2.61 Internal Combustion Engines
Spring 2008

2.615 Internal Combustion Engine
Final Examination - Spring, 2008

Open book, 3 hour Exam

Problem 1 (20 points)

(i)   At engine operating temperature, automotive lubricants comprise long chain hydrocarbon molecules which are normally tangled up, but align themselves at high shear rates. Thus the viscosity decreases as the shear rate increases (shear- thinning). Explain why would this property help or hurt engine lubrication. (2 points)

(ii)   Experimentally, the frictional mean effective pressure (fmep) needed to overcome the valve train friction decreases with engine speed; e.g., see Fig. 13-24 of text. Explain this trend. (2 points)

(iii) Synthetic diesel fuel (e.g. made by the Fischer Tropsch process which was invented in war time Germany to derive liquid fuel from coal and wood) has a very high cetane number (CN~80 compared to the normal diesel fuel with CN in the high 40's). Give two comments on the impact of this high CN value on diesel engine design and operation. (2 points)

(iv)   An inventor proposed that a turbo-compound diesel engine be which uses an additional power turbine to extract mechanical energy out of the exhaust gas to the drive shaft. The novelty of the proposal was that much of the shaft power was to be derived from the power turbine instead of the engine. Give two comments on whether the concept is good or bad (each comment could either be positive or negative respectively). (2 points)

(v)   Give two reasons why retarding the spark timing at constant idle speed at cold start would make the catalyst to light-off faster. (2 points)

(vi)   Give two consequences from operating a SI engine on Miller cycle (i.e. with a configuration such that the compression ratio is less than the expansion ratio. (2 points)

(vii) Give two reasons why for a given maximum power output of a SI engine, turbo-charging would lead to better fuel economy. (2 points)

(viii) The US Army is interested in developing a diesel engine that does not use liquid coolant. The primary reason for such an engine is the elimination of the radiator which is vulnerable at combat. Give two detrimental effects to the engine operation if such a configuration is used. (2 points)

(ix)   Why would one pursue a cylinder-deactivation strategy, i.e. deactivate some of the cylinders in certain part of the engine map? (1 point). Do you want to keep the valves open or closed for the deactivated cylinders and why (1 point).

(x)   One way to lower NOx emissions in diesel engines is to add water to the fuel. Since water is not mixable with diesel fuel, it has to been emulsified by a surfactant. Explain how it works and why this arrangement is more effective than injecting water in the intake manifold (2 points).

Problem 2 (20 points)

There has been substantial interest in using fuel cells as power sources in automobiles. The only practical reactants for current fuel cell systems are hydrogen and oxygen. It is difficult to use hydrogen directly in a vehicle because of the problems of storage and refueling. A proposed concept is to use gasoline as the fuel on-board and make hydrogen out of it. See press release below.

The method is to partially oxidize the fuel to CO and H_2 first. Then the CO is reacted with the H_2O (which is one of the end products in the exhaust) by the Water-Gas shift reaction to form H_2 and CO_2. The H_2 is used in the fuel cell.

You are to analyze the energetics of the process (i.e., energy balance analysis only; ignoring all the irreversibility losses). You may represent the gasoline as iso-octane and assume ideal reactions, i.e. the partial oxidation only forms CO and H_2., and that all CO is converted to CO_2 and H_2 in the Water-Gas shift reaction.

(a) On the basis of the energetics of the reactions, what is the maximum energy conversion efficiency of such a system?

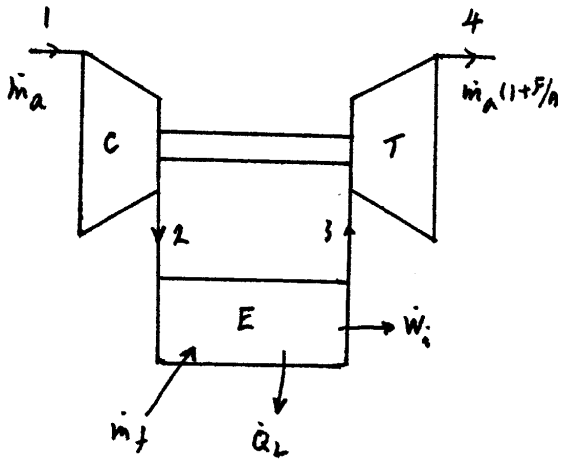(b) How would your answer change if the fuel is not iso-octane but ethanol? (What is the major difference?)

