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Effect of Pressure and Inlet Velocity on the Adiabatic Flame Temperature of a Methane-Air Flame

Rana Haj Khalil [a,*] Ahmad Sakhrieh [b], Mohammad Hamdan [c,*] and Jamil Asfar [b]

[a]*Department of Mechanical Engineering, Philadelphia University Jerash, Jordan*

[b]*Department of Mechaanical Engineering, University of Jordan, Amman, Jordan*

[c]*Al-Zaytoonah Private University of Jordan, Amman, Jordan*

Abstract

The present study focuses on the effect of pressure and high inlet velocity of turbulent premixed flames on the adiabatic flame temperature of a methane-Air Flame. Turbulent premixed flames are widely spread in technical applications and are used especially in stationary gas turbines for a high-efficient and low emission energy conversion of gaseous fuels. The simulation process was performed using Fluent software. The pressure was varied between 2 atmosphere and 10 atmosphere, while the inlet velocity varies between 5 and 10 m/s. it was found that and in general the temperature increase with pressure

Keywords: High pressure combustion, Methane fuel; High Veleocity; Gaseous Combustion.

1. Introduction

Although combustion has been used by mankind for already more than one million year, it is still the most important technology providing the energy supply for our modern day civilizations. Utilization of combustion leads to the release of unwanted pollutants such as carbon monoxide, unburned hydrocarbons and nitric oxides which affect our environment.

Environmental awareness and the need for better and more efficient power generation systems have fueled development of gas turbines for the past two decades. The improvement efforts were focused on reducing NO_X, CO and other pollutant levels in the exhaust, improving efficiency and increasing the reliability of equipments.

Flame temperature is one of the most important properties in combustion, since it has a controlling effect on the rate of chemical reaction. The flame temperature is determined by the energy balance between the reactants and the products at equilibrium. If the reaction zone is spatially very thin in comparison to the rest of the domain of interest, then it is a common practice to denote the maximum temperature in the reaction zone to be the flame temperature. If the combustion process takes place adiabatically, with no work, or changes in the kinetic or potential energy, then the flame temperature is referred to as the adiabatic flame temperature. This is the maximum temperature that can be achieved for the given reactants because any heat transfer from the reaction zone and any incomplete combustion would tend to lower the temperature of the products.

One of the most important parameter in any combustion system is its adiabatic flame temperature, which is the temperature under the condition of no heat loss takes place from the combustion system. This importance arise from the fact that it plays an important role in the pollutants emitted from the system such as carbon oxides and nitrogen oxides, in addition the temperature also affect drastically the thermal stresses set up in the combustion system, such stress may lead to the deterioration of the chamber if not well controlled. Consequently, it is essential and before the construction of the combustion chamber, a simulation process for the temperature distribution within the combustion system must be carefully carried to avoid local thermal stresses and to minimize both nitrogen and carbon dioxides. The concentration of oxides of nitrogen (NO_X) and carbon monoxide (CO), pollutants of great concern, are very much dependent on the flame temperature. [1-4].

2. Theoretical Background

The effect of both pressure and inlet velocity on the adiabatic flame temperature was simulated using a computational fluid dynamics (CFD) software package to simulate fluid flow problems. It uses the finite-volume method to solve the governing equations for a fluid. It provides the capability to use different physical models such as incompressible or compressible, inviscid or viscous, laminar or turbulent, etc. Geometry and grid generation is done using GAMBIT which is the preprocessor bundled with FLUENT.

Corresponding Author. mashamdan@yahoo.com

The model takes into account the following main equations:

Conservation of mass

-The rate of change of mass within any open system is the net flux of mass across the system boundaries

$$\frac{dm}{dt} = \sum_j \dot{m}_j$$

Conservation of species

– Equations tracking the evolution of species within the combustion chamber will be developed on a mass basis .

$$\dot{Y}_i = \sum_j \left(\frac{\dot{m}_j}{m} \right) \left(Y_i^j - Y_i^{cyl} \right) + \frac{\Omega_i W_{mw}}{\rho}$$

where 'm' denotes the total mass within the control cylinder. The species equations are deduced from their multi-dimensional counterparts by neglecting species diffusion terms, consistent with the zero-dimensional assumption.

