

« ١٥٠٠٠ »

دکتر فرامرز

I am going to be a doctor

Smith, Van Ness

Van Wylen

□ فصول اول و دوم کتاب اسمیت و ون نس (فصول چھوٹے ون واپس):

امتی‌ها در مضمون با مروف کویک و امتی‌ها در کل با مروف بزرگ خامش داده می‌شوند.

اگر خصوصیات معضوضون با معروف بزرگ نمایش داده شوند به تناسب بین بر حسب حجم یا طول و کمیت های کل را بصورت  $mH$

$nH$  خامس فراهم داد. انزاع و آینه‌های جریان دار  $\left. \begin{matrix} \frac{1}{n} \\ \frac{1}{n} \end{matrix} \right\}$  غیر  $\frac{1}{n}$

$$x \text{ کیفیت} = \frac{\text{مقدار بخار اشباع}}{\text{مقدار کل مواد}} = 100 - x$$

- خصوصیات فاز مایع مستقر از فشار آن است.

در صورتی جوش ها به بخار در صورتیک ماده خالص موجود نبود به تعادلات حالت گازهای ایزو آل و در مرحله ی سرم به تعادلات حالت

گازها کی واقعی مراجعہ سے نسیم۔

$$\frac{dm_{cv}}{dt} = \sum_i \dot{m}_i - \sum_e \dot{m}_e$$

1- ستم با است و است و

۲- مقتوای سیستم صیبت؟ بنابر؟؛ باز آید آن؟ سیل واقعی؟

$$q + W_{\text{net}} = h_e - h_i \quad q = \frac{\dot{Q}}{\dot{m}}$$

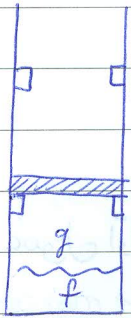
for Ideal gas:  $\Delta h = C_p^{ig} (T_i - T_e) = \int_{T_e}^{T_i} C_p^{ig} dT$

در سیستم های دوفازی / فانتیک یک فرمونت شبه مسطح باشد.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

برای گازهای ایده آل:  $\Delta h = \int_{T_1}^{T_2} C_p dT$   $\Delta U = m \int_{T_1}^{T_2} C_v dT$   $C_p = C_v + R$

مسئله:



مخلوط از مایع و بخار آب با کیفیت 0.2 و فشار 100 kPa در متوقف کننده‌ها

$$\begin{cases} h_t = (1-x)h_f + xh_g \\ u_t = (1-x)u_f + xu_g \\ v_t = (1-x)v_f + xv_g \end{cases} \rightarrow \text{در سیستم‌های بسته نیتری بیان نیست}$$

پایین قرار دارند

$$V_1 = 0.4 \text{ m}^3$$

برای حرکت پیستون به فشار 300 kPa نیاز داریم. پس سیستم را گرم کرده و به آن گرما می‌دهیم. هنگامی که فشار به استاندارد 300

می‌رسد و همچنان حجم ثابت است ولی پیستون به استاندارد حرکت قرار می‌گیرد. با ادامه دادن افزایش گرما پیستون به متوقف کننده‌ها

بالای خواهد رسید (فشار ثابت 300) و حجم به  $0.6 \text{ m}^3$  می‌رسد. دوباره با یک فرایند حجم ثابت آن چنان گرم

می‌دهیم که مخلوط به بخار اشباع کامل ( $x=1$ ) برسد. مطلوب است:  $W_t$ ,  $Q_t$ ,  $P_4$

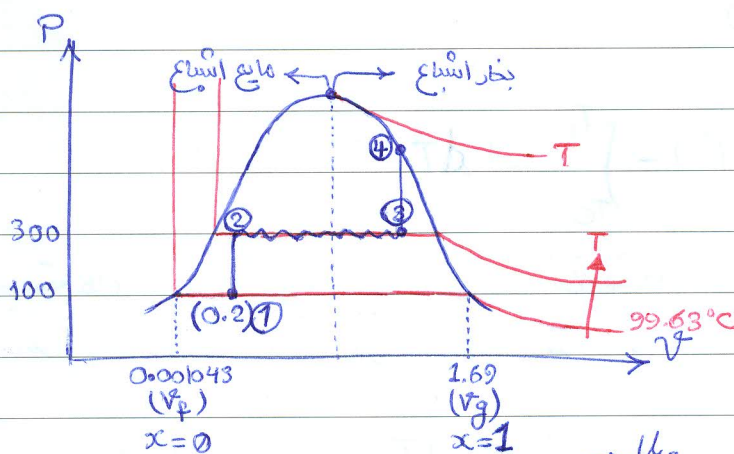
$$W_t = -P \Delta V = (-300)(0.2) = -60 \text{ kJ}$$

حل:

$$m = \frac{V \rightarrow \text{مقداری}}{v \rightarrow \text{نسبتی}} \quad \left\{ \begin{array}{l} m_1 = m_2 \\ v_1 = v_2 \end{array} \right\} \rightarrow v_1 = v_2 \quad \text{« در فرایند هم حجم »}$$

در هر مرحله نسبت و برابر ما معلوم است. با مشخص شدن یک خصوصیت شدنی دیگر همه حالت مشخص خواهد شد. آن خصوصیت

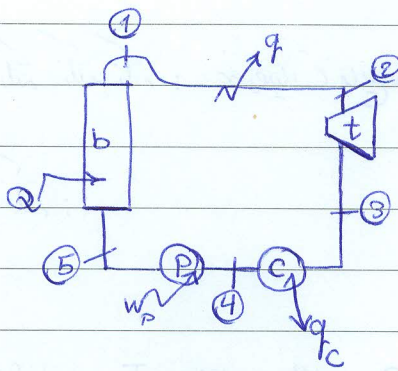
می‌تواند  $v$  (حجم مخصوص) یا  $x$  (کیفیت) در هر حالت باشد.



پیرامونی فرایندهای مسئله با توجه به نمودار:

$$Q_t + W = \Delta U = m \Delta u = m(u_4 - u_1) \rightarrow (1-x)u_f + xu_g$$

مثال:



pump } Adiabatic  
turbine }

$$W_{\text{pump}} = -4 \text{ kJ/kg}$$

location	P	T or x
①	2.0 MPa	300°C → تک فاز (مقد)
* ②	1.9 "	290°C → تک فاز
③	15 kPa	x = 0.9 → دو فاز
* ④	14 "	45°C

$$q_{\text{pipe}}, W_{\text{turbine}}, q_{\text{cond}}, q_{\text{boiler}} = ?$$

$$\begin{cases} Q - W_{\text{cv}} = h_e - h_i \\ W_{\text{cv}} = W_{\text{cv}} + W_{\text{flow}} \end{cases}$$

$$* \left\{ 1 \frac{\text{kJ}}{\text{kg}} = 1000 \frac{\text{m}^2}{\text{s}^2} \text{ practicality} \right\} **$$

$$q - W_{\text{cv}} = \underbrace{(h_e - h_i)}_{\text{kJ/kg}} + \underbrace{\frac{1}{2} (V_{e2}^2 - V_{e1}^2)}_{\text{m}^2/\text{s}^2} + \underbrace{g(z_e - z_i)}_{\text{m}^2/\text{s}^2}$$

قانون اول ترمودینامیک

$$Q_{\text{pipe}} - 0 = h_2 - h_1$$

$$0 - W_{\text{turbine}} = h_3 - h_2$$

$$Q_{\text{condenser}} - 0 = h_4 - h_3$$

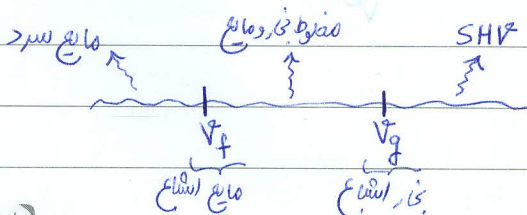
$$0 + 4 = h_5 - h_4$$

$$Q_{\text{boiler}} - 0 = h_1 - h_5$$

$$\text{given } T \rightarrow \begin{cases} P > P_{\text{sat}} & \text{CL} \\ P = P_{\text{sat}} & \text{sat Mix} \\ P < P_{\text{sat}} & \text{SHV} \end{cases}$$

$$\text{given } P \rightarrow \begin{cases} T > T_{\text{sat}} & \text{SHV} \\ T = T_{\text{sat}} & \text{sat Mix} \\ T < T_{\text{sat}} & \text{CL} \end{cases}$$

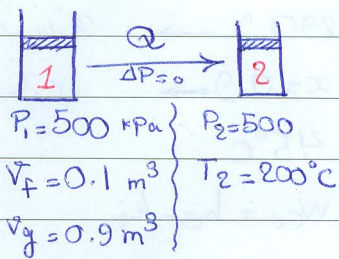
6.23 - 6.25 - 6.26 - 6.27 - 6.28 - 6.30 : تمرین هکولای



نکته: تغییرات حجم مخصوص

نکته: نکته: نکته: خصوصیات مایع سرد را تخمین میزنیم با خصوصیات مایع اشباع در همان دما.

نکته:  $\left\{ \begin{array}{ll} S_e = S_i & \text{isentropic} \\ h_e = h_i & \text{isenthalpic} \end{array} \right\}$  انتروپیک / آنتالپیک

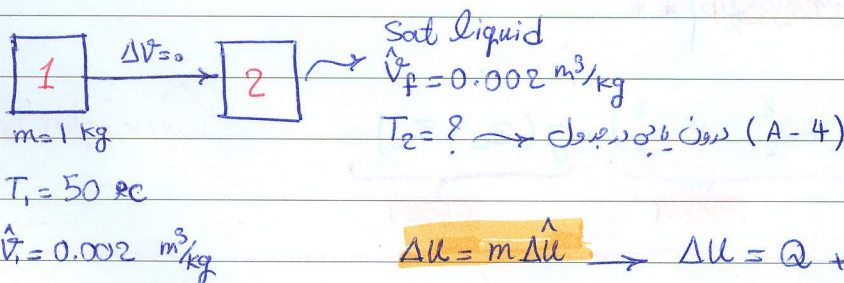


مثال:  $T_1$ ,  $m$ ,  $V_2$  و  $Q$  را محاسبه کنید.

$$T_1 = T_{\text{sat}} @ 500 \text{ kPa} = 151.86^\circ\text{C}$$

$$m_t = m_f + m_g = \frac{V_f}{\hat{V}_f} + \frac{V_g}{\hat{V}_g} = 23.89 \text{ kg}$$

$$V_f = m \hat{V}_f \rightarrow \hat{V}_f = 0.4249 \text{ m}^3/\text{kg}$$



مثال:  $T_2$  و  $Q$  را بیابید.

$$\Delta u = m \Delta \hat{u} \rightarrow \Delta u = Q + \dot{W}$$

کار = تغییر انرژی به شکل گرما یا کار.

$$\int_1^2 \delta W \neq W_2 - W_1 \quad \text{But} \quad \int_1^2 du = U_2 - U_1$$

