Thermodynamics and Energy Conversion (EN 203) – Autumn 2020-21

Problem Set - 3

2nd Law of Thermodynamics

1. **Heat engine: efficiency**
   A heat engine performs many cycles during which it develops 21 kJ work and receives 85 kJ heat from the source. Evaluate the thermal efficiency of and the heat rejected by the engine.

2. **COP calculation**
   In a reversed heat engine, the work done on the engine is 75 kJ and the heat transferred to the engine is 220 kJ. Evaluate the heat transfer from the engine and the COP of the engine (a) as a refrigerator and (b) as a heat pump.

3. **Heat engines in series**
   A heat engine, X, operates between a reservoir at a 1000 °C and a body at 600 °C. Heat transfer to the heat engine is 1000 kJ and work output is 220 kJ. Another engine, Y, operates between the body at 600 °C and the atmosphere at 27 °C. Heat rejected to the atmosphere is 400 kJ. The body at 600 °C maintains its temperature steady and has interactions only with the two engines, X and Y. Calculate the work output and thermal efficiency of engine, Y.

4. **Heat pump**
   The COP of a heat pump is 5 when the power supplied to drive it is 35 kW. (a) Evaluate the heat transfer from and to the working fluid. (b) The heat transfer from the heat pump is used to heat water flowing through the radiators. Evaluate the flow rate of radiator water in kg/s, given that its temperature increases by 20 °C. Neglect the change in velocity of water as it flows through the condenser.

5. **Heat engine running heat pump**
   A heat engine is used to drive a heat pump. The heat transfer from the heat engine and the heat pump are used to heat the water circulating through the radiators of a building. It is given that the efficiency of the engine is 30% and the COP of the heat pump is 4. How much heat is transferred to the radiator water, for every kJ heat transfer to the heat engine.

6. **Possibility to construct engine**
   Consider three hypothetical heat engines, A, B and C, each operating between 1000 K and 300 K. When each engine involves itself with a heat interaction of 1000 kJ with the high-temperature reservoir, it is clamed that while A develops a work of 600 kJ, B and C develop 700 kJ and 800 kJ, respectively. Use the Carnot statement and identify the engine A, B and C as reversible, irreversible or impossible.

7. **Checking reversibility**
   A direct heat engine A and a reversed heat engine B operate between 177°C and 27 °C. The COP of B as a heat pump is 2.5. A drives B. The magnitudes of heat interaction of A and B with the reservoir at 27 °C and 200 kJ and 50 kJ, respectively. The combined work output of A and B is 20 kJ. Identify whether the heat engine A is reversible or irreversible.

8. Heat transfer to H.E.

A reversible heat engine receives heat from three high-temperature reservoirs at 1000 K, 800 K and 600 K and rejected 200 kJ heat to the lone sink at 300 K. The work output of the engine is 300 kJ. The heat transfer from the reservoir at 600 K is twice that from the reservoir at 1000 K. Calculate the heat transfers to the engine from each of the high-temperature reservoirs.

9. Entropy of pure substance

A certain pure substance of constant $c_p = 0.6$ kJ/kg K undergoes a change of state at constant pressure from 1 to 2 because of heating accompanied by stirring. The mass of the system is 2.5 kg and the temperatures at the two states are 30 °C and 80 °C, respectively. At the end of this process, the substance is subjected to a reversible constant pressure cooling process which restores it to the initial state. Find the increase in entropy in the first process.

10. Entropy variation

(a) One kilogram of water in an open vessel at 30 °C is brought in contact with a reservoir at 100□. What are the entropy changes for water, the reservoir and the universe, when the water temperature just reaches the temperature of the reservoir? Assume, for water, $dh = cdT$ where $c = 4.2$ kJ/kg K. (b) What would be the entropy increase of the universe had the water been heated from 30 °C to 100 °C by first bringing it in contact with a reservoir at 65□ and then with the reservoir at 100 °C?

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