Ch.2 Some concepts and definitions

Thermodynamics: science of energy and entropy.

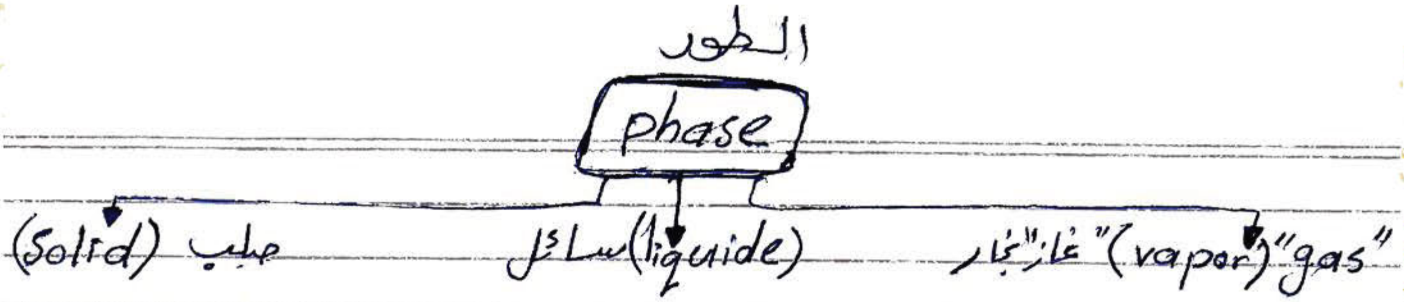
Thermodynamics: Science that deals with heat and work and those properties of substances that bear a relation to heat and work.

Classification of thermodynamic systems

① isolated system: System that isn't effect by surrounding.
((**NO**: mass, heat, work. cross the boundary))
نظام معزول عن المحيط الخارجي/ لا يسمح بدخول الطاقة (Q, W) والكتلة ثابتة.

② closed system (control mass): (no mass enter or leave the system) "الكتلة = ثابتة"
eg: piston cylinder arrangment

③ Open System (control volume): (mass can cross the boundary).
الكتلة = ليست ثابتة
eg: (compressor, pump, heat exchanger, nuzzle, turbine)
(محرك حراري ، وفوهة ، مبادل حراري ، ومضخة ، (



Properties

① Extensive properties: depends on mass (Volume, Energy)
② Intensive properties: independs on mass (temp., press., density)
(كثافة، ضغط، حرارة)

Specific property = $\frac{\text{Extensive properties}}{\text{mass}}$ = intensive proprty

eg: specific volume (v) = $\frac{\text{Volume}}{\text{mass}} = \frac{V}{m} = v \left[\frac{m^3}{kg}\right] = \frac{1}{\rho}$

☞ ($\rho = \frac{m}{V}$ الكثافة = الكتلةعلى الحجم)

Process and cycles

Ⓐ iso-choric process : v = constant

Ⓑ Iso-baric process : pressure = constant

Ⓒ iso-thermal process : temperature = constant

Ⓓ Adiabatic process: NO heat transfer (Q = zero)

Ⓔ Steady-flow process: NO change with time.

Some concepts

الضغوط

Pressure: Force per unit area.

$P = \frac{Force}{Area} \Rightarrow \boxed{P = \frac{F}{A}}$ $\left[\frac{N}{m^2}\right] = [pa]$ وحدة قياسه الباسكال

1000 pa = 1 kpa
1000 000 pa = 1 Mpa
1000 kpa =

* Some unit of Pressure common ly used in practice

حفظ

① bar ⇒ $1 bar = 10^5 pa = 100 kpa$
② Stanard atmosphere ⇒ $1 atm = 101.325 kpa$
③

Volume الحجم $[m^3]$ ← الوحدة

(v) specific volume : $\frac{V}{m} = \left[\frac{m^3}{kg}\right] = v$

Temprerature درجة الحرارة (T)

① C° (سيلسيوس) =
② K (كلفن) $= C^\circ + 273.15$
③ F° (فهرنهايت) $= \frac{9}{5} c^\circ + 32$

Zero law

Enegy → Stored $(PE + KE + U)$
Enegy → transient $(\underset{work}{W} + \underset{heat}{Q})$

Ch.3 Properties of a pure substance

تحدثنا في الوحدة السابقة عن المادة وخصائصها، مثل: (الضغط، درجة الحرارة، الحجم النوعي)

سنتحدث في هذه الوحدة عن المادة النقية وخصائصها وسنتعرف على كيفية حساب الضغط والحجم النوعي و... ، وستكون هذه الوحدة أساس لهذه المادة.

Pure Substance Is one that has a homogeneous and invariable chemical composition. It may exist in more than one phase, but chemical composition is the same in all phases. (liquid, solid, vapor)

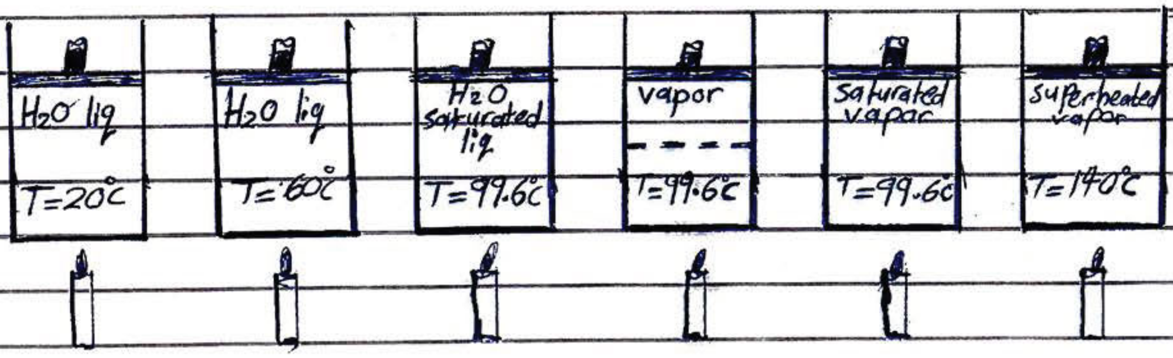
المادة النقية: هي المادة التي يكون تركيبها الكيميائي متجانس وثابت، ويمكن أن تتواجد بعدة أطوار مثل: (سائل، صلب، بخار).

note

ملاحظة: سنعتبر أن الهواء مادة نقية لكنه في الحقيقة ليس كذلك.

Consider as a system 1kg of water contained in the piston/cylinder and that the initial temp. is 20°c. As heat is transfered to the water, the ~~press.~~ temp. increases appreciably, the specific volume increases slightly, and the press. remains constant

لدينا piston/cylinder يحتوي على 1 كغم من الماء تحت ضغط ثابت مقداره 100 كيلوباسكال بدرجة حرارة ابتدائية مقدارها 20° درجة مئوية، علماً بأنه تم وضع بعض الأوزان على المكبس



شرح التجربة :

تم وضع ماء بدرجة حرارة 20 وضغط 100 كيلو باسكال وكتلة 1 كغم داخل (piston /cylinder) ثم تم تسخينه إلى درجة حرارة 60° وبقي الماء في حالة (liq) ثم سُخّن إلى 99.6 فبدأ الحجم بالإزدياد وبدأ ظهور فقاعات تدل على أن السائل بدأ يتبخر وتسمى هذه الحالة بـ (saturated liquid) (سائل مشبع) ودرجة الحرارة عند هذه الحالة تسمى درجة حرارة الإشباع (saturated temp) ، علماً أن الضغط ما زال ثابتاً ، ومع بقاء درجة الحرارة نفسها بدأت المادة بالتبخر وأصبح جزء من المادة بخار والجزء الآخر سائل وتسمى هذه الحالة (saturated mixture) مع بقاء درجة الحرارة ثابتة استمر التبخر وتبخرت المادة كاملة ، عند هذه اللحظة تسمى الحالة (saturated vapor) (بخار مشبع) ثم رفع درجة الحرارة إلى أن أصبحت 140° ويصبح اسم الحالة (superheated vapor) بخار محمص

الخلاصة : ١) sat. liq المادة كلها سائل وستبدأ بالتبخر.
٢) sat. mix خليط بين السائل والبخار.
٣) sat. vap المادة كلها بخار (لا يوجد سائل)
٤) sat. temp الدرجة التي يبدأ عندها السائل بالتبخر.
٥) sat. press. ضغط الإشباع.

In saturated phase

Quality → (نسبة كتلة بخار الماء إلى الكتلة الكلية)

$$\text{Quality} = x = \frac{\text{mass of vapor}}{\text{mass total}}$$

$$x = \frac{m_g}{m_g + m_f}$$

m_g: mass of vapor
m_f: mass of liquid

sat. liq → $x = 0$
sat. vap → $x = 1$
sat. mix → $0 < x < 1$
liquid → x = undefined
vapor → x = undefined

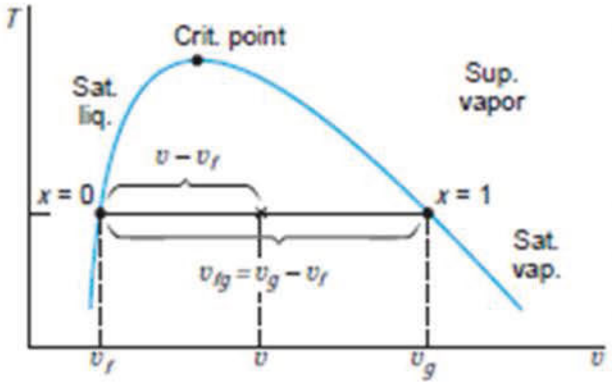


FIGURE 3.4 T–v diagram for the two-phase liquid–vapor region showing the quality–specific volume relation.

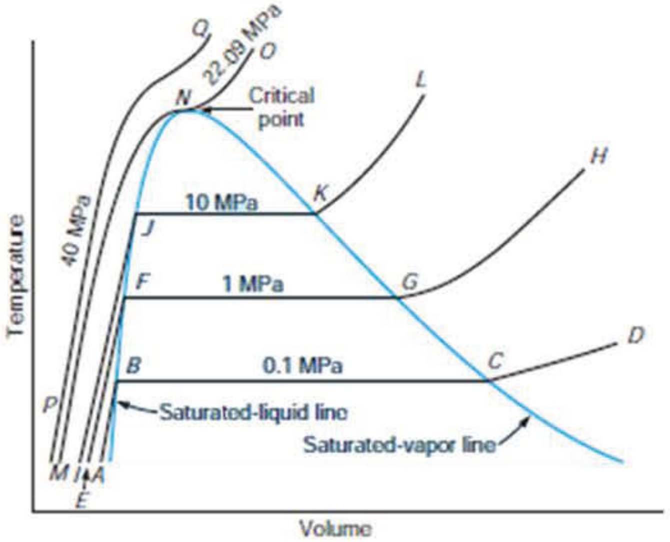


FIGURE 3.3 Temperature–volume diagram for water showing liquid and vapor phases (not to scale).

In mix phase

$$V_t = V_g + V_f$$

$$V_t = v_g m_g + v_f m_f \qquad \boxed{v = \frac{V}{m}} \Rightarrow \boxed{V = v \cdot m}$$

Remark

$$v_{fg} = v_g - v_f$$

تقسيم علي mt

$$\Rightarrow \frac{V_t}{m_t} = \frac{v_g m_g}{m_t} + \frac{v_f m_f}{m_t}$$

$$\boxed{v = v_g x + v_f (1 - x)} \xrightarrow{\text{بصورة أخرى}} \boxed{v = v_f + x v_{fg}}$$

$$\therefore \boxed{x = \frac{v - v_f}{v_{fg}}}$$

شرح الجداول

جداول الثيرموديناميك مهمة جداً وفهمك للجداول حالياً يسهل عليك فهم المادة للأمام.
الجداول مقسمة إلى أربعة تبويبات (4 Appendix) ⇐ (A, B, C, D)
سيكون جُلّ اهتمامنا عن تبويب (B)

Ⓑ

CH_4	N_2	R-134a	R-22	R-12	NH_3	H_2O
Methane	Nitrogen				Amonia	(steam) water
ميثان	نيتروجين				أمونيا	ماء (بخار)

* معظم المواد مقسمة إلى (Superheated و Saturated) عدا الماء فهو مفصل أكثر.

مثل ← الأمونيا (NH_3)

B.2.1 → Saturated ← له اسم المادة الثانية (الأمونيا)

B.2.2 → superheated vapor ← (اسم المادة الثانية (الأمونيا))

مثل ← الماء (H_2O)

B.1.1	B.1.2	B.1.3	B.1.4	B.1.5
(Sat. مدخل حرارة)	(Sat. مدخل ضغط)	(Superheated vapor)	(compressed liquid)	(Sat. solid-vapor)

العامود الأول في صفحات الـ Sat. يسمى المدخل وفي جميع المواد يكون المدخل (العامود الأول) هو درجة الحرارة. عدا الماء فإنه في B.1.1 يكون العامود الأول (المدخل)؛ B.1.2 يكون العامود الأول (المدخل) هو الضغط ... وسنتعرف أكثر على الجداول في حل الأمثلة

لتحديد طور المادة (phase) يجب ان يكون لدينا خاصيتين على الأقل:

- * If $T > T_s$ or $P < P_s$ ⟶ phase (superheated vapor)
- * If $T < T_s$ or $P > P_s$ ⟶ phase (compressed liquid)
- * If $v_f > v$ ⟶ phase (compressed liquid)
- * If $v > v_g$ ⟶ phase (superheated vapor)
- * If $v_f < v < v_g$ ⟶ phase (mixture)

EXAMPLE 3.1

Determine the phase for each of the following water states using the tables in Appendix B and indicate the relative position in the *P–v*, *T–v*, and *P–T* diagrams.

a. 120°C, 500 kPa
b. 120°C, 0.5 m^3/kg

a) H_2O, $T = 120°c$, $P = 500 kpa$

لتحديد الطور يجب أن يكون لدينا خاصيتين ومعرفة نوع المادة طبعاً ، هنا الخاصيتين هما الحرارة والضغط والمادة هي الماء.