کمیت تابع مسیر      کمیت تابع حالت

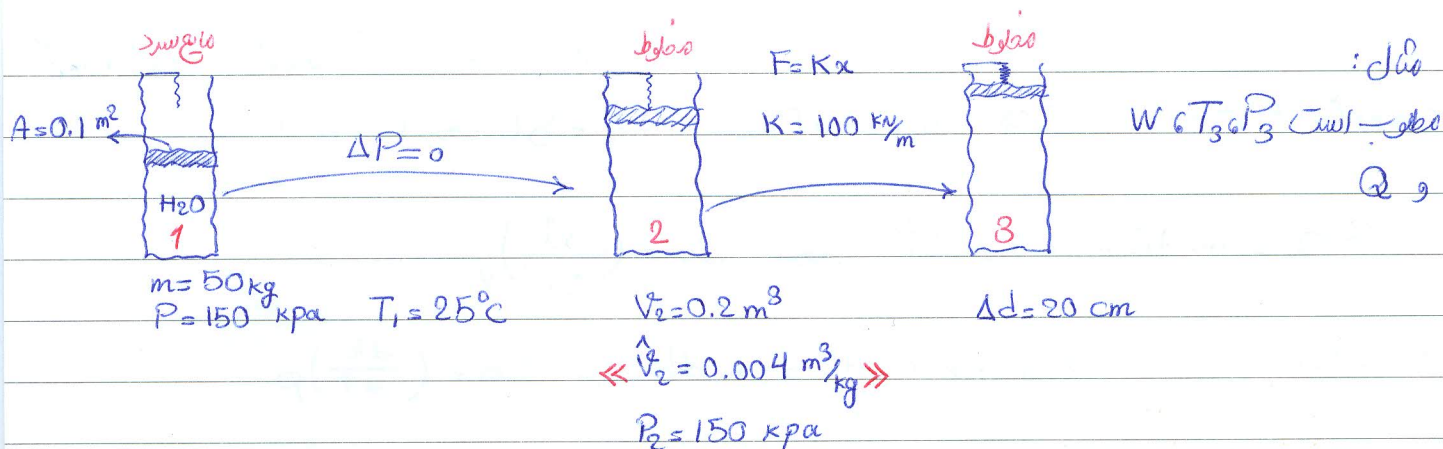
$$\delta W = F \cdot ds \rightarrow \delta W = P \Delta s = P dV \rightarrow W_{12} = \int_1^2 P dV$$

$$\ll 1 \text{ kPa} \cdot \text{m}^3 = 1 \text{ kJ} \gg$$

Isenthalpic expansion of an Ideal gas ( $\Delta T = 0$ ) : مثال

$$W_{12} = \int P dV = \int_1^2 mRT \frac{dV}{V} = mRT \ln \frac{V_2}{V_1} \ll P = \frac{mRT}{V} \gg$$

$$= mRT \ln \frac{\hat{V}_2}{\hat{V}_1} = mRT \ln \frac{P_1}{P_2}$$



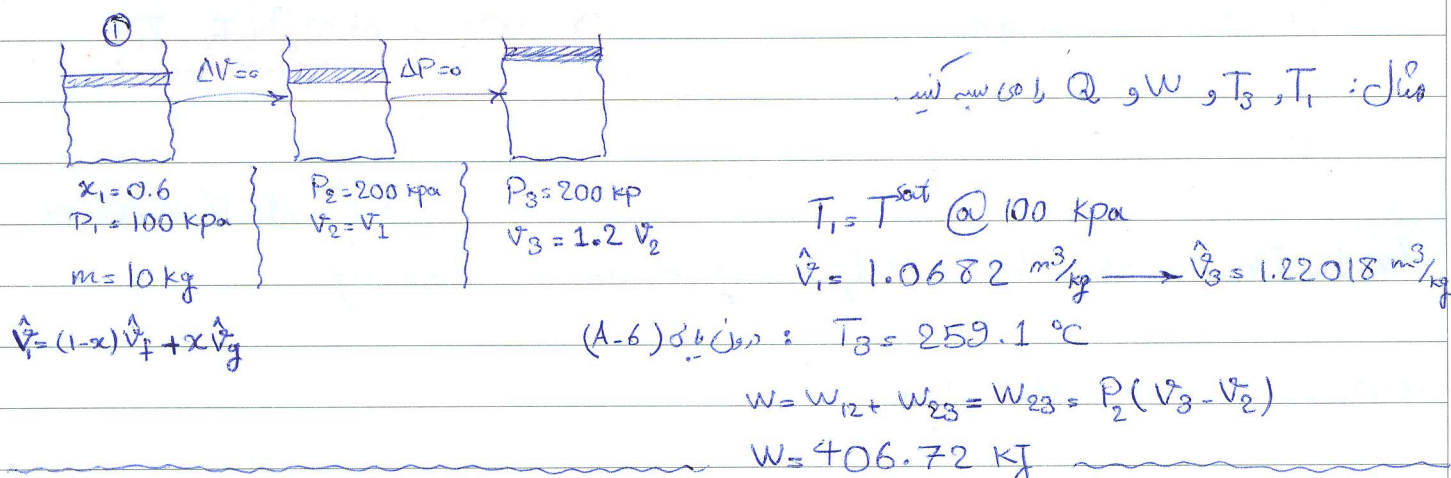
$$P_3 = P_2 + \frac{K \Delta d}{A} = 350 \text{ kPa} \rightarrow \begin{cases} V_3 = V_2 + A \Delta d = 0.22 \text{ m}^3 \\ \hat{V}_3 = 0.0044 \text{ m}^3/\text{kg} \end{cases}$$

نکته: دمای مخلوط مایع و بخار، اشباع (Sat) دمای اشباع است.  
 $T_3 = T_{\text{sat}} @ P_3 = 138.88^\circ\text{C}$

$$W_b = m \left[ P_1 (V_2 - V_1) + \frac{P_2 + P_3}{2} (V_3 - V_2) \right] = 27.5 \text{ kJ} \quad (1)$$

میانگین دما، انرژی درونی و دما در فرآیند

Ideal gas closed system:  $\text{const } V (w=0)$ ,  $\text{const } P (Q=\Delta H, w=-P\Delta V)$   
 $\text{const } T (\Delta U=0)$ ,  $\text{Adiabatic } (Q=0)$



$$\Delta P = 0 \Rightarrow Q - (P_2 V_2 - P_1 V_1) = U_2 - U_1 \Rightarrow Q = (U_2 + P_2 V_2) - (U_1 + P_1 V_1)$$

$$Q = H_2 - H_1 = \Delta H$$

گرمای ویژه: به ازای هر یک کیلوگرم و غیر ایده آل به قرار است

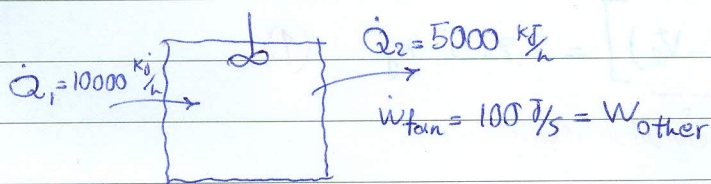
Constant  $V$ :  $\delta Q = m C_v dT \Rightarrow \delta Q = \delta U \Rightarrow U = m \hat{u}$

$$\delta Q = m d\hat{u} = m C_v dT \Rightarrow C_v = \left( \frac{\partial \hat{u}}{\partial T} \right)_v \quad (2)$$

Constant  $P$ :  $\delta Q = m C_p dT = m dh \Rightarrow C_p = \left( \frac{dh}{dT} \right)_p \quad (3)$

\*  $\Delta \hat{u} = \int_{T_1}^{T_2} C_v^{ig} dT$   $\Delta \hat{h} = \int_{T_1}^{T_2} C_p^{ig} dT$   $\left. \begin{array}{l} d\hat{u} = C_v^{ig} dT \\ dh = C_p^{ig} dT \end{array} \right\} \text{ only for Ideal gases } \quad (4)$

average  $C_p$ :  $\left\{ \begin{array}{l} C_p^{avg} = C_p @ \left( \frac{T_1 + T_2}{2} \right) \\ C_p^{avg} = \frac{C_p @ T_1 + C_p @ T_2}{2} \end{array} \right. \quad (5)$



$T_1 = 10^\circ\text{C}$   $T_2 = 20^\circ\text{C}$

$P_1 = 1 \text{ atm}$

$V = 4 \times 5 \times 7 \text{ m}^3$  Ideal gas

$Q - (W_v + W_o) = \Delta U$

$Q - W_{fan} = \Delta U = m(u_2 - u_1)$

$PV = \frac{m}{V} RT$

$Q - W_{fan} = m C_v^{ig} (T_2 - T_1)$   
 ← زمانی که  $C_v$  معطای ثابت باشد

شماره دو مسئله

step 1. Draw a sketch, identify the system and its Boundary

step 2. list given information

step 3. what do we know about the process? special cases, check process

Ticks

step 4. Draw a process diagram if ticks are available.

Step 5. what is the behavior of the substance? ideal gas...

Step 6. Analysis of Problem.

- mass-energy Balance
- identify heat and work term
- 2<sup>nd</sup> law statement, state assumption

Step 7. Solution Technique

- determination
- trial and error
- check units

$$\Delta S^{ig} = C_p^{ig} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} \quad (6)$$

معادله تغییرات انتروپی برای گاز ایده آل:

\* **Constant V:**  $W_b = 0$   $Q = m \int_{T_1}^{T_2} C_v^{ig} dT \quad (7)$   $Q = C_v \Delta T = \Delta U$

فرآیند هم‌حجم، هم‌انرژی:

\* **Constant P:**  $W_b = \int P dV = P_2 V_2 - P_1 V_1$   $Q = \Delta H = m \int_{T_1}^{T_2} C_p^{ig} dT \quad (8)$   $Q = C_p \Delta T = \Delta H$

\* **Constant T:**  $\Delta U = 0 \Rightarrow Q = W_b = m R T \ln \frac{P_1}{P_2} \quad (9)$

فرآیند ایزوثرم، هم‌انرژی، هم‌انتروپی

**Polytropic**

$$* W = P_1 V_1 \ln \frac{V_2}{V_1} *$$

$P_1 V_1 = P_2 V_2$

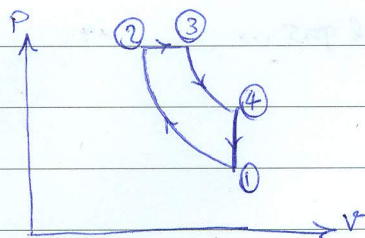
\* **Adiabatic:**  $Q = 0$   $W_b = \Delta U \rightarrow -W_b = \Delta U = -m \int_{T_1}^{T_2} C_v^{ig} dT \quad (10)$

①  $\frac{T_2}{T_1} = \left( \frac{V_1}{V_2} \right)^{\gamma-1}$   $\gamma = \frac{C_p^{ig}}{C_v^{ig}}$   $(1-\gamma) \ln \frac{V_2}{V_1} = \ln \frac{T_2}{T_1} \quad (11)$

رابطه‌های بین متغیرهای حالت برای گاز ایده آل

②  $\frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \quad (12)$

③  $\frac{P_2}{P_1} = \left( \frac{V_1}{V_2} \right)^{\gamma} \Rightarrow W_b = \frac{m(P_1 V_1 - P_2 V_2)}{\gamma-1} \quad (13)$



$$T_1 = 400 \text{ K} \quad q_{23} = 1500 \text{ kJ/kg}$$

$$P_1 = 100 \text{ kPa}$$

$$\frac{v_1}{v_2} = 20 \quad c_v = \frac{5}{2}R \quad c_p = \frac{7}{2}R \quad R = 0.3$$

لیس:

سیستم های جریان دار:

$$\left. \begin{array}{l} \delta m_i = \dot{m}_i \delta t \\ \delta m_e = \dot{m}_e \delta t \end{array} \right\} \rightarrow \text{Acc} = m_{cv} \Big|_{t+\delta t} - m_{cv} \Big|_t \Rightarrow \dot{m}_i - \dot{m}_e = \frac{dm_{cv}}{dt}$$

$$\sum_i \dot{m}_i - \sum_e \dot{m}_e = \frac{dm_{cv}}{dt}$$

$$W = \underbrace{CvW}_{\text{CvW, b}} + \text{flow } W$$

$$\left\{ \begin{array}{l} W_{\text{flow @ inlet}} - P_i V_i \delta m_i \\ W_{\text{flow @ exit}} + P_e V_e \delta m_e \end{array} \right.$$

$$\delta Q - \delta W_{cv} - \left[ \delta m_e V_e P_e - \delta m_i V_i P_i \right] + \underbrace{\delta m_i e_i - \delta m_e e_e}_{\left( u_i + \frac{1}{2} V_{el_i}^2 + g z_i \right) - \left( u_e + \frac{1}{2} V_{el_e}^2 + g z_e \right)} = E_{t+\delta t} - E_t$$

$$\dot{Q} - \dot{W}_{cv} + \sum_i \dot{m}_i (h_i + k_i + P_i) - \sum_e \dot{m}_e (h_e + k_e + P_e) = \frac{dE_{cv}}{dt} \leftarrow \text{SSSF, USat (14)}$$

$$1. \text{SSSF} \Rightarrow \frac{dm_{cv}}{dt} = 0 \quad \frac{dE_{cv}}{dt} = 0$$

$$\sum_i \dot{m}_i - \sum_e \dot{m}_e = 0$$

2. Single inlet - single outlet

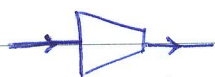
$$\dot{m}_i - \dot{m}_e = 0$$

$$\dot{m}_i = \dot{m}_e = \dot{m}$$

$$\dot{Q} - \dot{W}_{cv} = \dot{m} \left[ (h_e - h_i) + \underbrace{\frac{1}{2} (V_{el_e}^2 - V_{el_i}^2)}_{\times 0.001} + \underbrace{g(z_e - z_i)}_{\times 0.001} \right]$$

(14-B)

سبب و مقادیر استهلاک



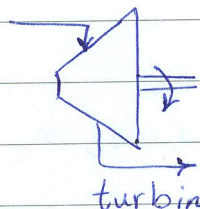
: Nozzle di

$$q \approx 0 \quad W_{cv} = 0 \quad \Delta E_p = 0 \quad \Delta E_k = \checkmark$$



diffuser

دیفیوزر و برعکس نازل به کار می آید.



