Quiz 2
ChE Thermodynamics
January 19, 2017

The largest diesel engine in the world is built by a Swedish firm for ships at the Aioi Works of Japan with a 1820 L displacement per cylinder and 14 cylinders (38 inch base and a 98 inch stroke). The engine uses 1,660 gallons of diesel per hour in the most efficient operation with an efficiency of 60% (80% of the maximum theoretical efficiency for a diesel engine).

Consider three of the stages for this two-cycle engine,

a) The compression cycle (isothermal at 75C) P goes from atmospheric to 20 bar,

b) Ignition (at constant volume), P goes from 20 bar to 100 bar, T_i = 75 C (ignore the combustion enthalpy),

c) The power stroke with Q = 0, V reversibly goes from 79L to 1820L. Use $T_i = T_{f \text{ from part b}}$; and $P_i = P_{f \text{ from part b}}$. P_f = 1 bar.

Calculate ΔU, ΔH, Q, and W_{EC} for these three stages using the ideal gas law and $C_p = 22.7R$.

d) A large diesel generator generally usually has an efficiency of about 35%. Why do you think this enormous engine has a higher efficiency? (Do think that size is related to efficiency?)

1 liter = 0.001 m^3. 1 atmosphere is 14.7 psi, 1.01 bar, 0.101 MPa, 760 mmHg, 29.9 inHg

Gas Constant, R

= 8.31447 J/mole-K = 8.31447 cm^3-MPa/mole-K = 8.31447 m^3-Pa/mole-K

= 8,314.47 cm^3-kPa/mole-K = 83.1447 cm^3-bar/mole-K = 1.9859 Btu/lbmole-R(see note 1)

= 82.057 cm^3-atm/mole-K = 1.9872 cal/mole-K(see note 2) = 10.731 ft^3-psia/lbmole-R

Process Type	Work Formula (ig)
Isothermal	$W_{EC} = -\int P dV = -RT\int \frac{dV}{V} = -RT\ln\frac{V_2}{V_1}$ (ig)
Isobaric	$W_{EC} = -\int P dV = -P(V_2 - V_1)$ (ig)
Adiabatic and reversible	$W_{EC} = -\int P dV = -\int \text{const}\frac{dV}{V^{(C_P/C_V)}}$ (*ig) or $\Delta U = C_V(T_2 - T_1) = W_{EC}$ (*ig) $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(R/C_P)} = \left(\frac{V_1}{V_2}\right)^{(R/C_V)}$ (*ig)

$\Delta H = \Delta U + \Delta(PV) = \Delta U + R(\Delta T)$ Exact for an ideal gas.

$C_P = C_V + R$ Exact for an ideal gas.

Answers Quiz 2
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COMPRESSION

a) Isothermal $T = 75C$

$p_i = 0.101$ MPa

$P_f = 2.0$ MPa

$\boxed{\Delta H = \Delta U = 0}$

$\boxed{-Q = W_{EC}} = -\int P\,dV = -RT \ln \frac{V_2}{V_1} = -RT \ln \frac{P_1}{P_2}$

$= -8.31 \frac{J}{mol°K}\ 348°K \ln\left(\frac{1}{20}\right)$

$= \boxed{8.66 \frac{kJ}{mol}}$

IGNITION

b) Constant Volume

$\boxed{W_{EC} = 0}$

$P_i = 20\text{ bar} = 2.0\text{ MPa} \quad T_i = 75C\ (348°K)$

$P_f = 100\text{ bar} = 10.0\text{ MPa}$

$T_f = T_i\left(\frac{P_f}{P_i}\right) = 348°K\,(5)$

$= 1,740\ °K$

$\boxed{\Delta H} = \int C_p\,dT = (22.7)\, 8.31 \frac{J}{mol°K}(1740-348)°K$

$\boxed{= 263 \frac{kJ}{mol}}$

$\boxed{Q} = \boxed{\Delta U} = \Delta H - R\Delta T = 263\ kJ/mol - 8.31 \frac{J}{mol°K}(1740-348)°K \frac{kJ}{1000J} = \boxed{251 \frac{kJ}{mol}}$

c) POWER STROKE

Adiabatic & Reversible $\boxed{Q=0}$

$V_i = 79$ Liter $V_f = 1820$ Liter

$T_i = 1740°K$ $T_f = ?$

$P_i = 100$ bar (10 MPa) $P_f = 1$ bar (0.1 MPa)

$$T_f = T_i \left(\frac{(PV)_f}{(PV)_i}\right)^{-1} = 1740 \left(\frac{7900}{1820} \frac{l\ bar}{l\ bar}\right)^{-1}$$

$= 400K$ (127 C)

$$\boxed{\Delta H =} \int_{T_i}^{T_f} C_p\, dT = (22.7)\ 8.31 \frac{J}{mole\,K} (400 - 1740)°K$$

$$\boxed{= -253 \frac{kJ}{mole}}$$

$\boxed{\Delta U} = \Delta H - \Delta(PV)$

$= -253 \frac{kJ}{mole} + \frac{608}{54.6} \frac{kJ}{mole}$

$$\boxed{= -242 \frac{kJ}{mole}}$$

$$\boxed{W_{EC} = -242 \frac{kJ}{mole} = \Delta U}$$

$\underline{\Delta PV} = 182\ l\,MPa - 790\ l\,MPa$

$= -608\ l\,MPa$

$= -608$ kJ

$$n = \frac{P_i V_i}{R T_i} = \frac{10\,MPa\ 79\,L\ \frac{m^3}{1000\,L}\ \frac{10^6 cm^3}{m^3}}{8.31 \frac{MPa\,cm^3}{mole}\ 1740\,K}$$

$= 54.6$ mole

d) Larger cylinders have a smaller surface area per volume

$$\frac{S}{V} = \frac{2}{R} + \frac{2}{H}$$

The temperature gradient is at the surface so smaller S/V means less thermal loss & higher efficiency.

Friction losses are smaller also due to less surface area per volume.

Combustion may be more efficient