⇐ نذهب إلى جداول الـ sat لمادة الماء ونستخرج T_s أو P_s ولأن الماء له مدخل حرارة وضغط لنا حرية الذهاب لأي منها.

* الطريقة الأولى: نذهب إلى Table B.1.1 ونستخرج P_s ويكون P_s مقابل لدرجة الحرارة المعطاه بالسؤال وهي 120°

$\therefore$ at 120° → $P_s = 148.5$ kpa ($P > P_s$, compressed liq.)

* الطريقة الثانية: نذهب إلى Table B.1.2 ونستخرج T_s وتكون T_s مقابلة لقيمة الضغط المعطاه في السؤال وهي 500 kpa

$\therefore$ at 500 kpa → $T_s = 151.86°c$ ($T < T_s$, compressed liq.)

ملاحظ: أنه باستخدام أي طريقة يمكننا ايجاد الطور.

b) H_2O, $T = 120°c$, $v = 0.5 m^2/kg$

لتحديد الطور في هذه الحالة يجب ايجاد v_g ، v_f ومقارنتهم مع v

$$\left.\begin{array}{l} \text{at } T = 120°c \rightarrow v_f = 0.00106 \\ \qquad\qquad\quad \rightarrow v_g = 0.89186 \end{array}\right\} v_f < v < v_g \quad \therefore \underline{\underline{mix}}$$

EXAMPLE 3.2

Determine the phase for each of the following states using the tables in Appendix B and indicate the relative position in the *P–v*, *T–v*, and *P–T* diagrams, as in Figs. 3.11 and 3.12.

a. Ammonia 30°C, 1000 kPa

solution

a)

نذهب إلى (table-B.2.1) مدخل الحرارة لإيجاد P_s

نتذكر أنه في المواد غير الماء يوجد فقط مدخل حرارة.

$T=30^\circ \longrightarrow P_s = 1167$ kpa

$(P<P_s$, phase: superheated vapor)

EXAMPLE 3.3

Determine the temperature and quality (if defined) for water at a pressure of 300 kPa and at each of these specific volumes:

a. 0.5 m^3/kg
b. 1.0 m^3/kg

solution:

a) $@P=300\text{kpa} \longrightarrow v_f = 0.001073$

$v_g = 0.60582$

$v_f < v_\beta < v_g \longrightarrow$ phase: mixture, $\begin{pmatrix} T=T_s \\ x=\text{defined} \end{pmatrix}$

$T = T_s = 133.55\ c^\circ$

to find x we must to find v_{fg}

$\Rightarrow$ @ 300 kpa $\longrightarrow v_{fg} = 0.60475$

$$x = \frac{v - v_f}{v_{fg}} = \frac{0.5 - 0.001073}{0.60475}$$

$\underline{\underline{ans.}}$ $\begin{cases} x = 0.825 \\ T = T_s = 133.55\ c^\circ \end{cases}$

b) @ 300 kpa $\longrightarrow v_f = 0.001073$
$\longrightarrow v_g = 0.60582$

$v > v_g \longrightarrow$ Super heated vapor (x = undifined)
(T from table B.1.3)

نذهب الى الجدول لإيجاد درجة الحرارة (table B.1.3) عند ضغط (300kpa) نذهب لنرى ما يقابل ($v = 1 m^3/kg$) من درجات الحرارة، والمشكلة هنا لا يوجد (~~1~~ واحد صحيح) مقابل (الواحد صحيح 1) لذلك نعمل عملية توليد لقيمة (temp.) عن طريق ما يسمى (interpolation)

	P	T	v
①	300	300	0.87529
②	300	T	1
③	300	400	1.03151

$$\frac{T - 300}{400 - 300} = \frac{1 - 0.87529}{1.03151 - 0.87529}$$

$\Rightarrow T = 379.8337291\ c^\circ$

EXAMPLE 3.4

A closed vessel contains 0.1 m^3 of saturated liquid and 0.9 m^3 of saturated vapor R-134a in equilibrium at 30°C. Determine the percent vapor on a mass basis.

solution

R-134a → $V_f = 0.1 m^3$ sat. liq $(v = v_f)$

→ $V_g = 0.9 m^3$ sat. vap $(v = v_g)$

$T = 30°C$ $m = 152.3 kg$

المطلوب ايجاد $\underline{x}$

$$\boxed{x = \frac{m_g}{m_g + m_f}}$$

From table B.5.1

at 30°C → $v_f = 0.000843$

→ $v_g = 0.02671$

$$\boxed{v = \frac{V}{m}} \rightarrow \boxed{m = \frac{V}{v}}$$

$$m_g = \frac{V_g}{v_g} = \frac{0.9}{0.02671} = 33.7 kg \quad \Big\| \quad m_f = \frac{V_f}{v_f} = \frac{0.1}{0.000843} = 118.6 kg$$

$$x = \frac{m_g}{m_g + m_f} = \frac{33.7}{33.7 + 118.6} = 0.221$$

EXAMPLE 3.6

Determine the missing property of *P–v–T* and *x* if applicable for the following states.

a. Nitrogen: –53.2°C, 600 kPa

b. Nitrogen: 100 K, 0.008 m^3/kg

solution a) N_2 : −53.2°C, 600 kpa

* ملاحظة مهمة : في كل المواد تكون درجة الحرارة بالسيلسيوس ، ما عدا (CH_4, N_2) تكون بالكلفن ، لذلك نحول الحرارة اذا كانت معطاه بـ (C°) إلى كلفن اذا كانت المادة (CH_4, N_2)

$T = 273.2 + (-53.2) = 220 k$

عندما نبحث في الجداول الـ (saturated) لا نجد درجة حرارة (220k) ولأنها أعلى
من آخر درجة تكون sup.vap. ولأنها أعلى من (critical temp) في جدول A.2

P=600 kpa / T=220 k / superheated vapor $\Rightarrow$ $v = 0.10788\ m^3/kg$

EXAMPLE 3.7 Determine the pressure for water at 200°C with $v = 0.4\ m^3/kg$.

solution H_2O at 200°c with $v = 0.4\ m^3/kg$

→ Enter in table B.1.1 ($v_g = 0.12736$) $\Rightarrow$ $v > v_g$

$\therefore$ superheated vapor

لإيجاد الضغط نذهب إلى جداول الـ (sup.vap) ونبحث عن درجات الحرارة الـ (200)
ونعمل (انتربوليشين - interpolition)

T	v	P
200	0.42492	500
200	0.4	P
200	0.35202	600

$$\rightarrow \frac{0.4 - 0.42492}{0.35202 - 0.42492} = \frac{P - 500}{600 - 500}$$

$\rightarrow$ P = 534.1838134 kpa

أمثلة إضافية (أفكار)

Example : find v.

H_2O / 2 Mpa / $T=160°C$

from table B.1.1 @ $T=160°C \rightarrow P_s = 617.8$ kpa

$P > P_s$ ∴ (compressed liq.)

⇐ اذهب إلى جداول الـ (compressed) للماء B.1.4

عند الحرارة والضغط المعطى بالسؤال ($v = 0.001101 \; m^3/kg$)

Example : find v.

H_2O / 100 kpa / $T=70°C$

from table B.1.1 @ $70°C \rightarrow P_s = 31.19$ kpa

$P > P_s$ ∴ (compressed liq)

⇐ نذهب إلى جداول (B.1.4) ونجد ان جداول الـ (compressed) للماء لا يوجد بها ضغط (100 kpa)

. لذلك هنا نجد الخواص من جداول الـ (saturated) يعني ($S=S_f$, $u=u_f$, $v=v_f$) وهكذا ...

$$\boxed{v = v_f = 0.001023 \; m^3/kg}$$

3.35 Determine the phase and the specific volume for ammonia at these states using the Appendix B table.

c. 60°C, quality 25%

ⓒ quality 25% $\xrightarrow{\text{هذا يعني}}$ $\boxed{X=0.25}$

3.34 Give the missing property of P, T, v, and x for R-134a at

b. $P = 300$ kPa, $v = 0.072$ m^3/kg

solution ⓑ R-134a / P=300kpa / v=0.072 m³/kg

Find $\underline{T}$, $\underline{X}$

∴ from table B.5.1 @ 294kpa → v_g=0.06919

عند ضغط (294) وهي أقرب قيمة للضغط (300) يكون $v>v_g$

∴ superheated vapor. $\underline{x = \text{undefined}}$

P	v	T
300	0.07111	10
300	0.072	$\boxed{T}$
300	0.07441	20

By interpolition $\boxed{T = 12.696\ °C}$

3.38 Give the missing property of P, T, v, and x for CH_4 at

b. $T = 350$ K, $v = 0.25$ m^3/kg

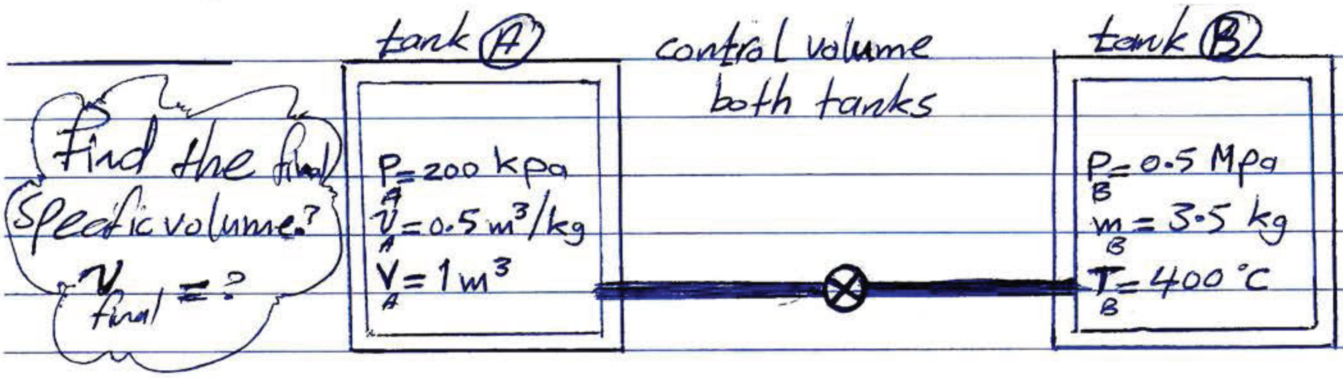
$T > T_{critical}$ ∴ (superheated vapor)
أعلى قيمة

To find pressure

T	v	P
350	0.2251	800
350	0.25	Ⓟ
350	0.30067	600

By interpolition ⇒ $\underline{P = 734.1 \text{ kpa}}$

3.52 Two tanks are connected as shown in Fig. P3.52, both containing water. Tank A is at 200 kPa, $v = 0.5\ \text{m}^3/\text{kg}$, $V_A = 1\ \text{m}^3$, and tank B contains 3.5 kg at 0.5 MPa and 400°C. The valve is now opened and the two tanks come to a uniform state. Find the final specific volume.



① $m_A = \dfrac{V_A}{v_A} = \dfrac{1}{0.5} = 2\text{kg}$

② from table B.1.3 $v_B = 0.6173\ \text{m}^3/\text{kg}$

$V_B = m_B\, v_B = (3.5) * (0.6173) \Rightarrow V_B = 2.1606\ \text{m}^3$

$$v_{final} = \frac{V_{total}}{m_{total}} = \frac{V_A + V_B}{m_A + m_B} = \frac{1 + 2.1606}{2 + 3.5} = 0.5746\ \text{m}^3/\text{kg}$$

The P-V-T Behavior of Low and moderate-density GASES

* سنتحدث هنا عن قانون الغازات (يستخدم في حالة الغازات فقط)

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

P: Pressure الضغط
V: volume الحجم
n: no. of moles عدد المولات
$\bar{R}$: gases constant ثابت الغازات
T: tempreture درجة الحرارة

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

نشتق القانون ← (نقسم على Mw)

$$\Rightarrow PV = (n * M_w)\left(\frac{\bar{R}}{M_w}\right)(T)$$

$$\Rightarrow \boxed{PV = mRT}$$

m: mass
R: particular gas constant [kJ/kg.K°]
(قيمة موجودة في table A.5)

Remark

$m = n * M_w$

$R = \bar{R}/M_w$

EXAMPLE 3.8 What is the mass of air contained in a room 6 m × 10 m × 4 m if the pressure is 100 kPa and the temperature is 25°C?