Conservation of energy.

–The generalized energy equation for an open thermodynamic system may be written as

$$\underbrace{\frac{d(mu)}{dt}}_{\text{Internal Energy}} = \underbrace{-p\frac{dV}{dt}}_{\text{Displacement Work}} + \underbrace{\frac{dQ_{ht}}{dt}}_{\text{Heat Transfer}} + \underbrace{\sum_j \dot{m}_j h_j}_{\text{Enthalpy Flux}}$$

3. Discussion of Results

The general trend of the obtained data is a rapid increase in the temperature within the reaction zone, where the temperature reaches a peak value; this is due to the heat generated as a result of burning of the combustible mixture. Moving away from the reaction zone the temperature either remains almost constant (with a slight drop) or it decreases, this depends on both the pressure within the chamber and on the inlet velocity of combustible mixture.

As indicated in figures 2 though 6, temperature value depends on the pressure, and at any location within the combustion chamber, the temperature increase with pressure, this is due to the fact that the combustion products at this high temperature behaves as an ideal fluid The temperature increases with pressure which is a general behavior of the ideal gas law this is an agreement with Sakhrieh [5]. He studied the effect of pressure on the adiabatic flame temperature at stocichiometric conditions and ambient initial air temperature which is given by the following equation:

Figures 7 through 11 show the variation of adiabatic flame temperature along the combustion chamber as a function of both the pressure and inlet flow velocity. It may be noticed that at any location and for low pressure values (2 to 6 bar), the temperature increases with the inlet velocity of the combustible mixture. This is caused by the increase in the amount of the combustible mixture entering the combustion chamber as a result of the increase in the velocity. Consequently, more heat is generated and hence the temperature increases. However, at high pressure (8 and 10 bar), the adiabatic flame temperature is dominated by the pressure and it decreases with pressure in spite of increasing the inlet velocity, this is might be due to the fact that the high pressure inside the combustion chamber creates a back pressure that apposes the flow of the entering mixture into the chamber and hence a drop in the heat generation and hence lower temperature.

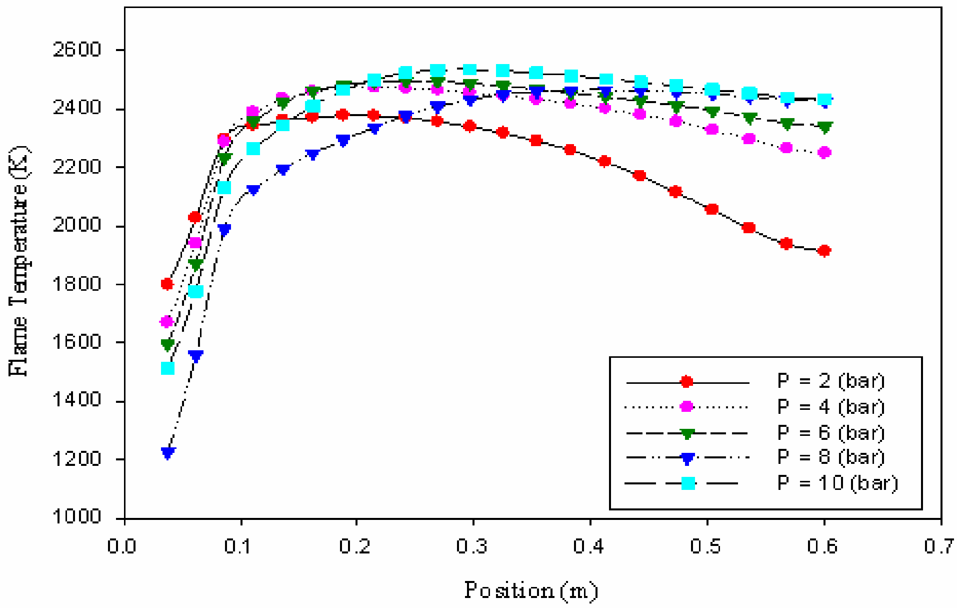

Figure 1. Flame Temperature Distribution, (Velocity = 5 (m/s), at Different Pressures).

