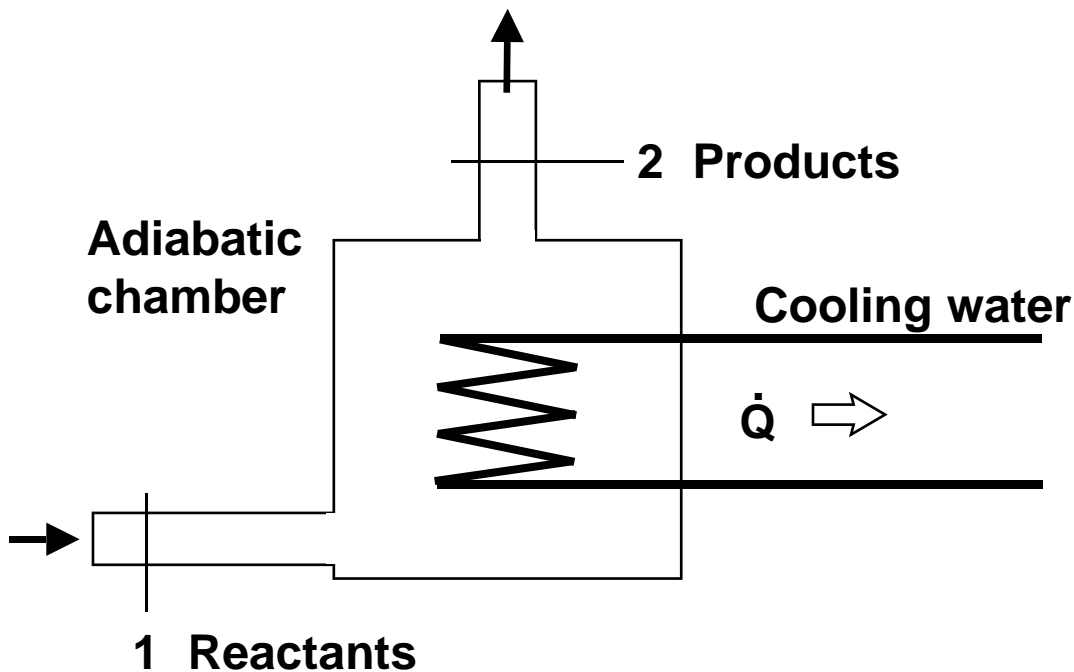


FIRST LAW APPLIED TO COMBUSTION

Steady Flow Calorimetry

The aim is to extract the maximum energy (heat) from the products of combustion and to reduce the product's temperature to the reactant's temperature.

ie as per the Gas Calorimeter



Applying the SFEE:-

$$\dot{Q} + \dot{W} = \dot{m} \{ (h_2 - h_1) + \text{DKE} + \text{DPE} \}$$

$$\text{NB : } \dot{m} = \dot{m}_{\text{fuel}} + \dot{m}_{\text{air}} = \dot{m}_{\text{fuel}} (1 + \text{AFR})$$

The change in KE & PE is negligible, & $\dot{W}=0$, therefore:

$$\dot{Q} = \dot{m} (h_2 - h_1) = \dot{H}_P - \dot{H}_R$$

NB: \dot{Q} is negative since it flows out of the system.

$|\dot{Q}|$ is a maximum when exit temperature is a minimum

$H_P < H_R$ therefore the products of combustion contain less stored energy than the reactants (as we would expect).

In order to obtain a standard measure of the heat released by combustion it is necessary to standardise the temperature of the reactants and products. This temperature is 25°C (see your tables). 15°C is also used.

This standard measure is known as the Enthalpy of Combustion and is usually expressed in kJ or MJ per kmol.

In practice the temperatures of the reactants and products will not be standard, so we may write :-

$$Q = (\dot{M}_P - \dot{M}_{P0}) + \dot{M}_{P0} - (\dot{M}_R - \dot{M}_{R0}) - \dot{M}_{R0}$$

where subscript 'o' denotes standard conditions.

ie.
$$Q = (\dot{M}_P - \dot{M}_{P0}) - (\dot{M}_R - \dot{M}_{R0}) + D\dot{M}_0$$

The first two terms are the sensible heat differences and relate to the specific heat capacity C_p .

