RELATION OF ADIABATIC FLAME TEMPERATURE WITH VARYING INSULATION OF OCTANE FUEL

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ABSTRACT

This Research paper combines the work of Adiabatic Flame Temperature (AFT) and Critical Radius (C_r), the Hydrocarbon Combustion of Stoichiometric Equation of Pure form of Petrol (Octane) in Constant Volume Process and its Characterization for AFT, according to the initial temperature. The AFT found depends on the type of fuel and the amount of air. By applying this algorithm, we actually get Adiabatic Flame Temperature in the Combustion Chamber and relation between the Critical Radius of insulation and Adiabatic Flame Temperature.

KEYWORDS: Adiabatic Flame Temperature with Insulation, AFT & AFT Insulation

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INTRODUCTION

Adiabatic Flame Temperature Calculation

"Adiabatic flame temperature" means the temperature of the products when burning an adiabatic fuel without any work on the shaft. In a combustion process, the heat that is generated during the exothermic chemical reaction releases its product and the temperature of the products is increased. There is no way to dissipate heat in the environment and the process will be adiabatic as there will be no heat loss in the environment. As a result, the temperature of the products suddenly rises and produces a flame. This will heat the gases generated in the area of the flame and the temperature rise will be maximum. This higher temperature is known as the temperature of the adiabatic flame. The increase in temperature depends on the amount of excess air used or the air-fuel ratio. The temperature of the flame has the highest value for the use of pure oxygen and decreases with the air. Therefore, accurate stoichiometric air must be provided for a better result. Excessive excess air will reduce the flame temperature. When the heat in the environment loses or is diluted by inert gases and incineration is incomplete. Therefore, the temperature of the products will be lower. The temperature of the flame is determined by the energy balance of the equilibrium reaction.

There is two type of adiabatic flame temperature:

- Constant pressure adiabatic flame temperature.
- Constant volume adiabatic flame temperature.

Figure 1: Adiabatic Flame Temperature Graph

For a combustion process that takes place adiabatically with no shaft work, the temperature of the products is referred to as the adiabatic flame temperature. This is the maximum temperature that can be achieved for given reactants. Heat transfer, incomplete combustion, and dissociation all result in lower temperature. The maximum adiabatic flame temperature for a given fuel and oxidizer combination occurs with a stoichiometric mixture (correct proportions such that all fuel and all oxidizer are consumed). The amount of excess air can be tailored as part of the design to control the adiabatic flame temperature. The considerable distance between present temperatures in a gas turbine engine and the maximum adiabatic flame temperature at stoichiometric conditions is shown in Figure 2, based on a compressor exit temperature of 1200°F (922 K).

Figure 2: Schematic of Adiabatic Flame Temperature

An initial view of the concept of adiabatic flame temperature is provided by examining two reacting gases, at a given pressure, and asking what the end temperature is. The process is shown schematically, where the temperature is plotted versus the percentage completion of the reaction. The initial state is *i* and the final state is *f*, with the final state at a higher temperature than the initial state. The solid line in the figure shows a representation of the “actual” process.

ADIABATIC FLAME TEMPERATURE FOR C_8H_{18}

Formula

Where,

$$\text{X}_s = m + \frac{n}{2} - \frac{p}{4}$$

Considering This Equation,

We get the Air-Fuel Ratio by the following formula:

$$\text{A/F} = \frac{[(12.5 * \text{Molar mass of Oxygen}) + (47 * \text{Molar mass of Nitrogen})]}{[(8 * \text{Molar mass of Carbon}) + (18 * \text{Molar mass of Hydrogen})]}$$

$$\text{A/F} = \frac{[(12.5 * 32) + (47 * 28)]}{[(8 * 12) + (18 * 1)]}$$

A/F = 15.05 (Stoichiometric Air-Fuel Ratio)

We Know that,

$$Q - W = H_{\text{product}} - H_{\text{reactant}}$$

Here,

$$W = 0,$$

$$Q = H_{\text{product}} - H_{\text{reactant}}$$

$$Q = H \text{ of } (8\text{CO}_2 + 9 \text{H}_2\text{O} + 47 \text{N}_2) - H \text{ of } (\text{C}_8\text{H}_{18} + 12.5 \text{O}_2 + 47 \text{N}_2)$$

Table 1: Enthalpy Table for Gases

Sr. No	Components	h°_f	h @ 298K (Atm)	h' @ 301K (Reactant)	h' @ 823K (Product)
		MJ/kg.k	MJ/kg.k	MJ/kg.k	MJ/kg.k
1.	C_8H_{18}	-208.45	-	-	-
2.	O_2	0	8.682	9.0594	-
3.	N_2	0	8.669	9.0431	26.344
4.	CO_2	-393.52	9.364	-	36.5057
5.	$\text{H}_2\text{O (g)}$	-241.82	9.904	-	31.1511