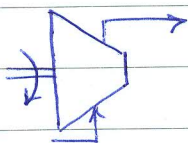
turbine

$$q = \text{small}$$

$$W_{cv} > 0$$

$$\Delta K_e = \text{small}$$

$$\Delta P_e = \text{neglegible}$$



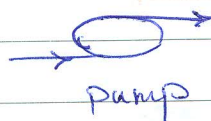
Compressor

$$W_{cv} < 0$$

$$q = \text{small}$$

$$\Delta K_e = \text{small}$$

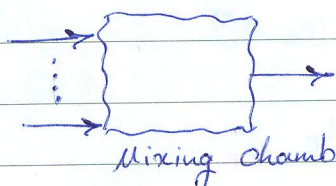
$$\Delta P_e = \text{neglegible}$$



pump

$$W_{cv} < 0$$

$$q = \text{small}$$

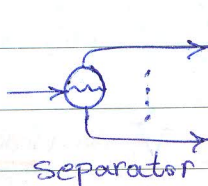


Mixing chamber

$$q \approx 0 \quad \Delta K_e \approx 0$$

$$W_{cv} = 0 \quad \Delta P_e = 0$$

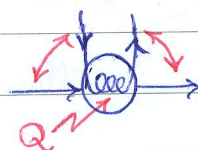
$$m_e = \sum_i m_i$$



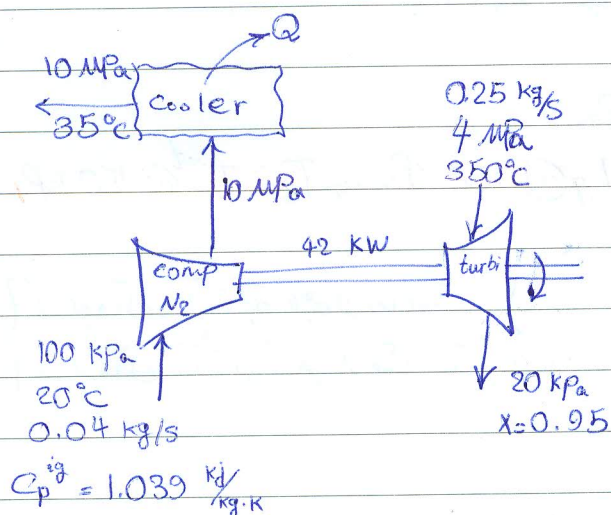
separator

$$m_i = \sum_e m_e$$

(Heat Exchanger) مبدل حرارتی



: حل



$$\text{turbine: } \dot{Q} - W_{cv} = \dot{m} [h_e - h_i]$$

$$W_{cv} = 150.2 \text{ kW} = \frac{\text{kJ}}{\text{s}}$$

$$W_{\text{gen}} = W_{cv} - 42 \text{ kW}$$

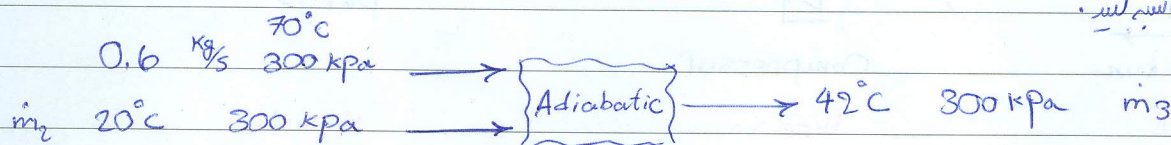
Cooler/comp  $\dot{Q} - \dot{W}_{cv} = m[h_e - h_i]$

$h_e - h_i = C_p^{ig} (T_e - T_i)$   $\dot{W}_{cv} = -42 \frac{kJ}{s}$

$\dot{V}_e = \frac{\dot{m} \hat{V}_e}{A_e}$  (15)

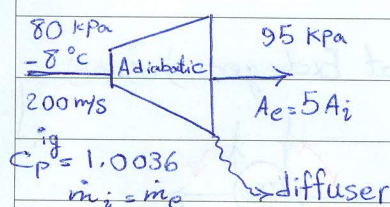
نکته نکته نکته :

مسئله :  $\dot{m}_1, \dot{m}_2$  را حساب کنید.



$\dot{m}_3 h_3 = \dot{m}_1 h_1 + \dot{m}_2 h_2$   
 $\dot{m}_3 = \dot{m}_1 + \dot{m}_2$

$\rightarrow \begin{cases} h_1 = h_f @ 70^\circ C \\ h_2 = h_f @ 20^\circ C \end{cases}$



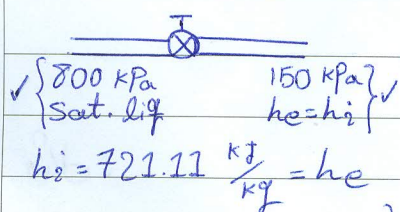
$\dot{q} - \dot{w} = (h_e - h_i) + \frac{1}{2}(\dot{V}_e^2 - \dot{V}_i^2) + g(z_e - z_i)$

مسئله :

?  $\dot{V}_e, T_e$

$\dot{m}_i = \frac{\dot{V}_i}{\hat{V}_i} = \frac{\dot{V}_e \cdot A_i}{\frac{RT_i}{P_i}} = \dot{m}_e = \frac{\dot{V}_e \cdot A_e}{\frac{RT_e}{P_e}}$  \*\*\*

$\Delta h = C_p^{ig} (T_e - T_i) \Rightarrow C_p^{ig} (T_e - T_i) + \frac{1}{2}(\dot{V}_e^2 - \dot{V}_i^2) = 0$



Adiabatic  $\Delta K = \Delta U = 0$

مسئله :  $\hat{V}_e, \Delta T$  :

$\dot{q} - \dot{w} = (h_e - h_i) \Rightarrow h_i = h_e$

$h_i = 721.11 \frac{kJ}{kg} = h_e$

$T_i = T^{sat} @ 800 \text{ kPa}$

\*\*\*  $h_e : h_f < h_e < h_g @ 150 \text{ kPa} \Rightarrow T_e = T^{sat} @ 150 \text{ kPa}$

$\alpha_e = \frac{\hat{V}_e - \hat{V}_f}{\hat{V}_g - \hat{V}_f} = \frac{h_e - h_f}{h_g - h_f}$  (16)

نکته :  
 { گاز ایده آل : آنتالپی تابع از دما است.  
 غیر ایده آل : آنتالپی تابع از فشار است.

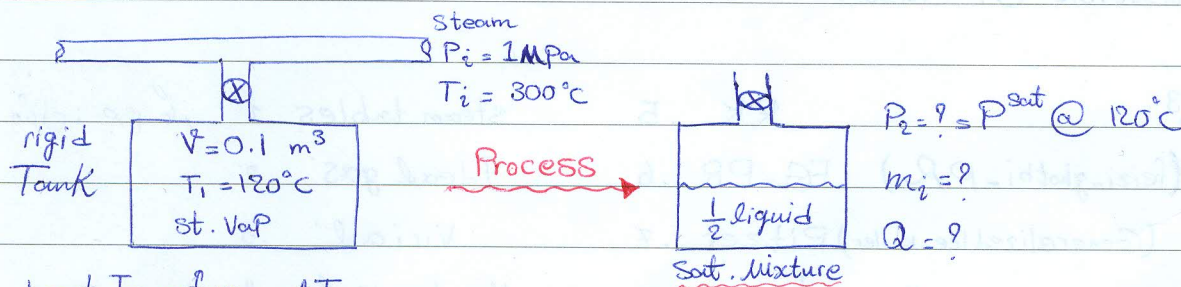
① Mass Balance:  $m_i - m_e = m_2 - m_1$  (17)

$m_i, m_e$  = جريان ورودی و خروجی (مجموعه)

$m_1, m_2$  : جريان کنترل در ابتدای و انتهای

② Energy Balance:

$$Q - W_{cv} + \sum m_i \left( h_i + \frac{1}{2} V_{el_i}^2 + g z_i \right) - \sum m_e \left( h_e + \frac{1}{2} V_{el_e}^2 + g z_e \right) = m_2 \left( u_2 + \frac{1}{2} V_{el_2}^2 + g z_2 \right) - m_1 \left( u_1 + \frac{1}{2} V_{el_1}^2 + g z_1 \right) = \frac{dE_{cv}}{dt} \quad (18)$$



heat Transfer,  $\Delta T=0$

charging  $\Rightarrow m_i - m_e = m_2 - m_1$

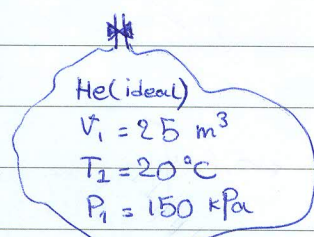
$Q - W_{cv} + m_i h_i - m_e h_e = m_2 u_2 - m_1 u_1$

@ state ②:  $m_2 = m_g + m_f = \frac{V_g}{\hat{v}_g} + \frac{V_f}{\hat{v}_f} = 47.226$  (19)

$m_1 = \frac{V_g}{\hat{v}_g} = 0.112$

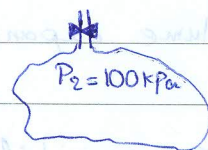
$\rightarrow m_i = m_2 - m_1 = 47.114$

$m_2 u_2 = m_f u_f + m_g u_g$  (20)



$C_p^{ig} = 5.1926$   
 $R = 2.0769$   
 $C_v^{ig} = 3.1156$

Adiabatic Process



???  $m_e, T_2$  : Joo

$Q - W_{cv} - m_e h_e = m_2 u_2 - m_1 u_1$

$-m_e = m_2 - m_1 \rightarrow m_e = m_1 - m_2$

$W_{cv} = \int_{V_1}^{V_2} P dV$

ideal gas law

$P_x = a + b V_x$   
 $P_1 = a + b V_1$   
 $P_2 = a + b V_2$   
 $a = -100 \text{ kPa}$

$$a = -100 \Rightarrow b = 10 \Rightarrow V_2 = 20 \text{ m}^3$$

$$W_b = \int_{V_1}^{V_2} P dV = \int_{V_1}^{V_2} (a + bV) dV = -625 \text{ kJ}$$

Reference:  $T_R = 0 \Rightarrow U_R = 0$

Reference:  $T_R = 0 \Rightarrow h_R = 0$

Reference 1  $\Rightarrow U_2 = C_v^{ig} T_2$

$U_2 = C_v^{ig} T_2$

ideal gas  $\Rightarrow m_1 = \frac{P_1 V_1}{RT_1}$

$m_2 = \frac{P_2 V_2}{RT_2}$

$m_e = m_1 - m_2$

Reference 2  $\Rightarrow h_e = C_p^{ig} T_e$

$h_i = C_p^{ig} T_i \rightarrow$  نهایی بیان نداریم

$T_2 = 188.42 \text{ K}$

$m_e = 0.91 \text{ kg}$

خواص حجم سیالات خالص: (فصل سوم کتاب دین)