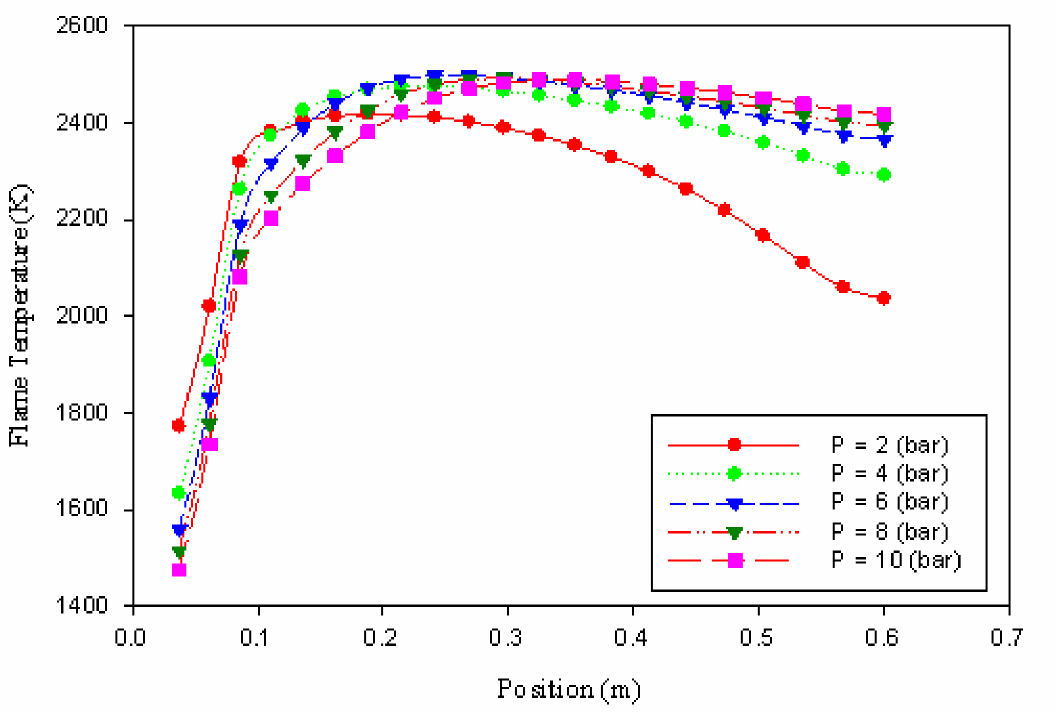

Figure 2. Flame Temperature Distribution, (Velocity = 6 (m/s), at Different Pressures).