$PV = mRT$

$(100)(240) = m\,(0.287)\,(25+273)$

$\Rightarrow m = 280.5$ kg

إذا كانت P[kPa]
يجب أن تكون
R [kJ/kg.K°]

$\boxed{PV = mRT}$ ⇒ for ideal gas

if not ideal gas ⇒ $\boxed{PV = ZmRT}$

Z: compressibilty Factor

T: temp. درجة الحرارة بالكلفن

$\boxed{\frac{PV}{mRT} = Z}$ ← * بشكل عام في الغازات

$\frac{PV}{mRT} = 1$ ⇐ * اذا كان غاز مثالي فإن 1=Z

if Z=1 → ideal gas
if Z=0.5 → not ideal gas
if Z=0.97 → ideal gas

Note

volume [m^3]

from ~~table~~ Fig D-1

mass [kg]

From table A.5

temp. [k°]

Pressure [kpa]

$\boxed{PV = ZmRT}$ القانون مهم

* To find Z From Figuer D-1 we must find P_r, T_r

P_r → Reduced pressure.

T_r → Reduced temperature.

$\boxed{P_r = \frac{P}{P_{critical}}}$ $\boxed{T_r = \frac{T}{T_{critical}}}$

(From table A.2)

EX: Find the voluem of 2 kg of ethylene at 270 k°, 2500 kpa using Z from Fig. D-1.

Solution $m = 2\,kg$ / Ethylene / $T = 270\,k$ / $P = 2500\,kpa$

$PV = ZmRT \Rightarrow V = \frac{ZmRT}{P}$ } R → table A.5 $R = 0.2964\,kJ/kg.k$

→ To find Z we must find T_r & P_r

$T_r = \frac{T}{T_{critical}} = \frac{270}{282.4} = 0.956$

$P_r = \frac{P}{P_{critical}} = \frac{2500}{5040} = 0.496$

} from fig D-1 $\underline{\underline{Z = 0.75}}$

$\underline{\underline{V = 0.0493\,m^3}}$

EX: Carbon dioxide at 330 K is pumped at a very high pressure, 10 MPa, into an oil well. As it penetrates the rock/oil, the oil viscosity is lowered so it flows out easily. For this process we need to know the density of the carbon dioxide being pumped.

Solution: $\rho = \frac{1}{v} = \frac{m}{V} \Rightarrow PV = ZmRT \Rightarrow \frac{V}{m} = \frac{ZRT}{P}$

$\Rightarrow \boxed{v = \frac{ZRT}{P}}$ from table A.5 $R = 0.1889\,kJ/kg.k$

From table A.2 → $P_{cr} = 7.38\,Mpa$

→ $T_{cr} = 304.1\,k$

$T_r = \frac{T}{T_{cr}} = \frac{330}{304.1} = 1.085$

$P_r = \frac{P}{P_{cr}} = \frac{10}{7.38} = 1.355$

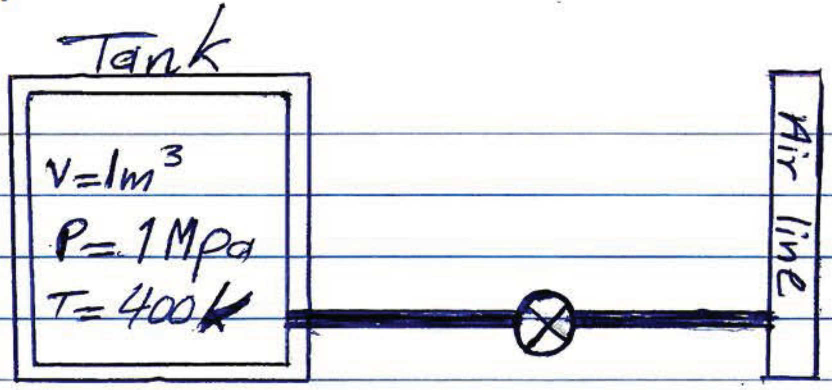
} from fig D-1 $\Rightarrow Z \simeq 0.45$

$\Rightarrow v = \frac{(0.45)(0.1889)(330)}{(10000)} = \boxed{\quad} \Rightarrow \rho = \frac{1}{v} = \underline{\underline{\quad}}$

3.82 A 1-m^3 rigid tank with air at 1 MPa and 400 K is connected to an air line as shown in Fig. P3.82. The valve is opened and air flows into the tank until the pressure reaches 5 MPa, at which point the valve is closed and the temperature inside is 450 K.

a. What is the mass of air in the tank before and after the process?

b. The tank eventually cools to room temperature, 300 K. What is the pressure inside the tank then?



a) Air → ideal gas   R from table A.5 ⇒ R = 0.287 kJ/kg.k

$$P_1V = m_1RT_1 \qquad m_1 = \frac{P_1V}{RT_1} = \frac{(1000)(1)}{(0.287)(400)} = 8.711\ kg$$

$$P_2V = m_2RT_2 \qquad m_2 = \frac{P_2V}{RT_2} = \frac{(5000)(1)}{(0.287)(450)} = 38.715\ kg$$

b)

$$P\,\underbrace{V = m\,R}_{\text{constant}}\,T$$

$$\frac{P}{T} = \frac{mR}{V} = \text{constant} \Rightarrow \frac{P_2}{T_2} = \frac{P_3}{T_3}$$

$$P_3 = \frac{(P_2)(T_3)}{T_2} = \frac{(5000)(300)}{450} \Rightarrow P_3 = 330\ kpa$$

نلاحظ أن الكتلة ثابتة بين الحالة ② والحالة ③.

Ch. 4

Work and Heat

Work: Force (F) acting through a displacement x, where the displacement is in the direction of the force.

$W = \int F \cdot dx$ from: $P = \frac{F}{A} \Rightarrow \boxed{F = P \cdot A}$

$\Rightarrow W = \int A \cdot P \cdot dx \Rightarrow \boxed{W = \int P dv}$ Joule

① الشغل في (tank) يساوي صفر؛ لأنه الحجم ثابت ويصبح القانون $W = P\overset{0}{\Delta V}$
$\boxed{W = 0}$

② الشغل في (cylinder piston):

في (cylinder piston) الضغط ثابت.

$W = P\int_{v_1}^{v_2} dv \Rightarrow W = P\Delta V$

$\Rightarrow \boxed{W = P(v_2 - v_1)}$

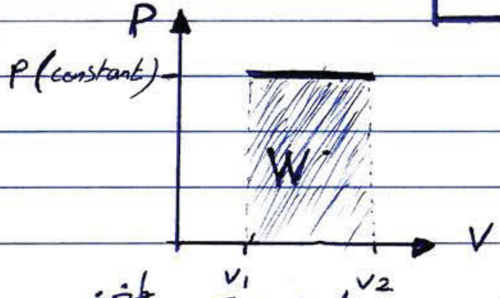
EXAMPLE 4.1 Consider as a system the gas in the cylinder shown in Fig. 4.7; the cylinder is fitted with a piston on which a number of small weights are placed. The initial pressure is 200 kPa, and the initial volume of the gas is 0.04 m³.

a. Let a Bunsen burner be placed under the cylinder, and let the volume of the gas increase to 0.1 m³ while the pressure remains constant. Calculate the work done by the system during this process.

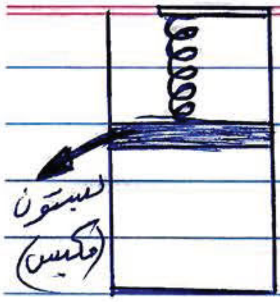
a) $V_1 = 0.04 m^3$
$V_2 = 0.1 m^3$
$P = 200$ kpa (constant)

$_1W_2 = P\Delta V = P(v_2 - v_1)$
$= 200(0.1 - 0.04)$
$\Rightarrow {_1W_2} = 12 kJ$

Fig: 4.7



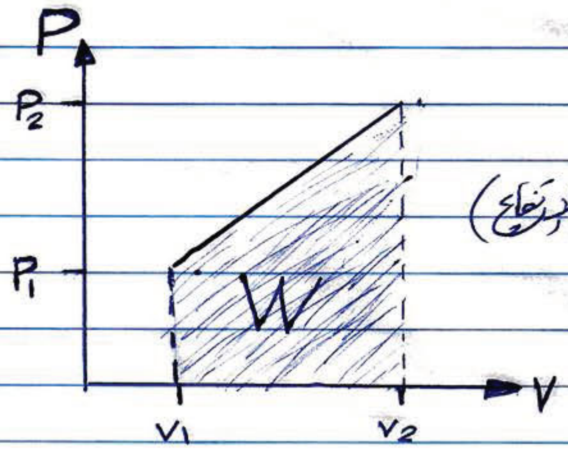
الشغل = المساحة تحت المنحنى



في حال كان الزنبرك ملامس للبستون
يكون هنا الحجم متغير وايضاً الضغط متغير وذلك بسبب الزنبرك

فيكون القانون كالآتي :

$$ {}_1W_2 = \frac{1}{2}(P_1+P_2)(V_2-V_1) $$



الشغل = المساحة تحت المنحنى

مساحة شبه المنحرف = $\frac{1}{2}$ (مجموع القاعدتين)(الارتفاع)

Ex: 4.3 NH_3 / $m = 0.5\ kg$ / $T_1 = -20°c$ / $X_1 = 0.25$ / $T_2 = 20°c$

$\boxed{V_2 = 1.41\ V_1}$, find P_f & W ? ($\therefore$ phase ? sat. mix.)

solution يجب إيجاد V_1 لكي نتمكن من إيجاد V_2 و v_2 و يكون لدينا v_2 و T_2

$(T_1, X_1) \Rightarrow P = P_s = 190.2\ kpa$ (table B.2.1)

$v_1 = v_f + x\, v_{fg}$

$\Rightarrow (0.001504) + (0.25)(0.62184)$

$\Rightarrow v_1 = 0.15696\ m^3/kg$

$V_1 = m v_1 \Rightarrow = (0.5)(0.15696) \Rightarrow \boxed{V_1 = 0.07848\ m^3}$

$V_2 = V_1 * 1.41 \Rightarrow = (0.07848)(1.41) \Rightarrow \boxed{V_2 = 0.1106568\ m^3}$

$v_2 = \frac{V_2}{m} \Rightarrow = \frac{0.1106568}{0.5} \Rightarrow \boxed{v_2 = 0.2213136\ m^3/kg}$

State 2

(V_2, T_2) $P_2 = 600\,kpa$ (From table B.2.2)

$$1W_2 = \frac{1}{2}(P_1 + P_2)(V_2 - V_1)$$

$$1W_2 = \frac{1}{2}(190.2 + 600)(0.1106568 - 0.07848)$$

$$\boxed{1W_2 = 12.71\ kJ}$$

Polytropic Process

رقم

$$\boxed{PV^{n} = C}$$

ثابت

ضغط حجم

هو نظام (عملية حرارية) تخضع للقانون الآتي :

المعادلة مفيدة وتستخدم في عمليات التوسع والضغط والتي تشمل نقل حرارة وشغل

if $n \neq 1 \Rightarrow$ $\boxed{W = \frac{P_2V_2 - P_1V_1}{1-n}}$

if $n = 1 \Rightarrow$ $\boxed{W = P_1V_1 \ln \frac{V_2}{V_1}}$

Ex: 4.1 (b)

هناك معطى بالسؤال هو $T = C$

* حتى نعرف أنه Polytropic أم لا .. نذهب لمعادلة الغاز

$$\Rightarrow PV = \underbrace{m R T}_{\text{constant}} \Rightarrow \boxed{PV = C} \Rightarrow \boxed{PV^{1} = C} \therefore n = 1$$

$$\text{so } \underline{n = 1} \Rightarrow {}_1W_2 = P_1 V_1 \ln \frac{V_2}{V_1} = (200)(0.04) \ln \frac{0.1}{0.04}$$

$$\Rightarrow \boxed{{}_1W_2 = 7.33 \text{ kJ}}$$

Ex: 4.1 (C)

$\boxed{PV^{1.3} = C}$ مُعطى في السؤال

$\therefore n \neq 1$

$$W = \frac{P_2 V_2 - P_1 V_1}{1 - n}$$

هنا لدينا مجهولين هما $(W \text{ و } P_2)$

← لذلك ~~[illegible]~~ نجد P_2

من خلال $\boxed{P_1 V_1^{1.3} = C = P_2 V_2^{1.3}}$

$$P_1 V_1^{1.3} = C = P_2 V_2^{1.3}$$

$$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^{1.3} \Rightarrow = (200)\left(\frac{0.04}{0.1}\right)^{1.3} \Rightarrow \boxed{P_2 = 60.77 \text{ kpa}}$$

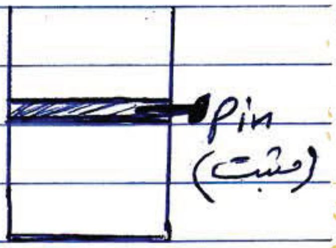
$${}_1W_2 = \frac{(60.77)(0.1) - (200)(0.04)}{1 - 1.3}$$

$$\Rightarrow \boxed{{}_1W_2 = 6.41 \text{ kJ}}$$

Ex: 4.1 (d)

$V = \text{constant}$

$W = P \underset{0}{\Delta V} \Rightarrow \underline{W = 0}$



البستون ثابت (الحجم ثابت)

NOTE

* اذا كان ناتج الشغل (work) موجب ⟸ work done by system

* اذا كان ناتج الشغل (work) سالب ⟸ work don on system

حالات خاصة من Polytropic process

① $n \neq 1$ لكن الحرارة ليست ثابتة (T_1 & T_2)

$P_1V_1 = mRT_1$ m → ثابت

$P_2V_2 = mRT_2$ R → ثابت

$$W = \frac{P_2V_2 - P_1V_1}{1-n} \Rightarrow W = \frac{mRT_2 - mRT_2}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$$

---

② $n = 1$ والحرارة متغيرة ⟸ $P_1V_1 = mRT_1$

$$W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right) \Rightarrow \boxed{W = mRT_1 \ln\left(\frac{V_2}{V_1}\right)}$$

ملاحظة

حالة خاصة

اذا كان معطينا في السؤال ضغطين أحدهم خارجي والآخر داخلي

⟸ نستخدم الخارجي في القانون $_1W_2 = P(V_2 - V_1)$

$P = P_{external}$

⟸ كما في سؤال (Problem 4.68)

4.38 A piston/cylinder assembly contains 1 kg of liquid water at 20°C and 300 kPa, as shown in Fig. P4.38. There is a linear spring mounted on the piston such that when the water is heated, the pressure reaches 3 MPa with a volume of 0.1 m^3.

a. Find the final temperature.

b. Plot the process in a *P–v* diagram.

c. Find the work in the process.

