

ME 18b, HW 7

Due Tuesday June 2, 2009 (accepted until 4 pm)

Note: This homework is due on a Tuesday not a Thursday

TAs for HW #7:

Dan Alvarez, Sunday 8-10 pm, SFL 229;

Mary Dorman, Monday 7-9 pm, SFL 331

Number of classes attended: _____

Hours spent on homework: _____

1. **Fuels and Combustion Processes** A sample of pine bark has the following ultimate analysis on a dry basis, percent by mass: 5.6% H, 53.4% C, 0.1% S, 0.1% N, 37.9% O and 2.9% ash. This bark will be used as a fuel by burning it with 100% theoretical air in a furnace. Determine the air-fuel ratio on a mass basis.

Solution:

Converting the Bark Analysis from a mass basis to a molar basis:

Substance	S	H ₂	C	O ₂	N ₂
c/M	0.1/32	5.6/2	53.4/12	37.9/32	0.1/28
kmol/100 kg fuel	0.003	2.80	4.45	1.184	0.004
Product	SO ₂	H ₂ O	CO ₂		
O ₂ required	0.003	1.40	4.45	--	--

Combustion requires: $0.003 + 1.40 + 4.45 = 5.853$ kmol O₂. The bark has 1.184 kmol O₂ so the net required from the air is: 4.669 kmol O₂ per 100 kg of bark.

AF = $4.669(4.76)(28.97)/100 = \mathbf{6.44}$ kg air/kg bark

2. Enthalpy of Combustion: On many weekends Ashley Force Hood drives her car for just 4.5 seconds. In her car, the engine turns at 8000 rpm and has a displacement of 500 in³ and a compression ratio of 7.5. Because she likes a lot of power, she has a supercharger on the engine that raises the intake pressure on the cylinders to 5 atm. She prefers to burn nitromethane in the car claiming it provides more power than gasoline even though the enthalpy of combustion for nitromethane is about -10.5 MJ/kg while that of gasoline is about -44.5 MJ/kg. Find out why nitro gives more power than gasoline in this application by computing the following:

The mass flow rate of air for the engine in kg/sec

The theoretical air/fuel ratio for both nitromethane and gasoline.

The mass of fuel burned on just one short weekend drive for both nitro and gasoline.

The amount of power produced by the engine assuming 30% of the heat gets used as work for both nitro and gasoline. You should give your answer in both MW and horsepower to give you a physical sense of scale.

So what do you think of Ashley's car?

Solution:

Mass flow rate of air: $V_{\max} - V_{\min} = 500 \text{ in}^3$ and $V_{\max}/V_{\min} = 7.5$, so $V_{\max} = 577 \text{ in}^3$.

4-stroke engine draws air in on every other cycle so the volumetric air flow rate is:

$$V_{\text{air}} = 0.5(8000\text{rpm})(500 \text{ in}^3)/(60 \text{ sec/min})/(61,024 \text{ in}^3/\text{m}^3) = 0.55 \text{ m}^3/\text{sec at 500 kPa.}$$

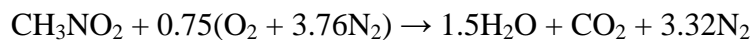
To find the mass flow rate, need to find the temperature of the air entering the engine after the supercharger, assuming isentropic compression:

$$T_2 = T_1(P_2/P_1)^{(k-1)/k} = 298(5)^{0.4/1.4} = 472\text{K or } 199^\circ\text{C}$$

Ideal gas law gives specific volume: $v = RT_2/P_2 = 0.287(472\text{K})/(500 \text{ kPa}) = 0.27 \text{ m}^3/\text{kg}$

The air mass flow rate is: $m_{\text{air}} = V_{\text{air}}/v = (0.55 \text{ m}^3/\text{sec})/(0.27 \text{ m}^3/\text{kg})$, **$m_{\text{air}} = 2.02 \text{ kg/sec}$**

Combustion reaction is:



Air Fuel Ratio: $AF = 3.57 \text{ mol Air/mol Fuel}$. MW of nitromethane = 61 kg/mol

$$AF = 3.56(28.97)/61 = \mathbf{1.7 \text{ kg Air/kg Fuel (nitromethane)}}$$

for gasoline the air fuel ratio is: **14.6 kg Air/kg Fuel gasoline**

Amount of fuel burned in 4.5 sec:

$$m_{\text{nitro}} = (4.5 \text{ sec})(2.02 \text{ kg air/sec})/(1.7 \text{ kg Air/kg Fuel}); \quad m_{\text{nitro}} = \mathbf{5.4 \text{ kg}}$$

$$m_{\text{gasoline}} = (4.5 \text{ sec})(2.02 \text{ kg air/sec})/(14.6 \text{ kg Air/kg Fuel}); \quad m_{\text{gasoline}} = \mathbf{0.62 \text{ kg}}$$

Amount of Power Produced by the engine:

$$P = \eta(m_{\text{fuel}})(h_{\text{fuel}})$$

$$P_{\text{nitro}} = 0.30(2.02/1.7)(10.5 \text{ MJ/kg}) = \mathbf{3.7 \text{ MW or 5000 horsepower}}$$

$$P_{\text{gasoline}} = 0.30(2.02/14.6)(44.5 \text{ MJ/kg}) = \mathbf{1.8 \text{ MW or 2500 horsepower}}$$

where: 1 MW = 1340 horsepower

By the way, the compressor work by the supercharger is about 550 horsepower.

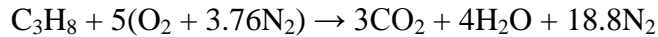
Ashley's car:



- 3. A real life application:** A few months ago, a custom built furnace was made to test a prototype Venus Lander thermal protection system. The furnace operated at 465°C. The heat source was provided by a propane burner. The air flow into the furnace was at 8 m³/min. The average fuel flow rate was 62 standard liters per minute (nominally at 25°C and 1 atm pressure). Determine the excess air in the combustion process and the molar fractions of the products. What is the heat loss from the combustion products by the time they reach the furnace? The following page shows a schematic diagram and photo of the test set up.

Solution:

Combustion of propane is given by:



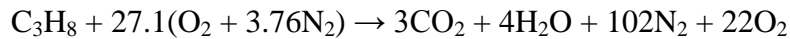
The theoretical Air-Fuel ratio for propane is 23.8 mol air/mol fuel. The actual Air-Fuel ratio is:

$$\text{AF} = 8 \text{ m}^3 \text{ air} / 0.062 \text{ m}^3 \text{ fuel} = 129 \text{ mol air/mol fuel}$$

The excess air is: $(129 - 23.8)/23.8 = \mathbf{442\%}$

100% theoretical air = 0% excess air, so we have 542% theoretical air in this process.

which means the combustion reaction can be written as:



The total moles of products are: $3 + 4 + 102 + 22 = 131$

The molar fractions are then given by:

$$\text{CO}_2 = 3/131 = \mathbf{2.2\%}$$

$$\text{H}_2\text{O} = 4/131 = \mathbf{3.0\%}$$

$$\text{O}_2 = 22/131 = \mathbf{16.8\%}$$

$$\text{N}_2 = 102/131 = \mathbf{77.9\%}$$

Energy Balance: $Q_{\text{in}} = \Delta h_p + Q_{\text{loss}}$

Q_{in} = enthalpy of combustion of propane = 46,350 kJ/kg

using CATT3 Table for ideal gases or Table A.9 from text at 465°C:

$$\Delta h_p = 3(19,660 \text{ kJ/kmol}) + 4(15,630 \text{ kJ/kmol}) + 102(13,120 \text{ kJ/kmol}) + 22(13,760 \text{ kJ/kmol})$$

$$\Delta h_p = (1,760,000 \text{ kJ/kmol})/44 \text{ kg/kmol} = 40,000 \text{ kJ/kg fuel}$$

$$Q_{\text{loss}} = 46,350 - 40,000; \mathbf{Q_{\text{loss}} = 6350 \text{ kJ/kg fuel}}$$