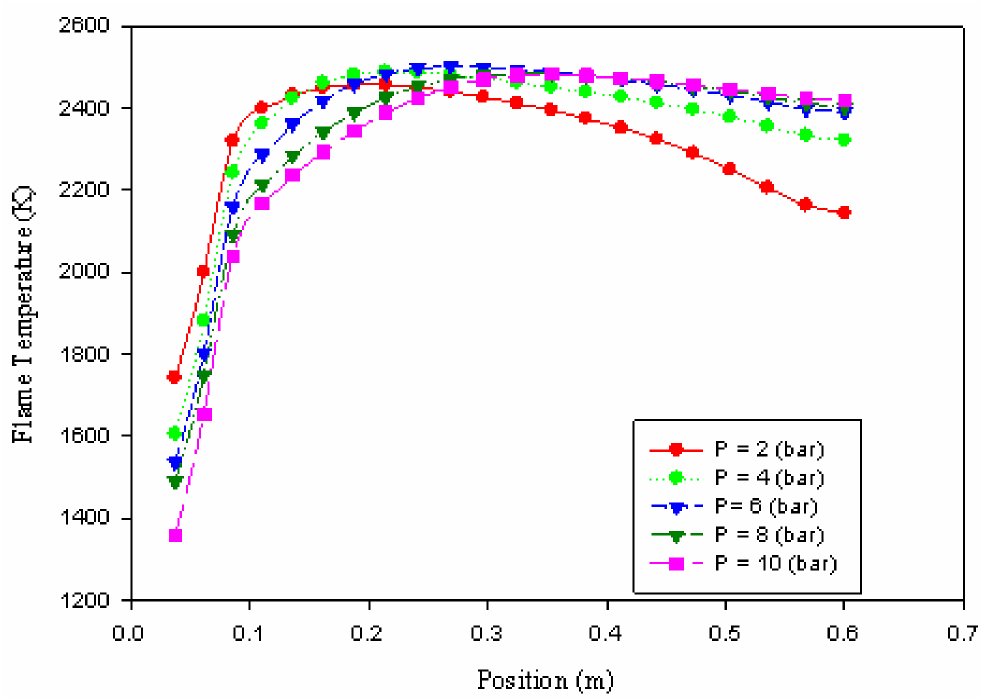

Figure 3. Flame Temperature Distribution, (Velocity = 7 (m/s), at Different Pressures).

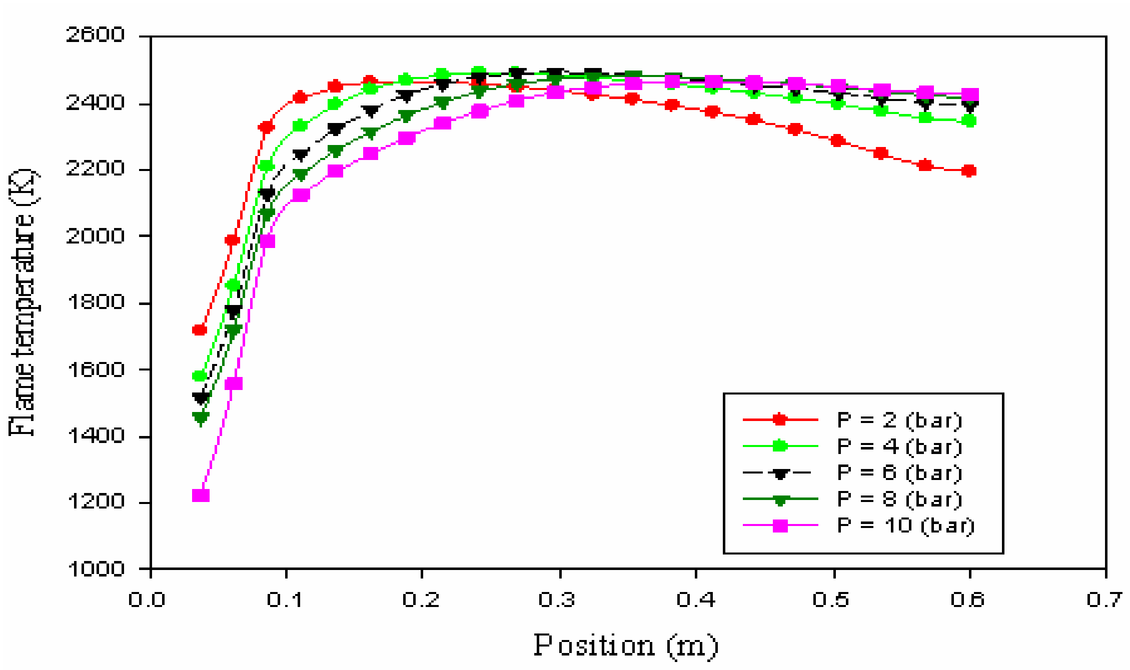

Figure 4. Flame Temperature Distribution, (Velocity = 8 (m/s), at Different Pressures).

