Problem Sheet 1

(Engineering Thermodynamics)

1. Air at 0.02 m^3 at 200 kPa and 30°C is compressed to 1/10 th of its initial volume. The process obeys the law $PV^{1.3}$ = constant. What is the final temperature and work done in the process? [Ans. 331.5°C]

2. 2 kg of a gas is contained in a piston-cylinder assembly at initial conditions of 2 m^3 and 100 kPa. The gas is allowed to expand to a final volume of 5 m^3. Determine the amount of work done for the following processes:
   (a) pressure remains constant, (b) isothermal process, (c) PV^2 is constant.
   [Ans (a) 300 kJ, (b) 183.26 kJ, (c) 120kJ)]

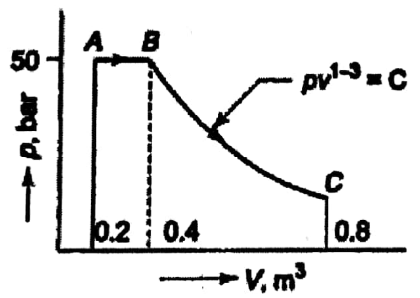
3. The piston of an oil engine of area 0.0045 m^2, moves downwards by 75 mm, drawing in 0.00028 mm^3 of fresh air from the atmosphere. The pressure in the cylinder is uniform at 80 kPa during the process while the atmospheric pressure is 101.325 kPa, the difference being due to the flow resistance in the induction pipe and the inlet valve. Estimate the displacement work done by the air in the cylinder. [Ans: 27 J]

4. An engine cylinder has a piston of area 0.12 m^2 and contains gas at a pressure of 1.5 MPa. The gas expands according to a process which is represented by a straight line on the pressure-volume diagram. The final pressure is 0.15 MPa. Calculate the work done by the gas on the piston if the stroke length is 0.30 m. [Ans: 29.7 kJ]

5. A mass of gas is compressed in a quasi-static process from 80 kPa, 0.1 m^3 to 0.4 MPa, 0.03 m^3. Assuming that the pressure and volume are related by PV^n = constant, find the work done by the gas system. [Ans: -11.83 kJ]

6. At the beginning of the compression stroke of a two-cylinder internal combustion engine, the air is at a pressure of 101.325 kPa. Compression reduces the volume to a fifth of the original volume, and the law of compression is given by $PV^{1.2}$ = constant. If the bore and stroke of each cylinder is 0.15 m and 0.25 m respectively, determine the power absorbed in kW by compression strokes when the engine speed is such that each cylinder undergoes 500 compression strokes per minute. [Ans: 17.72 kW]

7. Determine the total work done by a gas system following an expansion process as shown in the figure below:



[Ans: 2.251 MJ]

8. A system of volume V contains a mass m of a gas at pressure P and temperature T. The macroscopic properties of the system obey the following relationship.
   $\left(P + \frac{a}{V^2}\right)(V - b) = mRT$, where a, b and R are constants. Obtain an expression for the displacement work done by the system during a constant temperature expansion from volume V_1 to a volume V_2. Calculate the work done by the system which contains 10 Kg of this gas expanding from 1 m^3 to 10 m^3 at a temperature of 293 K. Use the values: a = 15.7x10^4 Nm^4, b = 1.07x10^{-2} m^3 and R = 0.278 kJ/kg.K. [Ans: 1742.14 kJ]

9. An elastic sphere initially has a diameter of 1 m and contains a gas at a pressure of 1 atmosphere. Due to heat transfer, the diameter of the sphere increases to 1.1 m. During the heating process the gas pressure inside the cylinder is proportional to the sphere diameter. Calculate the work done by the gas. [Ans: 18.4 kJ]

10. A piston-cylinder device contains 0.05 m^3 of a gas initially at 200 kPa. At this state, a linear spring having a spring constant of 150 kN/m is touching the piston but exerting no force on it. Now heat is transferred to the gas, causing the piston to rise and to compress the spring until the volume inside the cylinder doubles. If the cross-sectional area of the piston is 0.25 m^2, determine (a) the final pressure inside the cylinder, (b) the total work done by the gas and (c) the work done against the spring to compress it. [Ans: 320 kPa, 13 kJ, 3 kJ]

Problem Sheet - 2
(Engineering Thermodynamics)

1. A gas of mass 8 kg expands within a flexible container so that the p-v relationship is of the form $pv^{1.2}$ = constant. The initial pressure is 1000 kPa and initial volume is 1 m^3, the final pressure is 5 kPa. If the specific energy of the gas decreases by 40 kJ/kg, find the heat transfer in magnitude and direction. [Ans (2612.4 KJ, to the gas)]

