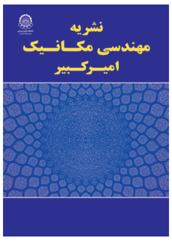

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Study the Effects of Uniform Magnetic Fields and Pressures on the Concentration of Main Species of Methane Combustion

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ABSTRACT: The effects of magnetic fields on combustion to control and optimize the flame deformation and the flame brightness is a well-known fact. The kinetics and equilibrium properties of chemical reactions of combustion are influenced by the magnetic force exerted on paramagnetic species. In this study, the numerical consideration of the effects of the uniform magnetic fields on one stage methane combustion reaction has been taken. With respect to this fact that NO, OH, and O2 are paramagnetic species and other species and methane have diamagnetic behavior, the effects of the uniform magnetic field at different pressures on 10 methane combustion main product species are studied by minimizing the Gibbs free energy. The results show that the uniform magnetic field at 1 atm pressure has considerable effects on paramagnetic species and their production is influenced dramatically. Also, the role of uniform magnetic fields on product species decreases by increasing the pressure. The results also indicate that uniform magnetic fields decreases the mole fraction of NO simultaneously with the increase in the temperature. Furthermore, applying uniform magnetic field and increasing the pressure reduce NO and CO pollutants and increase the temperature.

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1- Introduction

The effects of magnetic field on flames is a well-known fact. Magnetic field is known to influence the combustion in three ways:

- The effects of magnetic field on ionized species by Lorentz force.
- The effects of magnetic field on paramagnetic and diamagnetic species.
- The effects of magnetic fields on equilibrium thermodynamics and chemical kinetics of combustion.

The application of magnetic fields also affects equilibrium and chemical kinetics combustion characteristics. Consideration of this effects can be performed by modifying the Gibbs free energy equation in the presence of the magnetic field.

Baker and Saito [1] investigated the thermodynamic characteristics of equilibrium combustion in the presence of the uniform magnetic field. Their results indicated that the magnetic field has a significant impact on equilibrium combustion characteristics.

Wu et al. [2] investigated the influence of magnetic fields on the properties of methane laminar combustion. Their results showed that the gradient magnetic field exerts the effect on the production of thermal NOX. They notified that the concentration of NOX at least decreased by up to 60% on average.

In this study, thermodynamic analysis has been done to consider the effects of the uniform magnetic field on equilibrium combustion characteristics. For this purpose, the mole fraction of the product species under constant pressure condition is calculated by the Gibbs free energy method. The present study focuses on the emission reduction caused by the effects of magnetic fields on equilibrium thermodynamics.

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2- Formulation

Consider a closed, homogeneous, isotropic, stationary system is subject to the magnetic field. The work contribution, including both boundary and magnetic field work may be written as:

$$\delta W = -p\mathrm{d}V + \mathrm{d}\left(V \int H\mathrm{d}B\right) \tag{1}$$

Also, note that relation $B=\mu_0 H(1+x)$ was used in the development of Eq. (1). The total work on the system can then be represented by:

$$\delta W = -p\mathrm{d}V + H^2\mu_0 x\mathrm{d}V + VH\mu_0 x\mathrm{d}H + VH^2\mu_0\mathrm{d}x \tag{2}$$

Inserting Eq. (2) into the first law of thermodynamics and using the Gibbs free energy equation along with the definition of enthalpy used to find the Gibbs free energy of the system. The Gibbs free energy of the mixture of ideal paramagnetic and diamagnetic species is expressed by:

$$\frac{G}{R_u T} = \sum_{i=1}^{n_{Sp}} n_i \left(\frac{g_i^0}{R_u T} + \ln(y_i) + \ln(p) + H^2\mu_0 x_i \left(\frac{1}{y_i p} - 1\right) \right) \tag{3}$$

Equilibrium combustion composition characteristics under uniform Magnetic Field conditions have primarily been computed using the equilibrium constant method or by minimizing the changes in the Gibbs free energy. The method of Lagrange multipliers was used to obtain the solution to the system. Following the formulation outlined by Morley, the pseudo algorithm was used to determine equilibrium compositions [3].

3- Results and Discussion

The methane-air model reaction is used to investigate the impact of a magnetic field on combustion characteristics. The specific products of the reaction of methane in the air are:

$$\begin{aligned}&\mathrm{CH_4}+n_{air}\left(\mathrm{O_2}+3.76\mathrm{N_2}\right)\rightarrow n_{CO_2}\mathrm{CO_2}\\&+n_{CO}\mathrm{CO}+n_{H_2O}\mathrm{H_2O}+n_H\mathrm{H}+n_{H_2}\mathrm{H_2}\\&+n_{O_2}\mathrm{O_2}+n_{OH}\mathrm{OH}+n_O\mathrm{O}+n_{N_2}\mathrm{N_2}+n_{NO}\mathrm{NO}\end{aligned} \tag{4}$$

Magnetic susceptibility is utilized to quantify paramagnetic and diamagnetic behavior in the present magnetic field. The magnetic susceptibilities to product species are obtained from the CRC Handbook of Chemistry and Physics [4] whose values are provided in Table 1.

Table 1. Magnetic susceptibility of some species in methane combustion [4]

Species	*x* (cgs unit)
CO_2	-21×10^{-6}
CO	-9.8×10^{-6}
H_2O	-12.63×10^{-6}
H	-2.93×10^{-6}
H_2	-3.99×10^{-6}
N_2	-12×10^{-6}

Table 2 shows a comparison of the equilibrium mole fraction of CO_2 between the present work and that of Baker and Saito [1]. As shown in Table 2, there is a good agreement between two sets of results.