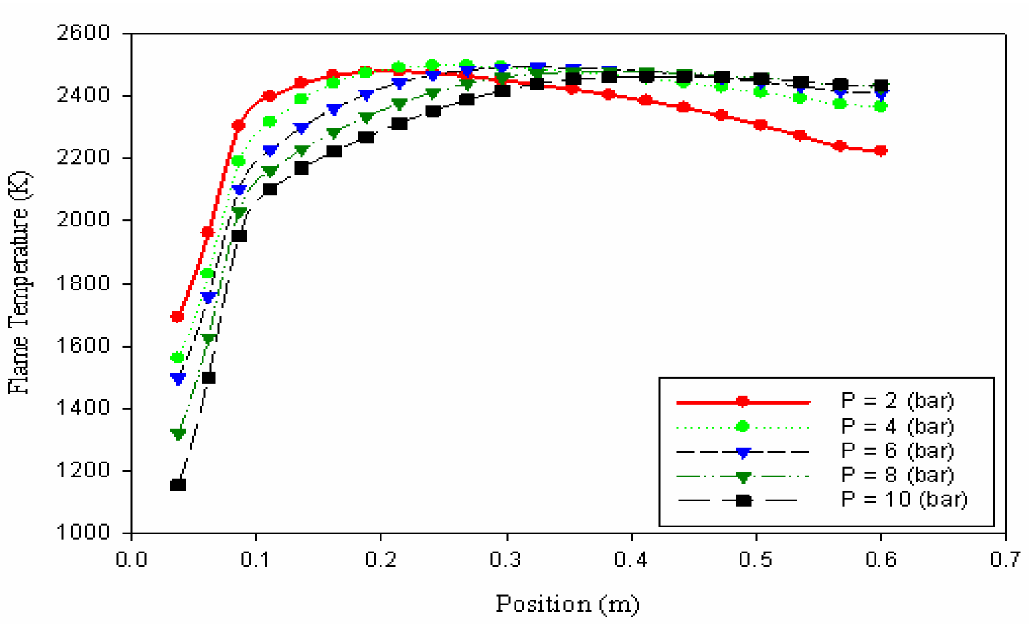

Figure 5. Flame Temperature Distribution, (Velocity = 9 (m/s), at Different Pressures).

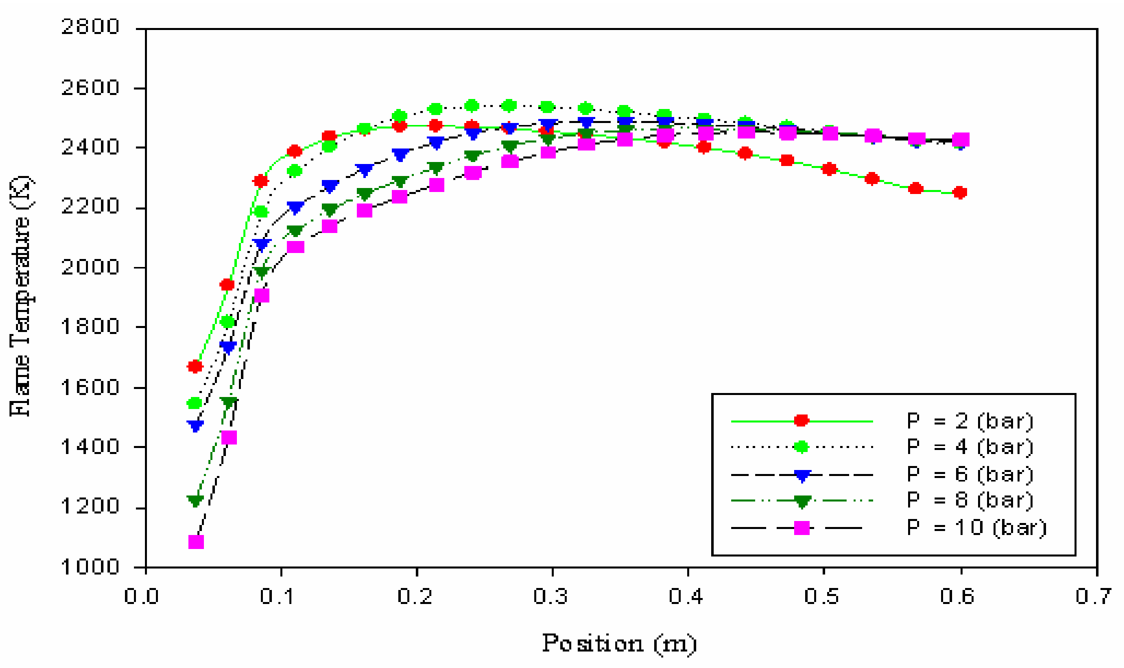

Figure 6. Flame Temperature Distribution, (Velocity = 10 (m/s), at Different Pressures).

