ex> 3.1

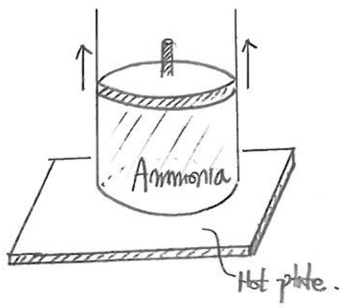
포화증기, 0.1lb → 수직형 피스톤 실린더 장치.
암모니아

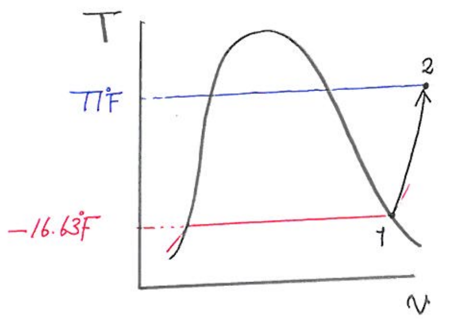
초기 압력 : 20 lbf/in²

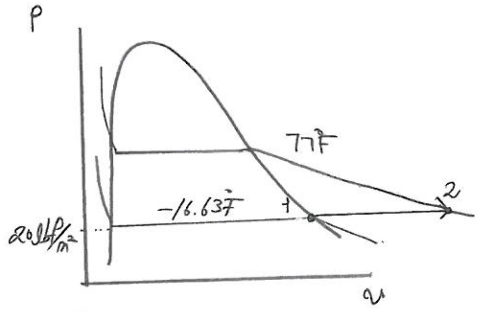
점점 가열되며, 일정한 압력하에서 최종온도가 77F 까지 팽창!

a> 최종부피 (ft³)

b> 일량 (Btu)







Table> A-15E

20lbf/in²에서의 $T_{sat} = -16.63F$

a>

상태1

$$V_1 = m v_1 = m \cdot v_g = (0.1 lb) \times (13.497 ft^3/lb) = 1.35 ft^3$$

Table> A-14E

$P_1 = 20 lbf/in^2 \rightarrow v_g = 13.497 ft^3/lb$

상태>2 과증기!

Table> A-15E → $P_2 = 20 lbf/in^2$ →
$T_2 = 77°F$

T	v (ft³/lb)
T= 70F	16.436
T= 77F	x
T= 80F	16.765.

$$\frac{77-70}{80-70} = \frac{x-16.436}{16.765-16.436} \rightarrow x = v_2 = 16.663 ft^3/lb$$

$$\therefore V_2 = m \cdot v_2 = (0.1 lb) \cdot (16.663 ft^3/lb) = 1.67 ft^3$$ Ans.

b>

$$W = \int_{V_1}^{V_2} P dV = P(V_2 - V_1)$$

$$= (20 lbf/in^2) \cdot (1.67 - 1.35) ft^3 \cdot \left| \frac{144 in^2}{1 ft^2} \right| \cdot \left| \frac{1 Btu}{778 ft \cdot lbf} \right|$$

$$= 1.18 Btu$$ Ans.

Example > 3-3

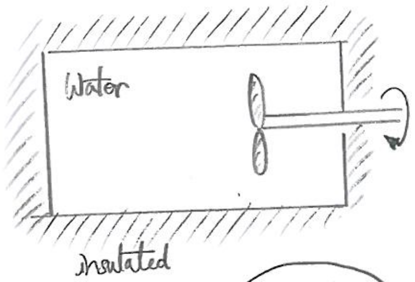
절연된 탱크 : $V_1 = 10\,ft^3$ ⟶ 급하게 휘저어서 ⟶ $P_2 = 20\,lbf/in^2$ 이 될때까지!

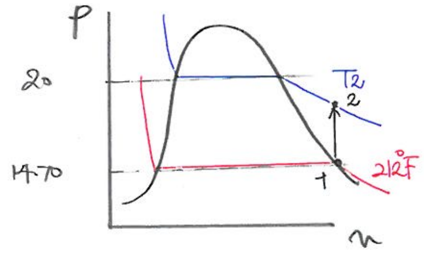
$T_1 = 212°F$

(포화수증기).

* < $T_2 = ?$ (°F)

$W = ?$ (Btu)





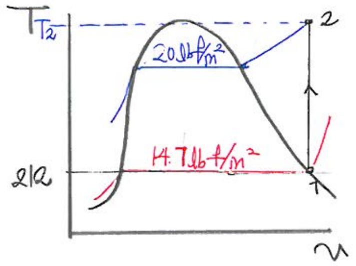


Table > A-2E ⟶ $T_1 = 212F$ ⟶ $P_1 = 14.70\,lbf/in^2$

a> T_2 : $v_1 = v_2$ 의 특징을 이용!

Table > A-2E ⟶ $T_1 = 212°F$ ⟶ $v_1 = v_g = 26.80\,ft^3/lb$

$u_1 = u_g = 1077.6\,Btu/lb$

Table > A-4E ⟶

	v (ft^3/lb)	u (Btu/lb)
$T = 400°F$	23.90	1145.1
$T = x$	25.43	y
$T = 500°F$	28.46	1181.5

$$\frac{x-400}{500-400} = \frac{25.43-23.90}{28.46-23.90} = \frac{y-1145.1}{1181.5-1145.1}$$

$\therefore x = T_2 = 445°F$ Ans.

$\therefore y = u_2 = 1161.6\,Btu/lb$

b> W : energy balance.

$$\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = \cancel{Q} - W.$$

$$W = -(U_2 - U_1) = -m(u_2 - u_1) \leftarrow m = \frac{V_1}{v_1} = \frac{10\,ft^3}{26.80\,ft^3/lb} = 0.373\,lb$$

$$= -(0.373\,lb) \times (1161.6 - 1077.6)\,Btu/lb$$

$$= -31.3\,Btu$$

Ans.

Example > 3.8 공기를 이상기체로 간주한 사이클.

피스톤 실린더 장치내부 : 1lb의 공기.

1~2 과정 : 정적 $\quad T_1 = 540°R$, $P_1 = 1atm$ → $P_2 = 2atm$

2~3 과정 : 등온 팽창.