EOS: Equation of State

500 °C
3 MPa
H <sub>2</sub> O

1 m<sup>3</sup>

(feizi-ghotbi-PR) FG-PR .6

(Generalized lee-kesler) Pitzer .7

your choice .8

RK .5

steam tables .1

Ideal gas .2

Virial .3

Von der Waals .4

$PV^3 - (Pb + RT)V^2 + aV + (-ab) = 0 \quad (2.1)$

$a = \frac{27R^2 T_c^2}{64 P_c}$

$b = \frac{RT_c}{8 P_c}$

Van der Waals

چند جمله ای  
(برای یافتن جواب)

انواع صورت معادلات حالت

$$\begin{cases} V = V(P, T) \rightarrow \text{جواب معمول} \\ P = P(V, T) \rightarrow \text{معادله معمول} \\ T = T(P, V) \end{cases}$$

معادلات حالت تک فاز:

$V = V(P, T) \rightarrow$  Volume expansivity

$\beta = \frac{1}{V} \left( \frac{dV}{dT} \right)_P$

تک فاز

Isothermal compressibility

$K = -\frac{1}{V} \left( \frac{dV}{dP} \right)_T$

تک فاز

$\frac{dV}{V} = \beta dT - K dP$

(تک فاز - 1)

1. Incompressible fluid  $\beta, \kappa = 0$

2.  $\beta, \kappa$  (small) (Constant)  $\ln \frac{V_2}{V_1} = \beta(T_2 - T_1) - \kappa(P_2 - P_1)$  (2-فاز)

Ideal gas:  $PV = \text{constant} = a + bP + cP^2 + \dots$   
 $= a(1 + b'P + c'P^2 + \dots)$

\* at low  $P$  truncation after 1<sup>st</sup> term is OK.

\* at higher  $P$  truncation after 2<sup>nd</sup> or 3<sup>th</sup> term is OK.

\* The "a" parameter is constant.

\* The "a" is a function of Temperature.

$$\frac{PV}{RT} = Z = 1 + B'P + c'P^2 + \dots \Rightarrow \frac{PV}{RT} = Z = 1 + \frac{B}{V} + \frac{C}{V^2} + \frac{D}{V^3} + \dots \quad (2.2)$$

$$B' = \frac{B}{RT}$$

$$C' = \frac{C - B^2}{(RT)^2}$$

$$D' = \frac{D - 3BC + 2B^3}{(RT)^3}$$

(2.3) ضرایب ویلیال

\* Pitzer:

$\omega$ : acentric factor  $\rightarrow \omega, T_c, P_c$ : Critical Constants

$$\frac{BP_c}{RT_c} = B^{(0)} + \omega B^{(1)} \quad (2.4)$$

$$B^{(0)} = 0.083 - \frac{0.422}{T_r^{1.6}}$$

$$B^{(1)} = 0.139 - \frac{0.172}{T_r^{4.2}}$$

$$T_r \cdot T_c = T$$

$$\frac{PV}{RT} = Z = 1 + \frac{B}{V} = 1 + B'P \quad (2.5)$$

Types of Problem functions and answer ways: (Virial and Pitzer)

①  $T, V \rightarrow P = ?$   $Z = \frac{PV}{RT} = 1 + \frac{B}{V} \rightarrow 0 B \rightarrow 0 Z \rightarrow P = \frac{ZRT}{V}$

②  $T, P \rightarrow V = ?$   $Z = \frac{PV}{RT} = 1 + B'P \rightarrow 0 B \rightarrow B' = \frac{B}{RT} \rightarrow 0 Z \rightarrow 0 V$

③  $P, V \rightarrow T = ?$  Guess  $T^{\text{old}} \rightarrow \text{Obtain } B \rightarrow 0 Z \rightarrow \text{Recalculate}$   

$$T^{\text{new}} = \frac{PV}{ZR}$$

\* 0 = obtain

\* Van der Waals Equation:

$$\left( P = \frac{RT}{V-b} - \frac{a}{V^2} \right) \quad a = \frac{27R^2 T_c^2}{64 P_c} \quad b = \frac{RT_c}{8 P_c} \quad (2.6)$$

\* Redlich-Kwong Equation:

$$\left( P = \frac{RT}{V-b} - \frac{a}{V(V+b)\sqrt{T}} \right) \quad b = 0.08664 \frac{RT_c}{P_c} \quad (2.7)$$

$$a = \frac{0.42748 R^2 T_c^{2.5}}{P_c}$$

at  $T_c, P_c, V_c \Rightarrow \begin{cases} \left( \frac{\partial P}{\partial V} \right)_T = 0 \\ \left( \frac{\partial^2 P}{\partial V^2} \right)_T = 0 \end{cases} \quad (2.8)$

\* Peng-Robinson Equation:

$$\left( P = \frac{RT}{V-b} - \frac{a(T)}{V(V+b)+b(V-b)} \right) \quad (2.9)$$

□ R-K  $\rho$  equation:  $V^3 - \frac{RT}{P} V^2 - \left( b^2 + \frac{bRT}{P} - \frac{a}{P\sqrt{T}} \right) V - \frac{ab}{P\sqrt{T}} = 0 \quad (2.10)$   
(Redlich-Kwong)

Redlich-Kwong  $\begin{cases} 1) Z = \frac{1}{1-h} - \frac{a}{bRT^{1/2}} \left( \frac{h}{1+h} \right) \quad h = \frac{bP}{ZRT} \quad (2.11) \end{cases}$

$$2) Z = \frac{1}{1-h} - \frac{4.934}{T_r^{1/2}} \left( \frac{h}{1+h} \right) \quad h = \frac{0.08664 P_r}{Z \cdot T_r} \quad (2.12)$$

$$T_r T_c = T, P_r P_c = P, Z = Z(T_r, P_r)$$

## □ W of Pitzer Equation:

« ضریب همگرایی مولی حالت پیترز »

$$Z = Z(T_r, P_r, \omega) \quad (2.14) \quad \omega = -1.0 - \log(P_r^{\text{sat}})_{T_r=0.7} \quad (2.13)$$

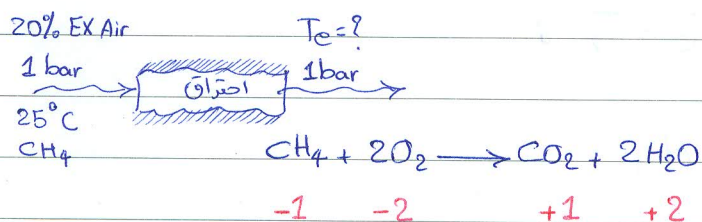
$$Z = \omega Z' + Z^0 \quad \begin{cases} Z' = Z'(T_r, P_r) \\ Z^0 = Z^0(T_r, P_r) \end{cases} \quad \begin{cases} P_r^{\text{sat}} \cdot P_c = P^{\text{sat}} \\ T_r \cdot T_c = T \end{cases}$$

\*\*\* نمودار  $\log(P_r^{\text{sat}})_{T=0.7}$  بر حسب  $\frac{1}{T_r}$  بصورت یک منحنی خطی است که شیب منفی خواهد داشت.

## \*\*\* Racket Equation:

$$V^{\text{sat}} = V_c^{\text{sat}} Z_c^{(1-T_r)^{0.2857}}$$

□ آثار گرما در راکتورهای سیمپل: (فصل چهارم کتاب اسمیت و ون شین)



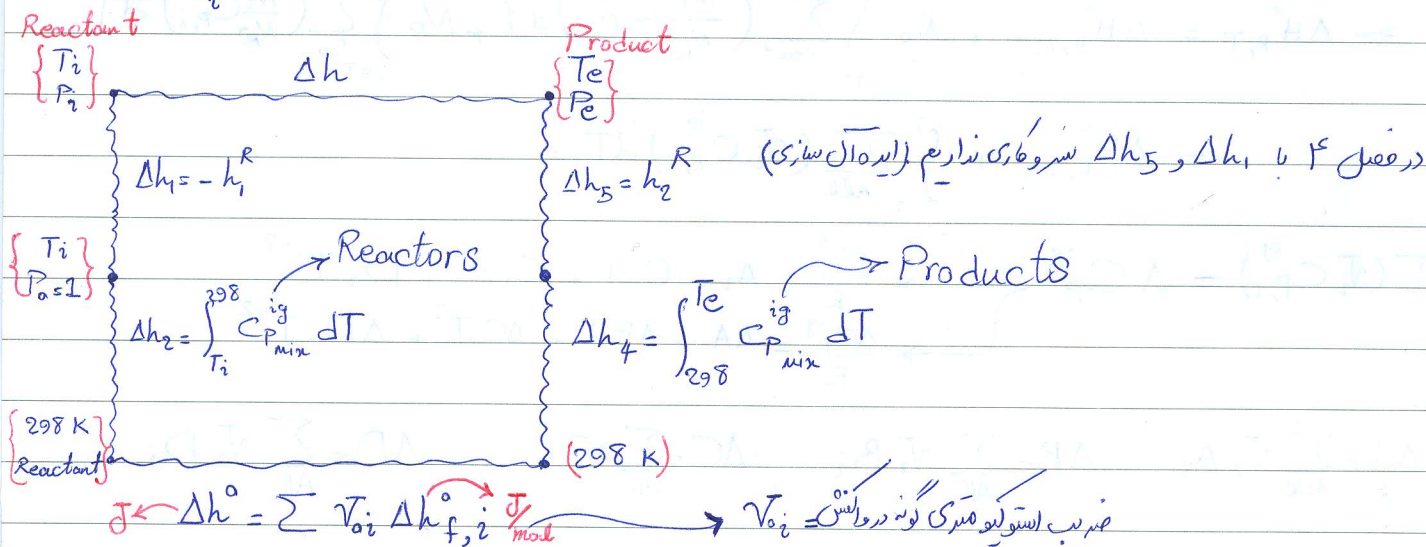
مثال: در آلکتردهای خروجی (هواک آدیاباتیکی) را محاسبه کنید.  
[Kajou]

$$h_f - h_{cv} = h_e - h_i \Rightarrow h_e = h_i$$

$$\text{Basis} = 1 \text{ mol CH}_4 \Rightarrow 1.2 \times (2) = 2.4 \text{ mol O}_2 \Rightarrow 9.03 \text{ mol N}_2$$

$$\text{Products: } 1 \text{ mol CO}_2, 2 \text{ mol H}_2\text{O}, 0.4 \text{ O}_2, 9.03 \text{ mol N}_2$$

$$C_{P_{\text{mix}}}^{\text{ig}} = \sum_i y_i C_{P_i}^{\text{ig}}, \quad h^R = h - h^{\text{ig}} \rightarrow \text{آنتالپی باقیمانده}$$



$$\Delta H_{\text{Reaction}} = \Delta h_2 + \Delta h^\circ + \Delta h_4 \quad (J)$$

نکته: در آلکتردهای خروجی هنگامی اتفاق می افتد که فرآیند آدیاباتیکی باشد.

$$C_P^{ig} = C_v^{ig} + R$$

گرمای ویژه در فازهای ایده‌آل:

$$\frac{C_P^{ig}}{R} = A + BT + CT^2 + DT^{-2}$$

Table in chapter 4

$$\text{Mixture: } \frac{C_{P, \text{mix}}^{ig}}{R} = \sum_i y_i \frac{C_{P, i}^{ig}}{R}$$

$$\frac{C_{P, \text{mix}}^{ig}}{R} = A_{\text{mix}} + B_{\text{mix}}T + C_{\text{mix}}T^2 + D_{\text{mix}}T^{-2}$$

$$A_{\text{mix}} = \sum y_i A_i \quad B_{\text{mix}} = \sum B_i y_i \quad C_{\text{mix}} = \sum C_i y_i \quad D_{\text{mix}} = \sum D_i y_i$$