2. Given the properties of a certain fluid as : $u = 196+0.718t$; $pv = 0.287(t+273)$; u (kJ/kg) is the sp. internal energy, t (°C) is the temp, p (kPa) is the pressure and v (m^3/kg) sp volume. A stationery system consisting of 2 kg of fluid expands in an adiabatic process according to the law $pv^{1.2}$ = constant. The initial conditions are 1MPa and 200°C, and the final pressure is 0.1 MPa. Find W and ΔE for the process. Why is the work not equal to $\int pdV$? [Ans W = 217.35KJ, ΔE = - 217.35KJ, $\int pdV$ = 434.4 KJ)]

3. A gas undergoes a thermodynamic cycle consisting of the following processes: (i) Process 1-2: Constant pressure p = 1.4 bar, V_1 = 0.028 m^3, W_{12} = 10.5 kJ, (ii) Process 2-3: Compression with pv = constant, $U_3 = U_2$, (iii) Process 3-1: Constant Volume, $U_1 - U_3$ = -26.4 kJ. There are no significant changes in KE and PE. (a) Sketch the cycle on a p-v diagram. (b) Calculate the net work for the cycle in kJ. (c) Calculate the heat transfer for the process 1-2. (d) Show that $\sum_{cycle} Q = \sum_{cycle} W$.
[Ans (b) -8.28 kJ (c) 36.9 kJ]

4. A gas of mass 1.5 kg undergoes a quasi-static expansion which follows a relationship $p=a+bV$, where a and b are constants. The initial and final pressures are 1000 kPa and 200 kPa respectively and the corresponding volumes are 0.20 m^3 and 1.20 m^3. The specific internal energy of the gas is given by the relation $u = (1.5pv - 85)$ kJ/kg, where p is in kPa and v is in m^3/kg. Calculate the net heat transfer and the maximum internal energy of the gas attained during expansion.
[Ans 660 kJ, 503.25 kJ]

5. The compressor of a large gas turbine receives air from ambient at 100 kPa, 20°C, with a low velocity. At the compressor discharge, air exits at 1 MPa, 400°C, with velocity of 100 m/s. the power input to the compressor is 4000 kW. Determine the mass flow rate of air through the unit. [Ans (10.34 kg/s)]

6. Steam flows through a turbine at a rate of 2.5 kg/s. the inlet and exit enthalpy of steam are 2700 kJ/kg and 1800 kJ/kg respectively. Velocity of steam at inlet and outlet are 35 m/s and 250 m/s. there is heat loss to the surroundings at 40 kW. Calculate the power output from the turbine. [Ans (2133.4 kW)]

7. A steam turbine in a power plant develops 5000 kW. The heat supplied to the steam is 4700 kJ/kg, the heat rejected by the steam in the boiler is 2200 kJ/kg. The feed-pump work required to pump the condensate back into the boiler is 10 kW. Calculate the mass-flow rate of the steam. [Ans (1.996 kg/s)]

8. A blower handles 1 kg/s of air at 293 K and consumes a power of 15 kW. The inlet and outlet velocities of air are 100 m/s and 150 m/s respectively. Find the exit air temperature assuming adiabatic conditions. Take C_p of air to be 1.005 kJ/kg-K.
[Ans 28.38°C]

9. A nozzle is a device for increasing the velocity of a steadily flowing stream. At the inlet to a certain nozzle, the enthalpy of the fluid passing is 3000 kJ/kg and the velocity is 60 m/s. At the discharge end, the enthalpy is 2762 kJ/kg. The nozzle is horizontal and there is negligible heat loss from it. (a) Find the velocity at exit from the nozzle. (b) If the inlet area is 0.1 m^2 and the specific volume at inlet is 0.187 m^3/kg, find the mass flow rate. (c) If the specific volume at the nozzle exit is 0.498 m^3/kg, find the exit area of the nozzle. [Ans : (a) 692.5 m/s, (b) 32.08 kg/s (c) 0.023m^2]

10. Consider a compressor with air at 1 bar and 15°C, compressing to the pressure 27.59 bar by (i) isothermal process (ii) Polytropic process, with polytropic index, n=1.3.
For each case, find the (i) work done, (ii) heat exchange with the surroundings (iii) final temperature and (iv) change in internal energy due to the compression per unit mass of air.
Assume, air to be an ideal gas.
[Ans : (i) w = q = -263.47kJ/kg, Δu=0, $T_2=T_1$ (ii) T_2= 619.2K, Δu= 237.61kJ/kg , w= -316.84 kJ/kg, q= - 79.23 kJ/kg]

