

1. An inventor claims to have developed a heat engine that receives 1,500 kJ/s of heat from a source at 600 K and produces 900 kJ/s of net work while rejecting the waste heat to a sink at 300 K. Is this a reasonable claim? Why? (5 Marks)

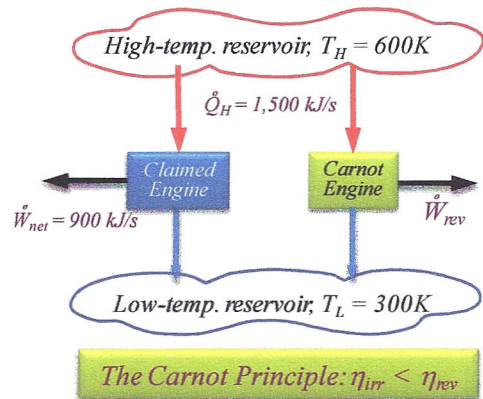
**System:** the claimed heat engine

**Analysis:** Use the Carnot principle at the same operating conditions

$$\eta_{th} < \eta_{carnot}$$

Consider the claimed engine.

$$\begin{aligned} \eta_{th} &= \frac{\dot{W}_{net}}{\dot{Q}_H} \times 100\% \\ &= \frac{900 \text{ kW}}{1,500 \text{ kW}} \times 100\% = 60\% \triangleleft \end{aligned}$$



Consider a Carnot heat engine operates at the same  $T_H, T_L$  and  $\dot{Q}_H$

$$\begin{aligned} \eta_{rev} &= 1 - \frac{T_L}{T_H} = 1 - \frac{300K}{600K} = 0.50 \\ &\text{or } = 50\% \triangleleft \end{aligned}$$

∴  $\eta_{th} > \eta_{rev}$ . which violates the Carnot principle

Therefore, this claimed is unreasonable Answer

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2) An air conditioning system is used to maintain a house at a constant temperature of  $26^\circ\text{C}$ . The house is gaining heat from outdoors at a rate of  $20,000 \text{ kJ/h}$ , and the heat generated in the house from the people, lights, and appliances amounts to  $8,000 \text{ kJ/h}$ . For a COP of 2.5, determine the required power input to this air conditioning system. (5 Marks)

**System:** Air Conditioner: a heat pump

**Analysis:**

$$\text{COP}_R = \dot{Q}_L / \dot{W}_{\text{net}}$$

**Solution:**

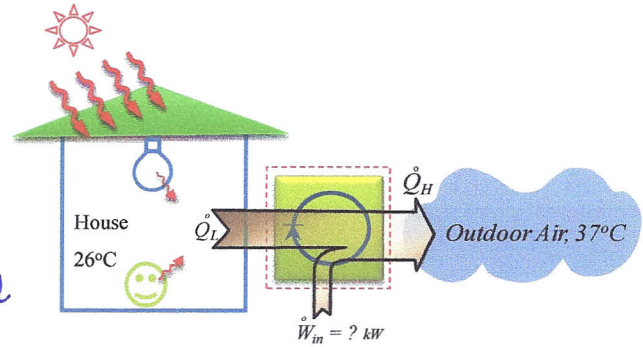
$$\dot{Q}_L = \dot{Q}_{\text{gained}} + \dot{Q}_{\text{generated}}$$

$$= (20,000 \text{ kJ/h}) + (8,000 \text{ kJ/hr})$$

$$= 28,000 \frac{\text{kJ}}{\text{h}} \times \frac{1}{3,600 \text{ s/h}} = 7.78 \text{ kW} \quad \triangleleft$$

$$\dot{W}_{\text{net}} = \frac{\dot{Q}_L}{\text{COP}}$$

$$= \frac{7.78 \text{ kW}}{2.5} = 3.11 \text{ kW}$$



The required power input is  $3.11 \text{ kW}$  Answer.

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3. A piston-cylinder device contains refrigerant-R-134a initially as saturated vapor at 400 kPa,  $0.5 \text{ m}^3$ . Heat is transferred from the refrigerant to the surroundings at  $35^\circ\text{C}$  until all of the refrigerant becomes saturated liquid. If the process occurred at constant pressure determine (a) the entropy change of the refrigerant, (b) the entropy change of the heat source, and (c) the total entropy change for this process. (d) does this process violates the principle of increase of entropy, why. (10 marks)

**System:** R-134a and the heat source

**Analysis:**

$$\begin{aligned} (a) \quad \Delta S_{\text{system}} &= m(s_2 - s_1) \\ (b) \quad \Delta S_{\text{source}} &= Q_o/T_o = -{}_1Q_2/T_o \\ (c) \quad \Delta S_{\text{total}} &= \Delta S_{\text{system}} + \Delta S_{\text{source}} \\ (d) \quad \Delta S_{\text{total}} &\geq 0 \end{aligned}$$

**Solution:**

Property of R-134a.  $\rightarrow$  Table A-15b

State 1 Sat. vap. at 2 MPa

$$v_1 = v_g = 0.0069 \text{ m}^3/\text{kg}, \quad h_1 = h_g = 279.17 \frac{\text{kJ}}{\text{kg}}, \quad s_1 = 0.8854 \frac{\text{kJ}}{\text{kgK}}$$

$$m = \frac{V_1}{v_1} = \frac{0.5 \text{ m}^3}{0.0069 \text{ m}^3/\text{kg}} = 72.46 \text{ kg}$$

