3.5 EXERCISES

Efficiency of a thermal engine

Ex 3.5.1. A heat engine operates between two temperatures such that the working substance of the engine absorbs 5000J of heat from the high temperature bath and rejects 3000 J to the low temperature bath. The rest of the energy is converted into the mechanical energy of the turbine. Find (a) the amount of work produced by the engine and (b) the efficiency of the engine.

Ex 3.5.2. A thermal engine produces 4 MJ of electrical energy while operating between two thermal baths of different temperatures. The working substance of the engine rejects 5 MJ of heat to the cold temperature bath. What is the efficiency of the engine?

Ex 3.5.3. A coal power plant consumes 100,000 kg of coal per hour and produces 500 MW of power. If the heat of combustion of coal is 30 MJ/kg, what is the efficiency of the power plant?

Ex 3.5.4. A Carnot engine operates in a Carnot cycle between a heat source at 550°C and a heat sink at 20°C. Find the efficiency of the Carnot engine.

Ex 3.5.5. A Carnot engine operating in a Carnot cycle between 400°C and an unknown lower temperature has an efficiency of 0.3. How much heat must be rejected to the cold bath for every kJ of heat absorbed from the hot bath.

Ex 3.5.6. A Carnot engine employs 1.5 moles of the Nitrogen gas as the working substance, which will be considered as a diatomic ideal gas with $\gamma = 7/5$ at the working temperatures of the engine. The Carnot cycle goes in the cycle $A-B-C-D-A$ with $A-B$ being the isothermal expansion. The volume at points A and C of the cycle are 5 L and 150 L respectively. The engine operates between two thermal baths of temperature 500 K and 300 K.

(a) Find the values of the volume at B and D.

(b) How much heat is absorbed by the gas in the AB-isothermal expansion?

(c) How much work is done by the gas in the AB-isothermal expansion?

(d) How much heat is given up by the gas in the CD-isothermal compression?

(e) How much work is done by the gas in the CD-isothermal compression?

(f) How much work is done by the gas in the BC-adiabatic expansion?

(g) How much work is done by the gas in the DA-adiabatic compression?

(h) Find the value of the efficiency of the engine based on the net work and heat input. Compare this value of the efficiency to the value of the efficiency of the Carnot engine based on the temperatures of the two baths.

Ex 3.5.7. A Carnot engine employs 2 moles of the Helium as the working substance, considered as a monatomic ideal gas. The Carnot cycle goes in the cycle $A - B - C - D - A$ with $A - B$ being the isothermal expansion. The volume at points A and C of the cycle are 6 L and 12 L respectively. The engine operates between two thermal baths of temperature 450 K and 298 K.

(a) Find the values of volume at B and D.

(b) How much heat is absorbed by the gas in the AB-isothermal expansion?

(c) How much work is done by the gas in the AB-isothermal expansion?

(d) How much heat is given up by the gas in the CD-isothermal compression?

(e) How much work is done by the gas in the CD-isothermal compression?

(f) How much work is done by the gas in the BC-adiabatic expansion?

(g) How much work is done by the gas in the DA-adiabatic compression?

(h) Find the value of the efficiency of the engine based on the net work and heat input. Compare this value of the efficiency to the value of the efficiency of the Carnot engine based on the temperatures of the two baths.

Ex 3.5.8. A Carnot engine working between two heat baths of temperatures 600 K and 273 K completes each cycle in 5 sec. In each cycle, the engine absorbs 10 kJ of heat. Find the power of the engine.

Ex 3.5.9. An engine working in a Carnot cycle between two heat baths of temperatures 600 K and 273 K runs an electric motor that uses 60 W of power. If each cycle is completed in 10 seconds, how much heat does the engine absorb in each cycle?

Refrigerators

Ex 3.5.10. A kitchen refrigerator uses a Carnot cycle between the inside temperature 0°C and the outside temperature of 20°C. (a) What is its coefficient of performance? (b) If the refrigerator cycle is reversed, it would produce work. Find the efficiency of the Carnot engine that would result by reversing the refrigerator cycle.

Ex 3.5.11. A Carnot cycle working between 100°C and 30°C is used to drive a refrigerator between −10°C and 30°C. How much energy must the Carnot engine produce per second so that the refrigerator is able to discard 10 Joules of energy per second?