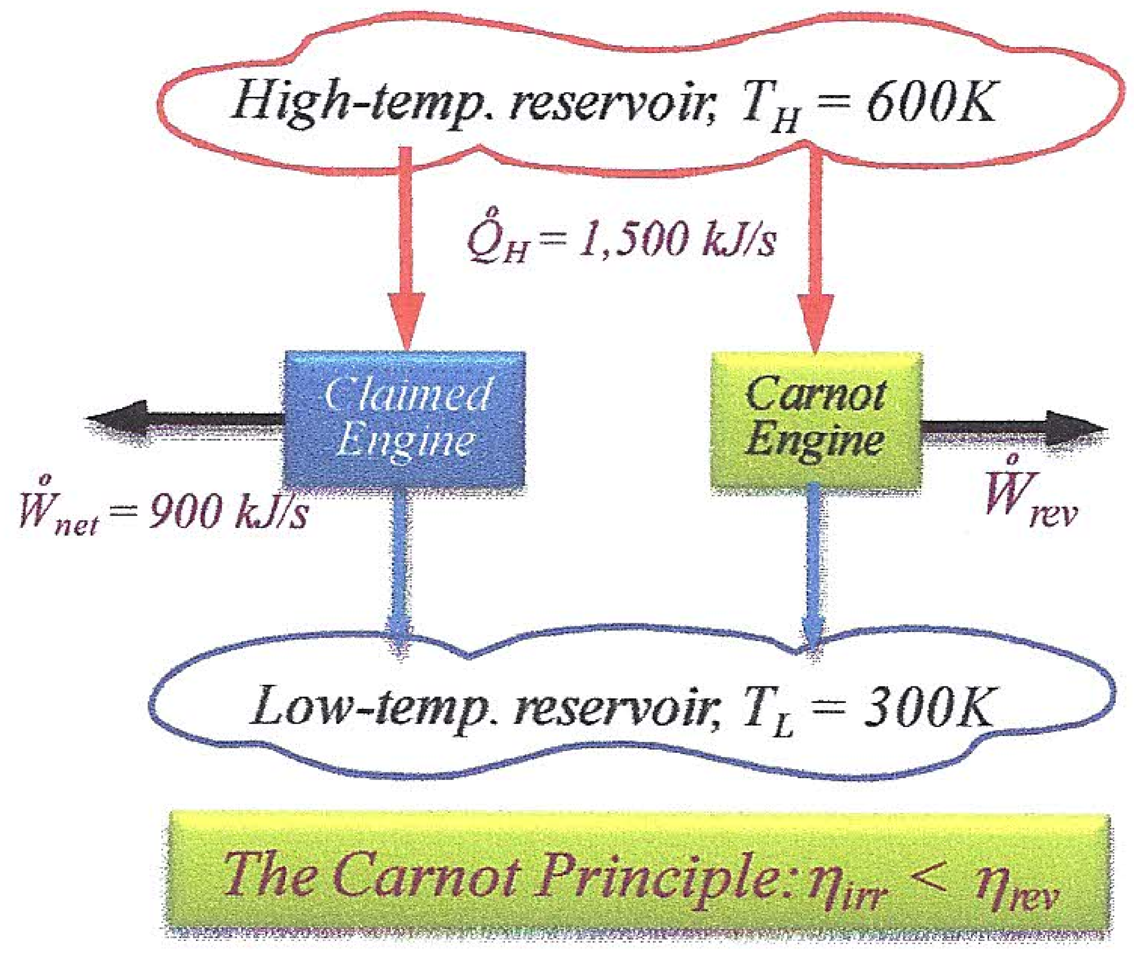
Thermodynamics I Section 1 *Test #3* *Saturday 28 August 2010 Time 1 hr 30 min*

เลขที่สอบ......... Name .... Sommai Priprem ....

Examiner: *Assoc.Prof.Sommai Priprem, PhD.*

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.

