2.61 Internal Combustion Engine
Quiz 3/16/2017 — Open book

Problem 1 (10 points)

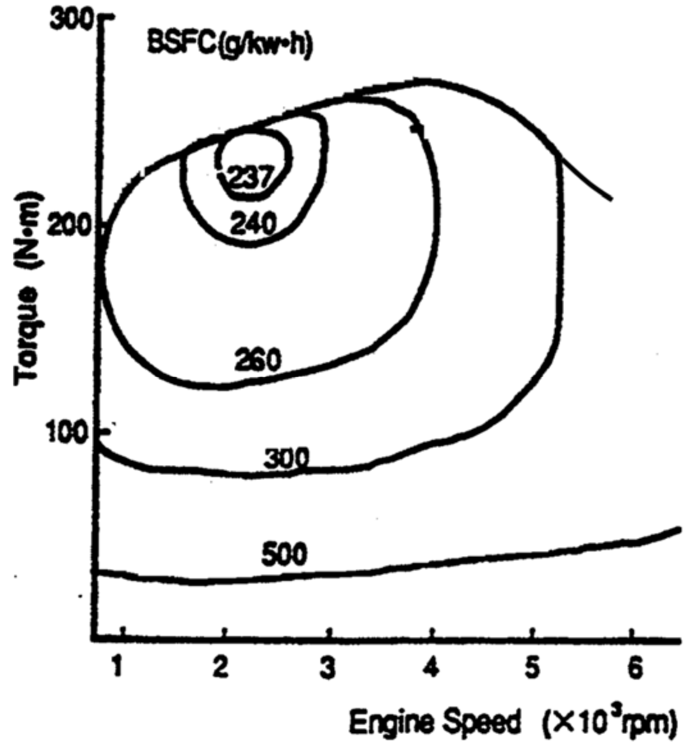
The engine map for a passenger car is shown in the accompanying figure. (It is the Toyota 3 liter, 6-cylinder SI engine for the Camry vehicle.) The vehicle specifications are:

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

The overall gear ratio is the product of the gear ratio and the final drive ratio.

Tire is P205/55R16; tire diameter = 0.63 m.
Drag coefficient of the vehicle 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 Toyota 1MZ-FE 3 liter-6 cylinder engine. The engine is for the Camry vehicle.

Other useful numbers:
Density of gasoline fuel = 0.78x10^3 kg/m^3; heating value = 44 MJ/kg; 1 gallon = 3.785 L

Consider vehicle operation on a level road cruising at 65 mph (29.1 m/s) at 5th gear.

1. What are the engine speed and brake mean effective pressure (BMEP)?
2. Locate the operating point on the engine map. What are the specific fuel consumption in g/kW-hr, and gas mileage in miles per gallon?
3. Cylinder deactivation technology is applied to dynamically reconfigure the engine from a 6-cylinder/ 3 liter to a 3-cylinder/1.5L one under this cruise condition. Assuming the engine BMEP map is the same for the new engine configuration, what are the specific fuel consumption (g/kW-hr) and gas mileage (mpg)? (In practice, the friction of the 3-cylinder engine will be higher because the 3 activated cylinders have to drive the 3 deactivated cylinders.)
4. Explain where the gain in efficiency comes from.

Problem 2 (10 points)

There are a lot of "stranded" natural gas; i.e. natural gas in areas where delivery of the gas to the market is not feasible. For example, in oil fields in remote areas, natural gas is discovered together with the oil. The gas is difficult to be transported because of its low density (compared to a liquid fuel) so that the gas is either flare off or pumped back into the ground. A solution to utilize this natural gas is to convert it to methanol, a liquid, which can then be readily transported.

The first step in the conversion process is to produce synthesis gas (a mixture of CO and H_2) from which methanol can be synthesized. The process is exothermic. A proposed scheme is to use an internal combustion engine to process the gas under fuel rich condition to produce the synthesis gas. Then the mechanical energy extracted by the engine is used to run the conversion plant.

The engine is to be run at significantly fuel rich condition ($\lambda<1$). The exhaust is a mixture of CO, CO_2, H_2, H_2O and N_2. The species composition corresponds to the equilibrium composition of the water gas shift reaction at 1900K. (This temperature is higher than the conventional value at 1740K because of the very rich condition.) The water gas shift reaction is $H_2 + CO_2 \rightleftarrows CO + H_2O$

The measured CO to CO2 molar ratio is 3:1 in the exhaust. To simplify the analysis, the natural gas is assumed to be pure methane (CH_4). The heat of formations and equilibrium constants for the individual species are shown in the accompanying table.

Species	$\Delta\tilde{h}_f^0$ **(MJ/kmol)**	$\mathbf{Log_{10}K_p}$ **@1900K**
CH_4	-74.9	-3.281
CO_2 (gas)	-393.5	10.898
CO (gas)	-110.5	7.631
H_2O (gas)	-241,8	3.886
H_2 (gas)	0	0
N_2 (gas)	0	0

(a) What is the equilibrium constant at 1900K for the water gas shift reaction?

(b) For each mole of CH_4, how many moles each of CO, CO_2, H_2 and H_2O are produced in the exhaust? (Hint: the exhaust gas is frozen with the thermal equilibrium composition at 1900K)

(c) What is the air equivalence ratio (λ)?

(d) What is the heat of reaction (i.e. energy released in converting the reactants to products at 298K and 1 atmosphere, with the H_2O in vapor state) per kmol of CH_4 consumed?

(e) The lower heating value for CH_4 is 50MJ/kg. What is the combustion efficiency of the engine?

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