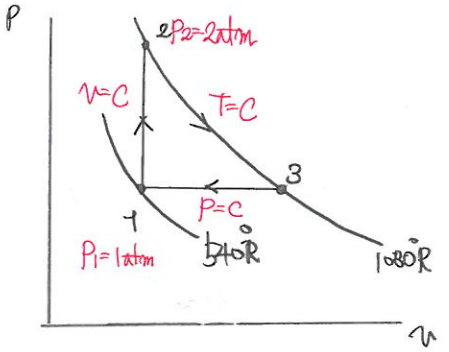
3~1 과정 : 정압 압축.

a> P-v 선도에 사이클을 그려라.

b> 상태 2 에서의 온도 (°R)를 구하라

c> 상태 3 에서의 비체적 (ft^3/lb)을 구하라.

a>



b> $Pv = RT$

$$T_2 = \frac{P_2 v_2}{R} \leftarrow v_2 = v_1 = \frac{RT_1}{P_1} \quad (\because 정적)$$

$$= \frac{P_2}{\cancel{R}} \cdot \frac{\cancel{R} T_1}{P_1} = \frac{P_2}{P_1} T_1$$

$$= \left(\frac{2atm}{1atm}\right) \cdot (540°R) = 1080°R$$ Ans.

c> $Pv = RT \rightarrow v_3 = \frac{RT_3}{P_3} \leftarrow$ $T_2 = T_3$. ($\because$ 등온팽창), $P_3 = P_1$ ($\because$ 정압 압축), $R = \bar{R}/M$

↓

$$v_3 = \frac{\bar{R} \cdot T_2}{M P_1}$$

$$= \left[\frac{1545\left(\frac{ft \cdot lbf}{lbmol \cdot °R}\right)}{28.97 \frac{lb}{lbmol}}\right] \cdot \frac{(1080°R)}{(14.7\ lbf/in^2)} \left|\frac{1ft^2}{144in^2}\right| = 27.2\ ft^3/lb$$ Ans.

↑ 공기의 분자량 : Table > A-1E

Example> 3.9

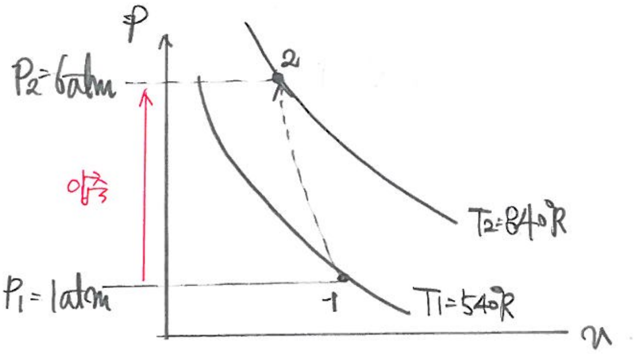
압축되는 중 공기에서 주위로 20Btu의 열전달.

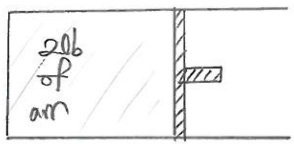
$T_1 = 540°R \longrightarrow T_2 = 840°R$

$P_1 = 1atm \qquad P_2 = 6atm$ (압축)

$m = 2lb$ (공기) · 피스톤-실린더

* 이상기체모델을 이용하여 과정 중 일 (Btu)을 구하라.





< Energy Balance >

$$\boxed{\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U = Q - W.}$$

$$W = Q - \Delta U$$

$$= Q - m(u_2 - u_1)$$

$$= (-20\ Btu) - (2lb)\cdot(143.98 - 92.04)\ Btu/lb$$

$$= -123.9\ Btu$$

Ans.

Table> A-22E Ideal Gas Properties of Air

$T_1 = 540°R \rightarrow u_1 = 92.04\ Btu/lb$

$T_2 = 840°R \rightarrow u_2 = 143.98\ Btu/lb.$

⊖ 부호는 과정 중, 일이 시스템에 한것!

시스템이 압축과정을 통해 일을 받았다. ☆☆

Problem> 3.96

* Determine the final temperature and pressure.

★★ 이 문제에서 사용된 가정은 T_2 미지의 C_v의 결정!
350K~450K로 아주 큰 범위의 온도가 아니므로 괜찮다!

- Ideal Gas Specific Heats of Some Common Gases.

< Air: $C_v = 0.726$ ← 400K
CO2: $C_v = 0.750$ ← 400K

350K와 400K의 평균인 400K를 사용 ★★★

1.

온도를 찾기 위해서!

< Energy Balance >

$$\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U = \cancel{Q} - \cancel{W}$$

$$\Delta U = m_{air}\Delta u_{air} + m_{CO_2}\Delta u_{CO_2}$$

$$= m_{air}\cdot C_{v,air}(T_2 - T_{1,air}) + m_{CO_2} + C_{v,CO_2}\cdot(T_2 - T_{1,CO_2}) \quad \leftarrow \quad du = C_v dT$$

$$= 0$$

$$\therefore T_2 = \frac{m_{air}\cdot C_{v,air}\cdot T_{1,air} + m_{CO_2}\cdot C_{v,CO_2}\cdot T_{1,CO_2}}{m_{air}\cdot C_{v,air} + m_{CO_2}\cdot C_{v,CO_2}} = \frac{(1kg)\cdot(0.726\ kJ/kg\cdot K)\cdot(350K) + (3)\cdot(0.750)\cdot(450)}{(1kg)\cdot(0.726\ kJ/kg\cdot K) + (3)\cdot(0.750)}$$

$$= \underline{425.6\ K} \text{ Ans.}$$

2.

압력을 찾기 위해서!

$$PV = n\bar{R}T$$

V 부터 구하자.

$R_{,air} = \dfrac{\bar{R}\ (\text{공통기체상수})}{M\ (\text{분자량})}$, $\bar{R} = 8.314\ kN\cdot m/kmol\cdot K$, $M_{air} = 28.97$ (분자량)

$$V_{1,air} = \frac{m_{air}\cdot R_{air}\cdot T_{1,air}}{P_{1,air}} = \frac{(1kg)\cdot\left(\frac{8.314}{28.97}\frac{kJ}{kg\cdot K}\right)\cdot(350K)}{(5\ bar)}\cdot\left|\frac{1\ bar}{10^5\ N/m^2}\right|\cdot\left|\frac{10^3\ N\cdot m}{1kJ}\right| = \underline{0.201\ m^3}$$

$$V_{1,CO_2} = \frac{m_{CO_2}\cdot R_{CO_2}\cdot T_{1,CO_2}}{P_{1,CO_2}} = \frac{(3)\cdot\left(\frac{8.314}{44.01}\right)\cdot(450)}{(2)}\left|\frac{10^3}{10^5}\right| = \underline{1.275\ m^3}$$

$$\therefore V_{total} = 0.201 + 1.275 = \underline{1.476\ m^3}$$

$$\therefore P_2 = \frac{n_{tot}\bar{R}T_2}{V_{tot}} = \frac{(n_{air}+n_{CO_2})\bar{R}T_2}{V_{tot}} \quad \leftarrow \quad n = \frac{m\ (\text{질량})}{M\ (\text{분자량})}$$

$$= \frac{[(m_{air}/M_{air}) + (m_{CO_2}/M_{CO_2})]\cdot\bar{R}\cdot T_2}{V_{tot}}$$

$$= \frac{\left[\left(\frac{1kg}{28.97\ kg/kmol}\right) + \left(\frac{3}{44.01}\right)\right]\cdot\left(8.314\frac{kJ}{kmol\cdot K}\right)(425.6K)}{(1.476\ m^3)}\left|\frac{10^3\ N\cdot m}{1kJ}\right|\left|\frac{1\ bar}{10^5\ N/m^2}\right|$$

$$= \underline{2.462\ bar} \text{ Ans.}$$

★★추가! 기체는 왜 확산되는가?

