Indian Institute of Technology Kharagpur

Department of Mechanical Engineering

Internal Combustion Engine ME60111

Tutorial 1

Date: August 2, 2007

1. The engine of the Fiat car has four cylinders of 68 mm bore and 75 mm stroke. The compression ratio is 8. Calculate the cubic capacity of the engine and the clearance volume of each cylinder. [1089.48 cm^3, 38.9 cm^3]

2. Derive an expression for the dimensionless piston speed.

3. Derive an expression for the dimensionless cylinder volume $V(\theta)/V(0)=f(\theta, r_c, r/l)$.

4. Compute the mean piston speed, bmep, torque and power/area for three engines: Marine ($\dot{W}_b$ =1118 kW, B=0.136 m, N=2600 rpm, L=0.127 m, n_c = 12), Dragster ($\dot{W}_b$ =447 kW, B=0.108 m, N=6400 rpm, L=0.0.095 m, n_c = 8) and Formula One ($\dot{W}_b$ =522 kW, B=0.086 m, N=10500 rpm, L=0.057 m, n_c = 8).

5. A 3.8 L four-stroke fuel-injected automobile engine has a power output of 88 kW at 4000 rpm and volumetric efficiency of 0.85. The bsfc is 0.35 kg/kW-hr. If the fuel has a heat of combustion of 42 MJ/kg, what are the bmep, thermal efficiency, and air to fuel ratio? Assume atmospheric conditions of 298 K and 1 bar.

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Tutorial 2

Date: August 10, 2007

1. A two liter four-stroke indirect injection diesel engine is designed to run at 4500 rpm with a power output of 45 kW; the volumetric efficiency is found to be 80 per cent. The bsfc is 0.071 kg/MJ and the fuel has a calorific value of 42 MJ/kg. The ambient conditions for the test were 20^0C and 1 bar. Calculate bmep, the thermal efficiency and the air fuel ratio.

   (6 bar, 32% and 22.3)

2. A four-stroke 3 liter V6 spark ignition engine has a maximum power output of 100 kW at 5500 rpm, and a maximum torque of 236 Nm at 3000 rpm. The minimum bsfc is 0.090 kg/MJ at 3000 rpm, and the air flow rate is 0.068 m^3/s. The compression ratio is 8.9:1 and the mechanical efficiency is 90 per cent. The engine was tested under ambient conditions of 20^0C and 1 bar; take the calorific value of the fuel to be 44 MJ/kg.
   a) Calculate the power output at 3000 rpm and the torque output at 5500 rpm. **(74.14 kW, 173.6 Nm)**
   b) Calculate for both speeds the bmep and the imep. **(9.89 bar, 10.98 bar) (7.27 bar, 8.08 bar)**
   c) How does the mechanical efficiency at 3000 rpm compare with the corresponding air standard Otto cycle efficiency, k = 1.4 ? **(25.3 %, 58.3 %)**
   d) What is the volumetric efficiency and the air/fuel ratio at 3000 rpm? **(90.7 %, 12.12)**

3. A four-cylinder, four stroke petrol engine is to develop 40 kW at 40 rev/s when designed for a volumetric compression ratio of 10 to 1. The ambient air conditions are 1 bar and 18^0C, and the calorific value of the fuel is 44 MJ/kg.
   a) Calculate the specific fuel consumption in kg/MJ of brake work if the indicated overall efficiency is 50% of the corresponding air-standard Otto cycle, and the mechanical efficiency is 90%. The specific heat capacity ratio for air is 1.4. **(83.9gm/MJ)**
   b) The required gravimetric air-fuel ratio is 15.4 and the volumetric efficiency is 92%. Estimate the required total swept volume, the cylinder bore if the bore is to be equal to the stroke. Calculate also the brake mean effective pressure. **(2.35 L, 8.51 bar)**

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Tutorial 3

Date: August 17, 2007

1. A compression-ignition engine has a volumetric compression ratio of 15. Find the thermal efficiency of the following air-standard cycles having the same volumetric compression ratio as the engine. The specific heat capacity ratio is 1.4.
   a) an Otto cycle
   (0.661)
   b) a Diesel cycle in which the temperature at the beginning of compression is 180C, and in which the heat supplied per unit mass of air is equal to the energy supplied by the fuel (in terms of its calorific value). The gravimetric air:fuel ratio is 28:1; the calorific value of the fuel is 44 MJ/kg; assume the specific heat of air at constant pressure is 1.01 kJ/kgK and is independent of temperature.
   (0.566)

2. A petrol engine of volumetric compression ratio 9 to 1 takes in a mixture of air and fuel in the ratio 17 to 1 by weight; the calorific value of the fuel is 44 MJ/kg. At the start of compression the temperature of the charge is 50^0C. Assume that compression and expansion are reversible with pv^n = constant, and n = 1.325 and 1.240 respectively, and that combustion occurs instantaneously at minimum volume. Combustion can be regarded as adding heat equal to the calorific value to the charge.