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_H} \times 100\%$$

$$= \frac{900 \text{ kW}}{1,500 \text{ kW}} \times 100\% = 60\% \quad \triangleleft$$

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

$$\eta_{rev} = 1 - \frac{T_L}{T_H} = 1 - \frac{300 K}{600 K} = 0.50$$

$$\text{or} = 50\% \quad \triangleleft$$

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

Therefore, this claimed is unresonable <u>Answer</u>

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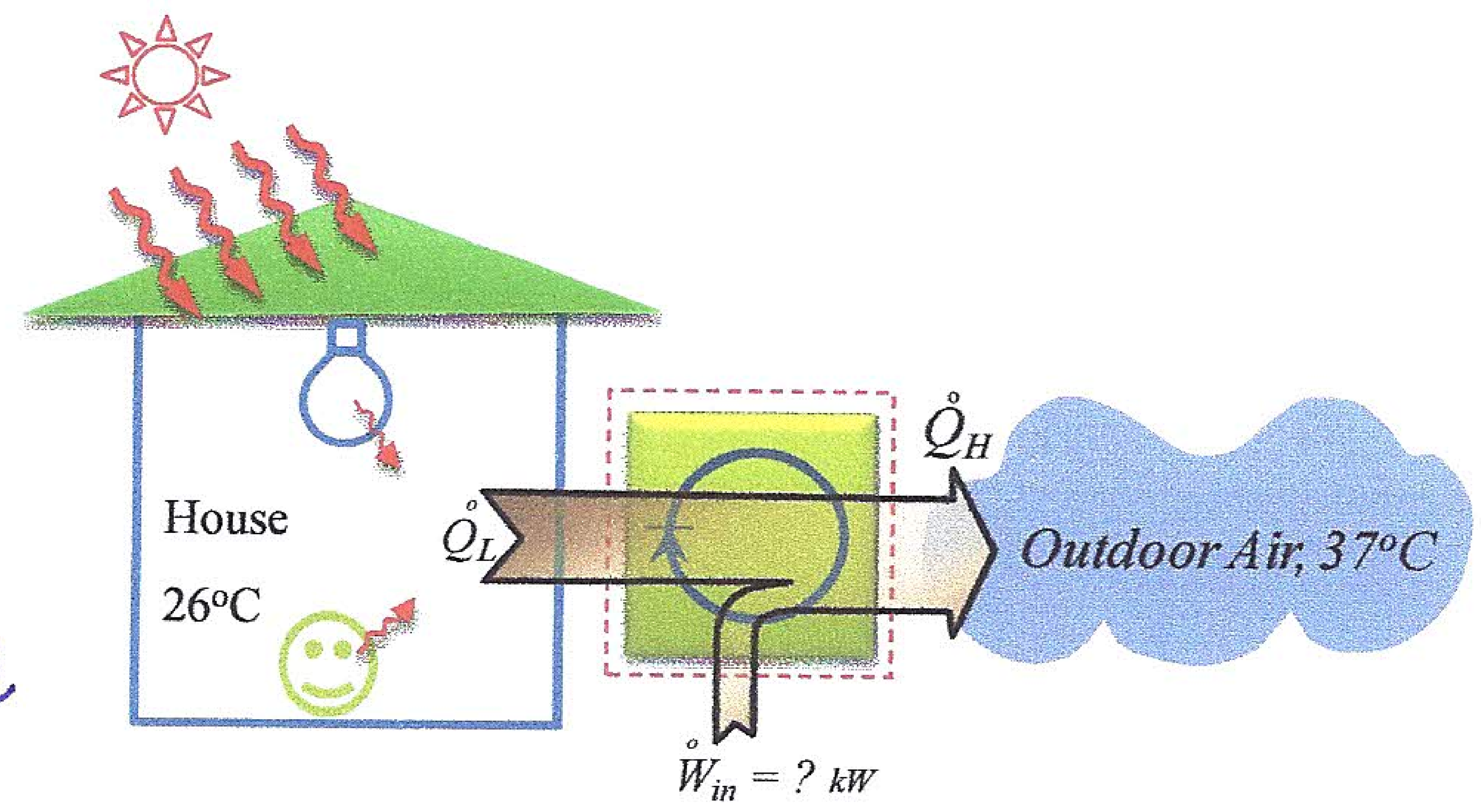
2) An air conditioning system is used to maintain a house at a constant temperature of 26°C. The house is gaining heat from outdoors at a rate of 20,000 kJ/h, and the heat generated in the house from the people, lights, and appliances amounts to 8,000 kJ/h. For a COP of 2.5, determine the required power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