Solution

a) Find T_2?

$v_2 = \frac{V_2}{m} = \frac{0.1}{1} = 0.1\ m^3/kg$

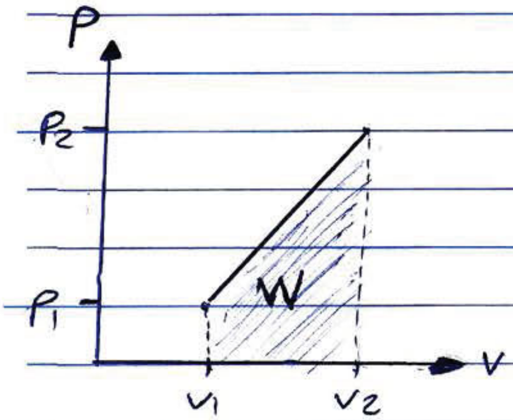
→ from table B.1.3 $(v_2, P_2) \Rightarrow v_2 > v_g \therefore$ (superheated vapor) table (B.1.3)

P	T	v
3000	400	0.09936
3000	$\boxed{T}$	0.1
3000	450	0.10787

By interpolition

$\Rightarrow \boxed{T = 404°C}$

b) plot P–v



c) Find W?

$(T_1, P_1) \rightarrow v_1 = v_f = 0.001002$

$V_1 = v_1 m \Rightarrow = (0.001002)(1) \Rightarrow \boxed{V_1 = 0.001002}$

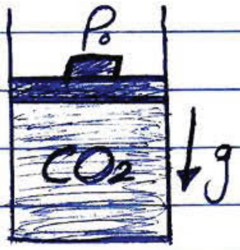
$_1W_2 = \frac{1}{2}(P_1 + P_2)(V_2 - V_1) \Rightarrow = \frac{1}{2}(300 + 3000)(0.1 - 0.001)$

$\Rightarrow \boxed{_1W_2 = 163.35\ kJ}$

P: 4.51

$P_1 = 300\ kpa$ / $T_1 = 100°C$ / $V_1 = 0.2\ m^3$

$PV^{1.2} = c$ / $T_2 = 200°C$



solution

$n = 1.2 \Rightarrow \neq 1$

$$\therefore\ {}_1W_2 = \frac{mR(T_2 - T_1)}{1-n}$$

$${}_1W_2 = \frac{(0.1608)(200-100)}{1 - 1.2}$$

$$\Rightarrow \boxed{{}_1W_2 = -80.4\,kJ}$$

دائما

درجة الحرارة

نعوض بالكلفن

$P_1 V_1 = m_1 R_1 T_1$

$\frac{P_1 V_1}{T_1} = m_1 R_1$

$m_1 R_1 = \frac{(300)(0.2)}{373.15}$

$m_1 R_1 = \boxed{0.1608\ kJ/k}$

$m_1 R_1 = mR = m_2 R_2$

ملاحظة هنا لو عوضنا بالكلفن أو بالسيليسيوس نفس الإشي (لأنه عبارة عن فرق بينهم)

P: 4.57

حجم الكرة

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi\left(\frac{d}{2}\right)^3$$

$$\Rightarrow V = \left(\frac{4}{24}\pi\right) d^3$$

→ constant

$$\sqrt[3]{V} = (\sqrt[3]{C^3})(\sqrt[3]{D^3})$$

$$\boxed{V^{1/3} = CD}$$

$$V^{1/3} \propto D$$

$$P \propto D^2 \rightarrow P = CD^2 \Rightarrow \boxed{PD^{-2} = C}$$

$$P(V^{1/3})^{-2} = C \Rightarrow \boxed{PV^{-2/3} = C}$$

Follow....

$n = -\frac{2}{3}$ / $m = 2\,kg$ / NH_3 / $x = 0.6$ / $T = 0°C$

$P_2 = 600\ kpa$ / m & T constant

$$1W_2 = \frac{P_2 v_2 - P_1 v_1}{1-n}$$

$$\Rightarrow 1W_2 = \frac{(600)(0.5758) - (429.3)(0.3485)}{1 - (-\frac{2}{3})}$$

$$\Rightarrow \boxed{1W_2 = 117.5\ kJ}$$

$$v_1 = v_f + x\, v_{fg} \ @ \ T = 0°C \ NH_3$$

$$\Rightarrow = (0.00156 + (0.6)(0.28783))$$

$$\Rightarrow v_1 = 0.174264\ m^3/kg$$

$$P_1 = P_s = 429.3\ kpa$$

$$\underline{V_1 = v_1 m} \Rightarrow (0.174264)(2)$$

$$\Rightarrow \boxed{V_1 = 0.348528}\ m^3$$

$$P_1 V_1^{-2/3} = P_2 V_2^{-2/3}$$

$$V_2 = V_1 \left(\frac{P_2}{P_1}\right)^{3/2}$$

$$\Rightarrow \boxed{V_2 = 0.5758\ m^3}$$

P: 4.65 find $_1W_3$? in state ① & state ② & state ③

Solution

State ① $T_1 = 180°C$ / $P_1 = 2000\ kpa$ / $_1W_3 = ?$

* لإيجاد الشغل يجب ايجاد الضغط و الحجم لكل حالة ومن ثم الرسم لإيجاد المساحة التي تمثل الشغل.

$T > T_s$ **or** $T > T_{critical}$ (superheated vapor)
$P < P_s$

$v_1 = 0.10571\ m^3/kg$

$\frac{V_1}{m} = v_1 \Rightarrow V_1 = v_1 m \Rightarrow = (0.10571)(1)$ *

$\Rightarrow \boxed{V_1 = 0.10571\ m^3}$

State ② ~~sat~~ sat. vap. / $T = 40°C$

$\text{sat. vap}, T = 40°C \rightarrow x = 1 \rightarrow \underset{\text{صح}}{v = v_g} \rightarrow \boxed{P = P_s}$ جدول B

$v_2\big|_{T=40°C} = 0.08313\ m^3/kg$ $\quad P_2\big|_{T=40°C} = 1554.9\ kpa$

$V_2 = v_2 m \Rightarrow V_2 = (0.08313)(1) = 0.08313\ m^3$

State ③ $T = 20°C$ / $x = 0.5$

$x = 0.5 \rightarrow \text{sat. mix.} \rightarrow v_3 = v_f + x\, v_{fg}$

$\Rightarrow v_3 = (0.001638 + (0.5)(0.14758)) \Rightarrow v_3 = 0.07543\ m^3/kg$

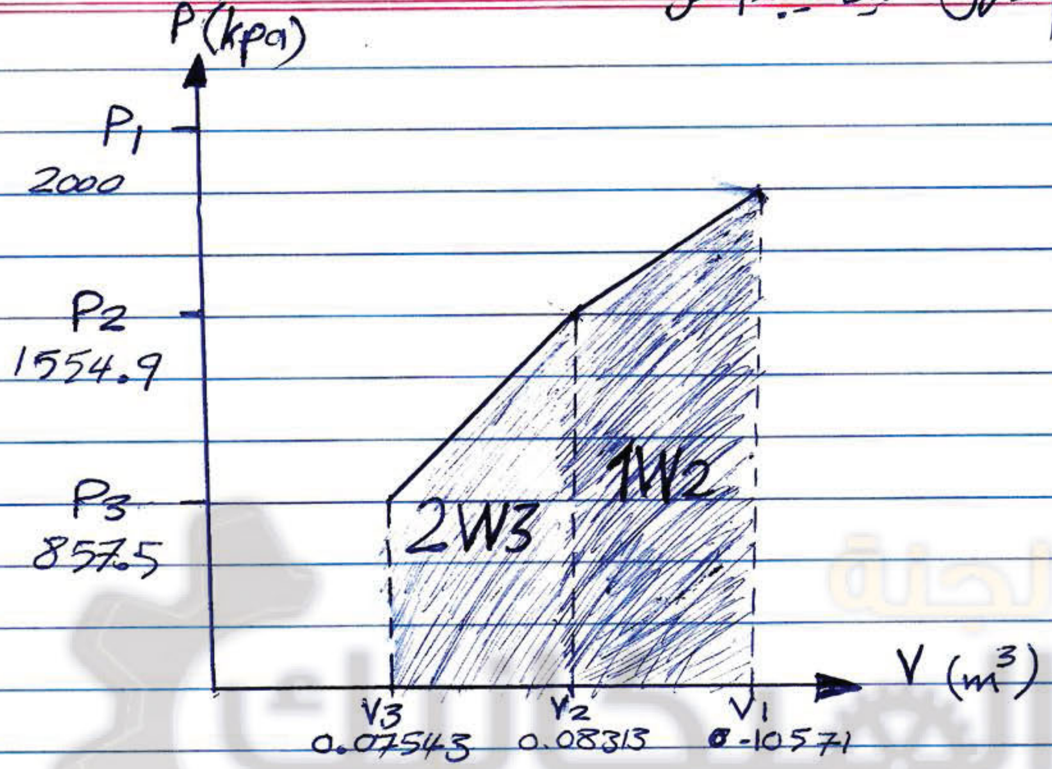
$V_3 = v_3 m \Rightarrow = (0.075431)(1)$
$= 0.075431\ m^3$

∴ يتبين لدينا أنه هناك ثلاثة أحجام وثلاثة ضغوط مختلفة

⟵ Follow...

Following
Ps 4-60

* نرسم ليسهل علينا ايجاد الشغل



$$_1W_3 = {}_1W_2 + {}_2W_3$$

$$= \frac{1}{2}(P_1+P_2)(V_2-V_1) + \frac{1}{2}(P_2+P_3)(V_3-V_2)$$

$$= \frac{1}{2}(2000+1554.9)(0.08313-0.10571) + \frac{1}{2}(1554.9+857.5) * (0.07543-0.0831)$$

$$\Rightarrow \boxed{_1W_3 = -49.422 \text{ kJ}}$$

ترجمة للسؤال

P: 4.129

زمبركين يملكان نفس ثابت الزمبرك (k) تم تثبيتهما مع اسطوانة تحتوي على مكبس (piston) مهمل الكتلة مع وجود هواء خارج الإسطوانة بضغط ($P_0 = 100$ kpa) . اذا كان المكبس في القاع (bottom) يكون الزمبركين غير ملامسين له. وفي حالة غير مضغوطة، الزمبرك الثاني لامس المكبس عند حجم ($V = 2m^3$) (هذا الحجم ليس الحجم الابتدائي لأنه في السؤال لم يصرح بذلك) . في البداية الاسطوانة تحتوي أمونيا NH_3 بدرجة حرارة (-2C°) و ($x = 0.13$) وحجم ($V = 1m^3$) ، تم تسخين النظام إلى أن أصبح الضغط النهائي ($P = 1200$ kpa) . جد ما يلي :

① مقدار الضغط الذي يلامس فيه الزمبرك المكبس ② الحرارة النهائية

③ الشغل من الأمونيا .

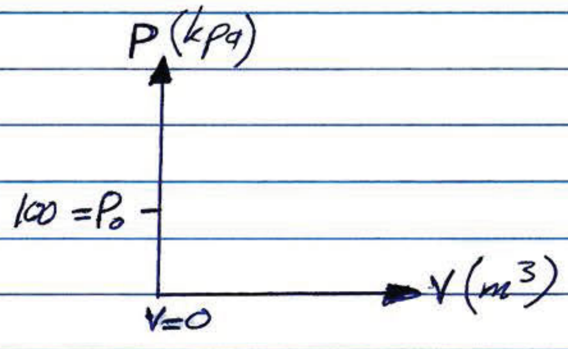
في طريقة الحل

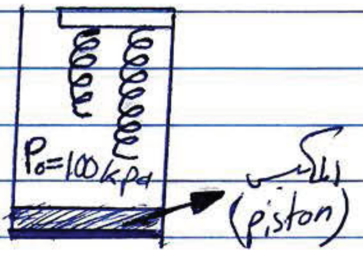
لحل مثل هذه الأسئلة يجب إيجاد الـ (states) الموجودة في السؤال ويجب الرسم حتى نتمكن من الحل.

