ME410

Internal Combustion Engines

Fall 2002

Test 2

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Name_____

Box_____

Grade_____

Instructions

1. Closed text, notes, and neighbor.
2. Partial credit will be given as merited if you show your work.
3. If you are not sure what is being asked, be sure and check with me.
4. Refer as needed to the reference page attached.

1. A small laboratory test engine is supplied with propane fuel (C_3H_8) at a rate of 1.8 x 10^{-3} kg/sec. The fuel air equivalence ratio, ϕ, is 0.75.

   a) Calculate the air flow rate in kg/sec.

a_s=3+8/4=5. $$\frac{F}{A} = \frac{3(12)+8(1)}{\left(\frac{5}{0.75}\right)(2(16)+3.773\cdot 2(14))} = 0.04804$$

$$\dot{m}_a = \dot{m}_f / \frac{F}{A} = \frac{0.0018}{0.04804} = 0.0375 \text{ kg/s}$$

   b) Write and balance the chemical equation describing the combustion process.

$$C_3H_8 + \left(\frac{5}{0.75}\right)(O_2 + 3.773N_2) = bCO_2 + cH_2O + dO_2 + eN_2$$

carbon:	$3 = b$	Solving: b=3, c= 4
hydrogen:	$8 = 2c$	d=1.667
oxygen:	$\left(\frac{5}{0.75}\right)2 = 2b + c + 2d$	e=25.15
nitrogen:	$\left(\frac{5}{0.75}\right)2(3.773) = 2e$	$n_T = 3 + 4 + 1.667 + 25.15 = 33.82$

   c) Calculate the mole fractions of each of the gases making up the exhaust.

$$y_{CO_2} = \frac{3}{33.82} = 0.0887 \qquad y_{H_2O} = \frac{4}{33.82} = 0.1183$$

$$y_{O_2} = \frac{1.667}{33.82} = 0.0493 \qquad y_{N_2} = \frac{25.15}{33.82} = 0.7437$$

   d) If we set ϕ = 1.2, describe how this problem would be different and how you would solve it.

- The products would now be CO_2, CO, H_2, H_2O and N_2. No O_2.
- Balancing C, H, O, and N as above would give 4 equations.
- The fifth equation necessary to solve would be a chemical equilibrium equation associated with the reaction,

$$CO_2 + H_2 = CO + H_2O\,.$$

- You would be given the equilibrium constant at the temperature of interest, K_p. Let the number of moles of a substance be n. Then the final equation would be

$$K_p = \frac{n_{CO}n_{H_2O}}{n_{CO_2}n_{H_2}}$$

2. This is a continuation of the previous problem. The heating value of the fuel is 46400 kJ/kg. The mechanical efficiency is 0.88, the fuel conversion efficiency (based on brake work/power) is 0.40, and the combustion efficiency is 0.96. We estimate that 35% of the energy entering the engine in the fuel is transferred to the cooling system. Calculate in kW

a) the brake power $\eta_f = \dfrac{P_b}{\dot{m}_f Q_{HV}}$

$$0.40 = \frac{P_b}{\left(1.8\times10^{-3}\,kg/s\right)\left(46400\,kJ/kg\right)} \qquad P_b = 0.4\left(83.52\,kJ/s\right) = 33.4\,kW$$

b) the friction power $\eta_m = \dfrac{P_b}{P_b + P_f}$ $\qquad 0.88 = \dfrac{33.4\,KW}{33.4\,Kw + P_f}$

$P_f = 4.56\,kW$

c) the indicated power

$$P_i = P_b + P_f = 33.4\,kW + 4.56\,kW = 38.0\,kW$$

d) the heat transfer

$$\dot{Q} = 0.35\dot{m}_f Q_{HV} = 0.35\left(83.52\,kW\right) = 29.2\,kW$$

e) the sensible power in the exhaust gas
First Law: (see diagram below).

$$0 = \dot{m}_f Q_{HV} - \dot{m}h_{exh} + \dot{Q} - (P_b + P_f)$$

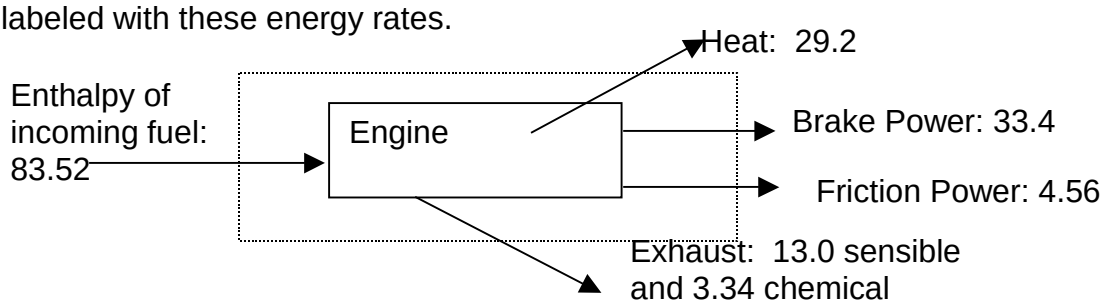
$$0 = 83.52\,kW - \dot{m}h_{exh} - 29.2\,kW - 38.0\,kW \qquad \dot{m}h_{exh} = 16.32\,kW$$

We subtract the chem energy below to get sensible 16.32-3.34=13.0 kW

f) the rate at which chemical energy leaves the engine in the exhaust gas

4% of incoming fuel energy is not converted. 0.04(83.52) = 3.34 kW

In the space below, draw a control volume containing the engine and labeled with these energy rates.