System: Air Conditioner: a heat pump

Analysis:

$$COP_R = \dot{Q}_L / \dot{W}_{net}$$

Solution:



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

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

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

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

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

The required power input is 3.11 kW Answer.

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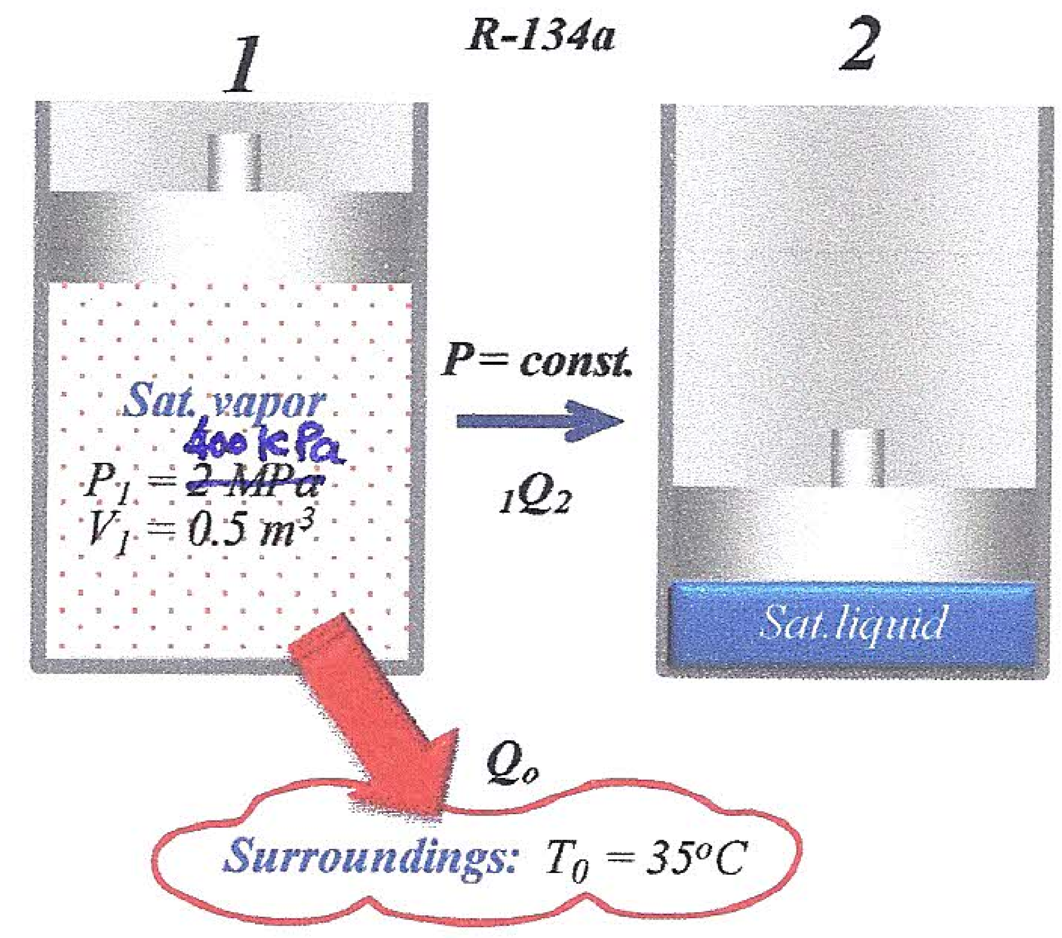
Question 1