irreversible process.

gas	vacuum
V	V

Joule expansion of ideal gas.

$$1\,\text{mole}\,(g, V, T) \xrightarrow{\text{adiabatic}} 1\,\text{mole}\,(g, 2V, T)$$

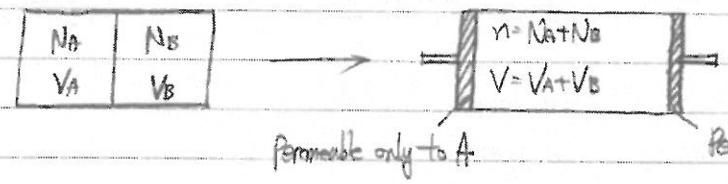
$$\Delta U = 0 = \delta q - \delta w \longrightarrow \delta q = \delta w$$

Reversible process : compress gas back to volume V isothermally irreversibly.

$\Delta U = 0$ $\quad \Delta S_{backward} = \int \frac{\delta q_{rev}}{T} = \int \frac{\delta w}{T} = \int_{2V}^{V} \frac{PdV}{T} = \int_{2V}^{V} \frac{R}{V} dV = R\ln\frac{1}{2}$

$\Delta S_{forward} = R\ln 2 > 0 \Rightarrow$ spontaneous !!!

★★추가! Mixing of ideal gases.



$$n_A A(g, V_A, T) + n_B B(g, V_B, T) \longrightarrow (n_A A + n_B B)(g, V, T)$$

reversible compression and "demixing"

$\Delta S_{demix} = -\Delta S_{mix}$ $\quad \Delta U_{demix} = 0 = q_{rev} - w_{rev}$

$dW_{rev} = \cancel{-P_A dV_A} - P_B dV_B$

$$\Delta S_{demix} = \int \frac{\delta q_{rev}}{T} = \int_V^{V_A} \frac{P_A dV_A}{T} + \int_V^{V_B} \frac{P_B dV_B}{T} = n_A R \ln\frac{V_A}{V} + n_B R \ln\frac{V_B}{V}$$

Mole fraction $X_A = \frac{n_A}{n} = \frac{V_A}{V}$, $X_B = \frac{n_B}{n} = \frac{V_B}{V}$

$$\Delta S_{demix} = nR(X_A \ln X_A + X_B \ln X_B)$$

$$\Delta S_{mix} = -nR(\underbrace{X_A \ln X_A}_{\ominus} + \underbrace{X_B \ln X_B}_{\ominus}) > 0$$

$\therefore \Delta S_{mix} > 0$

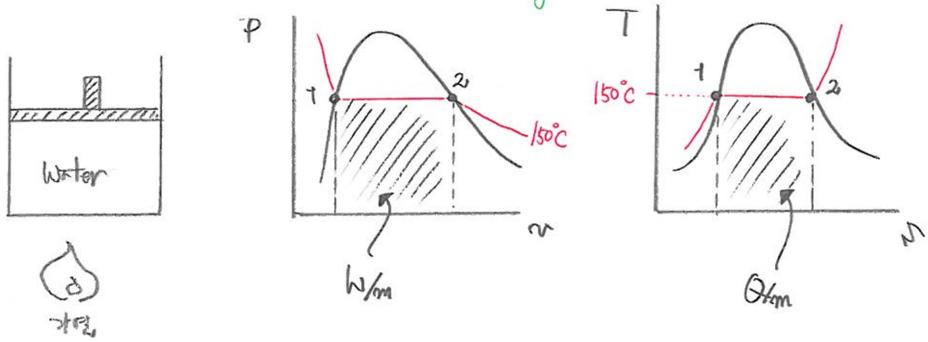
$(\because 0 < X_A, X_B : \text{fraction} < 1)$

Example > 6.4 ~~컴퓨터 부품의~~ 냉각

150°C (423.15K) 인 포화액체(물) → 피스톤-실린더 장치 → 포화증기 상태이다.

* 물을 가열하여 정압·등온하에서 내부가역과정

단위질량당의 일과 열전달량 [kJ/kg]을 구하라.



< 정압과정에서 일 > $W/m = \int_1^2 p\,dv = p(v_2 - v_1)$

Table > A-2 → $T = 150°C$ → $v_f = 1.0905 \times 10^{-3}\ m^3/kg$, $p = 4.758\ bar$

$v_g = 0.3928\ m^3/kg$

$$\therefore W/m = (4.758\,bar)(0.3928 - 1.0905 \times 10^{-3}) \left|\frac{m^3}{kg}\right| \cdot \left|\frac{10^5\ N/m^2}{1\ bar}\right| \cdot \left|\frac{1\ kJ}{10^3\ N \cdot m}\right|$$

$$= 186.38\ kJ/kg$$ Ans.

< 열전달량 > $Q = \int_1^2 T\,dS = m\int_1^2 T\,ds$

$Q/m = T(s_2 - s_1)$

Table > A-2 → $T = 150°C$ → $s_f = 1.8418\ kJ/kg \cdot K$

$s_g = 6.8379\ kJ/kg \cdot K$

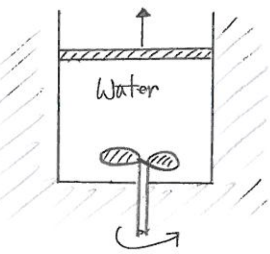
$$\therefore Q/m = (423.15K) \cdot (6.8379 - 1.8418)\ kJ/kg \cdot K = 2114.1\ kJ/kg$$ Ans.

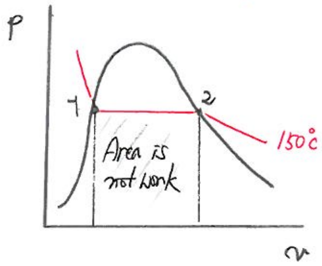
Example > 6.2 물의 비가역 과정.

