# Thermodynamics

## Assignment Set 2. [Second law of Thermodynamics and Entropy]

**1.** An air-conditioning system is used to maintain a house at $24^0$C when the temperature outside is $35^0$C. The house is gaining heat through the walls and windows at a rate of 800 kJ/min, and the heat generation rate within the house from people, lights and appliances amounts to 160 kJ/min. Determine the minimum power input required for this air conditioning system. **[0.59kW]**

**2.** A reversible engine works between three thermal reservoirs, A, B and C. The engine absorbs and 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, $\frac{T_A}{T_B} = (2\alpha - 1) + 2(1-\alpha)\frac{T_A}{T_C}$.

**3.** A heat engine operates between the maximum and minimum temperatures of 671°C and 60°C respectively, with an efficiency of 50% of the appropriate Carnot efficiency. It drives a heat pump which uses river water at 4.4 °C to heat a block of flats in which the temperature is to be maintained at 21.1 °C. Assuming that a temperature difference of 11.1 °C exists between the working fluid and the river water, on the one hand, and the required room temperature on the other, and assuming the heat pump to operate on the reversed Carnot cycle, but with a COP of 50% of the ideal COP, find the heat input to the engine per unit heat output from the heat pump. **[0.79kJ]**

**4.** 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 300 K at a rate twice than 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? **[326.58K, 86kW]**

**5.** Air ($C_p$=1.005kJ/kgK) is to be heated by hot exhaust gases in a cross flow heat exchanger before it enters the furnace. Air enters the heat exchanger at 95kPa and $20^0$C at a rate of 1.6m$^3$/s. The combustion gases ($C_p$=1.10kJ/kgK) enter at $180^0$C at a rate of 2.2 kg/s and leave at $95^0$C. Determine the rate of heat transfer to the air, the outlet temperature of the air and the rate of entropy generation. (**0.091kW/K)**

**6.** Two identical bodies of constant heat capacity are the same initial temperature $T_i$. A refrigerator operates between these two bodies until one body is cooled to temperature $T_2$. If the bodies remain at constant pressure and undergo no change of phase, show the minimum amount of work needed to do this is $W(\min) = C_p\left(\frac{T_i^2}{T_2} + T_2 - 2T_i\right)$

**7.** One kg of ice at $-10^0$C is exposed to the atmosphere which is at $30^0$C. The ice melts and comes into thermal equilibrium with the atmosphere. (a) Determine the entropy increase of the universe. (b) What is the minimum amount of work necessary to convert the water back into ice at $-10^0$C? $c_p$ of ice is 2.093 kJ/kgK and the latent heat of fusion of ice is 333.3 kJ/kg and $c_p$ of water is 4.2kJ/kgK. **[0.1501kJ/K, 45.8kJ]**

**8.** Air from a line at 12MPa, $15^0$C flows into a 500L tank that is initially contained air at ambient conditions, 100kPa, $15^0$C. The process occurs rapidly and is essentially adiabatic. The valve is closed when the pressure inside reaches some value, $P_2$. The tank eventually cools to room temperature, at which time the pressure inside is 5MPa. What is the pressure $P_2$ ? What is the net entropy change for the overall process?

**9.** Air flowing through a horizontal, insulated duct was studied by students in a laboratory. One student group measured the pressure, temperature and velocity at a location in the duct as 0.95bar, $67^0$C, 75m/s. At another location the respective values were found to be 0.8bar, $22^0$C, 310m/s. The group neglected to note the direction of flow, however. Using the known data, determine the direction. **[Flow is from right to left]**