3. A piston-cylinder device contains refrigerant-R-134a initially as saturated vapor at 400 kPa, 0.5m^3. Heat is transferred from the refrigerant to the surroundings at 35°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 surroundings, 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:

(a) $\Delta S_{system} = m(s_2 - s_1)$

(b) $\Delta S_{source} = Q_o/T_o = -{}_1Q_2/T_o$

(c) $\Delta S_{total} = \Delta S_{system} + \Delta S_{source}$

(d) $\Delta S_{total} \geq 0$

Solution:

Table A-15b. Sat. R-134a

State 1 Sat. vap @ 400 kPa

$v_1 = v_g = 0.0509\ m^3/kg$, $h_1 = h_g = 252.32\ kJ/kg$, $s_1 = s_g = 0.9145\ kJ/kgK$.

$m = \dfrac{V}{v_1} = \dfrac{0.5\ m^3}{0.0509\ m^3/kg} = \underline{9.8232\ kg}$

State 2 Sat liq. @ 400 kPa

$h_2 = h_f = 62.00\ kJ/kg$, $s_2 = s_f = 0.2399\ kJ/kgK$.

(a) Entropy change of R-134a, $\Delta S_{sys} = m(s_2 - s_1)$

$\Delta S_{sys} = (9.8232 kg)(0.2399 - 0.9145) kJ/kgK = \underline{-6.6267\ kJ/K}$ Answer

(b) Control mass R-134(a) 1st law: Closed system, P = const

${}_1Q_2 = m[{}_1w_2 + (u_2 - u_1)] = m[(P_2v_2 + u_2) - (P_1v_1 + u_1)] = m(h_2 - h_1)$

$= (9.8232 kg)(62.0 - 252.32) kJ/kg = -1,869.6\ kJ$.

$\Delta S_{surr} = \dfrac{Q_o}{T_o} = \dfrac{-{}_1Q_2}{T_o} = -\dfrac{(-1,869.6\ kJ)}{(273+35)\ K} = \underline{6.06996\ kJ/K}$ Answer

(c) $\Delta S_{total} = \Delta S_{sys} + \Delta S_{surr} = (-6.6267) + (6.06996)$

$= \underline{-0.5568\ kJ/K}$ Answer

(d) This process violates the principle of increase of enthropy.
Because $\Delta S_{total} < 0$, therefore it is impossible to occur.

[Fact: R-134a @ 400 kPa, T_{sat} = 8.93°C < T_{surr} (35°C) ⇒ heat should transfers from surroundings to R-134a]

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Question 2

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3. A piston-cylinder device contains refrigerant-R-134a initially as saturated vapor at ~~400 kPa;~~ 2MPa 0.5m^3. Heat is transferred from the refrigerant to the surroundings at 35°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