Solution:

state ①	state ②	state ③
$T_1 = -2C°$	$V_2 = 2m^3$	$P_3 = 1200$ kpa
$X_1 = 0.13$	$P_2 = ?$	$V_3 = ??$
$V_1 = 1m^3$		$T_3 = ??$

في الحالة صفر يكون المكبس عند القاع . اذاً الحجم هو صفر ($V = 0m^3$) ولكن الضغط المؤثر هو (100kpa)

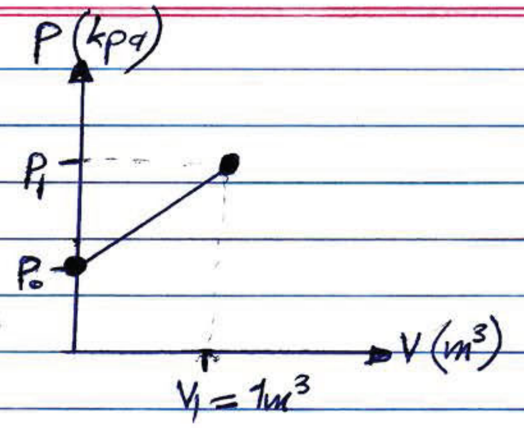




الرسم

Follow...

حالة ①



أصبحت الرسمة ⟵

heated (Q)
تسخين (إعطاء حرارة)

State① (T_1, x_1) → mix ⟹ $\underline{P_1 = P_s = ?}$
$-2°C, 0.13$

للتأكد من الرسمة نجد قيمة P_1

⟵ لإيجاد $P_s = P_1$ نذهب إلى جداول الـ(saturated) ونذهب إلى درجة حرارة $-2°C$ ولكن إذا لا نجدها.. فنقوم بعمل (interpolition) بين أقرب قيمتين لها.

From table (B.2.1)

T_1	P_1	x
-5	354.9	0.13
-2	$\boxed{P_1}$	0.13
0	429.6	0.13

By interpolition
$\Rightarrow P_1 = 399.7$ kpa

$\therefore P_1 > P_0 \Rightarrow \therefore$ الرسمة صحيحة

State②

حالة ②

$V_2 = 2m^3$ find $\underline{P_2}$

$\boxed{\text{Solution}}$

$$P_2 = P_1 + \frac{k}{A^2}(V_2 - V_1)$$

heated

$\frac{k}{A^2}$: constant قيمة ثابتة وتساوي ميل اقتران (P-V)
$\frac{k}{A^2} \Rightarrow \underline{C}$ ورمزه

} معلومة جديدة

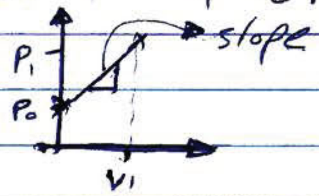
⟵ Follow...

Following

$$\boxed{P_2 = P_1 + C(V_2 - V_1)}$$ حفظ

نجيب الميل من الرسمة السابقة

$$C = \frac{\Delta P}{\Delta V} = \frac{\text{فرق الصادات}}{\text{فرق السينات}}$$



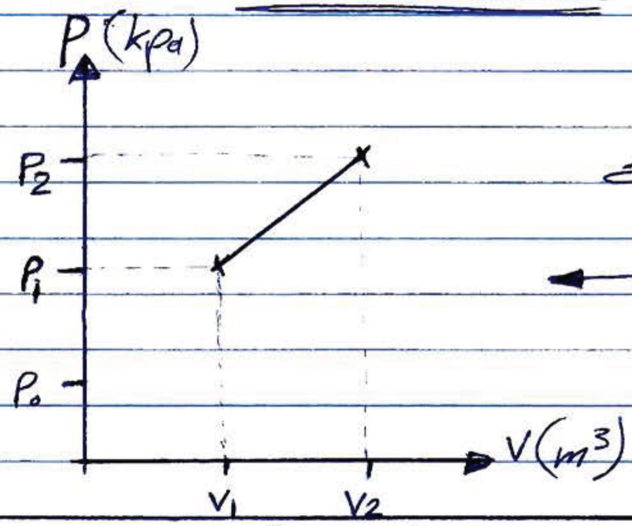
$$C = \frac{P_1 - P_0}{V_1 - V_0} \Rightarrow C = \frac{399.7 - 100}{1 - 0}$$

$$\Rightarrow C = 299.7 \text{ kpa/m}^3$$

we know that $P_2 = P_1 + C(V_2 - V_1)$

$$\Rightarrow P_2 = (399.7) + (299.7)(2-1)$$

$$\Rightarrow P_2 = 699.4 \text{ kpa}$$



∴ أصبحت الرسمة

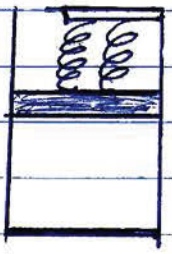
State ③

الحالة ③ لإيجاد الحرارة النهائية نجد الحجم النهائي

$$P_3 = P_2 + \underset{}{2C}(V_3 - V_2)$$

هنا c*٢ لأنهم زنبركين

$$\Rightarrow \boxed{V_3 = V_2 + \frac{(P_3 - P_2)}{2C}}$$



انتبه!! لاحظ أنه في الحالة الثالثة المكبس لامس الزنبركين

Follow...

Following

$$\Rightarrow V_3 = 2 + \frac{(1200 - 699.4)}{599.4}$$

$$\Rightarrow \boxed{V_3 = 2.833\ m^3}$$

$$\left\{ \begin{aligned} 2C &= (2)(299.7) \\ 2C &= 599.4 \end{aligned} \right.$$

$$\boxed{m = \frac{V_3}{v_3} = \frac{V_1}{v_1}}$$

لإيجاد الحرارة نجد v_3

$$v_f = \frac{0.001566 + 0.001550}{2}$$

$$\Rightarrow \boxed{v_f = 0.00156}$$

$$v_{fg} = \frac{0.28763 + 0.34493}{2} \Rightarrow \boxed{v_{fg} = 0.316}$$

$$v_1 = v_f + x\, v_{fg}$$

$$v_1 = (0.00156) + (0.13)(0.316)$$

$$\Rightarrow v_1 = 0.042\ m^3/kg$$

$$\rightarrow v_3 = \frac{V_3}{V_1} v_1 \Rightarrow = \frac{(2.835)(0.043)}{1} \Rightarrow \underline{\underline{v_3 = 0.1191\ m^3/kg}}$$

$v_3 > v_g$ ∴ (superheated

to find (T_3) → interpolition

v_3	T_3	P_3
0.11287	40	1200
0.1191	T	1200
0.11846	50	1200

By interpolition

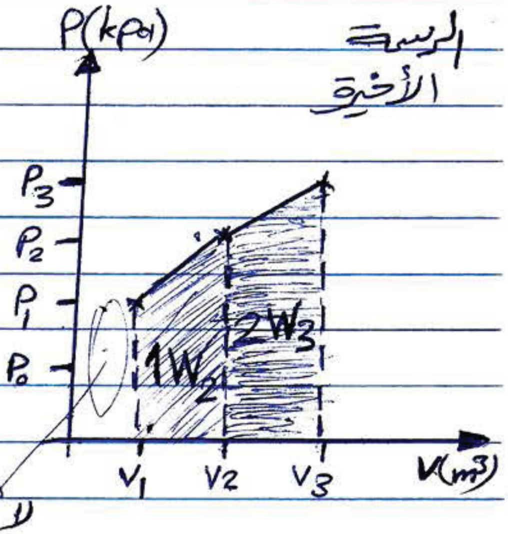
$$\boxed{T_3 = 51.14\ {}^\circ C}$$

$$_1W_3 = {}_1W_2 + {}_2W_3$$

$$= \frac{1}{2}(P_1+P_2)(V_2-V_1) + \frac{1}{2}(P_3+P_2)(V_3-V_2)$$

$$\Rightarrow \boxed{_1W_3 = 1342.6\ kJ}$$

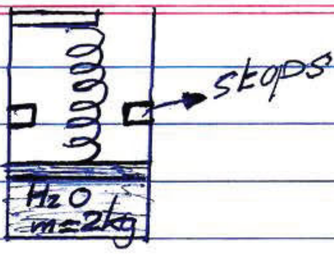
الرسمة الأخيرة



لا يوجد شكل هنا

P: 4.118

مسألة جديدة
وحالة جديدة



State① $P_1 = P_0 = 100 kPa$
$V_1 = 0.2 m^3$

State at stops

$V_s = 0.8 m^3$
$T_2 = 600°C$

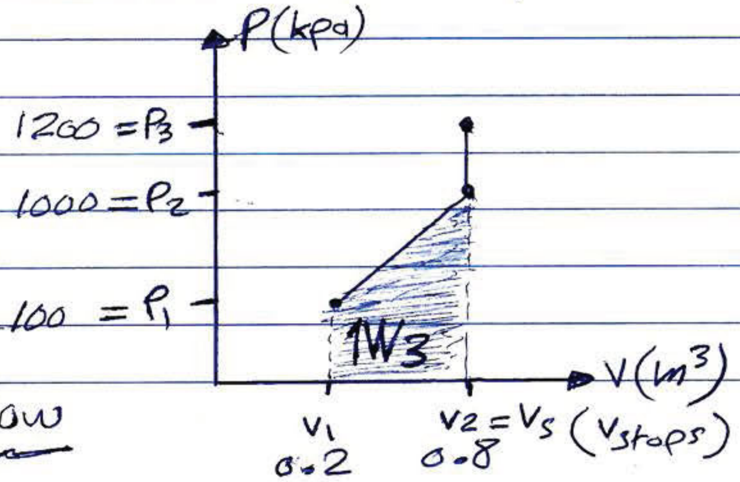
$P_f = 1.2 Mpa$
⊛ هنا عند هذه النقطة يثبت الحجم مهما رفعنا درجة الحرارة.
$T_f = ?$
⊛ Find W & Plot P-V diagram

$(T_2, ?)$ أولاً نجد P_2

$v_2 = \frac{V_s}{m} = \frac{0.8}{2} = 0.4 \, m^3/kg$

(T_2, v_2) $T_2 > T_{critical}$
∴ (superheated vapor)

From table B.1.3 → $P_2 = 1000 kpa$



هنا الحجم الثالث (V_3)
مساوٍ للحجم الثاني (V_2)
لأن المكبس وصل
إلى الـ(stops)

follow ←

$P_f = P_3 = 1200 kpa$

$V_3 = 0.8 \, m^3 = V_2$

$v_3 = v_2 = 0.4 \, m^3/kg$

$(P_3, v_3) \longrightarrow v_3 > v_g \therefore$ (super heated vapor) Table B.1.3

v_3	T_3	P_3
0.37294	700	1200
0.4	$\boxed{T}$	1200
0.41177	800	1200

By interpolition

$\boxed{T_3 = 770 \, C°}$

$_1W_3 = {}_1W_2 + {}_2\cancel{W_3}^{0.0}$

لأنه الحجم
ثابت ولم
يتغير

$_1W_3 = \frac{1}{2}(P_1 + P_2)(V_2 - V_1)$

$_1W_3 = \frac{1}{2}(100 + 1000)(0.8 - 0.2)$

$\boxed{_1W_3 = 330 \, kJ}$

Chapter 5: First Law of thermodynamics.

هذا القانون ببساطة هو أن الطاقة لا تفنى ولا تستحدث ؛ ولكن تتحول من شكل لآخر.

* نص القانون من الكتاب *

* The first law of thermodynamics that during any cycle a system (control mass) undergoes, the cyclic integral of the heat is proportional to the cyclic integral of the work.