11. Air enters an insulated diffuser operating at steady rate with a pressure of 0.7 bar, temperature 57°C and velocity of 200m/s. At the exit, the pressure is 1 bar. The exit flow area is 20% greater than the inlet flow area. Neglecting change in potential energy, determine the exit temperature and velocity of air. Take c_p= 1.005kJ/kgK, and R= 0.287 kJ/kg-K for air as an ideal gas.
[Ans : T_2= 342 K; V_2= 120.9 m/s]

12. A pump delivers water at a steady rate with volume flow rate 0.05 m^3/s through a pipe of diameter 18cm located 100m above the inlet pipe, which has a diameter of 15 cm. The pressure is 1 bar at both inlet and the exit of pipe and the temperature remains constant at 20°C, throughout. Determine the total power required by the pump in kW. Take g = 9.81m/s^2. ρ_{water} = 10^3 kg/m^3
[Ans: W= - 48.9 kW]

Problem Sheet – 3

(Engineering Thermodynamics)

1. A heat engine working on a Carnot cycle converts one-fifth of the heat input into work. When the temperature of the sink is reduced by 80°C, the efficiency gets doubled. Make calculations for the temperature of source and sink.
[**Ans**: Sink temp. = 320K, Source temp. = 400K]

2. A domestic food refrigerator maintains a temperature of -10°C while the ambient air temperature is 30°C. The heat leakage into the freezer is estimated to be at the continuous rate of 2 kJ/s. Determine the least power needed to pump out this heat continuously. [**Ans**: 0.304 kJ/s]

3. A heat pump working on the Carnot cycle takes in heat from a reservoir at 5°C and delivers heat to a reservoir at 60°C. The heat pump is driven by a reversible heat engine which takes in heat from a reservoir at 840°Cand rejects heat to a reservoir at 60°C. The reversible heat engine also drives a machine that absorbs 30 kW. If the heat pump extracts 17 kJ/s from the 5°C reservoir, determine (a) The rate of heat supply from the 840°C source (b) The rate of heat rejection to the 60°C sink.
[**Ans**: (a) 47.61^{0}C (b) 34.61kW]

4. Two reversible heat engines **A** and **B** are arranged in series, **A** rejecting heat directly to **B**. Engine **A** receives 200 kJ at a temperature of 421°C from a hot source, while engine **B** is in communication with a cold sink at a temperature of 4.4°C. If the work output of **A** is twice that of **B**, find (a) The intermediate temperature between **A** and **B** (b) The efficiency of each engine (c) The heat rejected to the cold sink. [**Ans.** 143.4°C, 40% and 33.5%, 80 kJ]

5. A reversible engine works between three thermal reservoirs, A, B and C. The engine absorbs an equal amount of heat from the thermal reservoirs A and B kept at temperatures T_A and T_B respectively, and rejects heat to the thermal reservoir C kept at temperature T_C. The efficiency of the engine is α times the efficiency of the reversible engine, which works between the two reservoirs A and C. Prove that $(T_A/T_B) = (2\alpha - 1) + 2(1-\alpha)(T_A/T_C)$.

6. Two Carnot engines **A** and **B** are connected in series between two thermal reservoirs maintained at 1000 K and 100 K respectively. Engine **A** receives 1680 kJ of heat from the high-temperature reservoir and rejects heat to the Carnot engine **B**. Engine **B** takes in heat rejected by engine **A** and rejects heat to the low-temperature reservoir. If engines **A** and **B** have equal thermal efficiencies, determine (a) The heat rejected by engine **B** (b) The temperature at which heat is rejected by engine, **A** (c)The work done during the process by engines, **A** and **B** respectively.
If engines **A** and **B** deliver equal work, determine (d) The amount of heat taken in by engine **B** (e) The efficiencies of engines **A** and **B**. [**Ans.** (a) 168 kJ, (b) 316.2 K, (c) 1148.7 kJ, 363.3 kJ, (d) 924 kJ, (e) 45%, 81.8%]

7. A heat pump is to be used to heat a house in winter and then reversed to cool the house in summer. The interior temperature is to be maintained at 20°C. Heat transfer through the walls and roof is estimated to be 0.525 kJ/s per degree temperature difference between the inside and outside. (a) If the outside temperature in winter is 5°C, what is the minimum power required to drive the heat pump? (b) If the power output is the same as in part (a), what is the maximum outer temperature for which the inside can be maintained at 20°C? [**Ans.** (a) 403 W, (b) 35.4°C]

8. A heat engine operating between two reservoirs at 1000 K and 300 K is used to drive a heat pump which extracts heat from the reservoir at 300K at a rate twice that at which the engine rejects heat to it. If the efficiency of the engine is 40% of the maximum possible and the COP of the heat pump is 50% of the maximum possible, what is the temperature of the reservoir to which the heat pump rejects heat? What is the rate of heat rejection from the heat pump if the rate of heat supply to the engine is 50 kW?
[**Ans**: 326.5 K, 86 kW]