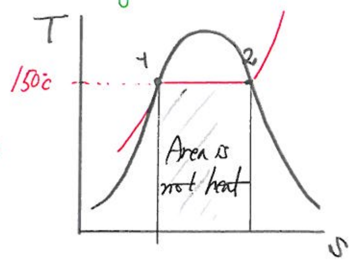
초기 상태 = 150°C
포화액체 (물) : 피스톤-실린더 장치 → 상태변화가 휘젓기차의 교란작용에 의해 이루어짐. 같은 온도의 포화증기로 상태변화.

(주위와의 열전달 X)

* 단위질량당 일 [kJ/kg], 단위질량 당 엔트로피 생성량 [kJ/kg·K] ?







이전의 예제 > 6.1 은 상태변화가 열전달에 의해 이뤄지며, 내부가역과정을 거친다.
→ 엔트로피 생성값 0

그러나 6.2는 변화과정 중, 비가역성이 존재.
→ 엔트로피 생성값 > 0.

초기 및 최종 상태가 동일 압력 / 온도에서 평형상태일지라도, 중간의 변화과정 (intervening state) 중에

압력과 온도가 전 시스템에 걸쳐 반드시 균일할 수 X (일정할 수 X)

→ ∴ 경로가 존재하지 X → 변화 상태가 없었을 뿐 면적과는 관계가 X

→ p-v 면적 : 일과 관련 X
T-s 면적 : 열전달과 관련 X.

< Energy Balance >

$$\boxed{\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = \cancel{Q} - W} \rightarrow W/m = -(u_2 - u_1)$$

Table > A-2 → T = 150°C → $u_f = 631.68$ kJ/kg, $u_g = 2559.5$ kJ/kg

∴ $W/m = -1927.82$ kJ/kg Ans.

음의 부호는 휘젓기차에 의한 입력일이 물의 팽창에 의한 일보다 더 크다는 것을 의미.

< Entropy Balance >

$$\boxed{\Delta S = \int_1^2 \cancel{\left(\frac{\delta Q}{T}\right)_b} + \sigma} \rightarrow \sigma/m = s_2 - s_1$$

∵ 열전달 X

$= 4.9961$ kJ/kg·K Ans.

Table > A-2 → T = 150°C → $s_f = 1.8418$ kJ/kg·K, $s_g = 6.8379$ kJ/kg·K

Example> 6.6 증기터빈 내에서의 엔트로피 생성

$\begin{cases} \text{압력 } 30\,bar \\ \text{온도 } 400^\circ C \\ \text{속도 } 160\,m/s \end{cases}$

증기 → 터빈으로 유입.

포화증기로

유출되는 상태 : $\begin{cases} \text{온도} = 100^\circ C \\ \text{속도} = 100\,m/s \end{cases}$

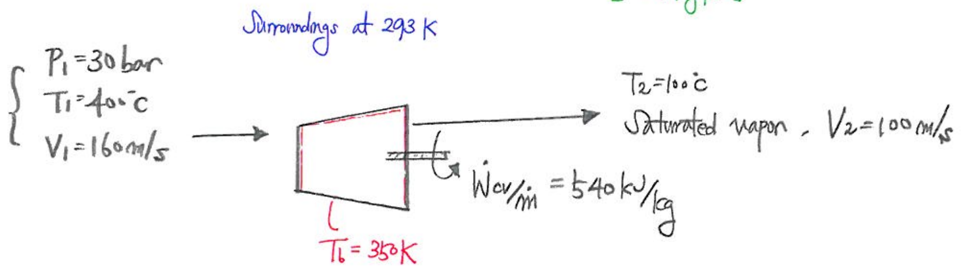
표면 외부표면온도 = 350K.

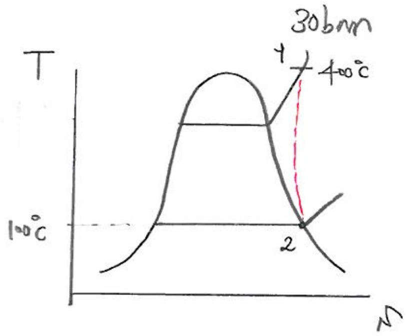
정상상태에서 터빈은

540kJ/kg 의 일을 발생.

* 흐르는 증기 kg 당 터빈내부에서 생성되는 엔트로피를 계산하라.

[kJ/kg·K]





< 정상상태에서 검사체적에 관한 질량과 엔트로피율 평형식 >

$$\boxed{\begin{cases} \dot{m}_1 = \dot{m}_2 \\ 0 = \sum_j \dfrac{\dot{Q}_j}{T_j} + \dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{\sigma}_{cv} \end{cases}}$$

$$\therefore 0 = \frac{\dot{Q}_{cv}}{T_b} + \dot{m}(s_1 - s_2) + \dot{\sigma}_{cv}$$

$$\frac{\dot{\sigma}_{cv}}{\dot{m}} = -\frac{\dot{Q}_{cv}/\dot{m}}{T_b} + (s_2 - s_1)$$

Table> A-2 → $T_2 = 100^\circ C$ → $s_g = s_2 = 7.3549\,kJ/kg$

Table> A-4 → $\begin{cases} P_1 = 30\,bar \\ T_1 = 400^\circ C \end{cases}$ → $s_1 = 6.9212\,kJ/kg$

< 정상상태에서 검사체적에 관한 질량과 에너지율 평형식 >

$$\boxed{\cancel{\frac{dE_{cv}}{dt}} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i\right) - \dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e\right)}$$

$$\frac{\dot{Q}_{cv}}{\dot{m}} = \frac{\dot{W}_{cv}}{\dot{m}} + (h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) = (540\,kJ/kg) + (2676.1 - 3230.9)(kJ/kg) + \left(\frac{100^2 - 160^2}{2}\right)\left(m^2/s^2\right) \cdot \left|\frac{1N}{1kg\cdot m/s^2}\right| \cdot \left|\frac{1kJ}{10^3 N\cdot m}\right|$$

$$= 540 - 554.8 - 7.8 = -22.6\,kJ/kg$$

Superheated

Table> A-4 → $\begin{cases} P_1 = 30\,bar \\ T_1 = 400^\circ C \end{cases}$ → $h_1 = 3230.9\,kJ/kg$

Table> A-2 → $T_2 = 100^\circ C$ → $h_g = h_2 = 2676.1\,kJ/kg$

$$\therefore \frac{\dot{\sigma}_{cv}}{\dot{m}} = -\frac{(-22.6\,kJ/kg)}{(350\,K)} + (7.3549 - 6.9212)\left(\frac{kJ}{kg\cdot K}\right) = 0.0646 - 0.4337 = 0.498\,kJ/kg\cdot K$$

Ans.