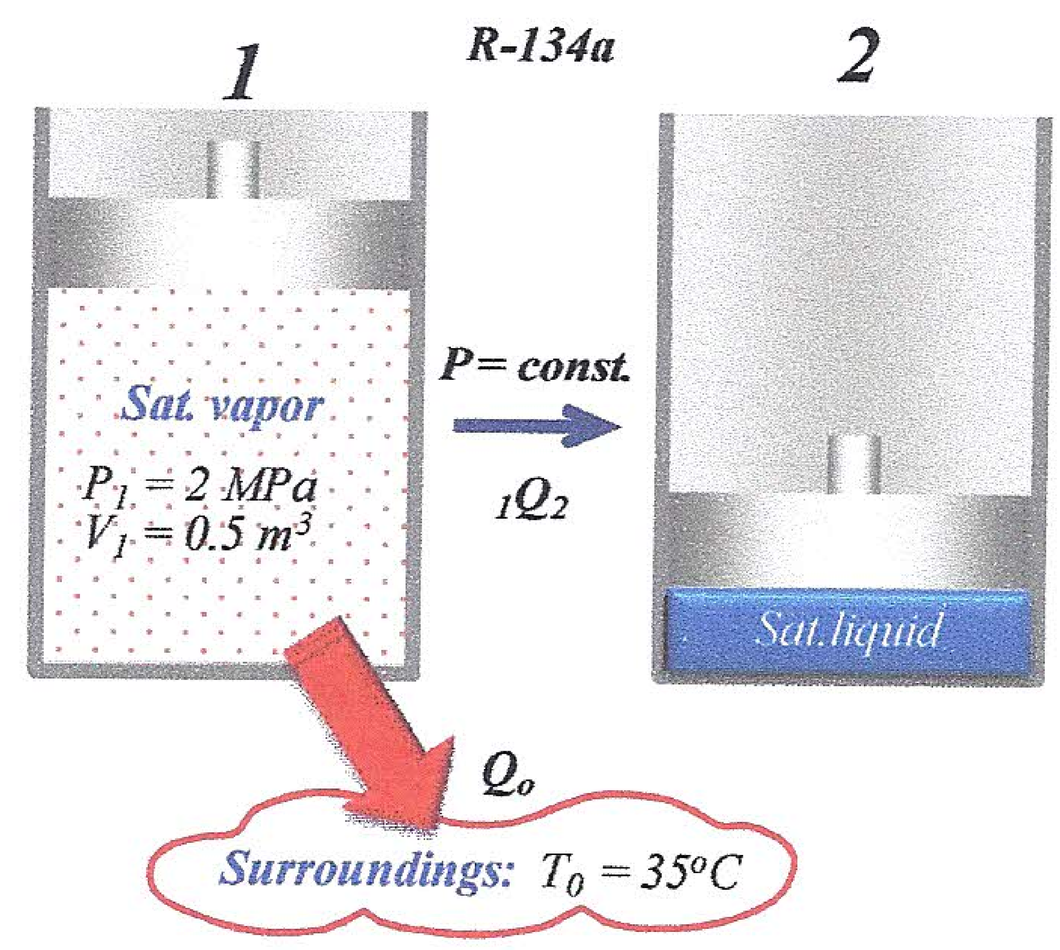
Analysis:

(a) $\Delta S_{system} = m(s_2 - s_1)$

(b) $\Delta S_{source} = Q_o/T_o = -{}_1Q_2/T_o$

(c) $\Delta S_{total} = \Delta S_{system} + \Delta S_{source}$

(d) $\Delta S_{total} \geq 0$



Solution:

Property of R-134a → Table A-15b

State 1   Sat. vap. at 2 MPa

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

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

State 2   Sat. liquid at $P_2 = P_1 = 2.0$ MPa

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

a) Entropy change of R-134a

$\Delta S_{sys} = m(s_2 - s_1) = 72.46 \text{ kg} (0.5687 - 0.8854) \frac{kJ}{kgK}$

$= -22.9493$ kJ/K   Answer

b) Entropy change of the surroundings

Control mass R-134a. 1st law: Closed system., P=const.