The last term is the standard chemical energy release.

thus
$$\dot{M}_P - \dot{M}_{P0} = \dot{m}_P (\bar{C}_p)_P (T_P - T_0)$$

and
$$\dot{M}_R - \dot{M}_{R0} = \dot{m}_R (\bar{C}_p)_R (T_R - T_0)$$

Because C_p varies with temperature it is necessary to use a mean value. The C_p value at the mean temperature is often sufficiently accurate. If more precise values are required actual molar enthalpies may be used.

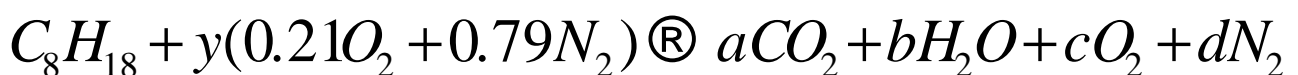
If we do not extract heat from the combustion reaction the products leave with the heat from the reaction. This is known as Adiabatic Combustion, and allows the maximum temperature of the products to be found. This maximum temperature is often called the 'adiabatic flame temperature'.

Putting $\dot{Q}=0$ in the above equation gives a method for determining the adiabatic flame temperature for a particular fuel, oxidant and fuel/oxidant ratio.

Example:

Octane (C_8H_{18}) vapour burns with air at an AFR of 60 by mass. Determine the adiabatic flame temperature given that the Enthalpy of Combustion of Octane is -5116.2 MJ/kmol. Assume the reactants enter the combustion chamber at standard temperature.

First write the combustion equation:



The molar mass of C_8H_{18} is 114 kg/kmol, & air is 29 kg/kmol.

$$\frac{29y}{114} = 60$$

$$y = 235.86$$

We may solve for a to d in the normal way to obtain:-

$$a = 8$$

$$b = 9$$

$$c = 37.03$$

$$d = 186.33$$

From the First Law equation:

$$\dot{m}_R (\bar{C}_p)_R (T_R - T_0) = \dot{m}_P (\bar{C}_p)_P (T_P - T_0) + D\dot{H}_0$$

This term is zero

$$\dot{m}_P (\bar{C}_p)_P (T_P - T_0) = - D\dot{H}_0$$

$$\text{also } \dot{m}_R = \dot{m}_{fuel} + \dot{m}_{air} = \dot{m}_{fuel} (1 + AFR)$$

$$\text{and } D\dot{H}_0 = \dot{m}_{fuel} \frac{Dh_0}{M_{fuel}}$$

enthalpy/kmol
molar mass of fuel

$$\text{so } (\bar{C}_p)_P (T_P - T_0) = - \frac{1}{(1 + AFR)} \frac{Dh_0}{M_{fuel}} = \frac{1}{61} \cdot \frac{5116.2}{114} = 0.73572 \text{ MJ / kg}$$

$$\text{or } (\bar{C}_p)_P (T_P - T_0) = 735.72 \text{ kJ / kg}$$

Before we can find T_P we need C_p , but before we can find C_p (at the average temp $\frac{1}{2}\{T_P+T_0\}$) we need T_P !

We estimate T_P , find C_p , then recalculate T_P etc.

A good first estimate for T_P can be found by putting $C_p=1\text{kJ/kg}$

whence $T_P \gg 760^\circ\text{C}$ (1033K) & $T_{av} \gg 386^\circ\text{C}$ (660K)

For the exhaust gas mixture which we found from the combustion equation we can now determine a mean C_p and use it to refine the value for T_P , etc.

An alternative method is to use the molar enthalpies directly.

$$\dot{H}_P - \dot{H}_{P0} = \dot{n}_A (h_{AT} - h_{A0}) + \dot{n}_B (h_{BT} - h_{B0}) + etc$$

'h' is the molar enthalpy of each of the gas mixture constituents A, B etc.