يعني أن تكامل الحرارة يتناسب مع تكامل الشغل.
ملاحظة : التكامل يكون على دورة (cycle).

$$\oint \delta Q \propto \oint \delta W$$

$\delta \rightarrow$ (d) زي كأنها
$W \rightarrow$ work (شغل)
$Q \rightarrow$ Heat (حرارة)

$$\Downarrow$$

يصبح القانون

$${}_1Q_2 - {}_1W_2 = E_2 - E_1$$

$E \rightarrow$ Energy (طاقة)

هنا الطاقة تكون عبارة عن:

Internal Energy $\longrightarrow$ (U) طاقة داخلية ①
Potential Energy $\longrightarrow$ (PE) طاقة وضع ②
Kinetic Energy $\longrightarrow$ (KE) طاقة حركية ③

$\Rightarrow E = U + PE + KE$ [Joule]

① $PE = mgh$ m: mass [kg] h or z: [m] الإرتفاع
or $PE = mgz$ g: 9.81 [m/s²] تسارع الجاذبية الأرضية

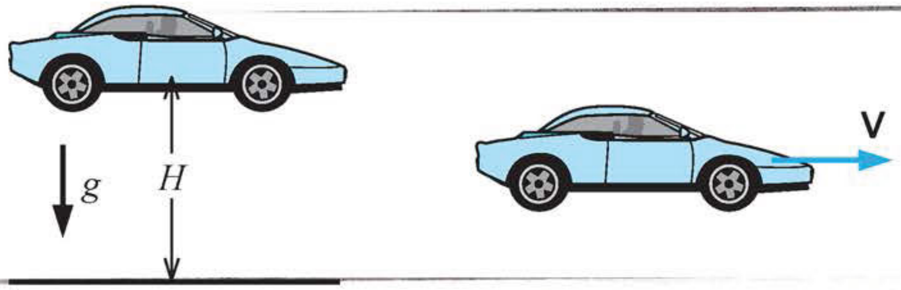
② $KE = \frac{1}{2} m V^2$ m: mass [kg] V: velocity [m/s]

③ $U = U$

سنأخذ مثال سريع للتعرف على الطاقة الحركية وطاقة الوضع

Ex:5.1

A car of mass 1100 kg drives with a velocity such that it has a kinetic energy of 400 kJ (see Fig. 5.4). Find the velocity. If the car is raised with a crane, how high should it be lifted in the standard gravitational field to have a potential energy that equals the kinetic energy?



solution

$m = 1100\ kg$
$K.E = 400\ kJ$ } find velocity

$$K.E = \frac{1}{2} m V^2 \Rightarrow V = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(400)(1000)}{(1100)}} = 27\ m/s$$

تم رفع السيارة برافعة، احسب الارتفاع (Z) اذا كانت KE = PE

$PE = mgh = mgz$

$PE = KE = 400\ kJ \Rightarrow 400 \times 10^3 = 1100 \times 9.81 \times Z$

$\Rightarrow Z = (400 \times 10^3) / (1100 \times 9.81)$

$\Rightarrow \boxed{Z = 37.1\ m}$

*ملاحظة: لاتنسى تحويل ال kJ الى J وذلك بالضرب ب 10^3

* عرفنا أن: $_1Q_2 - _1W_2 = E_2 - E_1$

$$E_1 = U_1 + (KE)_1 + (PE)_1 \qquad \Big\} \quad E_2 = U_2 + (KE_2) + (PE)_2$$
$$E_1 = U_1 + \left(\tfrac{1}{2} m V_1^2\right) + (mgz_1) \qquad \Big\} \quad E_2 = U_2 + \left(\tfrac{1}{2} m V_2^2\right) + (mg z_2)$$

$$\therefore\ _1Q_2 - {_1W_2} = \left(U_2 + \tfrac{1}{2} m V_2^2 + mgz_2\right) - \left(U_1 + \tfrac{1}{2} m V_1^2 + mgz_1\right)$$

$$\xrightarrow{\text{بترتيب المعادلة}} \boxed{_1Q_2 - {_1W_2} = U_2 - U_1 + \tfrac{1}{2} m (V_2^2 - V_1^2) + mg(z_2 - z_1)}$$

حل كل الأسئلة مبني على هذه المعادلة ..

* في معظم الأحيان لا يكون هناك طاقة وضع وطاقة حركية .. لذلك يصبح القانون:

$$\boxed{_1Q_2 - {_1W_2} = U_2 - U_1}$$

← حل الأمثلة (Ex: 5.2 و Ex: 5.3) للتعرف أكثر على PE و KE و U

---

* وكما مر معنا في (chapter 3) عندما نريد التحويل إلى (specific) نقسم على الـ (mass)

$$\boxed{u = \frac{U}{m}}$$

u: specific internal Energy [kJ/kg]
U: Internal Energy [kJ]
m: mass [kg]

$$\boxed{u = u_f + x u_{fg}} \xrightarrow{\text{mix في حالة الـ}} \boxed{u = (1-x) u_f + x u_g}$$

Ex: 5.4

Determine the missing property (P, T, or x) and v for water at each of the following states:

a. $T = 300°\text{C}$, $u = 2780$ kJ/kg

b. $P = 2000$ kPa, $u = 2000$ kJ/kg

For each case, the two properties given are independent properties and therefore fix the state. For each, we must first determine the phase by comparison of the given information with phase boundary values.

Solution

a) $T = 300\,°C$, $u = 2780\ \boxed{kJ/kg}$ → (طاقة نوعية specific) من الوحدة نعرف أنه

H_2O → B.1.1   لإيجاد (x, P, v) نستخدم نفس الطرق من ch.3

$u > u_g \Rightarrow$ (superheated vapor)

u	P	T
2781.03	1600	300
2780.0	ⓟ	300
2776.83	1800	300

By interpolation $\Rightarrow \boxed{P = 1648\ kpa}$

v	P	T
0.15862	1600	300
ⓥ	1642	300
0.14021	1800	300

By interpoliation $\Rightarrow v = \boxed{0.1542\ m^3/kg}$

b) $P = 2000\,kpa$, $u = 2000\ kJ/kg$, H_2O, $T = T_s = 212.42$

$u_f < u < u_g \Rightarrow$ (mix.)

$u = u_f + x u_{fg} \rightarrow x = \frac{u - u_f}{u_{fg}} \Rightarrow = 0.6456$

$v = v_f + x v_{fg}$

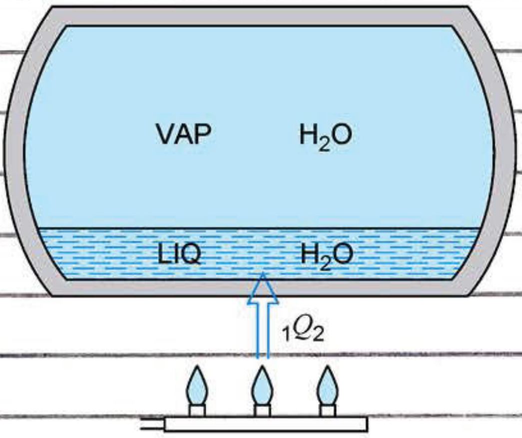
• from table B.1.2 @ $P = 2000\,kpa$

$\Rightarrow v = 0.06474\ m^3/kg$

u_f, u_{fg}, v_f, v_{fg}

Ex 5.5

A vessel having a volume of 5 m^3 contains 0.05 m^3 of saturated liquid water and 4.95 m^3 of saturated water vapor at 0.1 MPa. Heat is transferred until the vessel is filled with saturated vapor. Determine the heat transfer for this process.



solution

① هنا الحجم للنظام كامل ثابت $V_1 = V_2$

② المطلوب هو $_1Q_2$ ← هنا لا يوجد W على النظام بأكمله لأن الحجم ثابت. ولا يوجد تغير في الطاقة الحركية أو الوضع.

$$_1Q_2 - \cancelto{0.0}{_1W_2} = (U_2 - U_1) + \frac{1}{2}m\cancelto{0.0}{(V_2^2 - V_1^2)} + mg\cancelto{0.0}{(Z_2 - Z_1)}$$

State①

الحالة الأولى

$P = 100$ kpa

mix.

$$\Rightarrow {}_1Q_2 = U_2 - U_1$$

$$m_{lig} = \frac{V_{lig}}{v_f} = \frac{0.05}{0.001043}$$

$$m_{lig} \Rightarrow \boxed{= 47.94 \text{ kg}}$$

$$U_1 = mu_1 \Rightarrow U_1 = (m_{liq} u_{liq}) + (m_{vap} u_{vap})$$

$$\Rightarrow U_1 = (47.92 * 417.36) + (2.92 * 2506.1)$$

$$m_{vap} = \frac{V_{vap}}{v_g} = \frac{4.95}{1.6940}$$

$$\Rightarrow \boxed{m_{vap} = 2.92 \text{ kg}}$$

$$\Rightarrow U_1 = 27326 \text{ KJ}$$

هنا:

$u_f / u_g / v_f / v_g$

at $P = 100$ kpa

في الحالة الثانية

state ② (sat. vap) $\rightarrow x=1$, $v=v_g$, $u=u_g$

* لإيجاد الـ (u_2) نجد الـ (v_2) أولاً

$$v_2 = \frac{V_{total}}{m_{total}} = \frac{5}{47.92+2.92} = \boxed{0.09831\ m^3/kg}$$

$u_2=u_g$	$v_2=v_g$
2601.98	0.8875
(u) ?	0.09831
2600.26	0.9963

By Interpolation

$\Rightarrow u_2 \cong 2600.5$

$$U_2 = m_{tot} * u_2 \Rightarrow = (50.26 * 2600.5) \Rightarrow \boxed{U_2 = 132261\ kJ}$$

$$_1Q_2 = U_2 - U_1 \Rightarrow = 132261 - 27326$$

$$\Rightarrow \boxed{_1Q_2 = 104935\ kJ}$$

5.36 A 100-L rigid tank contains nitrogen (N_2) at 900 K and 3 MPa. The tank is now cooled to 100 K. What are the work and heat transfer for the process?

solution

state ① $V_1 = 0.1\ m^3$
$T_1 = 900\ K$
$P_1 = 3000\ kpa$

state ② $V_2 = 0.1\ m^3$
$T_2 = 100\ K$

$_1W_2 = 0$ because $V_1 = V_2$ (لايوجد تغير في الحجم)

$_1Q_2 - {_1W_2} = U_2 - U_1$

$_1Q_2 = (U_2 - U_1) + \cancel{_1W_2}^{0.0} \Rightarrow \underline{\underline{_1Q_2 = U_2 - U_1}} \Rightarrow \boxed{_1Q_2 = m(u_2 - u_1)}$

state①

(P_1, T_1) $T > T_c$ (superheated)

$\boxed{v_1 = 0.09003\ m^3/kg}$ $\boxed{u_1 = 691.65\ kJ/kg}$

$$m = \frac{V_1}{v_1} = \frac{0.1}{0.09003} = 1.111\ kg$$

state②

(T_2, v_2) $v_2 = v_1 = 0.09003$
$v_2 > v_g$ (superheated)

u_2	v_2
71.73	0.14252
(u_2)?	0.09003
69.3	0.06806

By interpolation
$\Rightarrow u_2 = 70\ kJ/kg$

$\Rightarrow$ $_1Q_2 = m(u_2 - u_1)$
$= 1.111(70 - 691.7)$
$\Rightarrow \boxed{_1Q_2 = -690.7\ kJ}$

5.44 A piston/cylinder device contains 50 kg water at 200 kPa with a volume of 0.1 m^3. Stops in the cylinder are placed to restrict the enclosed volume to a maximum of 0.5 m^3. The water is now heated until the piston reaches the stops. Find the necessary heat transfer.

solution

To find $_1Q_2$ $\Rightarrow$ $_1Q_2 = m(u_2 - u_1) + {_1W_2}$

$\boxed{\text{State ①}}$ ($P_1 = 200$ kPa, $V_1 = 0.1\,m^3$, $m = 50$ kg)

To find u_1 → we must must know 2 properties

$v_1 = \frac{V_1}{m} = \frac{0.1}{50} = 0.002\ m^3/kg$

$_1W_2 = P\Delta V$

$= (200)*(0.5 - 0.1)$

$\Rightarrow {_1W_2} = 80$ kJ

(P, v_1) → mix ($v_f < v < v_g$)

$u_1 = u_f + x\,u_{fg}$

$= 504.47 + (1.0614*10^{-3} * 2025.02)$

$\Rightarrow \boxed{u_1 = 506.61}$ kJ/kg

$x = \frac{v - v_g}{v_{fg}}$

$\Rightarrow x = \frac{0.002 - 0.001061}{0.88467}$

$\Rightarrow \boxed{x = 1.0614*10^{-3}}$

$\boxed{\text{State ②}}$ ($V_2 = 0.5\,m^3$, $P_2 = P_1 = P = 200$ kPa, $m_2 = 50$ kg)

$v_2 = \frac{V_2}{m} = \frac{0.5}{50} \Rightarrow \boxed{v_2 = 0.01\,m^3/kg}$

(P, v_2) → mix ($v_f < v_2 < v_g$)

$u_2 = u_f + x\,u_{fg} \Rightarrow = (504.47) + (0.0101 * 2025.02)$

$\Rightarrow \boxed{u_2 = 524.93}$ kJ/kg

$x = \frac{v_2 - v_f}{v_{fg}}$

$= \frac{0.01 - 0.001061}{0.88467}$

$\Rightarrow \boxed{x = 0.0101}$

$_1Q_2 = m(u_2 - u_1) + {_1W_2}$

$\Rightarrow = 50(524.93 - 506.61) + 80$

$\Rightarrow \boxed{_1Q_2 = 996\text{ kJ}}$

Enthalpy (H)

constant pressure

على افتراض أنه لدينا نظام لا يوجد به طاقة حركية (KE=0) ولا طاقة وضع (PE=0)
و يوجد فيه شغل (W) وأيضاً الضغط ثابت للنظام والكتلة ثابتة.

$$_1Q_2 = {}_1W_2 + m(u_2 - u_1)$$

$$_1Q_2 = P\Delta V + m(u_2 - u_1)$$

$$\boxed{P = P_1 = P_2}$$

h: specific enthalpy

$$\Rightarrow = P(V_2 - V_1) + m(u_2 - u_1)$$

$$= P_2V_2 - P_1V_1 + m(u_2 - u_1)$$

$$_1Q_2 = (mu_2 + P_2V_2) - (mu_1 + P_1V_1)$$

$$= (mu_2 + P_2 m v_2) - m(u_1 + P_1 m v_1)$$

$$= m(u_2 + P_2 v_2) - m(u_1 + P_1 v_1)$$

$$\boxed{v = \frac{V}{m}}$$

$$\boxed{V = mv}$$

$$\boxed{h_1 = u_1 + P_1 v_1} \qquad \boxed{h_2 = u_2 + P_2 v_2}$$

$$\Rightarrow {}_1Q_2 = mh_2 - mh_1$$

$$\Rightarrow \boxed{_1Q_2 = m(h_2 - h_1)}$$

In General

$$\boxed{h = u + Pv} \qquad \boxed{u = h - Pv} \qquad \boxed{h = \frac{H}{m}}$$

Ex: 5-6

A cylinder fitted with a piston has a volume of 0.1 m^3 and contains 0.5 kg of steam at 0.4 MPa. Heat is transferred to the steam until the temperature is 300°C, while the pressure remains constant.

