plane from the opposite sides from the two nozzles, the position of the generated flame can be formed in either side of the stagnation plate depending on the initial conditions of the fuel and oxidizer.

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2- Governing equations

The governing conservation equations of mass and energy are presented. To solve these equations, non-dimensional parameters are proposed. The conservation equations are rewritten based on the new parameters. To solve the equations analytically, a new coordinate system is proposed. The conservation equations are rewritten in the new coordinate system. Equations in the three zones: preheat, after vaporization and oxidizer, are solved completely with using boundary conditions in these zones and jump conditions at the interface of the zones.

3- Results

In Figure 1, the variations of flame temperature is shown as a function of fuel Lewis number for different values of mass particle concentration. It has been assumed that the oxidizer Lewis number is unity. It has been shown that the flame temperature decreases with the rise of fuel Lewis number. For example with increasing of fuel Lewis number from 0.1 to 1.4, the flame temperature decreases from 1943 K to 1473 K for mass particle concentration equal to 100 $\frac{gr}{m^3}$. Also, with increasing of mass particle concentration from 67 $\frac{gr}{m^3}$ to 100 $\frac{gr}{m^3}$, the flame temperature increases.

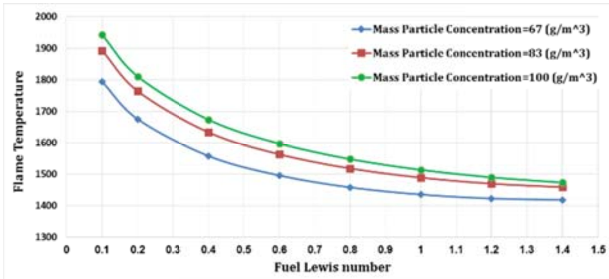

Fig. 1. The variation of flame temperature as a function of fuel Lewis number for different values of mass particle concentration

In figure 2 the temperature profile of gaseous fuel formed from the vaporization of solid fuel particles and the temperature profile of oxidizer is illustrated. It is shown that the flame temperature of gaseous fuel is rising from left to right and the oxidizer temperature is rising from right to left to achieving the flame temperature. Also it has been shown that the decreasing of oxidizer Lewis number from 1 to 0.8 and to 0.6, increases the flame temperature and moves the temperature location to left.

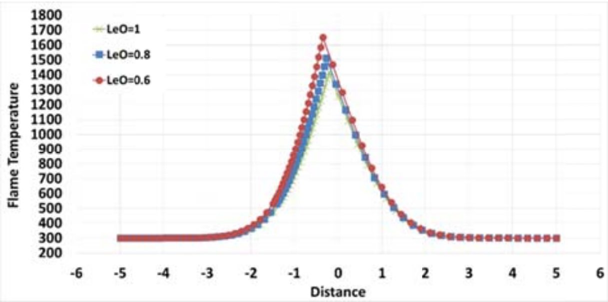

Fig. 2. The oxidizer and gaseous fuel Temperature profile as a function of distance

4- Conclusion

In the present study, modeling counterflow diffusion flame is investigated and a novel approach is presented. Flame features of diffusion flame such as temperature and mass fraction of the fuel and oxidizer are studied. It is considered that the organic dust cloud vaporized and generated a gaseous fuel that then reacts with air as the oxidizer. Since the fuel and oxidizers are at the opposite sides of the counterflow configuration and flow toward the stagnation plate, the location of the flame depends on the initial conditions of the fuel and oxidizer. Therefore, the flame can be formed in either side with regards to the stagnation plate. Conservation equations are analytically solved for various Lewis numbers and the flame temperature in terms of the change of the Lewis numbers of the fuel and oxidizer is investigated.