ESO201A

Lecture#28

(Class Lecture)

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By

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First-Law Analysis of Reacting Systems

The significance of the enthalpy of formation is that it is most convenient in performing a first-law analysis of a reacting system, because the enthalpies of different substances can be added or subtracted, since they are all given relative to the same base.

In such problems, we will write the first law for a steady-state, steady flow process in the form

$$Q - W = H_{products} - H_{reactants} \qquad (1)$$

$$\text{or} \quad Q - W = \sum_p N_e \bar{h}_e - \sum_r N_i \bar{h}_i$$

where

$i \rightarrow$ inlet

$e \rightarrow$ exit

$p \rightarrow$ products

$r \rightarrow$ reactants

In each problem it is necessary to choose one parameter as the basis of the solution. Usually this is taken as 1 kmol of fuel.

Example Problem # 1

Consider the following reaction, which occurs in a steady-state, steady-flow process.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O\,(l)$$

The reactants and products are each at a total pressure of 0.1 MPa and 25°C. Determine the heat transfer per kmol of fuel entering the combustion chamber. See Fig. 1

Solution

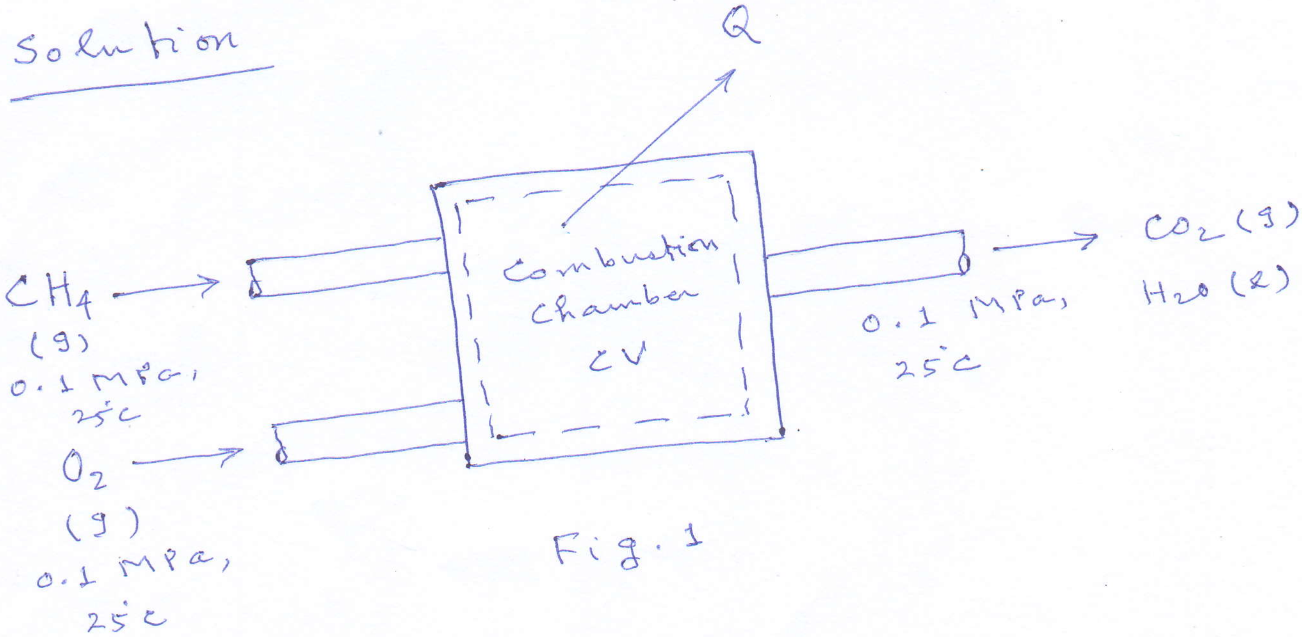

Fig. 1

First Law

$$Q - \cancel{W}^{\,0} = \sum_p N_e \bar{h}_e - \sum_r N_i \bar{h}_i$$

or $$Q = \sum_p N_e \bar{h}_e - \sum_r N_i \bar{h}_i$$

Using the values of Table A-26, we have

$$\sum_r N_i \bar{h}_i = (\bar{h}_f^\circ)_{CH_4} = -74{,}850 \text{ kJ}$$

Note: $\bar{h}^\circ_{f,O_2} = 0$

$$\sum_p N_e \bar{h}_e = (1)(\bar{h}_f^\circ)_{CO_2} + (2)(\bar{h}_f^\circ)_{H_2O(l)}$$

$$= (1)(-393{,}520) + (2)(-285{,}830)$$

$$= -393{,}520 - 571{,}660$$

$$= -965{,}180 \text{ kJ}$$

Therefore, $$Q = -965{,}180 - (-74{,}850)$$

$$= \boxed{-890{,}330 \text{ kJ}}$$

In most instances, however, the substances that comprise the reactants and products in a chemical reaction are not at a temperature of 25°c and a pressure of 0.1 MPa (the state at which the enthalpy of formation is given). Therefore, this change of enthalpy can usually be found from a table of thermodynamic properties or from specific heat data. For gases, assume ideal-gas behaviour between 25°c, 0.1 MPa, and the given state, if the deviation from ideal-gas behaviour is not significant.