State 2 Sat. liquid at  $P_2 = P_1 = 2.0 \text{ MPa}$

$$h_2 = h_f = 168.12 \frac{\text{kJ}}{\text{kg}}; \quad s_2 = s_f = 0.5687 \text{ kJ/kgK}$$

a) Entropy change of R-134a

$$\begin{aligned} \Delta S_{\text{sys}} &= m(s_2 - s_1) = 72.46 \text{ kg} (0.5687 - 0.8854) \frac{\text{kJ}}{\text{kgK}} \\ &= -22.9493 \text{ kJ/K} \quad \text{Answer} \end{aligned}$$

b) Entropy change of the surroundings

Control mass R-134a. 1<sup>st</sup> Law: Closed system.,  $P = \text{const.}$

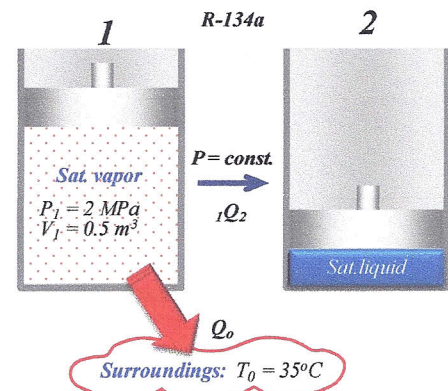
$${}_1Q_2 = m({}_1u_2 + (u_2 - u_1)) = m(h_2 - h_1)$$

$$= (72.46 \text{ kg})(168.12 - 279.17) \frac{\text{kJ}}{\text{kg}} = -8,047.1 \text{ kJ}$$

$$\Delta S_{\text{surroundings}} = \frac{-({}_1Q_2)}{T_o} = \frac{-(-8,047.1 \text{ kJ})}{(35 + 273) \text{ K}} = 26.13 \frac{\text{kJ}}{\text{K}} \quad \text{Ans}$$

$$c) \quad \Delta S_{\text{Total}} = (-22.95) + (26.13) = 3.18 \text{ kJ/K} \quad \text{Answer}$$

d) This process does not violate the principle of increase of entropy because  $\Delta S_{\text{Total}} > 0$  Answer



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4. Air enters an adiabatic turbine at 800°C and 1.5 MPa at a rate of 1.2 kg/s and exhausts at 200 kPa. If the power output of the turbine is 370 kW. Assume air is an ideal gas and uses constant specific heat at 900K, determine the isentropic efficiency of the turbine. (10 marks)

**System:** Air, SSSF process and adiabatic

**Assumptions:** Air is an ideal gas

constant specific heat

neglect  $\Delta KE$  and  $\Delta PE$

**Analysis:**

$$\eta_{\text{isentropic}} = w_a / w_s$$

**Solution:**

$$\begin{aligned} \text{actual work, } w_a &= \frac{\dot{W}}{\dot{m}} = \frac{370 \text{ kW}}{1.2 \text{ kg/s}} \\ &= 308.3 \text{ kJ/kg} \quad \Delta \end{aligned}$$

Find isentropic work,  $w_s$

Consider isentropic process ① → ②s

$$\frac{T_{2s}}{(P_2)^{(k-1)/k}} = \frac{T_1}{(P_1)^{(k-1)/k}}$$

$$T_{2s} = T_1 \left( \frac{P_2}{P_1} \right)^{(k-1)/k}$$

$$T_1 = (800 + 273) \text{ K} = 1073 \text{ K} \quad \Delta$$

$$\frac{P_2}{P_1} = \frac{200 \text{ kPa}}{1500 \text{ kPa}} = 0.1333$$

$$T_{2s} = (1073 \text{ K})(0.1333)^{0.2560} = 640.7 \text{ K} \quad \Delta$$

C.V. Turbine 1<sup>st</sup> law, SSSF (for isentropic process)

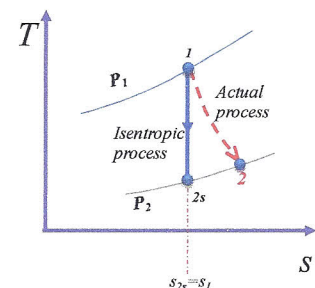
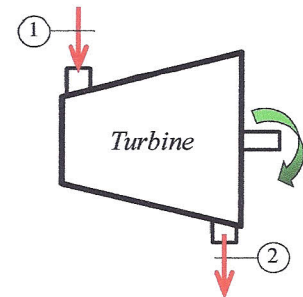
$$\cancel{q} + h_1 = w_s + h_{2s}$$

$$w_s = h_1 - h_{2s} = c_p(T_1 - T_{2s})$$

$$= (1.121 \text{ kJ/kgK})(1073 - 640.7) \text{ K} = 484.7 \text{ kJ/kg} \quad \Delta$$

$$\text{Isentropic efficiency, } \eta_{\text{isen}} = \frac{w_a}{w_s} \times 100\% = \frac{308.3}{484.7} \times 100\% = 63.62\%$$

Answer.



for Air

|                                     |
|-------------------------------------|
| Table A-2b at 900K                  |
| $C_p = 1.121 \text{ kJ/kgK}$        |
| $k = 1.344$                         |
| $\therefore \frac{k-1}{k} = 0.2560$ |