Fig. 1 is the plot of the equilibrium mole fraction of carbon dioxide as the function of temperature and the applied magnetic field. Fig. 1 shows that in a certain temperature range there is a nonlinear decrease in the mole fraction of CO_2 that increases magnetic induction.

Table 2. The comparison between the results of the present work and those of Baker and Saito's [1]

	T(K)	1600	2000	2200	2400
B=0 (Tesla)	Baker at el. [1]	0.095	0.0921	0.0864	0.0771
	Present	0.0942	0.0918	0.0864	0.0763
	Error (%)	0.7	0.3	0.07	1
B=0.04 (Tesla)	Baker at el. [1]	0.0946	0.0864	0.0682	0.0398
	Present	0.0945	0.0863	0.0722	0.0469
	Error (%)	0.1	0.2	5.9	17.6

Fig. 2 is the plot of the variations in the CO mole fraction of the uniform magnetic field of 0 and 0.04 Tesla at different pressures. The mole fraction of CO increases with the magnetic field strength in the certain temperature range. The variation of the mole fraction of CO decreased to negligible levels as the temperature and pressure increased to 20 atm.

Fig. 3 is the plot of the variations in the Nitrogen monoxide mole fraction of the uniform magnetic field of 0 and 0.04 Tesla at pressures of 1, 5 and 20 atm. The trend of decreasing mole fraction of NO is observed with the increase in the pressure strength and applying a magnetic field.

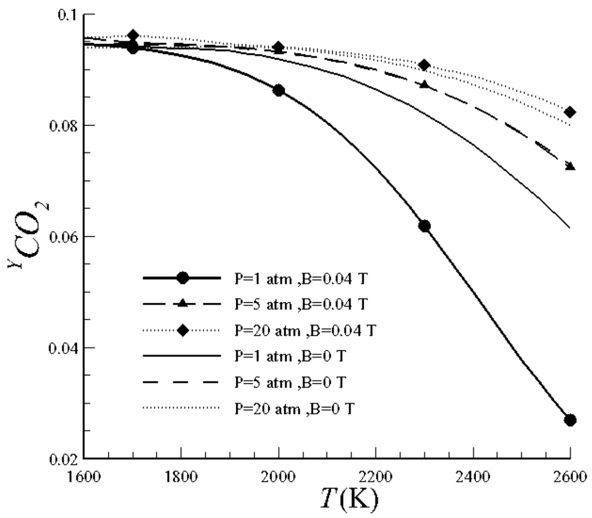

Figure 1. The variations in CO_2 mole fraction of the uniform magnetic field of 0 and 0.04 Tesla at different pressures

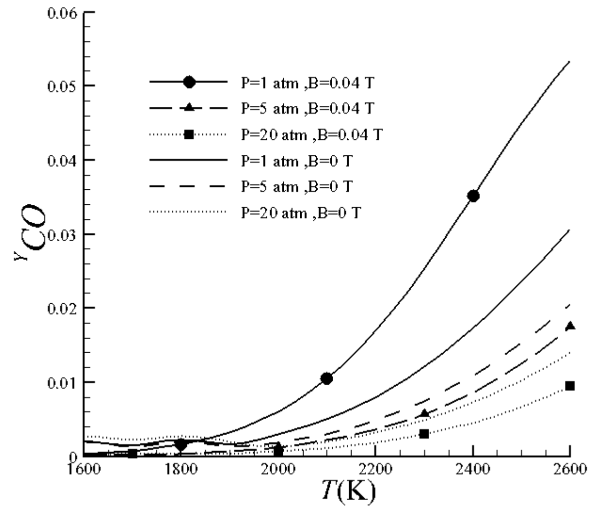

Figure 2. The variations in CO mole fraction of the uniform magnetic field of 0 and 0.04 Tesla at different pressures

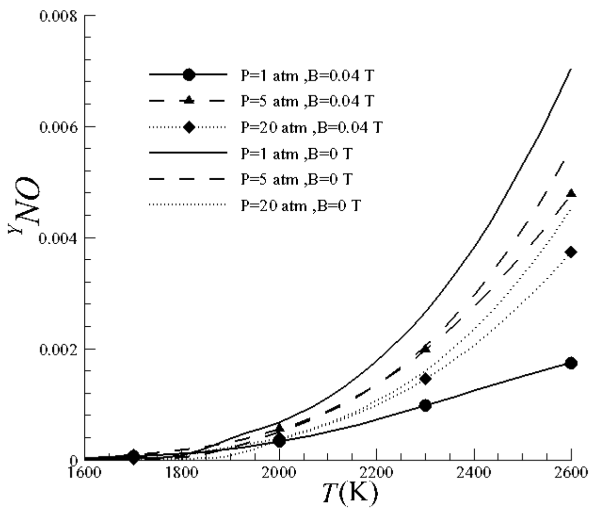

Figure 3. The variations in NO mole fraction of the uniform magnetic field of 0 and 0.04 Tesla at different pressures

4- Conclusions

The effect of the uniform magnetic field at different pressures on 10 methane combustion main product species is studied by minimization of the Gibbs free energy. The results show that applying uniform magnetic field and increasing the pressure give rise to reduce NO and CO pollutants simultaneously with the increase in the temperature.

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