   However, there is a finite combustion efficiency, and heat transfer from the combustion chamber. Combustion is thus equivalent to a net heat input that corresponds to 75% of the calorific value of the fuel being burnt.

   Calculate the temperatures: after compression, and at the start and end of expansion.
   (T_2=660, T_3=2590, T_4=1529)
   Calculate the net work produced by the cycle and thus calculate the indicated efficiency of the engine. **(1026 kJ/kg_mixture, 42%)**

   Use the following thermodynamic date: molar mass (kg) and c_v for air-fuel mixture 30, 0.95, for combustion products 28, 0.95.

3. A CI engine operating on the air-standard Diesel cycle has cylinder conditions at the start of compression of 65^0C and 130 kPa. Light diesel fuel is used at an equivalence ratio of φ=0.8 with a combustion efficiency η_c=0.98. Compression ratio is r_c=19. Take k=1.35. Calculate:

a) Temperature at each state of the cycle. [^{0}C]
b) Pressure at each state of the cycle. [kPa]
c) Cutoff ratio.
d) Indicated thermal efficiency. [%]
e) Heat lost in exhaust. [kJ/kg]

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Tutorial 4

Date: August 24, 2007

1. A compression ignition engine for a small truck is to operate on an air-standard Dual cycle with a compression ratio of r_c = 18. Due to structural limitations, maximum allowable pressure in the cycle will be 9000 kPa. Light diesel fuel is used at a fuel-air ratio of FA = 0.054. Combustion efficiency can be considered 100%. Cylinder conditions at the start of compression are 50^0C and 98 kPa. Calculate:
   a) Maximum indicated thermal efficiency possible with these conditions. [%] **(60.3)**
   b) Peak cycle temperature under conditions of part (a). [^{0}C] **(2777)**
   c) Minimum indicated thermal efficiency possible with these conditions. [%] **(53.3)**
   d) Peak cycle temperature under conditions of part (c). [^{0}C] **(2853)**

2. An in-line six, 3.3 L CI engine using light diesel fuel at an air-fuel ratio of AF = 20 operates on an air-standard Dual cycle. Half the fuel can be considered burned at constant volume and half at constant pressure with combustion efficiency η_c = 100%. Cylinder conditions at the start of compression are 60^0C and 101 kPa. Compression ratio r_c = 14:1.
   Calculate:
   a) Temperature at each state of the cycle. [K] **(839, 2072, 2712, 1347)**
   b) Pressure at each state of the cycle. [kPa] **(3561, 8794, 8794, 408)**
   c) Cutoff ratio. **(1.441)**
   d) Pressure ratio. **(2.47)**
   e) Indicated thermal efficiency. [%] **(58.9)**
   f) Heat added during combustion. [kJ/kg] **(2024)**
   g) Net indicated work. [kJ/kg] **(1192)**

3. The engine in Problem 2 produces 57 kW of brake power at 2000 rpm. Calculate:
   a) Torque. [N-m] **(272)**
   b) Mechanical efficiency. [%] **(76.3)**
   c) Brake mean effective pressure. [kPa] **(1036)**
   d) Indicated specific fuel consumption. [gm/kW-hr] **(189)**

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Tutorial 5

Date: September 7, 2007

1. A five cylinder, four stroke cycle SI engine has a compression ratio r_c = 11:1, bore B = 5.52 cm, stroke S = 5.72 cm, and connecting rod length r = 11.00 cm. Cylinder inlet conditions are 63^0C and 92 kPa. The intake valve closes at 41^0 aBDC and the spark plug is fired at 15^0 bTDC. Calculate:
   a) Temperature and pressure in the cylinder at ignition, assuming Otto cycle analysis (i.e. assume the intake valve closes at BDC and ignition is at TDC).
   b) Effective compression ratio (i.e. actual compression of the air-fuel mixture before ignition).
   c) Actual temperature and pressure in the cylinder at ignition.

2. A six-cylinder, four-stroke cycle SI engine is generating maximum power at WOT. At this condition, engine speed is 5800 RPM with stoichiometric gasoline and an inlet pressure of 101 kPa. At idle condition, the engine speed is 600 RPM with stoichiometric gasoline and an inlet pressure of 30 kPa. Volumetric efficiency can be considered 95% at all conditions. Consider AF ratio 14.6 and density of air 1.181 kg/m^3. Calculate:
   a) Fuel flow rate through an injector.
   b) Injection pulse duration in seconds at idle conditions.
   c) Injection pulse duration in degrees of engine rotation at idle conditions.