\* Calculating  $\Delta H_{\text{reaction}}^\circ$  at  $T = T_c = T_i$ :

$$\Delta H_{R, T}^\circ = \Delta H_{R, 298}^\circ + (N_R) \Delta h_f + (N_P) \Delta h_f$$

$$= \Delta H_{R, 298}^\circ + N_R \int_{298}^T (C_{P, \text{React, Mix}}^{ig} dT) + N_P \int_{298}^T (C_{P, \text{Product, Mix}}^{ig} dT)$$

$$C_{P, \text{mix}}^{ig} = \sum y_i C_{P, i}^{ig}$$

$$\Rightarrow \Delta H_{R, T}^\circ = \Delta H_{R, 298}^\circ + N_R \int_{298}^T \sum_{\text{React}} \left( \frac{N_i}{N_R} C_{P, i}^{ig} \right) dT + N_P \int_{298}^T \sum_{\text{Pro}} \left( \frac{N_i}{N_P} C_{P, i}^{ig} \right) dT$$

$$= \Delta H_{R, 298}^\circ + \int_{298}^T \sum_{\text{All}} (\nu_i C_{P, i}^{ig}) dT *$$

$$\sum (\nu_i C_{P, i}^{ig}) = \Delta C_P^{ig} \rightarrow \frac{C_{P, i}^{ig}}{R} = A_i + B_i T + C_i T^2 + D_i T^{-2}$$

$$\rightarrow \frac{\Delta C_P^{ig}}{R} = \Delta A + \Delta B \cdot T + \Delta C \cdot T^2 + \Delta D \cdot T^{-2}$$

$$\Delta A = \sum_{\text{All}} \nu_i A_i \quad \Delta B = \sum_{\text{All}} \nu_i B_i \quad \Delta C = \sum_{\text{All}} \nu_i C_i \quad \Delta D = \sum_{\text{All}} \nu_i D_i$$

$$\left\{ \begin{array}{l} \textcircled{1} A_i + B_i T + C_i T^2 \\ \textcircled{2} A_i + B_i T + \frac{D_i}{T^2} \end{array} \right\} \rightarrow C_P^{ig}$$

انواع ضرایب مطالب

## Solution of Example [kalou]

Comp	$\Delta H_{f,298}^\circ$	A	B	D
CH <sub>4</sub>	-74,520	1.702	$3.081 \times 10^{-3}$	$2.164 \times 10^{-6}$ [C]
O <sub>2</sub>	0	3.639	$5.06 \times 10^{-3}$	0.227
CO <sub>2</sub>	-393,509	5.457	$1.045 \times 10^{-3}$	0.157
H <sub>2</sub> O	-241,818	3.470	$1.450 \times 10^{-3}$	0.121
N <sub>2</sub>	0	3.280	$0.593 \times 10^{-3}$	0.040

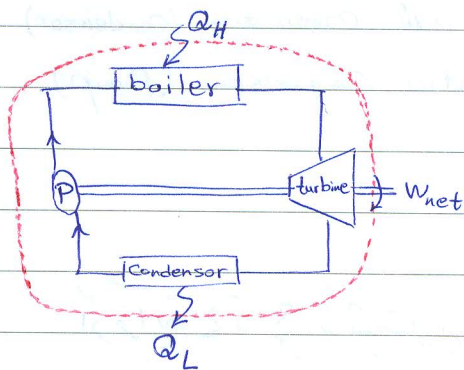
$$\Delta H_R = \sum_{T_i=298} \Delta h_{f,i} + \Delta h_2 + \Delta h_3 = \Delta h_2 + \Delta h_3 = \Delta H_{R,298}^\circ + \Delta h_3 = 0 \leftarrow \text{دنيايى}$$

$$\Delta h_2 = \Delta H_{R,298}^\circ = \sum \nu_i \Delta h_{f,i,298}^\circ = -802,625 \text{ J}$$

$$\Delta h_3 = \int_{298}^{T_2} \left( \sum_{Pro} N_p C_{P_i}^{ig} \right) dT$$

$$= \int_{298}^{T_2} R \left[ \sum n_i A_i + (\sum n_i B_i) T + (\sum n_i D_i) T^2 \right] dT \sim \text{داده مسئله و يافتى جواب}$$

□ بيان قانون دوم ترموديناميك (مخلو ۵ كتاب و ن ش - مخلو ۷ و ن وايلين)

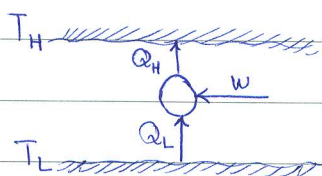


$$W_{net} = Q_H - Q_L \quad \eta = \frac{W_{net}}{Q_H}$$

$$\eta < 100\% \quad \text{Kelvin-Planck statement of 2<sup>nd</sup> law}$$

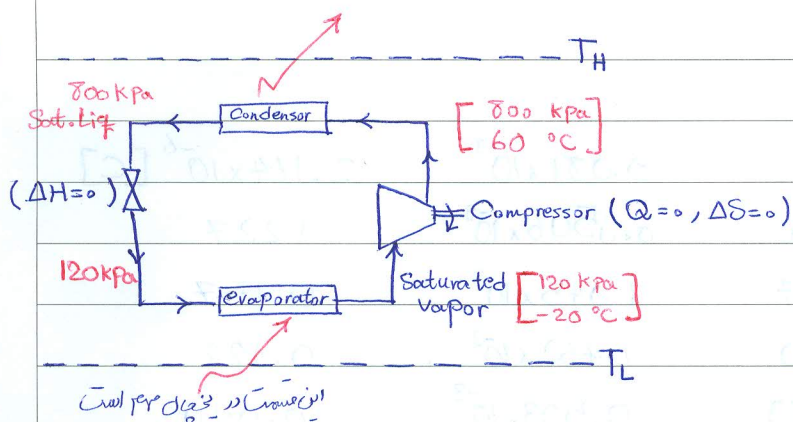
$$\eta_{inrev} < \eta_{rev} \quad \text{Carnot's 1<sup>st</sup> principle}$$

$$\eta_{rev} = 1 - \left( \frac{Q_L}{Q_H} \right) = 1 - \frac{T_L}{T_H} \rightarrow \text{داده مسئله (توليد)} \quad \left( \frac{Q_L}{Q_H} \right)_{rev} = \frac{T_L}{T_H}$$



$$COP = K = \frac{Q_L}{W} \quad W \neq 0$$

پمپال:



$$COP = \frac{1}{\frac{Q_H}{Q_L} - 1} = \left( \frac{1}{\frac{T_H}{T_L} - 1} \right)_{rev} = \frac{Q_L}{W}$$

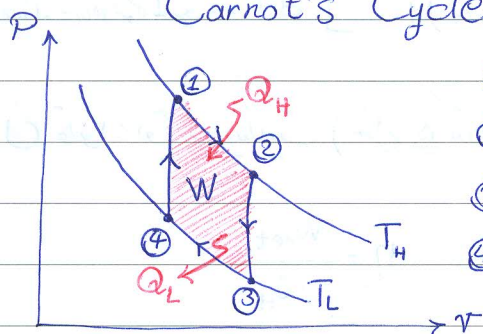
2. Heat pump  $\rightarrow COP = \frac{1}{1 - \frac{Q_L}{Q_H}} = \frac{Q_H}{W} COP_{rev} = \frac{1}{1 - \frac{T_L}{T_H}}$

Clausius statement of second law:

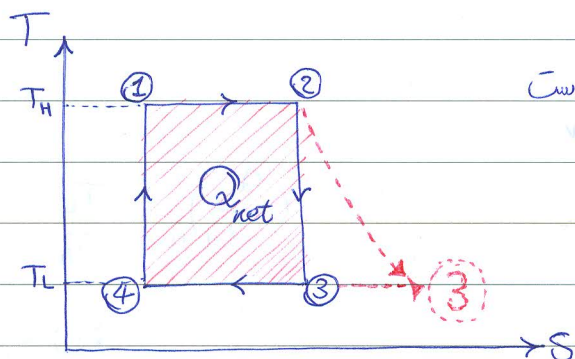
" $Q_L = Q_H, W = 0$  is impossible"

\* هر چه اختلاف دما  $T_L$  و  $T_H$  کمتر باشد بازگشت پذیری بیشتر می‌شود و هر چه اختلاف دما بیشتر باشد بازگشت پذیری کمتر خواهد بود.

Carnot's Cycle:

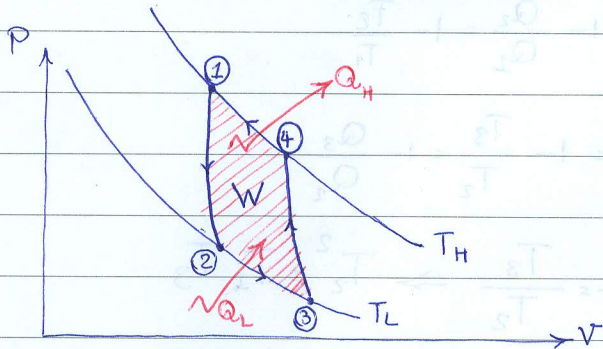


- ①-② Reversible isothermal expansion (boiler)
- ②-③ " Adiabatic expansion (turbine)
- ③-④ " isothermal compression (Condensor)
- ④-① " Adiabatic compression (Pump)



اگر فرآیند 2 تا 3 برگشت پذیر نبود، نقطه‌ای کمی به سمت راست حرکت می‌کرد.

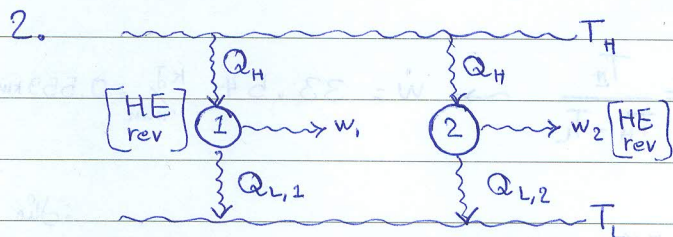
## Carnot's Cycle (Reverse)



## Carnot's Principles:

$$1. \left. \begin{array}{l} W_{rev} > W_{irrev} \\ Q_{L,rev} < Q_{L,irrev} \end{array} \right\} \Rightarrow \eta_{irrev} < \eta_{rev}$$

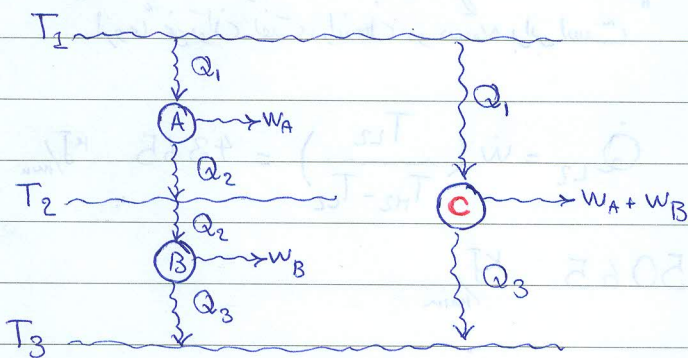
المرغوب كتم  $W_{rev} < W_{irrev}$  انكسره، انكسره Kelvin-Planck نقيضه.