Determine the heat transfer and the work for this process.

m = 0.5 kg

State ①
$V_1 = 0.1 m^3$
$P_1 = 0.4 MPa = 400 kpa$

State ②
$T_2 = 300°c$
$P_2 = P_1 = constant = 400 kpa$

Find $_1Q_2$, $_1W_2$

Solution $P = constant$

$_1Q_2 = m(h_2 - h_1)$

$h_1 = h_f + x_1 h_{fg} \Rightarrow x_1 = ?$

$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.2 - 0.00108}{0.4614}$

$v_1 = \frac{V_1}{m} = \frac{0.1}{0.5} = 0.2$

$\Rightarrow \boxed{x_1 = 0.4311}$

$\Rightarrow h_1 = h_f + x_1 h_{fg} \Rightarrow = 604.74 + (0.4311 * 2133.8)$

$\Rightarrow \boxed{h_1 = 1524.7 \ kJ/kg}$

$h_2 \Rightarrow (P_2, T_2)$ super heated

Table B.1.3
$P_2 = 400kpa$, $T_2 = 300°c$ $\Big\} h_2 = 3066.8 \ kJ/kg$

$\Rightarrow \boxed{h_2 = 3066.8 \ kJ/kg}$

$_1Q_2 = m(h_2 - h_1) \Rightarrow = 0.5(3066.8 - 1524.7) \Rightarrow {_1Q_2} = 771.1 \ kJ$

$_1W_2 = P\Delta V \Rightarrow = P(V_2 - V_1) \Rightarrow = P(mv_2 - mv_1)$

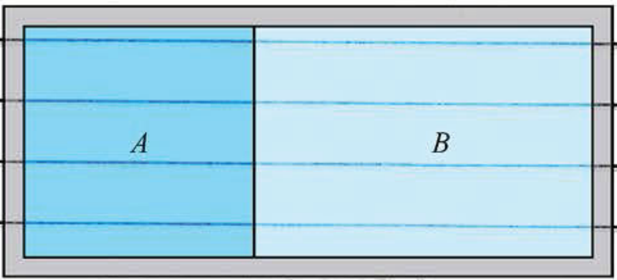
$\Rightarrow {_1W_2} = Pm(v_2 - v_1)$

$_1W_2 = (400 * 0.5)(0.6548 - 0.2)$

$\boxed{_1W_2 = 91 \ kJ}$

P- 5.61

A rigid tank is divided into two rooms, both containing water, by a membrane, as shown in Fig. P5.61. Room *A* is at 200 kPa, $v = 0.5\ \text{m}^3/\text{kg}$, $V_A = 1\ \text{m}^3$, and room *B* contains 3.5 kg at 0.5 MPa, 400°C. The membrane now ruptures and heat transfer takes place so that the water comes to a uniform state at 100°C. Find the heat transfer during the process.



$$1Q_2 = m(u_2 - u_1) + 1W_2$$
$$1Q_2 = m_2u_2 - m_1u_1 + 1W_2$$
$$1Q_2 = m_2u_2 - (m_Au_A + m_Bu_B) + 1W_2$$

$$\boxed{1Q_2 = m_2u_2 - m_Au_A - m_Bu_B + 1W_2}$$

State① الحالة الأولى مقسومة الى قسمين A و B

Ⓐ

$$m_{A1} = \frac{V_A}{v_A} = \frac{1}{0.5} = 2\text{kg}$$

$$(P_A, v_A) \rightarrow \text{mix.}$$

$$u_A = u_f + Xu_{fg} \qquad \left\{ X = \frac{v - v_f}{v_{fg}} \Rightarrow \boxed{X = 0.564} \right.$$

$$u_A = (504.47) + (0.564 * 2025.02) \Rightarrow \boxed{u_A = 164.6}$$

Ⓑ

$$m_{B1} = 3.5\ \text{kg}$$

$$(P_B, T_B) \rightarrow \text{superheated vapor} \quad \boxed{v_{B1} = 0.6173\ \text{m}^3/\text{kg}} \quad \boxed{u_{B1} = 2963.2\ \text{kg/kJ}}$$

$$V_B = v_{B1} * m_{B1} \Rightarrow \boxed{V_B = 2.16\ \text{m}^3}$$

$m_2 = m_{A1} + m_{B1}$

$m_2 = 2 + 3.5 = 5.5\,kg$

$\boxed{m_2 = 5.5\,kg}$

$v_2 = \frac{V_{total}}{m_{total}} = \frac{3.16}{5.5} \Rightarrow \boxed{v_2 = 0.5746\,m^3/kg}$

$V_{total} = V_A + V_B$

$= 1 + 2.16$

$\boxed{V_{total} = 3.16\,m^3}$

$\boxed{State②}$

$(T_2, v_2) \longrightarrow mix.$

$u_2 = u_f + x u_{fg}$ $\Big\}$ $x = \frac{v - v_f}{v_{fg}} \Rightarrow \boxed{x = 0.343}$

$u_2 = (418.91) + (0.343 * 2087.58)$

$\boxed{u_2 = 1134.95\,kJ/kg}$

$1Q_2 = m_2 u_2 - m_{A1} u_{A1} - m_{B1} u_{B1} + 0$

$\Rightarrow \boxed{1Q_2 = -7421\,kJ}$

$\underline{\underline{1W_2 = 0}}$

حجم النظام كامل (١، ٢)

هو ثابت $\Delta V = 0$

⟸ لذلك لا يوجد شغل

* constant volume and constant pressure specific heat.

$Q = \Delta U + W$

$\delta Q = \delta U + \delta W$

$\delta Q = \delta U + P dv$

① constant volume

$\boxed{P dv = 0}$ الحجم ثابت

$\therefore \boxed{\delta Q = \delta U}$

$\left(\frac{\delta Q}{m * \delta T}\right) = C_v$

$C_v = \frac{1}{m} * \frac{\delta Q}{\delta T} = \frac{1}{m} * \frac{\delta U}{\delta T} = \frac{\partial u}{\partial T}$

$\Rightarrow C_v = \frac{\partial u}{\partial T}$

$\boxed{\Delta u = C_v \Delta T}$

② constant pressure الضغط ثابت

$\delta Q = \delta H$

$C_p = \frac{1}{m} * \left(\frac{\delta Q}{\delta T}\right) = \frac{1}{m}\left(\frac{\delta H}{\delta T}\right) = \frac{\delta h}{\delta T}$

$\Rightarrow C_p = \frac{\partial h}{\partial T}$

$\boxed{\Delta h = C_p \Delta T}$

For ideal gas

$PV = mRT$

$P\frac{V}{m} = RT \Rightarrow \boxed{Pv = RT}$

$u(T) \rightarrow$ function of temp. only.

$C_{v_0} = \frac{\Delta u}{\Delta T} \Rightarrow \boxed{\Delta u = C_{v_0} \Delta T}$ $\quad u \rightarrow$ specific

$h(T) \rightarrow$ function of temp. only

$C_{p_0} = \frac{\Delta h}{\Delta T} \Rightarrow \boxed{\Delta h = C_{p_0} \Delta T}$

Note

$h = u + Pv$

For ideal gas: $\rightarrow$

$\boxed{h = u + RT}$

$\boxed{RT = Pv}$

In ideal gas

specific heat rate

$\boxed{k = \frac{C_{p_0}}{C_{v_0}}}$ $\quad \boxed{R = C_{p_0} - C_{v_0}}$

$\boxed{C_{v_0} = \frac{1}{k-1} R}$ $\quad \boxed{C_{p_0} = \frac{k}{k-1} R}$

طرق إيجاد كل من C_{p0} و C_{v0} و Δh

أولاً في حال ذكر في السؤال (assume constant specific heat)

⇐ نستخدم (Table A.5)

$$\left.\begin{aligned}\Delta h &= C_{p0}\,\Delta T\\ \Delta u &= C_{v0}\,\Delta T\end{aligned}\right\}$$

ثانياً في حال ذكر في السؤال (use Empirical equation)

⇐ نستخدم (Table A.6)

$$C_{p0} = C_0 + C_1\theta + C_2\theta^2 + C_3\theta^3$$

$$\boxed{\theta = \frac{T}{1000}}$$

T: temp. (kelvin)

$$h_2 - h_1 = \int_{T_1}^{T_2} C_{p0}\, dT$$

$$h_2 - h_1 = \int_{\theta_1}^{\theta_2} C_{p0}(\theta) * 1000\, d\theta$$

$$h_2 - h_1 = 1000\left[C_0\theta + \frac{C_1\theta^2}{2} + \frac{C_2\theta^3}{3} + \frac{C_3\theta^4}{4}\right]_{\theta_1}^{\theta_2}$$

ثالثاً هذه الحالة أسهل .. ويجب أن نحل عليها في معظم الأحيان

نستخدم (Table A.7) & (Table A.8)

A.7.1 ← (Air) هواء عند ضغط (100 kpa) أو (1 bar)

A.8 ← مادتين هما ← CO_2 (carbon dioxide)

← O_2 (Oxigen).

⊛ نجد في هذه الجداول (u و h) ونعوضها في المعادلات لإيجاد (C_{p0} و C_{v0})

For solids and liquids

$u \simeq h$ نستخدم جداول A-3 و A-4

$\therefore c_p \simeq c_v = c$ و نجد c_p و نعوضه في المعادلة

$\therefore \Delta h = c \Delta T$

Ex: 5.8 Calculate the change of enthalpy as 1 kg of oxygen is heated from 300 to 1500 K. Assume ideal-gas behavior.

⊛ في هذا المثال سوف نقوم بايجاد Δh بكل الطرق

$m = 1 kg$ $T_1 = 300 k$ $T_2 = 1500 k$

Solution

1 Use A-7 A-8

A-8 $\Rightarrow T_1 = 300 k \rightarrow h_1 = 273.2$

$T_2 = 1500 k \rightarrow h_2 = 1540.2$

$\Rightarrow \Delta h = h_2 - h_1 = \boxed{1267.0 \ kJ/kg}$

2 Assume Tavg

$T_{avg} = \frac{300 + 1500}{2} = 900 K$ $\Big\}$ $\theta = \frac{T_{avg}}{1000} = \frac{900}{1000} = 0.9$

$c_{p0} = C_0 + C_1\theta + C_2\theta^2 + C_3\theta^3$

$c_{p0} = (0.88) - (0.0001 * 0.9) + (0.54 * 0.9^2) - (0.3 * 0.9^3)$

$\Rightarrow c_{p0} = 1.0767 \ kJ/kg$

$\Delta h = 1.0767 * (1500 - 300) \Rightarrow \boxed{\Delta h = 1292.1 \ kJ/kg}$

3 Assume constant specific heat:

Table A-5 $c_{p0} = 0.922$ (if we use the value at 300 K)

$\Delta h = c_{p0} \Delta T \Rightarrow = 0.922 (1500 - 300)$

$\Rightarrow \boxed{\Delta h = 1106.4 \ kJ/kg}$

لاحظ هنا ان نسبة الخطأ كبيرة

$\boxed{4}$ Use empirical equation

$$h_2 - h_1 = \int_{T_1}^{T_2} C_p \, dT \qquad \theta_1 = \frac{T_1}{1000} = \frac{300}{1000} = 0.$$

$$h_2 - h_1 = \int_{\theta_1}^{\theta_2} C_{p}\theta \cdot 1000 \, d\theta \qquad \theta_2 = \frac{T_2}{1000} = \frac{1500}{1000} = 1.$$

$$\Delta h = 1000 \left[C_0\theta + \frac{C_1}{2}\theta^2 + \frac{C_2}{3}\theta^3 + \frac{C_3}{4}\theta^4 \right]_{0.3}^{1.5}$$

$$\Delta h = 1000 \left[0.88\,\theta - \frac{0.0001}{2}\theta^2 + \frac{0.54}{3}\theta^3 - \frac{0.33}{4}\theta^4 \right]_{0.3}^{1.5}$$

$$\boxed{\Delta h = 1241.5 \text{ kJ/kg}}$$

EXAMPLE 5.9

A cylinder fitted with a piston has an initial volume of 0.1 m^3 and contains nitrogen at 150 kPa, 25°C. The piston is moved, compressing the nitrogen until the pressure is 1 MPa and the temperature is 150°C. During this compression process heat is transferred from the nitrogen, and the work done on the nitrogen is 20 kJ. Determine the amount of this heat transfer.