3. An upper estimate of the amount of NO formed in an engine is made by considering the equilibrium reaction

$$1/2\ N_2 + 1/2\ O_2 = NO$$

Calculate the mole fraction of NO at a temperature of 2500 K and 30 atmospheres. The reaction has $\log_{10}(K_p) = -1.2$ under these conditions. Assume that we started with a mixture containing 15 moles of nitrogen gas and 1 mole of oxygen gas at room temperature.

Start with: $15N_2 + O_2$ End up with: $n_{N_2}N_2 + n_{O_2}O_2 + xNO$

Nitrogen: $30 = 2n_{N_2} + x$ Oxygen: $2 = 2n_{O_2} + x$

solving: $n_{N_2} = \frac{30-x}{2}$ $n_{O_2} = \frac{2-x}{2}$

$n_T = x + \left(\frac{30-x}{2}\right) + \left(\frac{2-x}{2}\right) = 16$ $y_{CO} = \frac{x}{16}$ $y_{N_2} = \frac{30-x}{32}$ $n_{O_2} = \frac{2-x}{32}$

Now turning to equilibrium,

$$10^{-1.2} = \frac{p_{NO}}{(p_{N_2})^{0.5}(p_{O_2})^{0.5}} = \frac{\frac{x}{16}P}{\left(\frac{30-x}{32}\right)^{0.5}P^{0.5}\left(\frac{2-x}{32}\right)^{0.5}P^{0.5}}$$

P cancels. Now you solve for x, get x=0.229. Therefore y_{NO}=0.229/16=0.01431

4. Write a brief essay (1-2 paragraphs) on EITHER of the two following questons:
   - What software is at our disposal for calculating the composition of high temperature exhaust gas? What algorithm or process is implemented in this software?
   - Discuss the relationship of combustion theory (stoichiometry and equilibrium) to engine process modeling.

First essay:

We have several implementations of an algorithm for high temperature equilibrium of exhaust gases. The algorithm works like this. We balance mass for 4 elements: C,H,O, and N. A further set of equations is associated with chemical equilibrium among subsets of the exhaust gases including disassociated radicals. The chemical equilibrium constants for these reactions are calculated by curve fitting JANAF table data.

The software at our disposal which implements this technique consists of an EES file written by J Fine and posted at the website for the course, another implementation which can be gotten at the EES website, (fChart.com) and an applet at the CSU engine group website.

Second essay:

An accurate modeling of the working fluid must take into account its chemical composition. It is very dependent on fuel air equivalence ratio, as well as other engine operating parameters, such as residual fraction. Therefore we use both stoichiometry and equilibrium procedures (described above) to make the determination of the composition of the gas being processed at the various strokes.

We use the laws of mixtures, which needs to employ the mole fractions to find the properties of importance, such as enthalpy, internal energy, entropy and specific heats. Having this more accurate description of the fluid allows modeling to be done more accurately than just representing the working fluid as an ideal gas with a constant specific heat ratio.

Equations

Constant Volume Combustion: $Q = (\Delta U)_{V,T}$

Constant Pressure Combustion: $Q = (\Delta H)_{p,T}$

Combustion Efficiency: $\eta_c = \dfrac{H_R - H_P}{m_f Q_{HV}}$

Fuel Conversion Efficiency: $\eta_f = \dfrac{P}{\dot{m}_f Q_{HV}}$

or $\eta_f = \dfrac{\text{Work per cycle}}{\text{Chem Energy per cycle}} = \dfrac{W_c}{m_f Q_{LHV}}$ where W_c is either brake or indicated.

Second Law Efficiency:

$$\eta_a = \frac{\text{Work per cycle}}{\text{Max Possible Work per cycle}} = \frac{W_c}{W_{c,max}} = \frac{W_c}{m_f a}$$

Thermal Conversion Efficiency $\eta_t = \dfrac{W_c}{\eta_c m_f Q_{LHV}}$

Equilibrium Constant $\ln(K_p) = -\dfrac{\Delta G^0}{RT}$

Equilibrium Constant $K_p = \prod_{\text{all } \upsilon} \left(\dfrac{p_i}{p_0} \right)^{\upsilon_i}$