$$\eta_{rev,1} = \eta_{rev,2}$$

$$3. \eta_{rev} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H} = \gamma(T_H, T_L)$$

$$\frac{Q_L}{Q_H} = 1 - \gamma(T_H, T_L) = f(T_H, T_L)$$



$$\frac{Q_1}{Q_2} = f(T_1, T_2)$$

$$\frac{Q_2}{Q_3} = f(T_2, T_3)$$

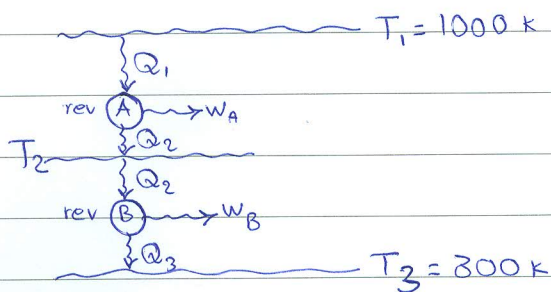
$$\frac{Q_1}{Q_3} = f(T_1, T_3) = f(T_1, T_2) \cdot f(T_2, T_3)$$

$$\phi(T) = T \Leftarrow \left( \frac{Q_L}{Q_H} \right)_{rev} = \frac{\phi(T_L)}{\phi(T_H)}$$

$$\Leftarrow f(T_1, T_2) = \frac{\phi(T_1)}{\phi(T_2)}$$

$\Downarrow$

$$\eta_{rev} > \eta_{irrev} \rightarrow \eta < 1 - \frac{T_L}{T_H}$$



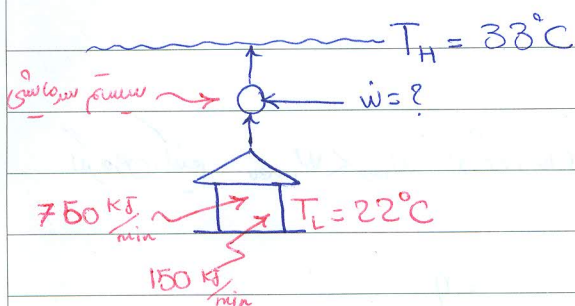
$$\eta_A = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

$$\eta_B = 1 - \frac{T_3}{T_2} = 1 - \frac{Q_3}{Q_2}$$

$$\eta_A = \eta_B \Rightarrow \frac{T_2}{T_1} = \frac{T_3}{T_2} \Rightarrow T_2^2 = T_1 T_3$$

$$\Rightarrow T_2 = 547.7 \text{ K}$$

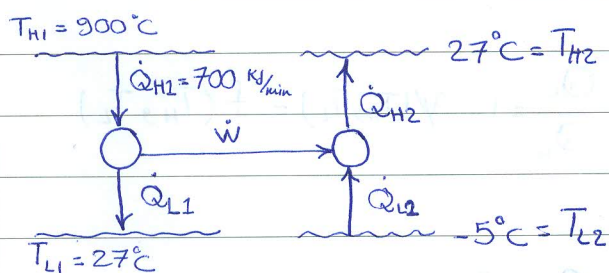
$T_2 = T_3$  :  $\text{mis}$



$$\text{COP} = \frac{\dot{Q}_L}{\dot{W}} = \frac{1}{\frac{T_H}{T_L} - 1}$$

$$\frac{\dot{Q}_L}{\dot{W}} = \frac{T_L}{T_H - T_L} \Rightarrow \dot{W} = 33.54 \frac{\text{kJ}}{\text{min}} = 0.559 \text{ kW}$$

:  $\text{mis}$



$$\dot{Q}_{L1} + \dot{Q}_{H2} = \text{گرمای آزاد شده} = \text{الودی درجه}$$

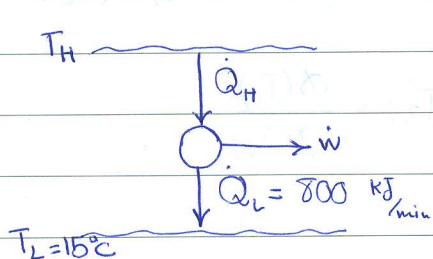
"لروما غن توان لغت راندهان دو دستگاه برابر است"

:  $\text{mis}$

$$\dot{W} = \dot{Q}_{H1} \left( \frac{T_{H1} - T_{L1}}{T_{H1}} \right)$$

$$\dot{Q}_{L2} = \dot{W} \left( \frac{T_{L2}}{T_{H2} - T_{L2}} \right) = 4365 \frac{\text{kJ}}{\text{min}}$$

$$\dot{Q}_L + \dot{Q}_{H2} = \dot{Q}_{H1} + \dot{Q}_{L2} = 5065 \frac{\text{kJ}}{\text{min}}$$



$$\eta_{\text{rev}} = 0.55 \Rightarrow \dot{W} = ? \quad T_H = ?$$

$$\dot{W} = 977.78 \frac{\text{kJ}}{\text{min}} \quad T_H = 640.3 \text{ K}$$

:  $\text{mis}$

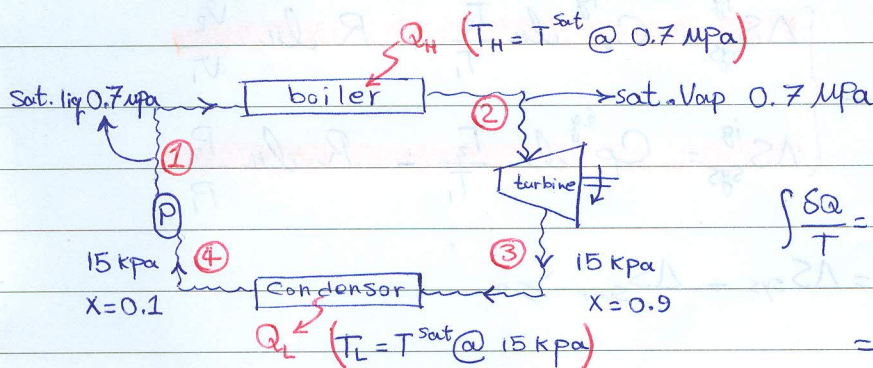
قضیه کلی:  $\oint \frac{\delta Q}{T} \leq 0$

+ For Reversible process:  $\oint \frac{\delta Q}{T} = \oint \frac{\delta Q_H}{T_H} - \oint \frac{\delta Q_L}{T_L} = 0$

$$= \frac{1}{T_H} \int \delta Q_H - \frac{1}{T_L} \int \delta Q_L = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0 \Rightarrow \left( \frac{Q_H}{Q_L} \right)_{\text{rev}} = \frac{T_H}{T_L}$$

+ For Irreversible process:  $Q_{L, \text{irrev}} > Q_{L, \text{rev}}$

$$Q_{L, \text{irrev}} - Q_{L, \text{rev}} = Q_{\text{Diff}} > 0 \Rightarrow \oint \left( \frac{\delta Q}{T} \right)_{\text{irrev}} = \frac{Q_H}{T_H} - \frac{Q_{L, \text{irrev}}}{T_L} < 0$$



مثال:

$$\oint \frac{\delta Q}{T} = \int_1^2 \frac{\delta Q}{T} + \int_2^3 \frac{\delta Q}{T} + \int_3^4 \frac{\delta Q}{T} + \int_4^1 \frac{\delta Q}{T}$$

$$= \frac{Q_{12}}{T_H} + \frac{Q_{34}}{T_L}$$

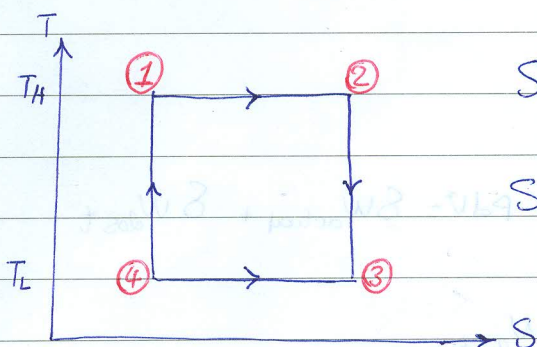
معادلات انرژیها طبق جدول بخار انجام خواهد شد.

$$Q_{12} = m(h_2 - h_1) \quad Q_{34} = m(h_4 - h_3)$$

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

تعریف آنتروپی:

چون کار و بر حسب آنتروپی:



$$S_2 - S_1 = \frac{Q_{12}}{T_H}$$

$$S_4 - S_3 = \frac{Q_{34}}{T_L}$$

$$S_2 = S_3$$

$$S_1 = S_4$$

رابطه اول و دوم گیبس (TdS):

$$1 \begin{cases} TdS = dU + PdV \\ Tds = du + Pdv \end{cases}$$

$$2 \begin{cases} TdS = dH - VdP \\ Tds = dh - vdp \end{cases}$$

## Gibbs Equations for Ideal gases:

$$\begin{cases} TdS = du + PdV \\ TdS = dh - \hat{V}dP \end{cases}$$

ideal gas: 1  $du = C_v^{ig} dT$

2  $dh = C_p^{ig} dT$

3  $P\hat{V} = RT$

4  $C_p^{ig} = C_v^{ig} + R$

$$\int_{S_1}^{S_2} dS = \int_{T_1}^{T_2} C_v^{ig} \frac{dT}{T} + \int_{V_1}^{V_2} \frac{R}{V} dV$$

$$\int_{S_1}^{S_2} dS = \int_{T_1}^{T_2} C_p^{ig} \frac{dT}{T} - \int_{P_1}^{P_2} R \frac{dP}{P} \rightarrow \text{Constant } C_v^{ig} \text{ and } C_p^{ig} :$$

Adiabatic Process:  $\Delta S_{sys}^{ig} = 0 \leftarrow \begin{cases} \Delta S_{sys}^{ig} = C_v^{ig} \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1} \\ \Delta S_{sys}^{ig} = C_p^{ig} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} \end{cases}$

دستور کلی تغییرات انتروپی:

$$dS \geq \frac{\delta Q}{T} \rightarrow \Delta S_{total} = \Delta S_{sys} + \Delta S_{surr} \geq 0$$

$\Delta S_{surr}$  { isothermal  
Adiabatic

$$\begin{cases} \text{Irreversible Process} \leftarrow dS > \frac{\delta Q}{T} & :1 \\ \text{reversible Process} \leftarrow \frac{\delta Q}{T} = dS & :2 \end{cases}$$

## lost Work:

$\delta Q - \delta W = dU$

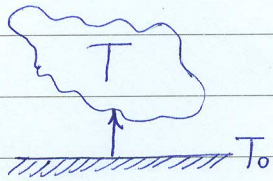
Gas Vacuum  $\xrightarrow{\text{irreversible}} \delta W = 0$   
 $\delta Q = dU$

$\xrightarrow{\text{reversible}} \delta W = PdV$   $PdV = \delta W_{actual} + \delta W_{lost}$

$$\begin{cases} TdS = dU + \delta W_{ac} + \delta W_{lost} \\ \delta Q = dU + \delta W_{ac} \end{cases} \rightarrow TdS = \delta Q + \delta W_{lost}$$

if Adiabatic + Reversible  $\Rightarrow$  isentropic

Increase in Entropy principle:



$$dS_{sys} > \frac{\delta Q}{T}$$

$$dS_{surr} = \frac{-\delta Q}{T_{surr}}$$

$$dS_{total} = dS_{sys} + dS_{surr} \geq \frac{\delta Q}{T} - \frac{\delta Q}{T_0}$$

$$dS_{total} \geq \delta Q \left( \frac{1}{T} - \frac{1}{T_0} \right)$$

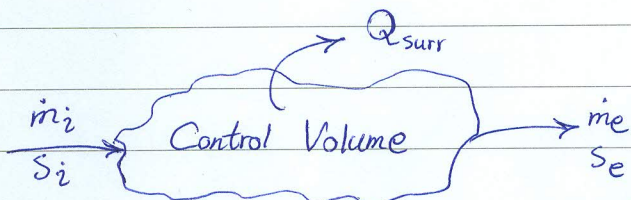
$$\left\{ \begin{array}{l} T_0 > T \rightarrow \delta Q > 0 \quad \left( \frac{1}{T} - \frac{1}{T_0} \right) > 0 \\ T_0 < T \rightarrow \delta Q < 0 \quad \left( \frac{1}{T} - \frac{1}{T_0} \right) < 0 \end{array} \right.$$

$$\Rightarrow \Delta S_{total} \text{ always } \geq 0$$

\* Closed system:  $S_{gen} = \Delta S_{total} = \Delta S_{sys} + \Delta S_{surr} \geq 0$

$$\Delta S_{sys} = m(S_2 - S_1)$$

$$\Delta S_{surr} = \frac{Q_{surr}}{T_{surr}} \rightarrow \text{Adiabatic: } Q_{sys} = -Q_{surr} = 0$$



