Internal Combustion Engine 1

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First Law of Thermodynamics

First Law of Thermodynamics

- Conservation of energy is the fundamental principle in the first law of thermodynamics.
- For a fixed mass system, energy conservation is expressed for a finite change between two state 1 and 2.
- The change in the total energy of the system is equal to the heat added to the system minus the work done by the system.

$$Q_{1\to 2} - W_{1\to 2} = \Delta E_{1\to 2}$$

Energy and Enthalpy Balance

- Systems changes from reactants to products (since mass is constant, apply first law for a closed system).

$$Q_{R\to P} - W_{R\to P} = U_P - U_R$$

$$W_{R\to P} = \int_R^P P\,dV = P(V_P - V_R)$$

$$Q_{R\to P} = PV_P - PV_R + U_P - U_R = PV_P + U_P - PV_R - U_R$$

$$Q_{R\to P} = H_P - H_R = \Delta H_{R\to P}$$

- Heat of reaction at constant pressure.

Enthalpies of Formation

- The enthalpy increase associated with the formation of one mole of a given compound from its elements, with each substance in its standard thermodynamic state at the specified temperature.
- A table of standard enthalpies of formation provides the value $h^{\circ}_{f,i}$ for each substance.

Standard Enthalpies of Formation, ΔH_f°, at 298 K

Substance	Formula	ΔH_f° (kJ/mol)	Substance	Formula	ΔH_f° (kJ/mol)
Acetylene	$C_2H_2(g)$	226.7	Hydrogen chloride	$HCl(g)$	−92.30
Ammonia	$NH_3(g)$	−46.19	Hydrogen fluoride	$HF(g)$	−268.6
Benzene	$C_6H_6(l)$	49.04	Hydrogen iodide	$HI(g)$	25.9
Calcium carbonate	$CaCO_3(s)$	−1207.1	Methane	$CH_4(g)$	−74.85
Calcium oxide	$CaO(s)$	−635.5	Methanol	$CH_3OH(l)$	−238.6
Carbon dioxide	$CO_2(g)$	−393.5	Propane	$C_3H_8(g)$	−103.85
Carbon monoxide	$CO(g)$	−110.5	Silver chloride	$AgCl(s)$	−127.0
Diamond	$C(s)$	1.88	Sodium bicarbonate	$NaHCO_3(s)$	−947.7
Ethane	$C_2H_6(g)$	−84.68	Sodium carbonate	$Na_2CO_3(s)$	−1130.9
Ethanol	$C_2H_5OH(l)$	−277.7	Sodium chloride	$NaCl(s)$	−411.0
Ethylene	$C_2H_4(g)$	52.30	Sucrose	$C_{12}H_{22}O_{11}(s)$	−2221
Glucose	$C_6H_{12}O_6(s)$	−1260	Water	$H_2O(l)$	−285.8
Hydrogen bromide	$HBr(g)$	236.23	Water vapor	$H_2O(g)$	−241.8

Enthalpies of Formation

- The enthalpy of the products, relative to the standard state enthalpy datum, is given by:

$$H_P^\circ = \sum_{PRODUCT} n_i \Delta h_{f,i}^\circ$$

- The enthalpy of the reactants is given by:

$$H_R^\circ = \sum_{REACTANT} n_i \Delta h_{f,i}^\circ$$

- The enthalpy increase $(\Delta H^\circ)_{R \to P, T_0}$ is then obtained from the difference:

$$(\Delta H^\circ)_{R \to P} = H_P^\circ - H_R^\circ$$

Heating Values

- The calorific value of a fuel is the magnitude of heat of reaction at constant pressure or at constant volume at standard temperature (usually $25^{\circ}C$) for the complete combustion of unit mass of fuel:

$$Q_{HV_P} = -(\Delta H)_{p,T_0}$$

$$Q_{HV_V} = -(\Delta H)_{v,T_0}$$

- The two heating values at constant pressure are related by:

$$Q_{HHV_P} = Q_{LHV_P} + \left(\frac{m_{H_2O}}{m_f}\right) h_{fg_{H_2O}}$$

- **Calorimeter** is a device used for heat measurements necessary for calorimetry.

Adiabatic Combustion Processes

- For an adiabatic constant volume combustion process

$$U_P - U_R = 0$$

- For an adiabatic constant pressure combustion process

$$H_P - H_R = 0$$

- The final temperature of the products in an adiabatic combustion process is called the adiabatic flame temperature
- Adiabatic flame temperature is the maximum temperature that can be achieved

Combustion Efficiency of ICE

- Combustion efficiency is simply a measure of how efficient is combustion process, it is given by:

$$\eta = \frac{H_R(T_A) - H_P(T_A)_c}{m_f Q_{HV}}$$

- where
  - Net chemical energy released with engine

$$H_R(T_A) - H_P(T_A)_c = \sum_{i,REACTANT} n_i \Delta h^{\circ}_{f,i} - \sum_{i,PRODUCT} n_i \Delta h^{\circ}_{f,i}$$

  - Maximum Fuel Energy

$$m_f Q_{HV}$$

Second Law of Thermodynamics

Second Law of Thermodynamics

- No process is possible whose sole result is the absorption of heat from a reservoir and the conversion of this heat into work.
- There exists for every system in equilibrium a property called entropy, which is a thermodynamic property of a system.
- The entropy change of any system and its surroundings, considered together, is positive.
- Entropy approaches zero for any process which approaches reversibility.
- Entropy is a function of the state of the system and can be found if any two properties of the system are known, for example.

$$s = s(p, T) \qquad s = s(T, v) \qquad s = s(p, v)$$

Max. Work from an ICE & Efficiency

- Availability conversion efficiency is a key measure of an internal combustion engine's effectiveness.

$$\eta_a = \frac{\Delta W}{\Delta W_{Umax}}$$

- Another is fuel conversion efficiency.

$$\eta_f = \frac{W_c}{m_f Q_{\mathrm{HV}}}$$

Max. Work from an ICE & Efficiency

- Thermal combustion efficiency is given by:

$$\eta_t = \frac{W_c}{H_R(T_A) - H_P(T_A)}$$

- The fuel conversion, thermal conversion, and combustion efficiencies are related by:

$$\eta_f = \eta_c \times \eta_t$$

End of Lecture 8