3. A 6.3 L, V8, four-stroke cycle SI engine is designed to have a maximum speed of 6500 RPM. At this speed, volumetric efficiency is 88%. The engine is equipped with a four-barrel carburetor, each barrel having a discharge coefficient of 0.95. The fuel used is gasoline at AF=15 (density of gasoline 750 kg/m^3). Calculate:
   a) The expression for maximum air flow through the carburetor.
   b) Minimum throat diameter needed in each carburetor venture.
   c) Fuel capillary tube diameter needed for each venture throat if tube discharge coefficient = 0.85 and the capillary height differential is small.

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Tutorial 6

Date: September 28, 2007

1. An automobile has a 3.2 liter, five cylinder, four-stroke cycle diesel engine operating at 2400 ROM. Fuel injection occurs from 20^0 bTDC to 5^0 aTDC. The engine has a volumetric efficiency of 0.95 and operates with fuel equivalence ratio of 0.80. Light diesel fuel is used. Stoichiometric air-fuel ratio is 14.5. Calculate:
    a. Time for one injection [0.00173 s]
    b. Fuel flow rate through an injector. [0.0229 kg/s]

   The volume of the average diesel fuel droplet is $3x10^{-14}$ m^3. The compression ratio of the engine is 18:1. as a rough approximation, it can be assumed that all fuel droplets have the same volume and are equally spaced throughout the combustion chamber at TDC. Density of the diesel fuel is ρ = 860 kg/m^3. Calculate:
    c. Number of fuel droplets in one injection. [$1.535x10^6$]
    d. Approximate distance between droplets in the combustion chamber at TDC. [0.36 mm]

2. C_4H_8 is burned in an engine with a fuel-rich air-fuel ratio. Dry analysis of the exhaust gives the following volume percents: CO_2 = 14.95%, C_4H_8 = 0.75%, CO = 0%, H_2 = 0%, O_2 = 0%, with the rest being N_2. Higher heating value of this fuel is Q_{HHV} = 46.9 MJ/kg. Write the balanced chemical equation for one mole of this fuel at these conditions. Calculate:
    a. Air-fuel ratio [12.325]
    b. Equivalence ratio [1.2]
    c. Lower heating value of fuel. [42.9 MJ/kg]

3. Write the balanced chemical reaction equation for one mole of C_9H_{20} burning with an equivalence ratio of φ = 0.7. Calculate the stiochimetric AF for this fuel. [15.1]

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Tutorial 7

Date: October 12, 2007

1. Two engine options are to be offered in a new automobile model. Engine A is naturally aspirated with a compression ratio of 10.5:1 and cylinder inlet conditions of 60^0C and 96 kPa. Engine B is supercharged with aftercooling and has cylinder inlet conditions of 80^0C and 130 kPa. To avoid knock problems, it is desirable to have the air-fuel temperature at the start of combustion in engine B to be the same as in engine A. Calculate the temperature reduction in the aftercooler of engine B if the compression has an isentropic efficiency of 82% amd inlet conditions are the same as in engine A. Take k = 1.35.

2. A spark ignition engine is fitted with a turbocharger that comprises a radial flow compressor driven by a radial flow exhaust gas turbine. The gravimetric air/fuel ratio is 12:1, with the fuel being injected between the compressor and the engine. The air is drawn into the compressor at a pressure of 1 bar and at a temperature of 15^0C. The compressor delivery pressure is 1.4 bar. The exhaust gases from the engine enter the turbine at a pressure of 1.3 bar and a temperature of 710^0C; the gases leave the turbine at a pressure of 1.1 bar. The isentropic efficiencies of the compressor and turbine are 75 % and 85% respectively. Treating the exhaust gases as a perfect gas with the same properties as air, calculate:
    a. the temperature of the gases leaving the compressor and turbine
    b. the mechanical efficiency of the turbocharger.

3. A turbocharged six-cylinder Diesel engine has a swept volume of 39 litres. The inlet manifold conditions are 2.0 bar and 53^0C. The volumetric efficieny of the engine is 95% and it is operating at a load of 16.1 bar bmep, at 1200 rpm with an air/fuel ratio of 21.4. The power delivered to the compressor is 100 kW, with an entry conditions of 25^0Cand 0.95 bar. The fuel has a calorific value of 42 MJ/kg. (Cp=1.01 kJ/kg-K). Calculate:
    a. the power output of the engine
    b. the brake efficiency of the engine
    c. the compressor isentropic efficiency
    d. the effectiveness of the inter-cooler.