Steady Flow Combustion

> Adiabatic flame temperature can be calculated by modeling combustion process as a constant-pressure, steady flow process with no heat loss and no shaft work.

□ Theoretical maximum temperature

Assume complete combustion (all reactants turn into products)

 \Box Enthalpy of the products = enthalpy of the reactants

> In a general steady-flow combustion process such as that inside a jet engine combustion chamber, not all reactants turn into products.

□ Excessive air left unburned (however, at a much higher temperature) and exhausted with the products for

- propulsive power
- □ Incomplete combustion
- Dissociation

Steady Flow Combustion Process



Combustion process:

 $C_8H_{18} + 12.5O_2$ (reactants) $\rightarrow 8CO_2 + 9H_2O$ (products)

With excessive air:

 $C_8H_{18} + XD.A.(Dry Air) \rightarrow 8CO_2 + 9H_2O + XD.A. - 12.5O_2$ (products)

Note: 1 kmole of C_8H_{18} requires 12.5 kmoles of O_2 to react completely and O_2 is only 20.95% of dry air. Therefore, 1 kmole of C_8H_{18} requires 12.5/0.2095=59.67 kmoles of dry air to complete.

Example 1

Liquid n-octane C8H18, is burned at a constant pressure with 20% excess dry air. The air and fuel are supplied at 298 K. Determine the adiabatic flame temperature for these conditions assuming complete combustion.

 $C_8H_{18} + XD.A.(Dry Air) \rightarrow 8CO_2 + 9H_2O + XD.A. - 12.5O_2$

In order to burn completely, 1 kmole of C_8H_{18} reuires 59.67 kmoles of dry air. There are 20% excess air left unburned after that, therefore:

$$20 = \left(\frac{X-59.67}{59.67}\right) \times 100, \quad X = 71.6(kmole)$$

$$C_8 H_{18} + 71.6D.A.(Dry Air) \rightarrow 8CO_2 + 9H_2O + 71.6D.A. - 12.5O_2$$

From energy balance:

 $Q = 0 = H_{pr} - H_{re}$, where Q=0 gives adiabtic flame temperature and it is the theoretically maximum temperature this combustion process can produce.

Example (1-2)

$$H_{re} = \Delta H_{f,C_{8}H_{18}} + Xh_{air,298K} = -249,957 (\text{from table 4.3}) + (71.6)(28.965)(-4.7)$$

=-259,704.3(J/mole)
For dry air
28.965 (kg/kmole)
From table B.1
Note: unit kJ/kg

Unfortunately, the temperature of the products is unknown. Assume

 $T \approx 1000$ K as the initial guess.

From table B.1: $h_{CO_2,1000k} = -360098.7 (kJ/kmole)$,

 $h_{H_{2}O,1000k}$ =-215829.0(kJ/kmole),

$$h_{DA,1000k} = 744(kJ/kg) = 21550.0(kJ/kmole),$$

 $h_{O_2,1000k} = 22705.5 (kJ/kmole).$

 $H_{pr,1000K} = \sum (n_i h_i)_{pr}$ =8(-360098.7)+9(-215829.0)+71.6(21550.0)-12.5(22705.5)=-3564089.4 $H_{re} \gg H_{pr}$

Temperature must be significantly higher. Assume T=2000K and iterate again.

Example (1-3)

$$T \approx 2000\text{K as the second guess.} \Rightarrow H_{\text{pr},2000\text{K}} = \sum (n_i h_i)_{\text{pr}}$$

From table B.1: $h_{\text{CO}_2,2000\text{k}} = -302107.6(\text{kJ/kmole}),$
 $h_{H_20,2000\text{k}} = -169015(\text{kJ/kmole}),$
 $h_{DA,2000\text{k}} = 1949.5(\text{kJ/kg}) = 56467.3(\text{kJ/kmole}),$
 $h_{0_2,2000\text{k}} = 59172(\text{kJ/kmole}).$
 $H_{\text{pr},2000\text{K}} = \sum (n_i h_i)_{\text{pr}}$
 $= 8(-302107.6) + 9(-169015) + 71.6(56467.3) - 12.5(59172) = -634589.4$
Much closer. Should be higher still.
Assume T $\approx 2150\text{K} \Rightarrow H_{\text{pr},2150\text{K}} = \sum (n_i h_i)_{\text{pr}}$
 $= 8(-293008.9) + 9(-161252) + 71.6(61924.3) - 12.5(64875) = -172499.5$
much closer.
 $T_{\text{int}} \approx 2000 + \frac{2150 - 2000}{[(-172499.5) - (-634589.4)]} [-259704 - (-634589.4)] = 2122(K).$

Should be good enough \Rightarrow Adiabatic flame temperature ≈ 2122 K