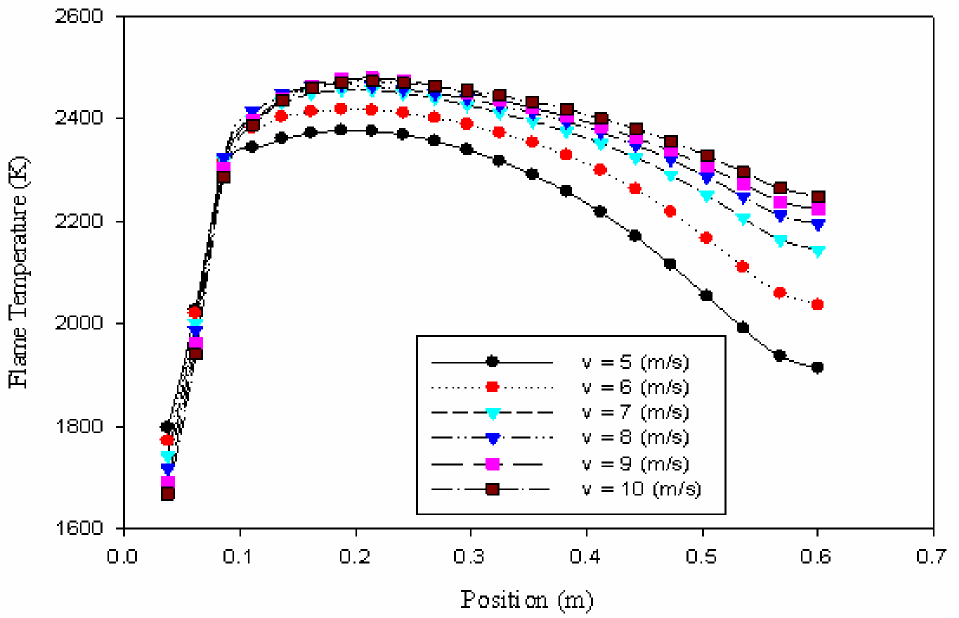

Figure 7. Flame Temperature Distribution, (P = 2 (bar) at Different Velocities).