Direction of Entropy

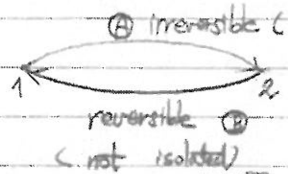
$\int_1^2 \frac{\delta Q}{T} + \int_2^1 \frac{\delta Q}{T})_{rev} \le 0.$

$\int_1^2 \frac{\delta Q}{T} + S_1 - S_2 \le 0.$

$dS = S_2 - S_1 \ge \int_1^2 \frac{\delta Q}{T}$

. 비가역과정에서의 Entropy : ↑

Isolated system : irreversible process.



→ any process (spontaneous)

* when it was isolated, it spontaneously irreversible

ex, ice – melting ($T > 0°$)

Ⓑ δ irrev = 0 reversibly melt. ← put the system in contact

it won't isolated anymore.

For the cycle : $\oint \frac{\delta Q}{T} \le 0$ (in fact < 0)

$= \cancel{\int_1^2 \frac{\delta Q}{T})_{irrev}} + \int_2^1 \frac{\delta Q}{T})_{rev} \le 0$

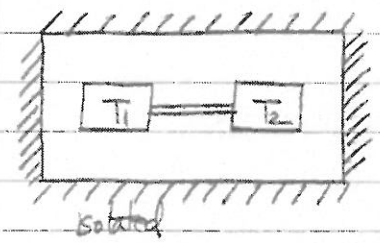
∵ isolated

(ΔS : showing direction of change)

$\int_2^1 \frac{\delta Q_{rev}}{T} = S_1 - S_2 = \Delta S_{backward} = -\Delta S_{forward} < 0$ ∴ $S_{forward} \ge 0$ ★

Isolated system :
- $\Delta S > 0$ irrev process
- $\Delta S = 0$ rev process
- $\Delta S < 0$ rever X.

연미기출★★★ 자발적인 열전달은 반드시 높은 온도에서 낮은 온도의 방향으로 흐른다 증명하시오.



isolated system

$\Delta U = 0$

$dS = dS_1 + dS_2 = \frac{\delta Q_1}{T_1} + \frac{\delta Q_2}{T_2} = \delta Q_1 \left(\frac{T_2 - T_1}{T_1 T_2}\right)$ ★

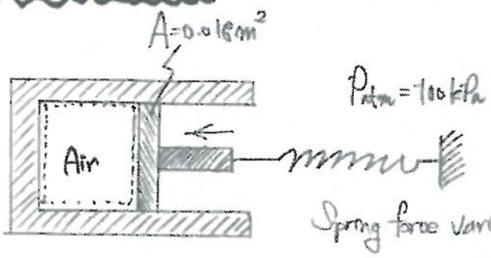
($\delta Q_1 = -\delta Q_2$) ★

$\Delta S > 0$ for the spontaneous change

if, T_2 = hotter → $\delta Q_1 > 0$: $T_1 \leftarrow T_2$

T_2 = cooler → $\delta Q_1 < 0$: $T_1 \rightarrow T_2$

Problem> 2.31

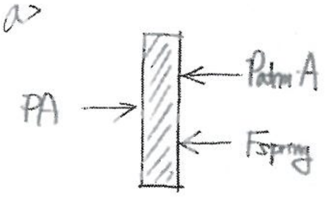


Spring force varies linearly from 900N when $V_1 = 0.003m^3$ to zero when $V_2 = 0.002m^3$

공기가 초기체적 0.003m²에서 최종체적 0.002m³으로 서서히 압축 과정중 스프링은 초기 900N에서 최종값 0으로 선형적으로 변하면서 힘을 가함.

* 공기의 경우 초기 최종압력 (kPa), 일(kJ)을 구하라.

a>



$PA = P_{atm} A + F_{spring}$ ★

· Initially : $F_{spring} = 900N$

$P_1 A = P_{atm} A + F_{spring}$ ★

$P_1 = P_{atm} + F_{spring}/A$

$= (100kPa) + \frac{(900N)}{(0.018m^2)} \times \left| \frac{1kPa}{10^3 N/m^2} \right| = 150kPa$ Ans.

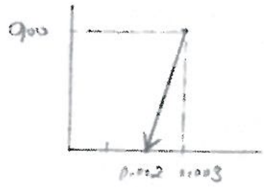
· Finally : $F_{spring} = 0 \rightarrow P_2 = 100kPa$ Ans.

b> $W = \int_{V_1}^{V_2} p\,dV$,

0.003 0.002

$V_1 \longrightarrow V_2$

$F_{spring} : 900 \rightarrow 0$



$\therefore F_{spring} = \frac{+900}{0.001}(V - 0.002)\ N$ ★

★

$W = \int_{V_1}^{V_2} \left(P_{atm} + \frac{F_{spring}}{A} \right) dV$

$= \int_{V_1}^{V_2} \left[(100kPa) + \frac{(\frac{+900}{0.001})N}{(0.018m^2)} \cdot \frac{(V - 0.002)}{10^3} \right] dV$

$= \int_{V_1}^{V_2} \underline{100 + 50000(V - 0.002)}\, dV = \frac{50000}{2} V^2 \Big]_{V_1}^{V_2}$

$= +50000V \cancel{+100} \cancel{-100}$

$= \frac{50000}{2}(0.002^2 - 0.003^2) \times \left| \frac{10^3 N/m^2}{1kPa} \right| \times \left| \frac{1kJ}{10^3 N/m^2} \right|$

$= -0.125\ kJ$ Ans.

4.100 Well-insulated piston-cylinder

air supply at 100 lbf/in², 80F.

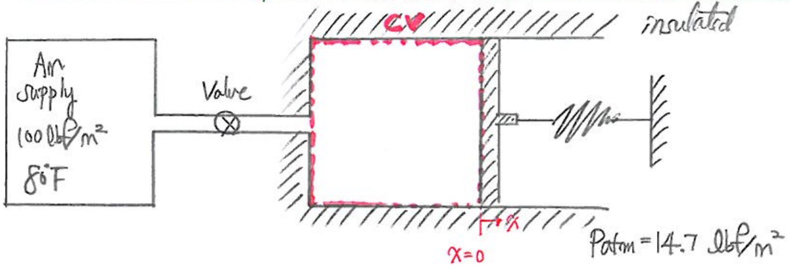
$F = kx$.
ideal gas model
no friction.

