2.61 Internal Combustion Engine
Quiz 3/19/2013 12:30 – 2:30 pm— Open book

Problem 1

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 $H_2 + CO_2 \rightleftarrows CO + H_2O$

To simplify the analysis, the natural gas is assumed to be pure methane (CH_4). The heat of formation and equilibrium constant for the individual species are:

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

The measured CO to CO2 molar ratio is 3:1 in the exhaust.

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

(b) For each mole of CH_4, how many moles of CO, CO_2, H_2 and H_2O are produced in the exhaust?

(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?

Problem 2

Car manufacturers often reintroduce classic cars in a more environmentally friendly package. The Dodge Viper (see attached) is one of the plausibility. A proposed plan is to re-issue the car with the capability of de-activating 8 of the 10 cylinders at light cruise condition. In this design, the deactivated cylinders have both the intake and exhaust valves closed for the whole cycle so that pumping loss in these cylinders is minimal (just due to heat loss and leakage). We are going to ignore these losses in the following simplified analysis.

The specifications given in the attached are mostly in US units. To convert to metric units:
1 lb = 0.454 kg; 1 inch = 2.54×10^{-2} m.

We are going to compare the 10-cylinder and the 2-cylinder engine at 40 mph (17.88 m/s) on a level road.

Rolling frictional coefficient = 0.012
Drag coefficient = 0.3; density of ambient air = 1.15 kg/m^3
Use the height and width of the car for calculating the frontal area.
For the P335/35ZR-17 tire:
rim diameter (d) = 17"; tire height (h) = 335 mm x 35%; tire diameter is d+2h = 0.6663 m.

Note that the overall drive ratio is the gear ratio x final drive ratio. The vehicle is operating in the 6th gear. The engine is operating at $\lambda = 1$.

(a) What is the engine brake power output (assume a transmission efficiency η_T of 0.8)?

First consider the 10 cylinder engine.

(b) What is the BMEP value?

(c) The engine is operating at manifold absolute pressure and temperature of 0.2 bar and 300K. The volumetric efficiency η_v based on manifold condition is 1 (i.e. the trapped air mass is equal to the manifold air density times the displacement). What is the fuel mass burned by the engine per cycle (to be precise, the fuel mass per cycle per cylinder multiplied by the number of cylinders)?

(d) What is the brake fuel conversion efficiency (η_b)?

(e) The BMEP comprises the following:

$$BMEP = GIMEP - PMEP - FAMEP$$

Where PMEP, the pumping mean effective pressure, reflects the loss due to throttling; FAMEP is the mean effective pressure due to rubbing friction and accessories. If the gross indicated fuel conversion efficiency $\eta_{i,g}$ is 38%, what is the value of FAMEP?

Now we look at the 2-cylinder engine. The FAMEP value of the 2-cylinder engine may be taken as 5 times that of the 10-cylinder engine, since the 2 cylinders have to drive all the rubbing friction and accessories. The gross indicated efficiency remains at 38%?

(f) What is the value of BMEP?

(g) What is the manifold absolute pressure (MAP)?

(h) What is the brake fuel conversion efficiency?

(i) You'll find that the answer to (h) is significantly larger than that to (d). Where is the gain?

Vehicle type: front-engine, rear-wheel-drive, 2-passenger, 2-door roadster

Estimated price as tested: $54,640

Estimated price and option breakdown: base Dodge Viper RT/10 (includes $1700 gas-guzzler tax, $700 freight, and $2240 luxury tax), $54,640

Major standard accessories: power steering, tilt steering

Sound system: Chrysler/Alpine AM/FM-stereo radio/cassette, 6 speakers

ENGINE

Type .... V-10, aluminum block and heads
Bore x stroke .... 4.00 x 3.88 in, 101.6 x 98.6mm
Displacement .... 488 cu in, 7990cc
Compression ratio 9.1:1
Engine-control system .... Chrysler with port fuel injection
Emissions controls .... 3-way catalytic converter, feedback fuel-air-ratio control
Valve gear .... pushrods, hydraulic lifters
Power (SAE net) .... 400 bhp @ 4600 rpm
Torque (SAE net) .... 450 lb-ft @ 3600 rpm
Redline .... 6000 rpm

DRIVETRAIN

Transmission 6-speed
Final-drive ratio .... 3.07:1, limited slip

Gear	Ratio	Mph/1000 rpm	Max. test speed
I	2.66	9.2	55 mph (6000 rpm)
II	1.78	13.8	83 mph (6000 rpm)
III	1.30	18.9	113 mph (6000 rpm)
IV	1.00	24.5	147 mph (6000 rpm)
V	0.74	33.2	159 mph (4800 rpm)
VI	0.50	49.0	120 mph (2450 rpm)

DIMENSIONS AND CAPACITIES

Wheelbase .... 96.2 in
Track, F/R .... 59.6/60.8 in
Length .... 175.1 in
Width .... 75.7 in
Height .... 44.0 in
Curb weight .... 3450 lb
Weight distribution, F/R 50/50%
Fuel capacity .... 22.0 gal
Oil capacity .... 11.0 qt
Water capacity .... 14.0 qt

CHASSIS/BODY

Type .... steel tubing frame integral with body
Body material .... fiberglass-reinforced plastic

INTERIOR

SAE volume, front seat .... 48 cu ft
luggage space .... 12 cu ft
Front seats .... bucket
Restraint systems .... door-mounted 3-point belts

SUSPENSION

F: .... ind, unequal-length control arms, coil springs, anti-roll bar
R: .... ind, unequal-length control arms with a toe-control link, coil springs, anti-roll bar

STEERING

Type .... rack-and-pinion, power-assisted
Turns lock-to-lock 2.4
Turning circle curb-to-curb .... 40.7 ft

BRAKES

F: .... 13.0 x 1.3-in vented disc
R: .... 13.0 x 0.9-in vented disc
Power assist .... vacuum

WHEELS AND TIRES

Wheel size .... F: 10.0 x 17 in, R: 13.0 x 17 in
Wheel type .... cast aluminum hub, spun aluminum rim
Tires .... Michelin XGT-Z, F: P275/40ZR-17, R: P335/35ZR-17
Test inflation pressures, F/R .... 35/35 psi