Problem 3 (20 points)

To examine the behavior of turbocharging, we shall consider the following example of a four stroke 2.0 L displacement passenger car diesel engine turbocharged with a single stage centrifugal compressor, and a single stage turbine. For simplicity, there is no waste-gate and no inter-cooler. You may assume the following:
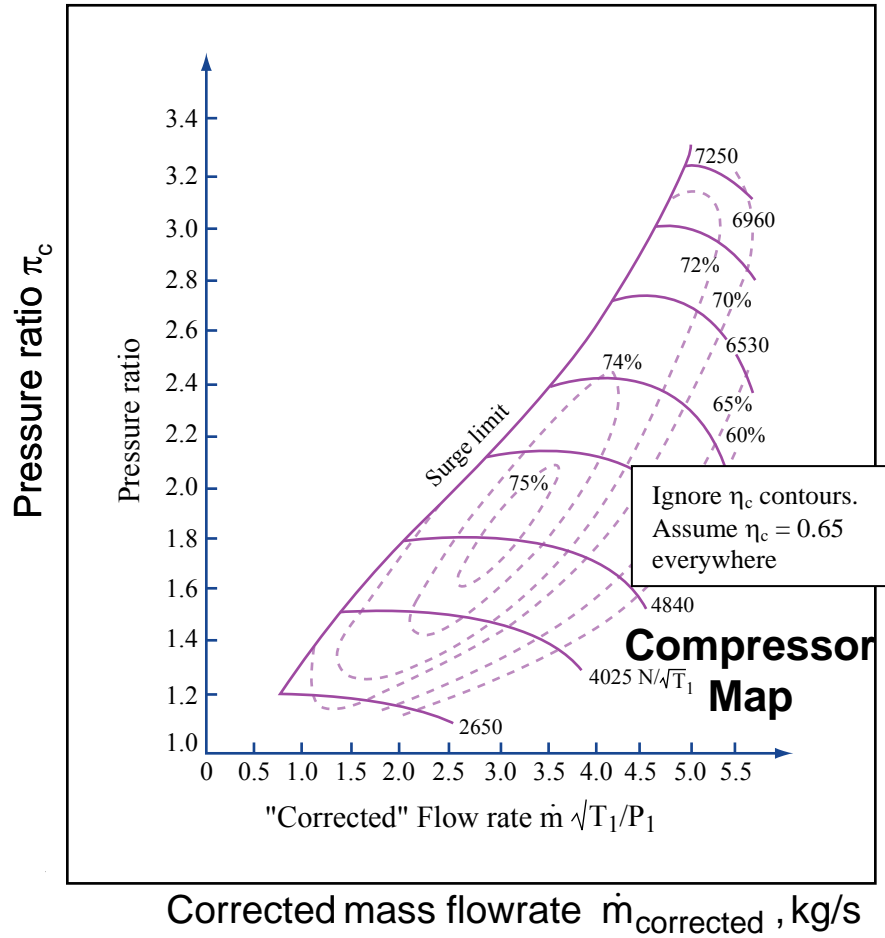
- The ambient conditions are $T_1=300K$ and $P_1=1$ bar. The working fluid may be assumed to have constant properties of $\gamma = 1.35$ and molecular weight of 29.
- The turbine and compressor have constant efficiencies: $\eta_t = 0.85$ and $\eta_c = 0.65$. You may also assume that the Mach no. is small so that the kinetic energy of the fluid is negligible.
- The compressor and turbine maps are shown in the accompanied figures. (For this simplified example, ignore the actual values of the η_c contours on the compressor map and assume η_c to be constant.)
- The reference conditions of these maps are the same as the ambient conditions: $T_{ref} = T_1$; $P_{ref} = P_1$.
- The engine volumetric efficiency based on the intake manifold condition is constant: $\eta_v = 0.8$.
- The heating value of the diesel fuel is 43 MJ/kg.
- Assume that 30% of the fuel energy is lost as heat transfer in the engine
- The engine indicated net fuel conversion efficiency is $\eta_f = 0.33$

We shall look at the engine operating at 3000 rpm with A/F ratio = 22, and compressor pressure ratio (π_c) of 1.5.

(a) What is the compressor outlet temperatures (T_2) at compressor pressure ratios $\pi_c = 1.5$?

(b) What is the engine intake air mass flow rate at this value of π_c?

(c) What is the compressor speed at this value of π_c?

(d) Draw on the compressor map the operating point corresponding to your answers of (b).

(e) What is the corresponding turbine inlet temperature?