$P_1 = 14.7\ \text{lbf/in}^2$
$T_1 = 80°F$
$V_1 = 0.1\ \text{ft}^3$

$V_2 = 0.4\ \text{ft}^3$

$P_{atm} = 14.7\ \text{lbf/in}^2$
$A_{piston} = 0.22\ \text{ft}^2$

* Plot the final pressure, in lbf/in² and the final temperature, in °F ($k = 650 \sim 750\ \text{lbf/ft}$)



$$\boxed{P \cdot A_{piston} = P_{atm} \cdot A_{piston} + kx}$$

$$P = P_{atm} + kx / A_{piston} \quad \longleftarrow \quad F = kx = k \cdot (V - V_1) / A_{piston}$$

$$= P_{atm} + \frac{k(V - V_1)}{A_{piston}^2}$$

$$V = V_2 \rightarrow P_2 = P_{atm} + \frac{k(V_2 - V_1)}{A_{piston}^2}$$

$$= (14.7\ \text{lbf/in}^2) + \frac{k \cdot (0.4 - 0.1)\ \text{ft}^3}{0.22^2\ \text{ft}^4} \cdot \left| \frac{1\ \text{ft}^2}{144\ \text{in}^2} \right|$$

$$= 14.7 + 0.043k \ (\text{lbf/in}^2)$$

< Energy rate Balance >

$$\boxed{\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}_i\left(h_i + \cancel{\frac{V_i^2}{2}} + \cancel{gz_i}\right) - \cancel{\dot{m}_o}\left(h_o + \cancel{\frac{V_o^2}{2}} + \cancel{gz_o}\right) = \frac{dU_{cv}}{dt}}$$

← CV에 in 밖에 없으므로!

$$\frac{dU_{cv}}{dt} = \cancel{\dot{Q}_{cv}} - \dot{W}_{cv} + \dot{m}_i h_i \quad \leftarrow \text{insulated}$$

$$\therefore \Delta U_{cv} = -W_{cv} + \int_1^2 h_i \, dm_{cv}$$

$$m_2 u_2 - m_1 u_1 = -W_{cv} + h_i (m_2 - m_1) \quad \longleftarrow \quad W_{cv} = \int_{V_1}^{V_2} P \, dV$$

$$= \int_{V_1}^{V_2} \left[P_{atm} + \frac{k(V - V_1)}{A_{piston}^2} \right] dV.$$

$$= \int_{V_1}^{V_2} \left[\left(P_{atm} - \frac{kV_1}{A_{piston}^2} \right) + \frac{kV}{A_{piston}^2} \right] dV$$

$$= P_{atm}(V_2 - V_1) - \frac{kV_1}{A_{piston}^2}(V_2 - V_1) + \frac{k}{2A_{piston}^2}(V_2^2 - V_1^2)$$

$$= P_{atm}(V_2 - V_1) + \frac{k}{A_{piston}^2} \left\{ -V_1 V_2 + V_1^2 + \frac{V_2^2}{2} - \frac{V_1^2}{2} \right\}$$

$$= \frac{1}{2}V_1^2 - V_1 V_2 + \frac{V_2^2}{2} = \frac{1}{2}(V_1 - V_2)^2.$$

$$W_{cv} = P_{atm}(V_2 - V_1) + \frac{k}{2A_{piston}^2}(V_1 - V_2)^2.$$

$$= (14.7\ \text{lbf/in}^2) \cdot \left| \frac{144\ \text{in}^2}{1\ \text{ft}^2} \right| \cdot (0.3\ \text{ft}^3)$$

$$+ \frac{k\ (\text{lbf/ft})}{2\ (0.22\ \text{ft}^2)} \cdot (0.3\ \text{ft}^3)^2 \cdot \left| \frac{1\ \text{Btu}}{778\ \text{ft} \cdot \text{lbf}} \right|$$

$$= \left[0.816 + (1.195 \times 10^{-3})k \right]\ \text{Btu}$$

$$m_1 = \frac{P_1 V_1}{R T_1} = \frac{(14.7 \times 144 \ lbf/ft^2) \cdot (0.1 \ ft^3)}{\left(\frac{1545}{28.97} \left| \frac{ft \cdot lbf}{lb \cdot R} \right|\right) \cdot (540 R)} = \underbrace{7.35 \times 10^{-3} \ lb}$$

$$m_2 = \frac{P_2 V_2}{R T_2} \longleftarrow \underbrace{P_2 = 14.7 + 0.043 k_r}$$

$h(540 R)$

$$m_2 u_2 - m_1 u_1 = -W_{cv} + h_i (m_2 - m_1) \quad Ans.$$

$u(T_2)$ $u(540 R)$

$$\underbrace{0.816 + (1.195 \times 10^{-3}) k.}$$

5.19 A Power cycle : $527^\circ C \sim 27^\circ C$.

For each case, determine if any principles of thermodynamics would be violated.

- a> $Q_H = 700\,kJ$, $W_{cycle} = 400\,kJ$, $Q_C = 300\,kJ$
- b> $Q_H = 640\,kJ$, $W_{cycle} = 400\,kJ$, $Q_C = 240\,kJ$
- c> $Q_H = 640\,kJ$, $W_{cycle} = 400\,kJ$, $Q_C = 200\,kJ$

a>

$$\eta = \frac{W_{cycle}}{Q_H} = \frac{400}{700} = 0.571 \rightarrow \underbrace{57.1\%}_{Ans.}$$

$$\eta_{max} = 1 - \frac{T_C}{T_H} = 1 - \frac{300}{800} = 0.625 \rightarrow \underbrace{62.5\%}_{Ans.}$$

∴ 열역학 제 2법칙을 만족!

$\eta < \eta_{max}$

b>

$$\eta = \frac{W_{cycle}}{Q_H} = \frac{400}{640} = 0.625 \rightarrow \underbrace{62.5\%}_{Ans.}$$

∴ 만족!

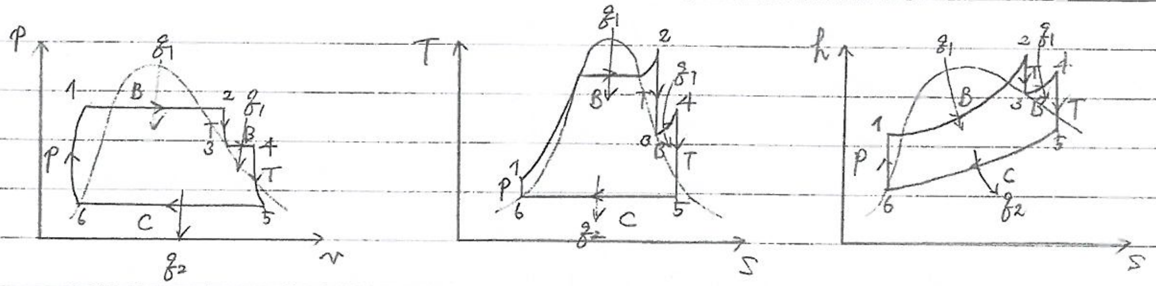
c>

$$W_{cycle} = Q_H - Q_C = 640 - 200 = \underline{440\,kJ} \longleftrightarrow$$ does not agree with the given value.