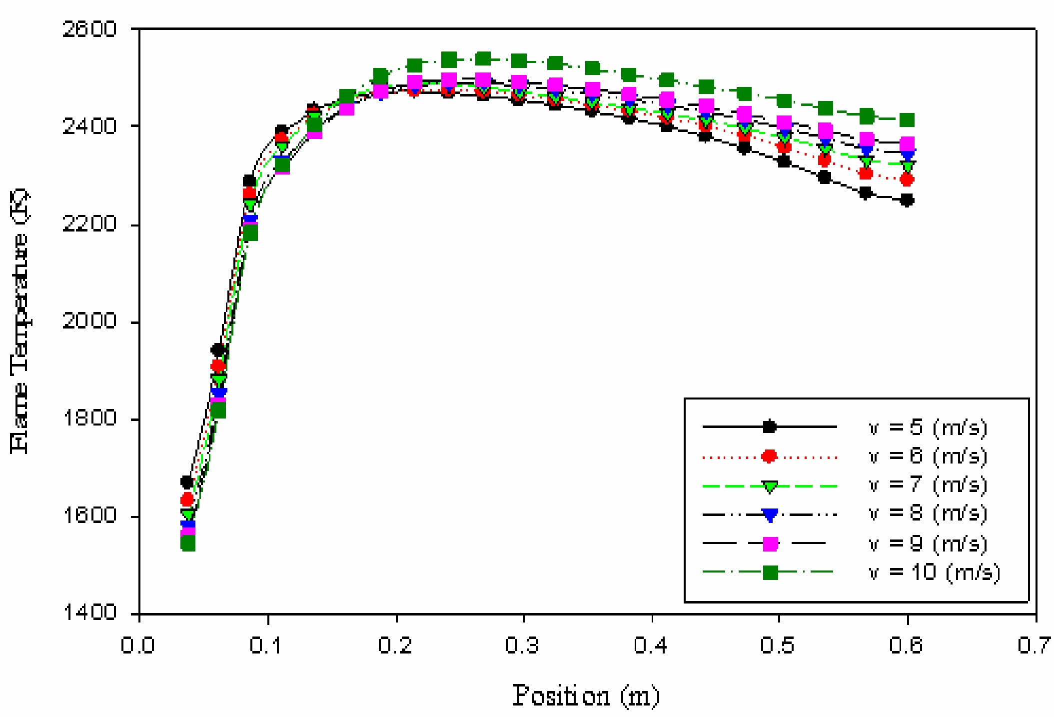

Figure 8. Flame Temperature Distribution, (P = 4 (bar) at Different Velocities).

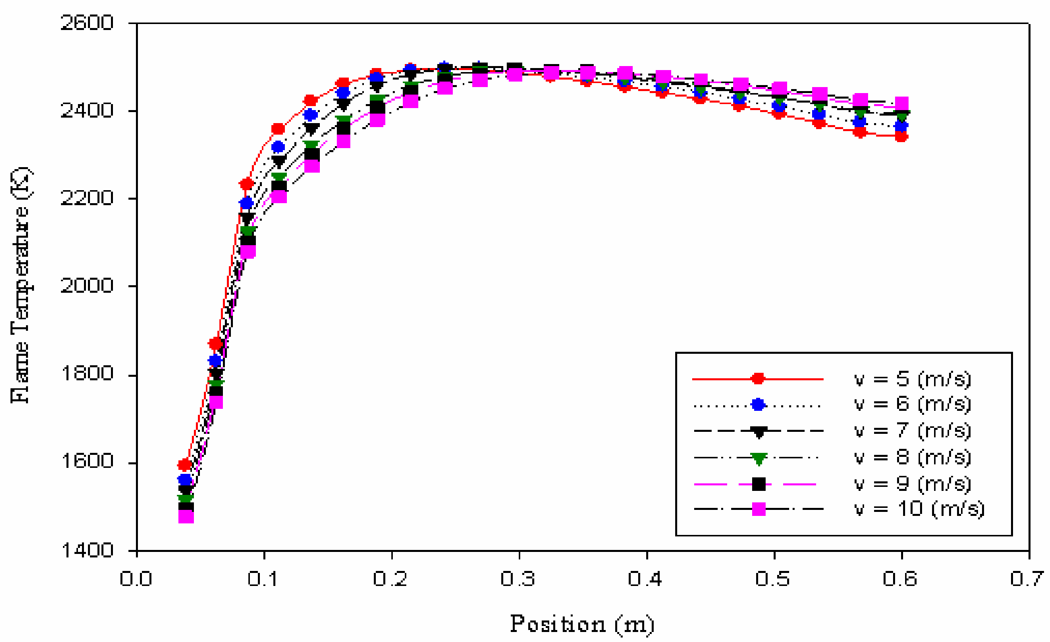

Figure 9. Flame Temperature Distribution, (P = 6 (bar) at Different Velocities).