طالت کلی برای فرآیندهای جریان دار:

$$\Delta S_{net} = \Delta S_{total} = \Delta S_{cv} + \Delta S_{surr} \geq 0$$

$$S_{gen} = \Delta S_{total} = (S_2 - S_1)_{cv} + (S_e - S_i) + \frac{Q_{surr}}{T_{surr}} \geq 0$$

$$\dot{S}_{gen} = \frac{dS_{cv}}{dt} + \frac{Q_{surr}}{T_{surr}} + \sum_e \dot{m}_e S_e - \sum_i \dot{m}_i S_i \geq 0 \quad \text{موازنه}$$

$$S_{gen} = \underbrace{(m_2 S_2 - m_1 S_1)}_{\text{طالت سیستم}} + \frac{Q_{surr}}{T_{surr}} + \sum \dot{m}_e S_e - \sum \dot{m}_i S_i \geq 0 \quad \text{USUF}$$

$$\text{SSSF} \rightarrow \frac{dS_{cv}}{dt} = 0$$

$$\dot{S}_{gen} = \frac{\dot{Q}_{surr}}{T_{surr}} + \sum \dot{m}_e S_e - \sum \dot{m}_i S_i \geq 0$$

Single inlet - single outlet  $\Rightarrow \dot{m}_i = \dot{m}_e = \dot{m}$

$$\dot{S}_{gen} = \frac{\dot{Q}_{surr}}{T_{surr}} + \dot{m}(S_e - S_i) \geq 0 \quad S_{gen} = \frac{\dot{q}_{surr}}{T_{surr}} + (S_e - S_i) \geq 0$$

if Adiabatic  $\rightarrow q_{\text{surr}} = 0$  and Reversible

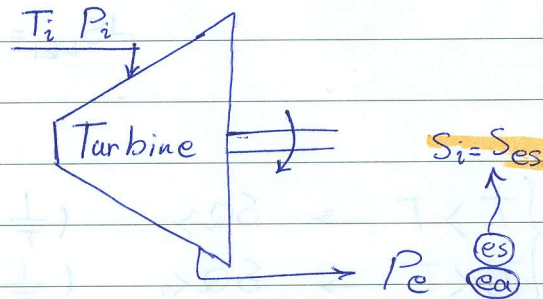
نکته:

Then  $S_e - S_i = 0 \Rightarrow$  Process is isentropic

Adiabatic efficiencies:

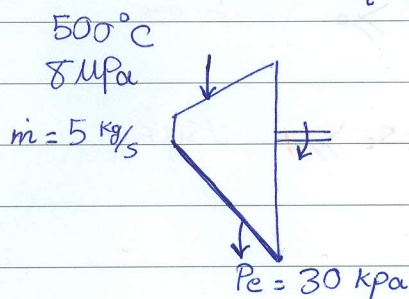
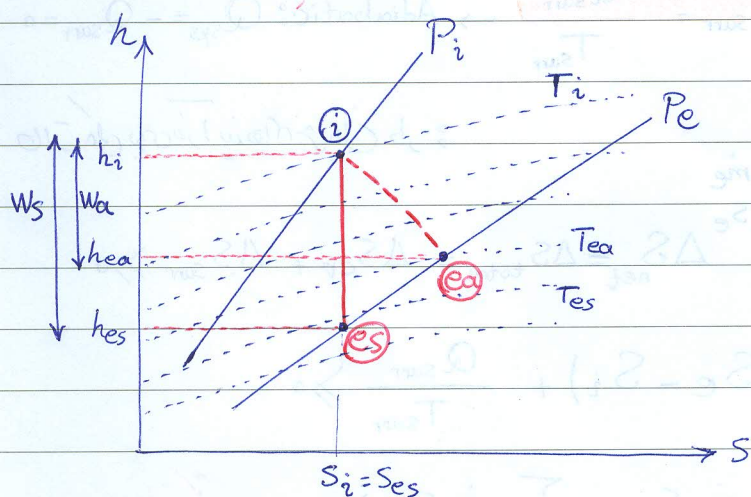
1) Turbine

$$\eta_T = \frac{w_a}{w_s} \quad \begin{cases} w_a = \text{actual work} \\ w_s = \text{isentropic work} \end{cases}$$



1st law SSSF: Adiabatic / neglect  $\Delta KE, \Delta PE$  / single inlet-single outlet

$$q - w = h_e - h_i \xrightarrow{\text{Adiabatic}} w = h_i - h_e \Rightarrow \begin{cases} w_s = h_i - h_{es} \\ w_a = h_i - h_{ea} \end{cases} \Rightarrow \eta_T = \frac{w_a}{w_s}$$



$$\eta_T = 0.85$$

$$T_i, P_i \Rightarrow \begin{cases} h_i = 3398.3 \\ S_i = 6.7240 \end{cases}$$

$$\textcircled{es} \quad \left. \begin{matrix} S_{es} = S_i \\ P_e \end{matrix} \right\} \rightarrow \begin{cases} h_f = 289.23 \\ h_g = 2625.3 \end{cases} \rightarrow S_f < S_{es} < S_g$$

$$X_{es} = \frac{S_{es} - S_f}{S_g - S_f} = \frac{h_{es} - h_f}{h_g - h_f} \Rightarrow h_{es} \checkmark \Rightarrow h_{ea} \checkmark \Rightarrow w_{ea} \checkmark$$

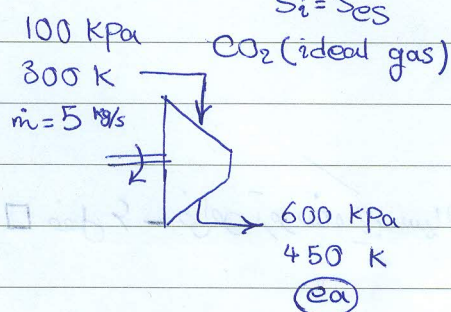
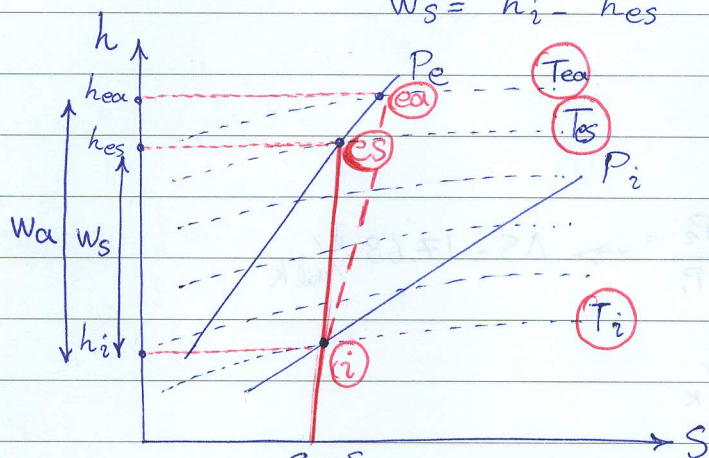
## 2) Compressor

$$q - W = h_e - h_i \Rightarrow W = h_i - h_e < 0$$

$$W_s = h_i - h_{es}$$

$$W_a = h_i - h_{ea}$$

$$\eta_c = \frac{W_s}{W_a}$$



$$\eta_c = \frac{W_s}{W_a} = \frac{h_i - h_{es}}{h_i - h_{ea}} = \frac{C_p^{ig}(T_i - T_{es})}{C_p^{ig}(T_i - T_{ea})}$$

$$\left(\frac{T_i}{T_{es}}\right) = \left(\frac{P_i}{P_e}\right)^{\frac{\gamma-1}{\gamma}} \Rightarrow \text{Adiabatic + reversible}$$

Reversible flow work:

$$\dot{S}_{gen} = \dot{m}(S_e - S_i) + \frac{\dot{Q}_{surr}}{T_{surr}} \geq 0 \quad \dot{Q}_{surr} = -\dot{Q} \Rightarrow \dot{m}(S_e - S_i) = \frac{\dot{Q}}{T_{surr}} \quad I$$

$$\dot{Q} - \dot{W} = \dot{m}(\Delta h + \Delta KE + \Delta PE) \Rightarrow \dot{W}_{ideal} = \dot{Q} - \dot{m}\Delta h \quad II$$

$$I, II \Rightarrow \dot{W}_{ideal} = \dot{m}(T_{surr} \Delta S - \Delta h) \Rightarrow \dot{W}_{actual} + \dot{W}_{lost} = \dot{W}_{ideal}$$

$$\dot{W}_{actual} = \dot{Q} - \dot{m}(\Delta h + \Delta KE + \Delta PE)$$

$$\dot{W}_{ideal} = \dot{m}(S_e - S_i)T_{surr} - \dot{m}(\Delta h + \Delta KE + \Delta PE)$$

$$\Rightarrow \dot{W}_{lost} = \dot{m}(S_e - S_i)T_{surr} - \dot{Q}$$

$$\dot{W}_{lost} = T_{surr} \cdot \dot{S}_{gen}$$

$$\dot{W}_{ideal} = \dot{m} \Delta S T_{surr} - \dot{m}(\Delta h + \Delta KE + \Delta PE)$$



A)  $T_2 \rightarrow \text{isenthalpic} \rightarrow 25^\circ\text{C}$  : سؤال

ideal gas  $C_p^{ig} = 3.5R$   $T_{surr} = 20^\circ\text{C}$   
 isenthalpic  $R = 8.314$   $\dot{n} = 1000 \text{ mol/h}$

B)  $\Delta S = ?$   $\Delta S = C_p^{ig} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1} \Rightarrow \Delta S = 17.68 \text{ J/mol K}$

C)  $\dot{S}_{gen} = \dot{n} \Delta S - \frac{\dot{Q}_{surr}}{T_{surr}} = 4.897 \text{ J/s K}$

D)  $\dot{W}_{lost} = \dot{S}_{gen} \cdot T_{surr} = 1435 \text{ J/s}$

□ فصل ٦ - خواص ترموديناميكي سيالات

$z = z(x, y) \Rightarrow dz = \left( \frac{\partial z}{\partial x} \right) dx + \left( \frac{\partial z}{\partial y} \right) dy = M dx + N dy$

$\left( \frac{\partial M}{\partial y} \right)_x = \left( \frac{\partial N}{\partial x} \right)_y$  ,  $\left( \frac{\partial x}{\partial z} \right)_y = \frac{1}{\left( \frac{\partial z}{\partial x} \right)_y}$

$\left( \frac{\partial x}{\partial y} \right)_z \left( \frac{\partial y}{\partial z} \right)_x \left( \frac{\partial z}{\partial x} \right)_y = -1$

$\left( \frac{\partial z_1}{\partial x} \right)_y = \left( \frac{\partial z_1}{\partial z_2} \right)_y \left( \frac{\partial z_2}{\partial x} \right)_y$