∴ 불만족!

Q. 재열사이클 (Reheat Cycle)에 대해 설명하시오.

Ans. Rankine Cycle의 열효율은 초온·초압을 올릴수록 증가한다.
그런데 초압을 높게 하면 터빈에서 팽창중에 증기의 건도가 저하되어 터빈의 날개를 부식시킨다.
그래서 재열사이클은 팽창일을 증대시키고, 터빈출구의 증기의 건도를 떨어뜨리지 않는 수단으로서 팽창도중에 증기를 뽑아내어 가열장치로 보내 재가열을 한 다음 터빈에 보내는 사이클이다.



i) 가열량 : $q_1 = (h_2 - h_1) + (h_4 - h_5)$

ii) 방열량 : $q_2 = h_5 - h_6$.

iii) 터빈일량 : $w_T = (h_2 - h_3) + (h_4 - h_5)$

iv) 펌프일량 : $w_p = h_1 - h_6$

* 열효율 $\eta_{Reh} = \dfrac{w_{net}}{q_1} = \dfrac{w_T - w_p}{q_1}$

$$= \frac{[(h_2 - h_3) + (h_4 - h_5)] - (h_1 - h_6)}{(h_2 - h_1) + (h_4 - h_3)}$$

if, 펌프일을 무시하면, $h_1 \approx h_6$.

$$\eta_{Reh} = \frac{(h_2 - h_3) + (h_4 - h_5)}{(h_2 - h_6) + (h_4 - h_5)}$$

* 개선율 : $\dfrac{\eta_{Reh} - \eta_R}{\eta_R} \times 100\ \%$

보일러의 압력↑ → 열효율도 증가, but 수분 함유량도 증가.

⇒ 해결방법.

1. 과열시킨다 → 금속재료학적 한계.

2. 터빈의 증기를 두단계로 팽창 → 재열단계를 추가!

그러나 단의 수를 너무 많게하면?

~ 이중재열은 과열배출이 일어날수 있다. → 방열의 평균온도 증가 → 효율은 감소.
(터빈입구의 압력이 높지 않다면)

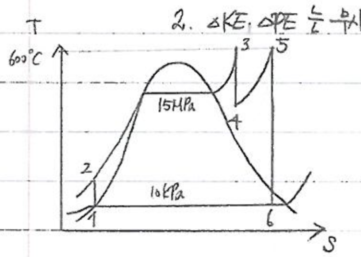
↳ 초임계압력 ($P > 22.09\,MPa$)의 발전소에서 주로 사용.

ex> 이상 재열 랭킨 사이클. 증기 = 15MPa, 600°C 에서 고압터빈으로 들어가서 10kPa의 압력으로 응축기에서 응축

터빈 출구에서 증기의 수분 함유량이 10.4%를 초과하지 않는다면, ⓐ 증기가 재열되어야 하는 압력 ⓑ 사이클의 열효율.

assumption> 1. 정상 유동상태가 존재한다.

2. ΔKE, ΔPE 는 무시한다



ⓐ 상태 6. $P_6 = 10\,kPa$, $x_6 = 0.896$ $\Rightarrow$ $h_6 = 2335.6\,kJ/kg$, $s_6 = 7.370\,kJ/kg\cdot K$

상태 5 $T_5 = 600°C$, $s_5 = s_6$ $\Rightarrow$ $P_5 = 4\,MPa$ Ans., $h_5 = 3674.4\,kJ/kg$

Ans. 수분함유량이 10.4% 이상되는 것을 막기위해 4MPa 또는 더 이하의 압력에서 재열.

ⓑ 상태 1 : $P_1 = 10\,kPa$, sat. liquid $\Rightarrow$ $h_1 = 191.83\,kJ/kg$, $v_1 = 0.001010\,m^3/kg$

상태 2 : $P_2 = 15\,MPa$, $s_2 = s_1$

$$w_{pump,in} = v_1(P_2 - P_1) = (0.001010\,m^3/kg)\left((15000-10)\,kPa\right)\left|\frac{1\,kJ}{1\,kPa\cdot m^3}\right| = 15.11\,kJ/kg$$

$$h_2 = h_1 + w_{pump,in} = (191.83 + 15.11)\,kJ/kg = 206.94\,kJ/kg$$

상태 3 : $P_3 = 15\,MPa$, $T_3 = 600°C$ $\Rightarrow$ $h_3 = 3582.3\,kJ/kg$, $s_3 = 6.6776\,kJ/kg\cdot K$

상태 4 : $P_4 = 4\,MPa$, $s_4 = s_3$ $\Rightarrow$ $h_4 = 3154.3\,kJ/kg$, $T_4 = 375.5°C$

$$q_{in} = (h_3 - h_2) + (h_5 - h_4) = \left((3582.3 - 206.94) + (3674.4 - 3154.3)\right)\,kJ/kg = 3895.46\,kJ/kg$$

$$q_{out} = h_6 - h_1 = (2335.6 - 191.83)\,kJ/kg = 2143.97\,kJ/kg$$

$$\eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{2143.97}{3895.46} = 0.45 = 45\%$$

Ans.

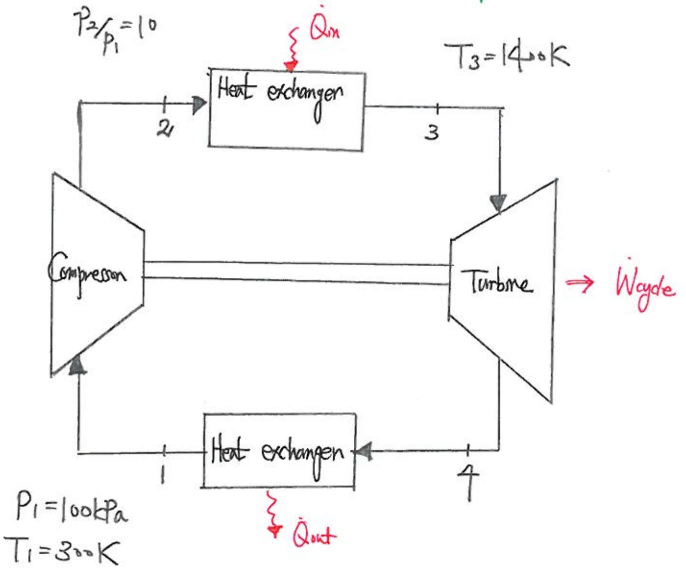
Example> 9.4 Analyzing the Ideal Brayton Cycle

