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Uniform Magnetic Fields and Equilibrium Flame Temperatures

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The impact of a constant uniform magnetic field on equilibrium flame temperature under constant volume conditions was examined. The equilibrium combustion compositions were found using an expression for Helmholtz free energy that included a magnetic-field contribution. Changes in the Helmholtz free energy for a mixture of paramagnetic and diamagnetic ideal gases were minimized using the method of Lagrange multipliers. The magnetic susceptibility for the paramagnetic gases was calculated using the Curie law. Equilibrium flame temperatures were obtained from the first law of thermodynamics for a closed adiabatic system with no work interactions. A model reaction of methane in air was used to quantitatively examine changes in the equilibrium flame temperature and product mole fractions as a function of volume and magnetic induction. Equilibrium flame temperature and product mole fractions were plotted as a function of magnetic-field strength and volume for all product species. The results indicate that with the increase in magnetic-field strength, the equilibrium flame temperature increases for all volumes considered.

Nomenclature

g_L = Lande's g factor
h = enthalpy
k = Boltzmann constant
m_i = molecular weight of species i
N_A = Avogadro's number
n = number of moles
R_u = universal gas constant
S_i = total electron spin of species i
T = absolute temperature
y = mole fraction
ε_u = internal energy residual
μ_B = Bohr magneton
μ_0 = magnetic permeability of vacuum
χ_i = magnetic susceptibility per unit mass of species i

Subscripts

equil = equilibrium flame temperature
f = formation
i = species i
p = products
r = reactants

Superscript

o = reference conditions

Introduction

RECENT increases in the cost of oil and the increasing debate over anthropogenic global warming highlights the fact that combustion processes are critical to our civilization. As such, it is imperative that a fundamental understanding of combustion processes and the phenomena that can be used to intelligently control such processes be developed. Magnetic fields have long been known to influence flame behavior through the paramagnetic and diamagnetic properties of the constituent species. A review of the literature associated with this interaction can be found in Baker and Calvert [1]. Application of a magnetic field has previously been shown to change flame shape, emission intensities, and temperature profiles [2–4]. In addition, a uniform magnetic field was previously shown to affect equilibrium compositions [5,6] and theoretical rocket performance [7].

Magnetic susceptibility is used to quantify paramagnetic and diamagnetic behavior and is defined as the degree to which a substance will be magnetized when placed in a given magnetic field. The magnetic susceptibility of paramagnetic species can be specified by the Curie law, given as [8]

$$\chi_i = \frac{N_A g_L^2 \mu_B^2 S_i (S_i + 1)\mu_0}{3kTm_i} \tag{1}$$

As can be deduced from the preceding equation, an increase in temperature decreases the magnetic susceptibility. The magnetic susceptibility for paramagnetic species decreases rapidly for temperatures less than 1500 K and then reaches an asymptotic value when the temperature increases beyond this point. On the other hand, diamagnetic susceptibility is independent of the temperature. The magnitude of the magnetic susceptibility of paramagnetic substances varies in the range of 10^{-3} to 10^{-6} cgs units and is positive. Among the product species for the model reaction considered in this study (i.e., methane in air), NO (nitric oxide), O_2 (oxygen), and OH (hydroxyl) are the only paramagnetic species.

The present study is a continuation of the work done by Gupta and Baker [6], who examined the effect that uniform magnetic fields have on constant volume equilibrium combustion compositions. It was found that under isothermal conditions, an applied magnetic field could significantly change the equilibrium composition and decrease the equilibrium pressure. The impact on equilibrium pressure was more pronounced at higher temperatures and higher values of the applied magnetic-field strength. For the investigation detailed here, the equilibrium flame temperature and the equilibrium composition are taken as variable. The motivation for the work presented in this paper is the fact that changes in temperature can have a dramatic effect on the production of several species that are considered to be pollutants. There is little, if any, information on the impact that magnetic fields have on chemical kinetics. A thermodynamic equilibrium model, such as the one used in this study, provides an ideal first step for developing a fundamental understanding of how

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