Some of the above values for h° and h' are calculated by **Interpolation Formula** from data book.

$$\mathbf{H = h_f + h - h'}$$

- **For Products**

- $\mathbf{H(CO_2) = h_f + h - h'}$

$$= -393.52 + 36.5057 + 9.364$$

$$= -366.3783 \text{ MJ/kmol}$$

- $\mathbf{H(H_2O) = h_f + h - h'}$

$$= -241.82 + 31.1511 + -9.904$$

$$= -220.5729 \text{ MJ/kmol}$$

- $\mathbf{H(N_2) = h_f + h - h'}$

$$= 0 + 26.344 - 8.669$$

$$= 17.675 \text{ MJ/kmol}$$

- $\mathbf{H_{product} = 8 (-366.3783) + 9 (-220.5729) + 47 (17.675)}$

$$= -2931.0264 - 1985.1561 + 830.725$$

$$= -4085.4575 \text{ MJ/kmol}$$

- **For Reactants**

- $\mathbf{H(C_8H_{18}) = h_f + h - h'}$

$$= -208.45 + 0 - 0$$

$$= -208.45 \text{ MJ/kmol}$$

- $\mathbf{H(O_2) = h_f + h - h'}$

$$= 0 + 9.0594 - 8.682$$

$$= 0.3774 \text{ MJ/kmol}$$

- $\mathbf{H(N_2) = h_f + h - h'}$

$$= 0 + 9.0431 - 8.669$$

$$= 0.3741 \text{ MJ/kmol}$$

- $\mathbf{H_{Reactant} = 1 (-208.45) + 12.5 (0.3774) + 47 (0.3741)}$

$$= -208.45 + 4.7175 - 17.5827$$

$$= -186.1498 \text{ MJ/kmol}$$

Sub in Q = $H_{product} - H_{reactant}$

Therefore we get,

$$\begin{aligned} Q &= -4085.4575 + 186.1498 \\ &= -3899.3077 \text{ MJ/kmol} \end{aligned}$$

Q = 3899.3077 KJ/mol (- ve sign is omitted since Heat is Rejected)

Amount of Heat Transfer for **Octane (C₈H₁₈)** is **3899.3077 KJ/mol**.

To find **C_p** for the Products, i.e. **CO₂, H₂O, and N₂**.

From Table – Using Interpolation Formula,

$$\frac{823 - 800}{900 - 800} = \frac{C_p - 1.169}{1.204 - 1.169}$$

$$C_p = 1.169 + 0.00805$$

$$= 1.17705 \text{ KJ/kg.K}$$

$$= 1.7705 * 44.01$$

$$= 51.79 \text{ KJ/kmol.K}$$

$$= 51.79/1000$$

$$C_p = 0.051 \text{ KJ/mol.K}$$

Similarly,

For **N₂**

$$C_p = 0.03154 \text{ KJ/mol.K}$$

For **H₂O**

$$C_p = 0.03893 \text{ KJ/mol.K}$$

Now we know that,

$$Q = C_p (T_f - 298) \quad [T_f \text{ is the Adiabatic Flame Temperature}]$$

$$3899.3077 = [8 (0.051) + 9 (0.03893) + 47 (0.03154)] * (T_f - 298)$$

$$3899.3077 = [0.408 + 0.35037 + 1.48238] (T_f - 298)$$

$$3899.3077 = 2.24075 (T_f - 298)$$

$$1740.179717 = T_f - 298$$

$$T_f = 1740.179717 + 298$$

$$T_f = 2038.1797 \text{ K}$$

Therefore, the **Adiabatic Flame Temperature** is **2038.1797 K**.

CRITICAL INSULATION FOR CYLINDER

To Find the Critical Radius of the Cylinder,

Thermal conductivity for Cast Iron, $k = 60 \text{ W/m.K}$ [Assumed, usually ranges from 47-80]

Heat Transfer Coefficient for air, $h = 150 \text{ W/m}^2.\text{K}$ [Assumed, Usually ranges from 0.5 – 1000]

Figure 3: Critical Radius Insulation for Cylinder

- **Critical Radius, $r_c = k / h$**
 $= 60 / 150$
 $= 0.4\text{m}$
- **Insulation Variation through Critical Radius (R)**

$$R = r_c - r$$

Where, r_c - Critical Radius

r - Actual Cylinder Radius or say Bore

$$R = 0.4 - 0.09032$$

$$R = 0.309\text{m}$$

CONCLUSIONS

According to the above research work done for the single cylinder shows that the critical temperature will vary for any insulation provided more or less than the critical radius insulation. In our research work, we found that the critical temperature was 2038.17K for the critical radius insulation of 0.4m and when the critical insulation was changed to 0.3m the critical temperature also changed to the difference of 17.34K. So, therefore, the research shows that there will be the loss of energy in the form of heat transfer for any critical radius insulation provided more or less than the 0.4m.

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