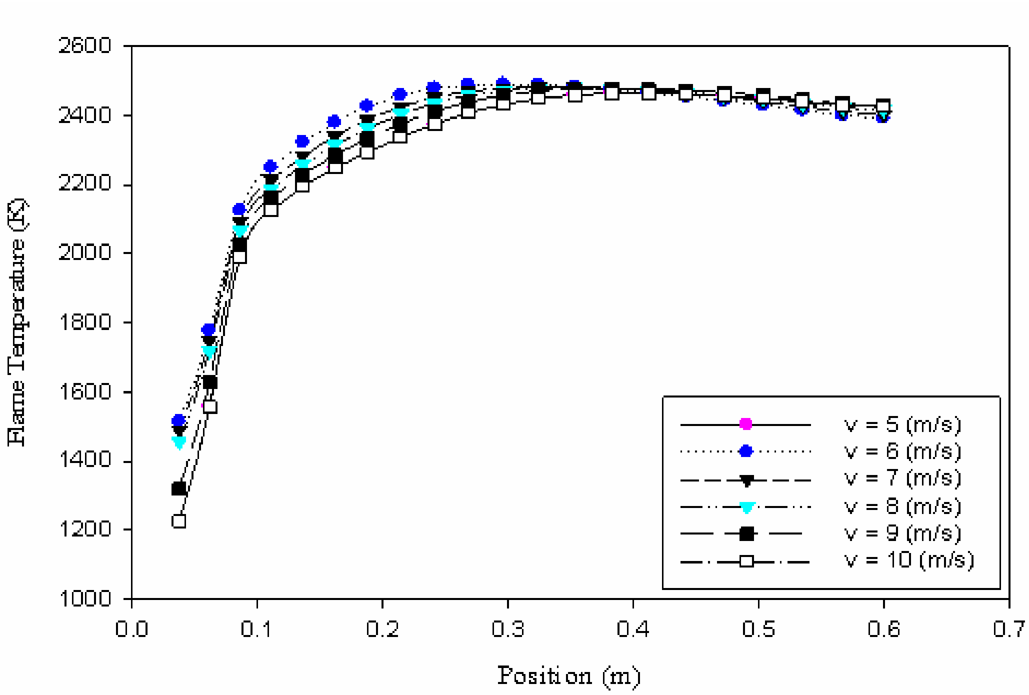

Figure 10. Flame Temperature Distribution, (P = 8 (bar) at Different Velocities).

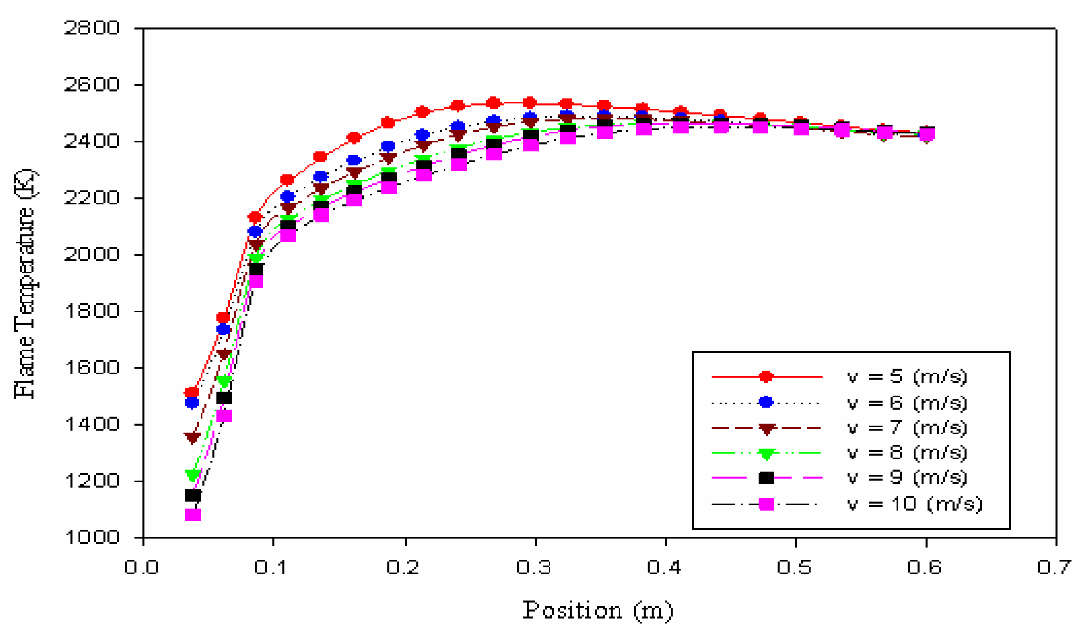

Figure 11. Flame Temperature Distribution, (P = 10 (bar) at Different Velocities).

4. Conclusions

It may be concluded from this work that the Fluent software was successfully used to simulate the variation of adiabatic flame temperature of Methane/air flame turbulent premixed flame. A further will be followed to completely simulate such flame.

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