(f) What is the turbine pressure ratio $(\pi_t)^{-1}$ that is required to power the compressor? (Assume that all mechanical losses are already incorporated into the definition of the compressor/turbine efficiencies.)

(g) The turbine and compressor run at the same speed. From the turbine map, using the result of (f), determine the mass flow rate required by the turbine to power the compressor.

(h) Put this point also on the compressor map; i.e. plot the mass flow rate required by the turbine versus the compressor pressure ratio π_c. Does this point match up to the point plotted in part (d)?
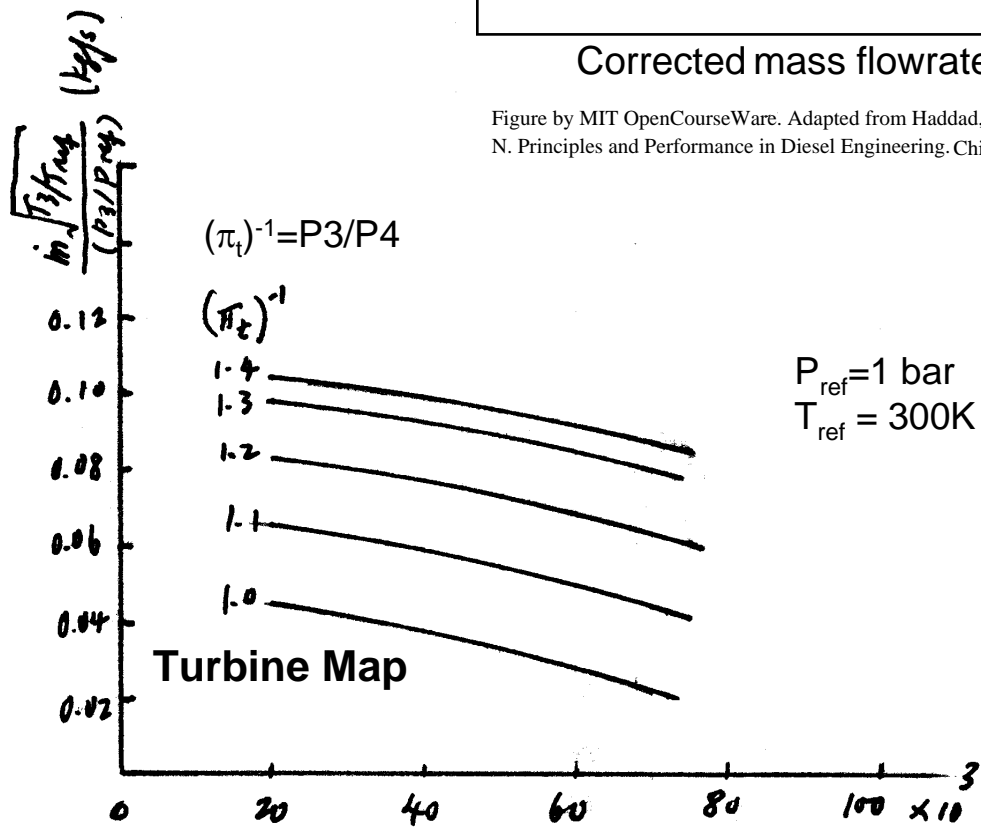
Simple turbo-charged diesel engine

$\dot{m}_a$

$\dot{m}_A(1+F/A)$

$\dot{W}_i$

$\dot{m}_f$

$\dot{Q}_L$

Compressor Map

Pressure ratio π_c

Pressure ratio

Surge limit

Ignore η_c contours. Assume $\eta_c = 0.65$ everywhere

7250
6960
72%
70%
6530
74%
65%
60%
75%
4840
4025 N/$\sqrt{T_1}$
2650

"Corrected" Flow rate $\dot{m}\sqrt{T_1}/P_1$

Corrected mass flowrate $\dot{m}_{corrected}$, kg/s

Figure by MIT OpenCourseWare. Adapted from Haddad, Sam David, and Watson, N. Principles and Performance in Diesel Engineering. Chichester, England: Ellis Horwood, 1984.

$\dot{m}_2\dfrac{\sqrt{T_3/T_{ref}}}{(P_3/P_4)}$ (kg/s)

$(\pi_t)^{-1}=P3/P4$

$(\pi_t)^{-1}$

1.4
1.3
1.2
1.1
1.0

$P_{ref}=1$ bar
$T_{ref} = 300K$

Turbine Map

0.12
0.10
0.08
0.06
0.04
0.02

0   20   40   60   80   100 ×10

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