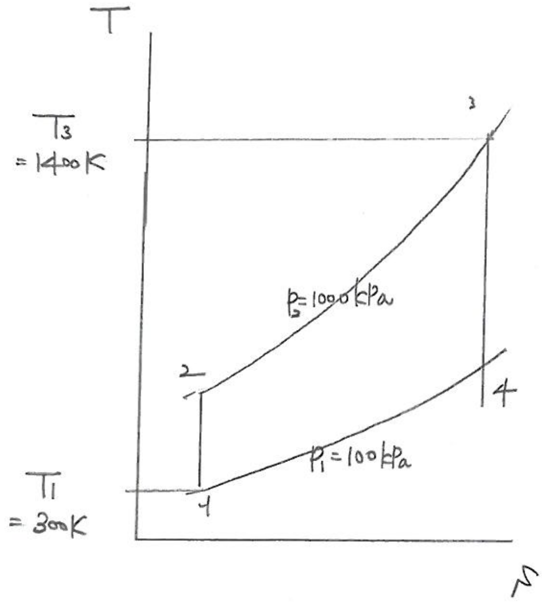
- Air enters the compressor (100 kPa, 300 K) ← $Q = 5\,m^3/s$
- The compressor pressure ratio = 10.
- Turbine inlet temperature is 1400 K

Determine a> the thermal efficiency of the cycle

b> the back work ratio

c> the net power developed [kW]





1. Table> A-22 ⟶ $T_1 = 300K$ ⟶ $h_1 = 300.19\ kJ/kg$, $P_{r1} = 1.386$

= Ideal Gas Properties of Air

2. $P_{r2} = P_{r1} \cdot \frac{P_2}{P_1} = (1.386)\cdot(10) = 13.86$ ⟶

h	P_r
575.59	13.50
x	13.86
586.04	14.38

⟶ $h_2 = 579.9\ kJ/kg$

3. Table> A-22 ⟶ $T_3 = 1400K$ ⟶ $h_3 = 1515.4\ kJ/kg$, $P_{r3} = 450.5$

4. $P_{r4} = P_{r3} \cdot \frac{P_4}{P_3} = (450.5)\cdot(\frac{1}{10}) = 45.05$ ⟶ $h_4 = 808.5\ kJ/kg$

a> $$\eta = \frac{(\dot{W}_t/\dot{m}) - (\dot{W}_c/\dot{m})}{\dot{Q}_{in}/\dot{m}} = \frac{(h_3-h_4)-(h_2-h_1)}{h_3-h_2} = \frac{(1515.4-808.5)-(579.9-300.19)}{1515.4-579.9}$$

$$= \frac{706.9-279.7}{935.5} = 0.457 = 45.7\%$$ Ans.

b> $$bwr = \frac{\dot{W}_c/\dot{m}}{\dot{W}_t/\dot{m}} = \frac{h_2-h_1}{h_3-h_4} = \frac{279.7}{706.9} = 0.396 = 39.6\%$$ Ans.

c)

$$\dot{W}_{cycle} = \dot{m}\left[(h_3-h_4)-(h_2-h_1)\right]$$

$$\dot{m} = \frac{Q_1}{v_1} \leftarrow v_1 = \frac{RT_1}{p_1} = \frac{(\bar{R}/M)T_1}{p_1}$$

$$= \frac{Q_1 \cdot p_1}{(\bar{R}/M)\,T_1}$$

$$= \frac{(5\,m^3/s)\cdot(100\times10^3\,N/m^2)}{\left(\frac{8314}{28.97}\cdot\frac{N\cdot m}{kg\cdot K}\right)\cdot(300K)} = \underline{5.807\ kg/s}$$

$$\therefore \dot{W}_{cycle} = (5.807\ kg/s)\cdot(706.9-279.7)\ (kJ/kg)\cdot\left|\frac{1\,kW}{1\,kJ/s}\right|$$

$$= \underline{2481\ kW}$$ Ans.

Example 9.6 Brayton Cycle with Irreversibilities.

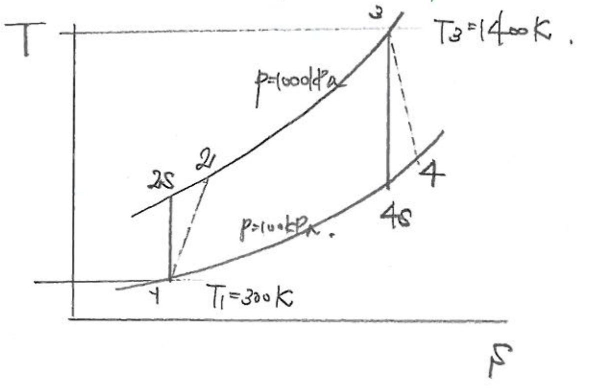
isentropic efficiency of 80%

Determine for the modified cycle

a) the thermal efficiency of the cycle

b) the back work ratio

c) the net power developed, in kW.



a) $\eta = \dfrac{(\dot W_t/\dot m) - (\dot W_c/\dot m)}{\dot Q_{in}/\dot m}$

$\boxed{\dfrac{\dot W_t}{\dot m} = \eta_t \left(\dfrac{\dot W_t}{\dot m}\right)_s}$ ← η_t: turbine efficiency.

$= (0.8)\cdot(706.9) = 565.5$ kJ/kg

$\boxed{\dfrac{\dot W_c}{\dot m} = \dfrac{(\dot W_c/\dot m)_s}{\eta_c}} = \dfrac{279.7}{0.8} = 349.6$ kJ/kg

$\dot W_c/\dot m = h_2 - h_1 \rightarrow h_2 = h_1 + \dot W_c/\dot m = 300.19 + 349.6 = 649.8$ kJ/kg

$\dot Q_{in}/\dot m = h_3 - h_2 = 1515.4 - 649.8 = 865.6$ kJ/kg

$\therefore \eta = \dfrac{565.5 - 349.6}{865.6} = 0.249 = 24.9\%$ Ans.

b) $bwr = \dfrac{\dot W_c/\dot m}{\dot W_t/\dot m} = \dfrac{349.6}{565.5} = 0.618 = 61.8\%$ Ans.

c) $\dot W_{cycle} = (5.807\ \text{kg/s})\cdot(565.5 - 349.6)\ \text{kJ/kg}\cdot\left|\dfrac{1\,\text{kW}}{1\,\text{kJ/s}}\right|$

$= 1254$ kW Ans.