Thus, in general, for applying the first law to a steady-state process involving a chemical reaction and negligible changes in kinetic and potential energy, we can write

$$Q - W = \sum_p N_e (\bar{h}_f^\circ + \Delta\bar{h})_e - \sum_r N_i (\bar{h}_f^\circ + \Delta\bar{h})_i \qquad (2)$$

where $\Delta\bar{h} = \bar{h} - \bar{h}_o$

$\Delta\bar{h}$ is also called sensible enthalpy relative to 25°c, 1 atm.

Example Problem # 2

A small gas turbine uses C_8H_{18} (l) for fuel and 400% theoretical air. The air and fuel enter at 25°C, and the products of combustion leave at 900 K. The output of the engine and the fuel consumption are measured, and it is found that the specific fuel consumption is 0.25 kg/s of fuel per megawatt output. Determine the heat transfer from the engine per kmol of fuel. Assume complete combustion except that there is free O_2 in the products. $M_{C_8H_{18}} = 114.23$ kg/kmol.
See Fig. 1

Solution:

Control volume: Gas-turbine + combustion chamber

Inlet state: T known for fuel and air (standard reference state)

Exit state: T known for combustion products

Process: Steady state

Assumption: All gases are ideal gases. ($T >> T_{cr}$ for all gases in the present reaction (Table A-1))

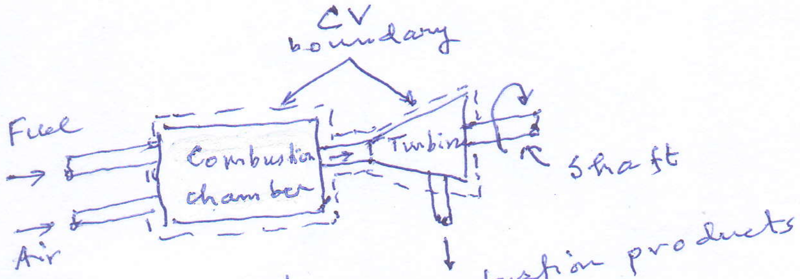

Fig. 1

The combustion equation is

$$C_8H_{18}(l) + 4(12.5)O_2 + 4(12.5)(3.76N_2)$$

$$\longrightarrow 8CO_2 + 9H_2O + 37.5O_2 + 188N_2$$

<u>First Law</u>

$$Q - W = \sum_p N_e(\bar{h}_f^o + \Delta\bar{h})_e - \sum_r N_i(\bar{h}_f^o + \Delta\bar{h})_i$$

Using Tables A-26, A-18, A-19, A-20, A-23,

$$\sum_R N_i(\bar{h}_f^o + \Delta\bar{h})_i = (\bar{h}_f^o)_{C_8H_{18}(l)}$$

$$= -249,950 \text{ kJ/kmol fuel}$$

Note:
$\bar{h}^o_{f,O_2} = 0$
$\bar{h}^o_{f,N_2} = 0$

$$\sum_p N_e(\bar{h}_f^o + \Delta\bar{h})_e = N_{CO_2}(\bar{h}_f^o + \Delta\bar{h})_{CO_2}$$

$$+ N_{H_2O}(\bar{h}_f^o + \Delta\bar{h})_{H_2O}$$

$$+ N_{O_2}(\Delta\bar{h})_{O_2} + N_{N_2}(\Delta\bar{h})_{N_2}$$

$$= 8(-393,520 + \bar{h}_{900K,CO_2} - \bar{h}_{298K,CO_2})$$

$$+ 9(-241,820 + \bar{h}_{900K,H_2O} - \bar{h}_{298K,H_2O})$$

$$+ 37.5(\bar{h}_{900K,O_2} - \bar{h}_{298K,O_2}) + 188(\bar{h}_{900K,N_2} - \bar{h}_{298K,N_2})$$

$$= 8(-393{,}520 + 37405 - 9364)$$
$$+ 9(-241{,}820 + 31{,}828 - 9904)$$
$$+ (27{,}928 - 8682)37.5$$
$$+ (26{,}890 - 8669)188$$

$$= 8(-365{,}479) + 9(-219{,}896)$$
$$+37.5(19246) + (18{,}221)188$$

$$= -2{,}923{,}832 - 1{,}979{,}064$$
$$+ 721{,}725$$
$$+ 3{,}425{,}548$$

$$= -755{,}623 \text{ kJ/kmol fuel}$$

$$W = \frac{1000 \text{ kJ/s}}{0.25 \text{ kg/s}} \times \frac{114.23 \text{ kg}}{\text{kmol}}$$

$$= 456{,}920 \text{ kJ/kmol fuel}$$

There fore, $Q - 456{,}920 = -755{,}623 - (-249{,}950)$

$$\Rightarrow Q = 456{,}920 + 249{,}950 - 755{,}623$$
$$= -48451 \text{ kJ/kmol fuel}$$