Using the listed molar enthalpies (*Haywood Table 3*) we can easily set up a table to determine $H_P - H_{P0}$ at different temperatures.

We need set up the table only for temperatures around our previous estimate.

	A	B	C	D	E	F
1	GAS	CO	H2O	O2	N2	
2	No. of kmol	8	9	37.03	186.33	
3	h(0)	9.37	9.9	8.66	8.67	
4	Temp(K)	h(T)	h(T)	h(T)	h(T)	-SUM
5	900	37.41	31.83	27.90	26.89	4529.08
6	1000	42.78	35.90	31.37	30.14	5342.74
7	1100	48.27	40.09	34.88	33.44	6169.23

target SUM = -5116.2 MJ

By linear interpolation:-

$T_p = 972\text{K} (699^\circ\text{C})$

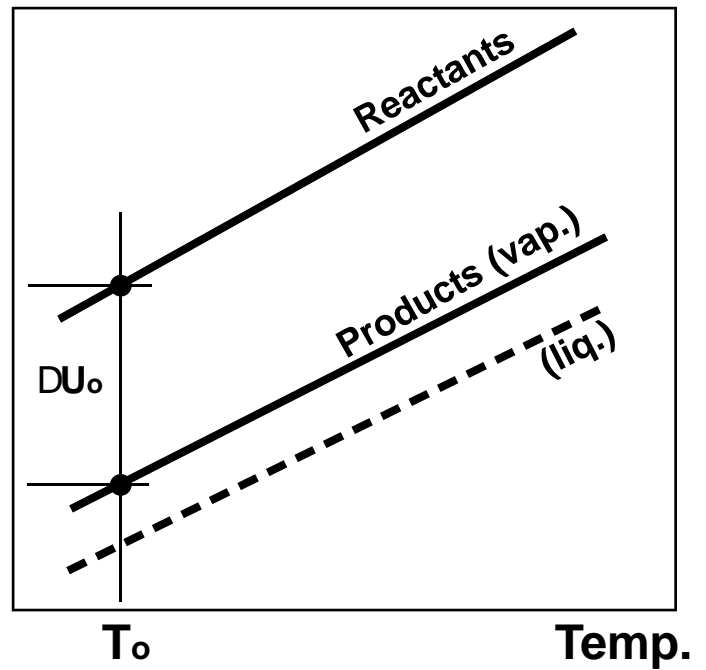
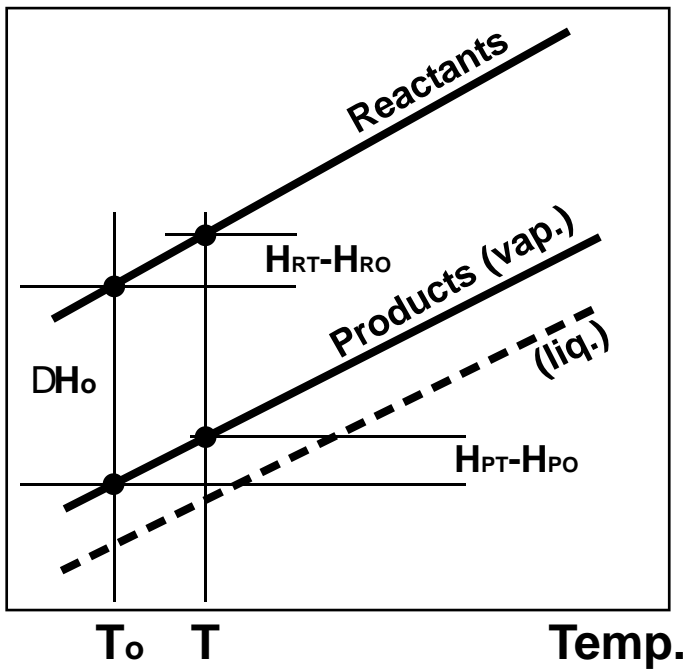
Diagrammatic Representation of Combustion Processes Calorimeter Processes (Const. Temperature)

Flow

Non-flow
(Bomb Calorimeter)

H

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