9. A reversible heat engine operates between a source at 1200 K and two sinks at 300 K and 400 K. If equal amount of heat is rejected to each sink, what is the efficiency of the heat engine? [**Ans**: 5/7]

10. A heat engine receives half of its heat supply at 1000K and half at 500K while rejecting heat to a sink at 300K.What is the maximum thermal efficiency of the heat engine? [**Ans**: 55%]

11. 300 kJ/s of heat is supplied reversibly at a constant fixed temperature of 290°C to a heat engine. The heat rejection takes place at 8.5°C. The following results were obtained: (i) 215 kJ/s heat are rejected. (ii) 150 kJ/s heat are rejected. (iii) 75 kJ/s heat are rejected. Classify, with reason, which of the result report a reversible cycle or irreversible cycle or impossible results.
[**Ans**: (i) irreversible (ii) reversible (iii) impossible]

PROBLEM SHEET – 4

(Engineering Thermodynamics)

1. In an air standard Diesel cycle, the compression ratio is 16 and at the beginning of isentropic compression, the temperature is 15°C and the pressure is 0.1MPa. Heat is added until the temperature at the end of the constant pressure process is 1480°C. Find the following: (i) the cut-off ratio (ii) the heat supplied per kg of air (iii) the Cycle Efficiency
[Ans: (i) 2.01 (ii) 884.4 kJ/kg (iii) 61.2%]

2. In a diesel engine, the compression ratio is 13:1 and fuel is cut off at 8% of the stroke. Find the air standard efficiency of the engine. Take $\gamma = 1.4$ for air. [Ans: 58.25%]

3. An engine working on the Otto cycle is supplied with air at 0.1MPa, 35°C. The compression ratio is 8. Heat supplied is 2100 kJ/kg. Calculate the maximum pressure, maximum temperature of the cycle and its efficiency. (For air, c_p=1.005 kJ/kgK, c_v= 0.718 kJ/kgK, R= 0.287 kJ/kgK) [Ans: p_{max}= 9.426 MPa, T_{max}= 3633 K, η= 56.5%]

4. Obtain the specific work done by an engine working on the Otto cycle in terms of the maximum (T_3) and minimum (T_1) temperatures of the cycle, the compression ratio r_k, and specific heat constants of working fluid (assumed to be an ideal gas).
Hence, show that the optimum compression ratio for maximum specific work output is given by

$$(r_k)_{optimum} = \left(\frac{T_3}{T_1}\right)^{\frac{1}{2(\gamma-1)}}$$

and at that time $T_2 = T_4 = \sqrt{T_3 T_1}$ and also show that the maximum specific work done is given by $w_{max} = C_v\left(\sqrt{T_3} - \sqrt{T_1}\right)^2$
Hence, calculate the maximum work done from the engine, if it runs between T_3 = 1457 K and T_1 = 313 K, for a mass flow rate of working fluid of 0.47 kg/s.

5. An engine equipped with a cylinder having a bore of 15cm and a stroke of 45 cm operates on an Otto cycle. If the clearance volume is 2000cm³, compute the air standard efficiency. [Ans: 47.4%]

6. An ideal Diesel cycle with air as the working fluid has a compression ratio of 18 and cut-off ratio of 2. At the beginning of compression process, the working fluid is at 100 kPa, 27°C, and 1917 cm³. Determine (i) the temperature and pressure of air at the end of each process, (ii) the net work output (iii) the thermal efficiency of the cycle.
[Ans: w_{net}= 1.35 kJ, η= 63.2%]

7. An engine working on Otto cycle has an air standard efficiency of 56% and rejects 544 kJ/kg of air. The pressure and temperature of air at the beginning of compression ratio are 0.1 MPa and 60°C respectively. Compute (i) the compression ratio of the engine, (ii) the work done per kg of air, (iii) the pressure and temperature at the end of compression (iv) the maximum pressure in the cycle. [Ans: (i) 7.79 (ii) 692.36 kJ/kg (iii) p_2= 1.77MPa, T_2= 756.9K (iv) p_{max}= 3.275MPa]

8. Two engines are to operate on Otto and Diesel cycles with the following data: Maximum temperature: 1400 K, exhaust temperature 700 K. State of air at the beginning of compression is 0.1 MPa, 300 K. Estimate the compression ratios, the maximum pressures, efficiencies and the rates of work outputs (for 1 kg/min of air) of the respective cycles.
[Ans : Otto – r_k= 5.656, p_{max}= 2.64 MPa, W= 2872 kJ/kg, η= 50%
Diesel- r_k= 7.456, p_{max}= 1.665 MPa, W= 446.45 kJ/kg, η= 60.8%]