①  $du = T ds - P dv$

②  $dh = T ds + v dP$

③  $a = u - TS \rightarrow da = -s dT - P dv$

④  $g = h - TS \rightarrow dg = -s dT + v dP$

①  $u = u(s, v) \rightarrow du = \underbrace{\left( \frac{\partial u}{\partial s} \right)_v}_T ds + \underbrace{\left( \frac{\partial u}{\partial v} \right)_s}_{-P} dv$  ,  $\left( \frac{\partial T}{\partial v} \right)_s = - \left( \frac{\partial P}{\partial s} \right)_v$   
 (معادلة ماكسويل الأولى)

$$\textcircled{2} \left(\frac{\partial h}{\partial s}\right)_P = T, \left(\frac{\partial h}{\partial P}\right)_S = V \Rightarrow \left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P \quad \text{معادله داف ماگنول}$$

$$\textcircled{3} \left(\frac{\partial a}{\partial T}\right)_V = -S, \left(\frac{\partial a}{\partial V}\right)_T = -P \Rightarrow \left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V \quad \text{معادله سرف ماگنول}$$

$$\textcircled{4} \left(\frac{\partial g}{\partial T}\right)_P = -S, \left(\frac{\partial g}{\partial P}\right)_T = V \Rightarrow -\left(\frac{\partial S}{\partial P}\right)_T = \left(\frac{\partial V}{\partial T}\right)_P \quad \text{معادله جرف ماگنول}$$

\* Clapeyron Equation:

$$\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial S}{\partial V}\right)_T \Rightarrow \left(\frac{dP}{dT}\right)_{\text{sat}} = \frac{S_g - S_f}{V_g - V_f} = \frac{S_{fg}}{V_{fg}} \quad \textcircled{1}$$

for a phase change @ Constant Temperature:

$$Tds = dh - v dP \xrightarrow{0} Tds = dh \Rightarrow T(S_g - S_f) = h_g - h_f$$

$$T S_{fg} = h_{fg} \quad \textcircled{2} \rightarrow \left(\frac{dP}{dT}\right)_{\text{sat}} = \frac{h_{fg}}{T V_{fg}} \quad \text{معادله کلایپرون - کلایپرون}$$

صورت ساده شده

$$\text{معادله کلایپرون} \rightarrow V_g \gg V_f, V_g = \frac{RT}{P} \Rightarrow \frac{d(\ln P)_{\text{sat}}}{d(1/T)_{\text{sat}}} = \frac{-h_{fg}}{R}$$

$$\ln\left(\frac{P_2}{P_1}\right) = \frac{h_{fg}}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right) \quad \leftarrow \text{صورت ساده شده}$$

مثال:  $h_{fg}$  برای  $\text{R-12}$  در  $-5^\circ\text{C}$  و  $P^{\text{sat}} = 0.26096 \text{ MPa}$  معلوم است.  $T'_{\text{sat}} = +4^\circ\text{C} \rightarrow P'_{\text{sat}} = 0.35124 \text{ MPa}$  Data

@  $T = 0^\circ\text{C} \rightarrow V_g = 0.05539, V_f = 0.0007159, R = 0.06876$  Data

$$\left(\frac{dP}{dT}\right)_{\text{sat}} = \left(\frac{\Delta P}{\Delta T}\right)_{\text{sat}} \times 1000 = 10.031 \frac{\text{kPa}}{\text{K}}$$

$$h_{fg} = T V_{fg} \left(\frac{dP}{dT}\right)_{\text{sat}} = 149.81$$

## General Relations for $du, dh, ds$ :

**internal Energy:**  $u = u(T, v)$   $du = \left(\frac{\partial u}{\partial T}\right)_v dT + \left(\frac{\partial u}{\partial v}\right)_T dv$

$\left(\frac{\partial u}{\partial T}\right)_v = C_v$   $du = C_v dT + \left(\frac{\partial u}{\partial v}\right)_T dv$  (I)

$S = S(T, v) \rightarrow ds = \left(\frac{\partial s}{\partial T}\right)_v dT + \left(\frac{\partial s}{\partial v}\right)_T dv$   $\left(\frac{\partial s}{\partial T}\right)_v = \frac{C_v}{T}$

$Tds = du + PdV \rightarrow du = Tds - PdV = T\left(\frac{\partial s}{\partial T}\right)_v dT + \left[T\left(\frac{\partial s}{\partial v}\right)_T - P\right]dv$  (II)

(I):  $du = C_v dT + \left(\frac{\partial u}{\partial v}\right)_T dv \rightarrow$  (I), (II)  $du = C_v dT + \left[T\left(\frac{\partial P}{\partial T}\right)_v - P\right]dv$  \*

$\Delta u = u_2 - u_1 = \int_{T_1}^{T_2} C_v dT + \int_{v_1}^{v_2} \left[T\left(\frac{\partial P}{\partial T}\right)_v - P\right]dv$  \*\* برای گاز ایده آل صفر است

## enthalpy:

برای گاز ایده آل صفر است  
 $dh = C_p dT + \left[v - T\left(\frac{\partial v}{\partial T}\right)_P\right]dP$  \*

$\Delta h = h_2 - h_1 = \int_{T_1}^{T_2} C_p dT + \int_{P_1}^{P_2} \left[v - T\left(\frac{\partial v}{\partial T}\right)_P\right]dP$  \*\*

## entropy:

$\Delta S = S_2 - S_1 = \int_{T_1}^{T_2} \frac{C_v}{T} dT + \int_{v_1}^{v_2} \left(\frac{\partial P}{\partial T}\right)_v dv$  \*\*

$\Delta S = \int_{T_1}^{T_2} \frac{C_p}{T} dT - \int_{P_1}^{P_2} \left(\frac{\partial v}{\partial T}\right)_P dP$  \*\*

روابط آنتروپی گازها ایده آل با توجه به همین روابط فوق و معادله حالت برست محاسبه میشود.

## Experimental tests :

1. Vapor pressure Data ( $T^{\text{sat}}$ ,  $P^{\text{sat}}$ )

4.  $T_c, P_c$

2.  $P$ - $V$ - $T$  in Vapor phase

5.  $C_p^{\text{ig}}$

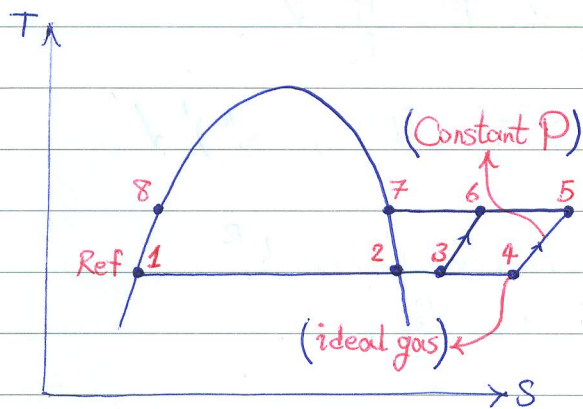
3. liquid phase Density

$$\text{Step 1: } \ln P^{\text{sat}} = A + \frac{B}{T^{\text{sat}}} + C \ln T^{\text{sat}} + D T^{\text{sat}}$$

$$\text{Step 2: } v_f = \frac{1}{\rho_f}$$

$$\text{Step 3: } P-x-t \rightarrow v_g$$

→ Ref state:  $h_f = 0$   $S_f = 0$



$$\textcircled{1} \rightarrow \textcircled{2} : \left( \frac{dP}{dT} \right)^{\text{sat}} = \frac{h_{fg}}{T(v_g - v_f)}$$

$$S_{fg} = \frac{h_{fg}}{T}$$

$$\textcircled{2} \rightarrow \textcircled{3} : h_3 - h_2 = \int_{T_2}^{T_3} C_p dT + \int_{P_2}^{P_3} \left[ v - T \left( \frac{\partial v}{\partial T} \right)_P \right] dP$$

تغییر  $\Delta S_{23}$  نیز محاسب می شود. (طبق رابطه زیر محاسب می شود)

$$\begin{cases} h^R = h - h^{\text{ig}} \\ P_4 = P_5 \approx 0 \end{cases} \rightarrow \begin{cases} \Delta h = h_7 - h_1 = (h_7 - h_5) + (h_5 - h_4) + (h_4 - h_1) \\ \Delta h = h_2^R + \Delta h^{\text{ig}} - h_1^R \end{cases}$$

$$\begin{cases} h_2^R = h_7 - h_5 = \int_0^{P_2} \left[ v - T \left( \frac{\partial v}{\partial T} \right)_P \right] dP * & \Delta h^{\text{ig}} = \int_{T_1}^{T_2} C_p^{\text{ig}} dT * \\ -h_1^R = h_4 - h_1 = - \int_0^{P_1} \left[ v - T \left( \frac{\partial v}{\partial T} \right)_P \right] dP * \end{cases}$$

$$\text{if } v = \frac{ZRT}{P} \rightarrow h^R = - \int_0^P R T^2 \left( \frac{\partial Z}{\partial T} \right)_P \frac{dP}{P}$$

$$\text{if } T = T_r T_c, P = P_r P_c \rightarrow \frac{h^R}{R T_c} = - T_r^2 \int_0^{P_r} \left( \frac{\partial Z}{\partial T_r} \right)_{P_r} \frac{dP_r}{P_r}$$

if  $z = z^{(o)} + \omega z^{(i)}$

$$\frac{h^R}{RT_c} = \frac{(h^R)^o}{RT_c} + \frac{(h^R)^i}{RT_c} \omega \rightarrow \text{برون } \omega \rightarrow T_r, P_r$$

$$\Delta S = S_2^R - S_1^R + \Delta S^{ig} = S_2^R - S_1^R + \int_{T_1}^{T_2} \frac{C_p^{ig}}{T} dT - R \ln \frac{P_2}{P_1}$$

$$\text{برون } \omega: \frac{S^R}{R} = \frac{(S^R)^o}{R} + \frac{(S^R)^i}{R} \omega \rightarrow T_r, P_r$$

مثال: گاز هیدروکربن نیترژن است. ① 225 K 6 MPa ② 300 K 10 MPa

$C_p^{ig}, R, T_c, P_c, \omega$  is available

$$A) \Delta h = -\underset{1}{h_1^R} + \underset{3}{\Delta h^{ig}} + \underset{2}{h_2^R} \quad \textcircled{1} \rightarrow T_r = \frac{T_1}{P_c} \checkmark \quad P_r = \frac{P_1}{P_c} \checkmark$$

$$P_r, T_r \rightarrow (h^R)^o, (h^R)^i \checkmark$$

$$\rightarrow h_1^R \text{ با توجه به موارد فوق بدست می آید}$$

$$\textcircled{2} T_r = \frac{T_2}{P_c} \checkmark \quad P_r = \frac{P_2}{P_c} \checkmark$$

$$P_r, T_r \rightarrow (h^R)^o, (h^R)^i \checkmark$$

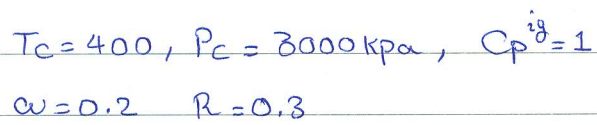
$$\rightarrow h_2^R \text{ با توجه به موارد فوق بدست می آید}$$

$$\textcircled{3} \Delta h^{ig} = C_p^{ig} (T_2 - T_1) \checkmark$$

$$B) \Delta S = -\underset{1}{S_1^R} + \underset{3}{\Delta S^{ig}} + \underset{2}{S_2^R} \quad \textcircled{1} \rightarrow T_r, P_r \rightsquigarrow S_R^o \text{ و } S_R^i \checkmark \rightsquigarrow S_1^R$$

$$\textcircled{2} T_r, P_r \rightsquigarrow S_R^o, S_R^i \checkmark \rightsquigarrow S_2^R$$

$$\textcircled{3} \Delta S^{ig} = C_p^{ig} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$


$$w = 0.2 \quad R = 0.3$$

$$W_S = h_i - h_{es} \quad ?$$

State ①  $\rightarrow T_r, P_r$  isobaric comp.  $\xrightarrow{\text{exp}}$   $S_r^o, S_r'$   $\rightarrow S_i^R$

State ②  $\rightarrow T_r, P_r$   $\xrightarrow{\text{isobaric expansion}} S_R^0, S_R^1 \rightarrow S_C^R$  (حرکتی)

if  $\Delta S = -S_i^R + \Delta S^{ig} + S_2^R = 0$ . Then our Guess is perfect.

Continue to find "T<sub>es</sub>"  $\rightarrow$  T<sub>es</sub>, P<sub>es</sub>  $\rightarrow$  he