2.61 Internal Combustion Engine

Final Examination
9:00 – 12:00, Tuesday, May 20, 2014, Room 3-370

Open book

Note that Problems 1-3 carry 10 points each, and Problem 4 carries 20 points.

Problem 1 (10 points)

Ethanol has been introduced as the bio-fuel entry to the transportation fuel market. We are to assess the charge cooling effect when ethanol is used in a 4-stroke direct injection spark ignition engine. Because of cold start consideration, E85 (which is 85% ethanol to 15% gasoline by volume) is used in practice. To simplify the problem, however, we'll compare the use of neat ethanol (i.e. E100) to gasoline (E0) in the engine.

The gasoline has hydrogen to carbon ratio of 1.85, with an averaged molecular weight of 110, and latent heat of vaporization of 305 kJ/kg.

Ethanol is C_2H_5OH, with a molecular weight of 46 and latent heat of vaporization of 840 kJ/kg.

For both engines, injection takes place during the intake stroke. To simplify the problem, assume that at IVC, all the fuel has evaporated and mixed with air to form a homogeneous trapped charge, and the engine speed is sufficiently low so that the cylinder pressure at IVC is equal to MAP. Furthermore:

- for the E0 engine, 30% of the liquid fuel lands on the wall and then evaporates (so that the latent heat is supplied by the wall), and 70% of the fuel evaporates in flight;
- for the E100 engine, 50% of the liquid lands on the wall and then evaporates (so that the latent heat is supplied by the wall), and 50% of the fuel evaporates in flight.

a) Using the ideal gas law, derive an expression for the trapped mass of air m_a per cycle as a function of MAP, temperature T of the trapped charge, volume at intake-valve-closing, V_{IVC}, A/F ratio, molecular weights and any other necessary quantities. You should show via the expression, the fuel vapor displacement effect, and the charge temperature effect on m_a.

b) To assess the displacement effect only: if the trapped charge temperature were the same, what would be the ratio of m_a for the engine using E100 and using E0?

c) The trapped charge temperature T will be different with the two fuels. What are the temperature drops, ΔT, for using the two fuels due to evaporative cooling? In this calculation, since the mass of fuel is small compared to that of the air, you may assume that the fuel does not contribute significantly to the sensible energy of the charge except for the latent heat of vaporization. The specific heat at constant pressure for the air is 10^3 J/kg-K

d) If the temperature of the charge without accounting for the evaporative cooling (i.e. the ΔT in part c) is 40^oC (313K), what is the ratio of m_a for using the two fuels when both the fuel vapor displacement and the charge cooling effects are accounted for?

e) If the end gas for both fuels follows a polytropic efficiency n=1.32 (i.e. pV^n=constant), what are the end gas temperatures for using the two fuels when the MAP is 1 bar and the end gas pressure is at 80 bar?

When E100 is used, the lower trapped charge temperature contributes to a better volumetric efficiency. The lower end gas temperature contributes to a better knock margin and lower NOx production.

Problem 2 (10 points)

In many of the severe knock occurrences, there is substantial damage to the top land of the piston because the knock-induced shock wave in the combustion chamber enters the top land crevice and detonates the fuel air mixture there; see picture.

(i) Explain why detonating the top land crevice gas would produce more damage than detonating the combustion chamber mixture?

(ii) For a typical piston top land crevice geometry (land height = 6mm; piston/liner clearance = 150 μm), and wall temperature of 500K, if the pressure of the crevice gas is 40 bar just prior to the detonation, estimate the crevice pressure induced by the detonation for an engine operating at λ =1 and with negligible residual gas. The crevice gas (both burned and unburned) may be modelled as an ideal gas with γ = 1.32 and molecular weight of 29.

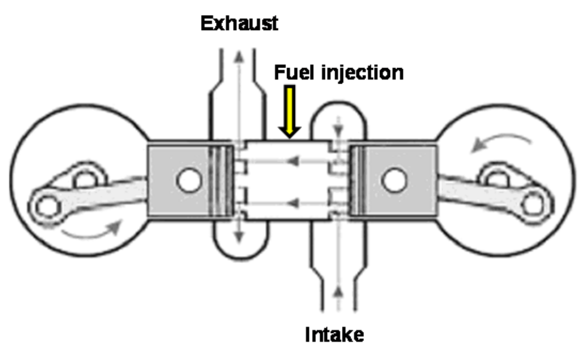
Problem 3 (10 points)

Two stroke opposed piston engines (see figures) have recently become popular as a means of achieving high power density and fuel conversion efficiency; for example, see following websites:

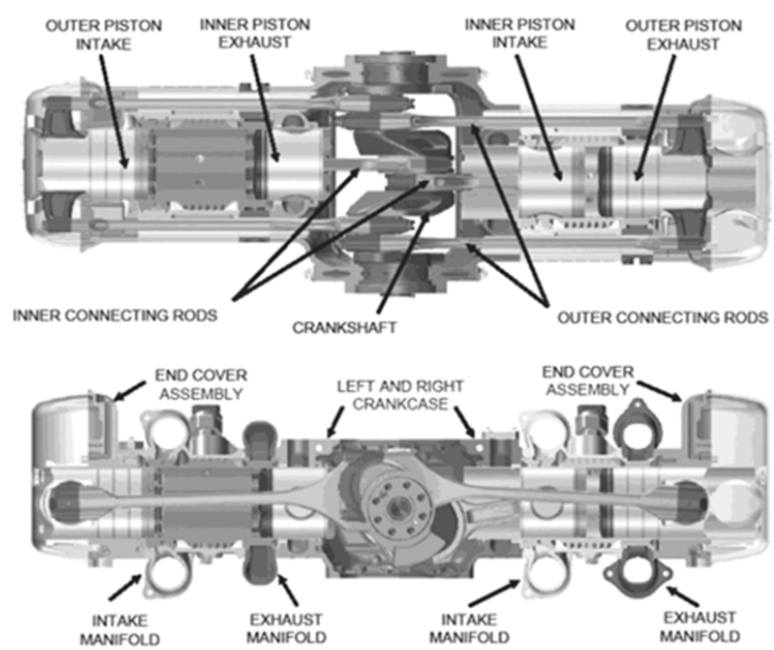
http://www.achatespower.com/
http://ecomotors.com/

Make five technical comparisons of this type of engine with the standard 4-stroke engines. The outcome of each can either be positive or negative.

Would you invest money in these engines?



Schematic of two-stroke opposed piston engine



Implementation of two-stroke opposed piston engine (Ecomotor)

Problem 4 (20 points)

Downsizing of the engine displacement is an effective way to improve fuel conversion efficiency. The loss in torque of the smaller size engine is recouped by turbo- or super-charging the engine. You are to assess the effects of this strategy.

Consider **engine A**: a 4-cylinder 2L displacement 4-stroke SI engine with a bore of 86 mm (bore-to-stroke ratio of 1). The peak torque of 175 N-m occurs at 2500 rpm. This is to be downsized to a turbo-charged 4 cylinder **engine B** with 1.2 L displacement but with the same torque output at 2500 rpm. The bore –to-stroke ratio of engine B is also 1. You are to calculate the changes in engine parameters.

At peak torque, engine A has manifold absolute pressure (MAP) of 1 bar and temperature at the intake manifold equal to 310^{o} K.

At the peak torque point:

(a) What are the BMEP values for these two engines?

(b) Assume that the turbo-charged engine B operates with an intercooler so that the temperature at the manifold is the same as engine A, what is the pressure ratio of the compressor? Both engines have the same volumetric efficiency with referenced to manifold density.

(c) What is the ratio of the total heat transfer per cycle of engine B to engine A?

(d) What is the ratio of the total piston (ring pack plus skirt) friction work transfer per cycle of engine B to engine A? You can assume that the frictional coefficient is proportional to the square root of the Sommerfeld number, the ring pack geometry, including the piston rings, scales as the piston bore, and the bore to stroke ratios of both engines are 1.

(e) Assume that for engine A at the peak torque point, 22% of the fuel energy goes to heat loss and 3.5% of the fuel energy goes to piston friction. Based on (c) and (d) only, what is the improvement in fuel conversion efficiency of engine B relative to engine A at the same operating point (we are neglecting the change in pumping, which is small at peak torque, and change in any other work transfer)? (Note: you only need to calculate the change, $\Delta\eta_f$, and not the efficiency values.)

Now consider the part load point: torque = 50 N-m at 2500 rpm. For the turbo-charged engine B, the intake is throttled and the engine exhaust pressure is approximately atmospheric.

(f) What are the BMEP values for these two engines?

(g) What is the ratio of the manifold absolute pressure (MAP) for engines A and B? (Assume that the intake air temperatures are the same.)

(h) Engine A operates at 0.35 bar MAP and an atmospheric exhaust pressure, what is the pumping work per cycle for each engine?

Obtain the following ratios for values of engine B to engine A at this part load point:

(i) What is the ratio of the total heat transfer per cycle of engine B to engine A?

(j) What is the ratio of the total piston (ring pack plus skirt) friction work transfer per cycle of engine B to engine A?

(k) Assume that for engine A at this part-load point, 28% of the fuel energy goes to heat loss, 6.5% of the fuel energy goes to piston friction, and 4% of the fuel energy goes into pumping loss. Based on (h), (i) and (j), what is the improvement in fuel conversion efficiency for engine B relative to engine A? (Note: you only need to calculate the change, $\Delta\eta_f$, and not the efficiency values.)