2.61 Internal Combustion Engine
Quiz 3/11/14 — Open book

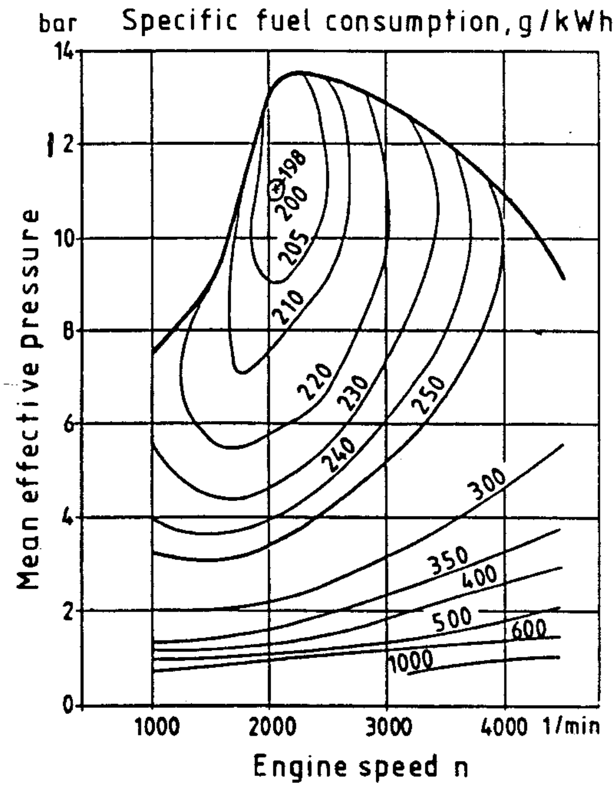
Problem 1 (10 points)

The engine map for a passenger car is shown in the accompanying figure. (It is the Audi 5 cylinder diesel engine.) The vehicle specifications are:

Vehicle weight with passengers= 1500 kg
Frontal width x height = 1.8m x 1.5 m
Gear ratios:

| | |
|---|---|
| 1st | 3.60 |
| 2nd | 1.88 |
| 3rd | 1.19 |
| 4th | 0.84 |
| 5th | 0.64 |
| Final drive | 3.89 |

Tire is P205/55R16; tire diameter = 0.63 m.
Drag coefficient is 0.3
Ambient air density is 1.2 kg/$m^3$
The coefficient of rolling friction is 0.015
The drive system transmission efficiency is 0.85.




Engine map of Audi 2.5L turbo-charged direct injection diesel engine; the MEP is brake value.

Other useful numbers:
Density of diesel fuel = $0.8 \times 10^3$ kg/$m^3$; heating value = 43 MJ/kg
1 gallon = 3.785 L

Consider vehicle operation on a level road.

1. The vehicle is cruising at 35 mph (15.7 m/s) at 5th gear. What are the brake mean effective pressure (BMEP) and engine speed?
2. What are the specific fuel consumption in g/kW-hr, and gas mileage in mpg?
3. The gas pedal is floored without change of gear. What is the vehicle acceleration?

Extra credit:

4. If the gear is first shifted from 5th to 3rd gear and then the gas pedal is floored, what is the vehicle acceleration?

Problem 2 (10 points)

In coal rich countries such as China, one fuel option is to convert the coal to Dimethyl Ether ($CH_3OCH_3$) as a transportation fuel. We are to evaluate the energetic (i.e. the energy balance) of this process.

To simplify the analysis, coal will be treated as solid carbon.

**Useful numbers**

DME MW = 46

Heat of formation

| | $\Delta\tilde{h}_f^0$ (MJ/kmol) |
|---|---|
| C (solid) | 0 |
| $CO_2$ (gas) | -393.5 |
| CO (gas) | -110.5 |
| $H_2O$ (gas) | -241,8 |
| $H_2O$ (liquid) | -285.8 |
| DME (gas) | -184.1 |

Equilibrium constant at 800K

| | Log10 ($k_p$) |
|---|---|
| $H_2$ | 0 |
| $CO_2$ | 25.830 |
| CO | 11.914 |
| $H_2O$ | 13.289 |

(a) The first step in coal to DME conversion is to convert the coal to syngas. Oxygen is used to oxidize coal under fuel rich environment so that the product (syngas) is only CO. How much energy is released per kilo mole of coal as represented by solid C?

(b) Production of DME needs both CO and $H_2$. The feed gas should have equal number of moles of CO and $H_2$. The $H_2$ is obtained by steam reforming the CO using a catalyst. The steam will react with the CO in the feed stream to form $CO_2$ and $H_2$. Thus the ideal overall reaction is as follows — input is water ($H_2O$ liquid) and the CO from the rich oxidation of coal; output is CO2 and $H_2$. The reaction is represented by:

$$H_2O\text{ (liq.)} + CO \rightarrow H_2 + CO_2$$

What is the energy released in this step at standard condition (1 atmosphere and 298K) per kmol of CO?

(c) In practice, not all the CO is steam-reformed to hydrogen and $CO_2$. The output stream is a mixture of $H_2O$, CO, $CO_2$ and $H_2$. If the feed stream has one mole each of $H_2O$ and CO, and the output is driven to equilibrium by the catalyst at a temperature of 800K. The equilibrium is represented by

$$H_2O + CO \leftrightarrow H_2 + CO_2$$

What is the composition of the output stream (i.e. how many moles of $H_2O$, CO, $CO_2$ and $H_2$ respectively) are made from 1 mole each of H2O and CO in the feed stream? The equilibrium constant informations are given in the accompanied table

(d) How much energy is released at stand condition (1 atmosphere and 298K) per mole of CO in the feed stream in process (c)?

(e) The final step is to convert the CO and $H_2$ to DME ($C_2H_6O$) via

$$3CO + 3H_2 \rightarrow C_2H_6O + CO_2$$

How much energy is released at standard condition per kmol of DME in this step?

Extra credit:

(f) How much energy is released per kmol of DME in the overall process if the path described in (c) is taken?