${}_1Q_2 = m({}_1w_2 + (u_2 - u_1)) = m(h_2 - h_1)$

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

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

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

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

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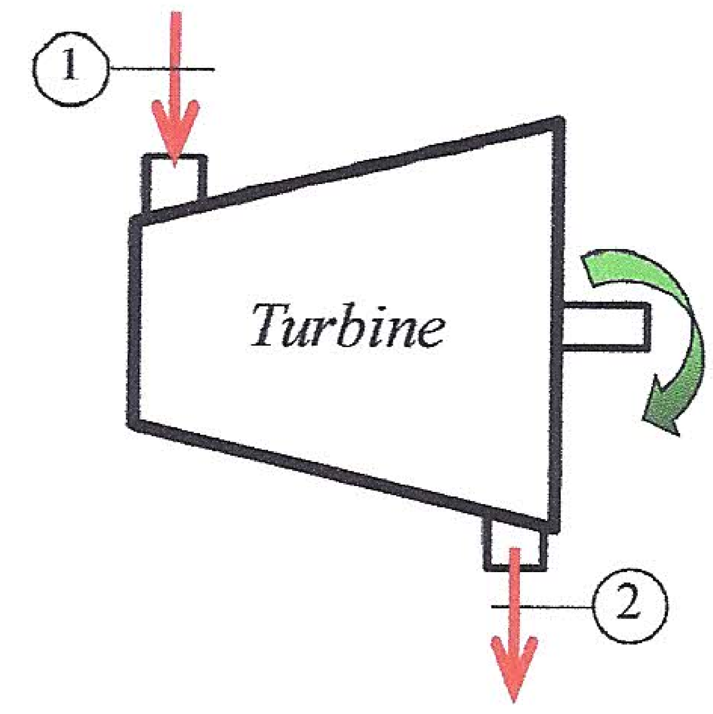
4. Air enters an adiabatic turbine at 800°C and 1.5 MPa at a rate of 1.2 kg/s and exhausts at 200 kPa. If the power output of the turbine is 370 kW. Assume air is an ideal gas and uses constant specific heat at 900K, determine the isentropic efficiency of the turbine. (10 marks)



System: Air, SSSF process and adiabatic

Assumptions: Air is an ideal gas

constant specific heat

neglect ΔKE and ΔPE

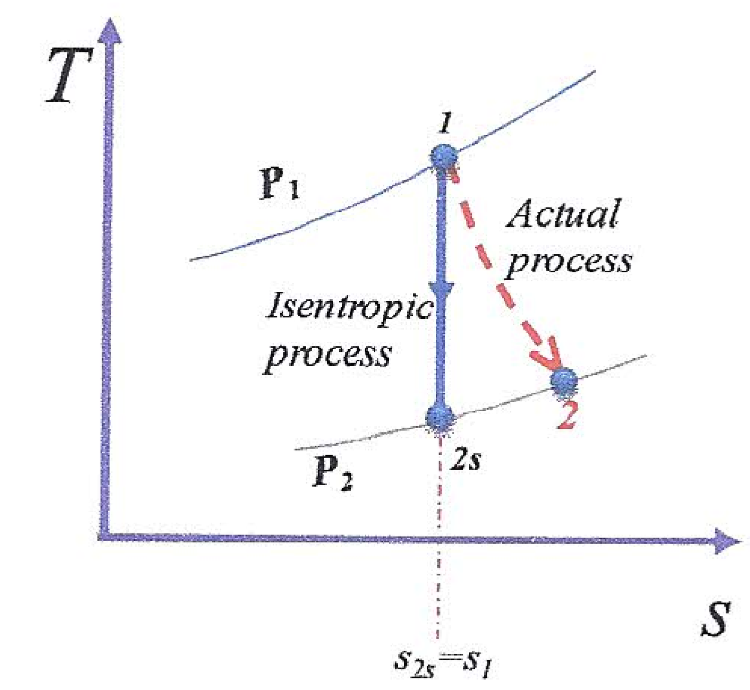
Analysis:

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

Solution:

actual work, $w_a = \dfrac{\dot{W}}{\dot{m}} = \dfrac{370\text{ kW}}{1.2\text{ kg/s}}$

$= 308.3\text{ kJ/kg}$ ◁



Find isentropic work, w_s

Consider isentropic process ① → ②s

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

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

for Air

Table A-2b at 900K

$c_p = 1.121\text{ kJ/kgK}$

$k = 1.344$

$\therefore \dfrac{k-1}{k} = 0.2560$

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

$\dfrac{P_2}{P_1} = \dfrac{200\text{ kPa}}{1{,}500\text{ kPa}} = 0.1333$

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

C.V. Turbine 1st law, SSSF (for isentropic process)

$\cancel{q}^{\,0} + h_1 = w_s + h_{2s}$

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

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

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

Answer.