$V_1 = 0.1 m^3$
$P_1 = 150 Mpa$ } initial state
$T_1 = 25°C$

$P_2 = 1000 kpa$ } final state
$T_2 = 150°c$

* Assuming constant specific heat OR room temp value.
* work done on N_2 ⇒ $_1W_2 = -20 kJ$

$_1Q_2 = m(u_2 - u_1) + {_1W_2}$ $\qquad \Delta u = C_{v_0} \Delta T$

$_1Q_2 = m \, C_{v_0} (T_2 - T_1) + {_1W_2}$

$_1Q_2 = (0.1695 * 0.745)(150 - 25) + -20$ $\qquad PV = mRT$

⇒ $_1Q_2 = -4.2 kJ$

$$m = \frac{P_1 V_1}{R T_1} = \frac{150 * 0.1}{0.2968 * 298.5}$$

$\boxed{m = 0.1695}$ kg بالكلفن

* يوجد طريقة أخرى لحل السؤال عن طريق Table B-5

5.111

An insulated cylinder is divided into two parts of 1 m^3 each by an initially locked piston, as shown in Fig. P5.111. Side *A* has air at 200 kPa, 300 K, and side *B* has air at 1.0 MPa, 1000 K. The piston is now unlocked so that it is free to move, and it conducts heat so that the air comes to a uniform temperature $T_A = T_B$. Find the mass in both *A* and *B* and the final *T* and *P*.

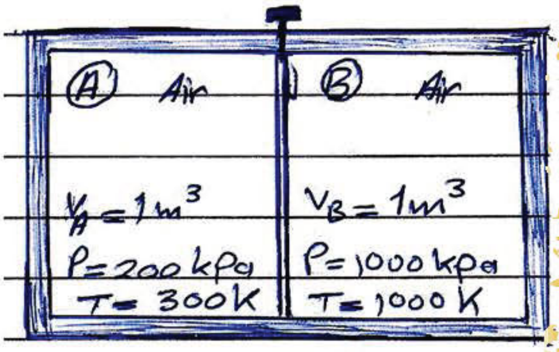


Figure P5.95

Solution

$m_A = \frac{P_A V_A}{R T_A} = \frac{(200)(1)}{(0.287)(300)} = \boxed{2.323 kg}$

R → from Table A.5

$m_B = \frac{P_B V_B}{R T_B} = \frac{(1000)(1)}{(0.287)(1000)}$

$m_B = 3.484 kg$

final state ⇒ $T_A = T_B$ (No Heat Transfer $_1Q_2 = 0$)

V → constant for process (No work $_1W_2 = 0$)

To find temp(P) .. we must know the u_2 and use Table A.7 because it gas (Air)

$_1\cancel{Q}_2^{\,0.0} = m_2 u_2 - m_1 u_1 + {}_1\cancel{W}_2^{\,0.0}$

$0 = m_2 u_2 - (m_A u_A + m_B u_B) \Rightarrow m_A u_A + m_B u_B = m_2 u_2$

$\Rightarrow u_2 = \frac{m_A u_A + m_B u_B}{m_2} \Rightarrow u_2 = 541.24$

$m_2 = m_A + m_B$
$= 2.322 + 3.484$
$= 5.807$

at $u_2 \rightarrow T$??

interpolation betwean 720 K & 740 K

$\Rightarrow T = 736 K$

Air Table (A.7)

u_A @ T = 300 k
$u_A = 214.364$
u_B @ T = 1000 k
$u_B = 759.189$

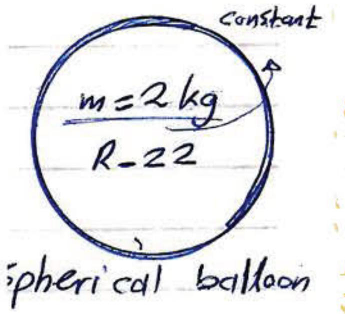
$P_2 V_2 = m_2 R T_2$

$P_2 = \frac{m_2 R T_2}{V_2} = \frac{(5.807)(0.287)(736)}{2}$

$V_2 = V_{tot}$
$= V_A + V_B$
$= 1 + 1$
$V_2 = 2 m^3$

$\Rightarrow P_2 = 613 kpa$

A spherical balloon contains 2 kg of R-22 at 0°C with a quality of 30%. This system is heated until the pressure in the balloon reaches 600 kPa. For this process, it can be assumed that the pressure in the balloon is directly proportional to the balloon diameter. How does pressure vary with volume and what is the heat transfer for the process?



$P \propto D \qquad V \propto D^3$

$V^{1/3} \propto D$

$P \propto D \propto V^{1/3}$

$P \propto V^{1/3}$

$P = c V^{1/3}$

$$\boxed{P V^{-1/3} = C}$$

$$\boxed{n = \frac{-1}{3}}$$

$(P)^3 = (c V^{\frac{1}{3}})^3$ ثابت

$P^3 = c^3 V \quad \boxed{c^3 = c}$

$P^3 = c V$

$$\boxed{c = \frac{P^3}{V}}$$

$\frac{P_1^3}{V_1} = \frac{P_2^3}{V_2}$

$\frac{V_2}{V_1} = \left(\frac{P_2}{P_1}\right)^3$

$$\boxed{V_2 = V_1 \left(\frac{P_2}{P_1}\right)^3}$$

State ① $(T = 0°C, X = 0.3)$ State ② $(P_2 = 600 \text{ kPa})$

$_1Q_2 = m(u_2 - u_1) + {}_1W_2$

To find u_1

$P_1 = P_s = 497.6 \text{ kPa}$

$u_1 = u_f + X u_{fg} \Rightarrow = (44.2) + (0.3 * 0.04636)$

$\Rightarrow \boxed{u_1 = 98.9 \text{ kJ/kg}}$

$v_1 = v_f + v_{fg} \Rightarrow v_1 = 0.014686 \text{ m}^3/\text{kg}$

$V_1 = v_1 m \Rightarrow = 0.029372 \text{ m}^3$

To find u_2 we must know v_2

$V_2 = 0.029372 \left(\frac{600}{497.6}\right)^3 \Rightarrow V_2 = 0.05149 \text{ m}^3$

$v_2 = \frac{V_2}{m} \Rightarrow = 0.02575 \text{ m}^3/\text{kg}$

المثال خارجي..

يمكن الإطلاع على p.5.168 نفس الفكرة

^_^

To find u_2 .. we need to 4 interpolation $(P_2, v_2) \rightarrow$ mix.

P	v_f
680.7	0.0008
600	v_f ?
523.8	0.00078

$v_f = 0.000794$

P	v_{fg}
680.7	0.03391
600	v_{fg} ?
583.8	0.03957

$v_{fg} = 0.03682$

u_f	P
55.92	680.7
?	600
50.03	583.8

$u_f = 52.89$

u_{fg}	P
173.87	680.7
?	600
178.15	583.8

$u_{fg} = 176.07$

$$x = \frac{v_2 - v_f}{v_{fg}} = \boxed{0.677}$$

$$u_2 = u_f + x u_{fg}$$

$$\boxed{u_2 = 165.8}$$

$$_1Q_2 = m(u_2 - u_1) + {}_1W_2$$

$$_1W_2 = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{(600 * 0.051493) - (498 * 0.02937)}{1 - (\frac{-1}{3})}$$

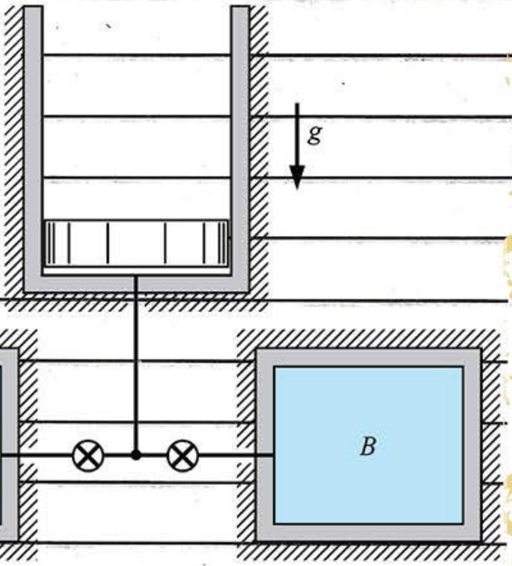
$$\Rightarrow \boxed{_1W_2 = 12.1 \text{ kJ}}$$

$$\Rightarrow {}_1Q_2 = 2(165.8 - 98.9) + 12.1$$

$$\Rightarrow \boxed{_1Q_2 = 145.9 \text{ kJ}}$$

5.75

A rigid tank *A* of volume 0.6 m^3 contains 3 kg of water at 120°C, and rigid tank *B* is 0.4 m^3 with water at 600 kPa, 200°C. They are connected to a piston/cylinder initially empty with closed valves as shown in Fig. P5.75. The pressure in the cylinder should be 800 kPa to float the piston. Now the valves are slowly opened and heat is transferred so



Solution

$$_1Q_2 = m_2u_2 - m_1u_1 + {}_1W_2$$
$$= m_2u_2 - (m_{A_1}u_{A_1} + m_{B_1}u_{B_1}) + {}_1W_2$$
$$_1Q_2 = m_2u_2 - m_{A_1}u_{A_1} - m_{B_1}u_{B_1} + {}_1W_2$$

⊛ نجد الحالات السهلة أولاً B_1 & A_1

State A1 $V = 0.6 \,/\, m_A = 3kg \,/\, T = 120°C \,/\, H_2O$

$$v_{A_1} = \frac{V}{m} = \frac{0.6}{3} = 0.2 \ m^3/kg$$

$(v_A, T) \rightarrow$ mix.

$u_A = u_f + x\,u_{fg}$ $\quad \Big\{ \; x = \frac{v - v_f}{v_{fg}} = \frac{0.2 - 0.00106}{0.89186}$

$\Rightarrow u_A = 503.48 + (0.223327 * 2025.76)$ $\quad x = 0.223327$

$\Rightarrow \boxed{u_A = 955.89}$

State B1 $(V=0.4 \,/\, P=600\,kpa \,/\, T=200°c)$

$(T, P) \Rightarrow$ superheated vapor

$\boxed{v_{B1} = 0.35202}$

$$m_{B1} = \frac{V_{B1}}{v_{B1}} = \frac{0.4}{0.35202} = \boxed{1.1363\,kg}$$

State ②

$$m_{tot} = m_2 = m_{A1} + m_{B1} = 1.1363 + 3 \Rightarrow = \boxed{4.1363\,kg}$$

⊛ هنا لا يوجد لدينا سوى خاصية واحدة وهي $\boxed{T_2 = 250}$ لذلك نستخدم الفرض ...

فرض ① نعتبر أن الحجم الكلي هو حجم الشكل (B+A) وعلى هذا الأساس يجب أن يكون لدينا الضغط أقل من (800 kpa) لأن الضغط اللازم لرفع المكبس هو (800) وإذا كان الناتج أكبر من (800) هنا يعني أن المكبس قد ارتفع قليلاً ← يعني أن الحجم قد زاد وهذا يبطل الفرض

$$\left.\begin{aligned} V_T &= V_A + V_B = 0.4 + 0.6 = 1\,m^3 \\ m_T &= 4.1363 \end{aligned}\right\} \rightarrow v = \frac{1}{4.1363} = \boxed{0.2417619}$$

$(T_2, v_2) \rightarrow$ superheated $P > 800$ kpa

← الفرض خاطئ (المكبس ارتفع ، أي أن الحجم زاد وهذا فرض خاطئ)

← يعني أن الحجم الكلي يجب أن يصبح $\boxed{V_T = V_A + V_B + V_C}$

فرض 2

نفرض ان الضغط النهائي هو (800 kpa) وهذا يعني أن هناك حجم يجب ان يضاف للحجم الأصلي وهو حجم الأسطوانة

$(P, T) \rightarrow$ super heated vapor

$v_2 = 0.29314$

$V_2 = v_2 * m_2 \Rightarrow (0.29314 * 4.1363) \Rightarrow \boxed{V_2 = 1.212515\ m^3}$

$\therefore \boxed{V_2 > V_1}$

(أي هناك حجم إضافي زاد على النظام، وهذا الفرض يصبح صحيح لأنه المكبس ......)

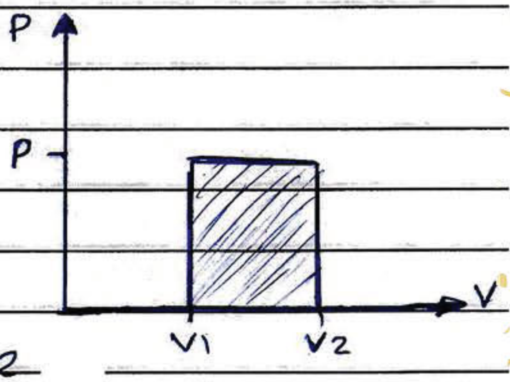
State ② (P, T) super heated vapor $\rightarrow u = 2715.46\ kJ/kg$

W

$_1W_2 = P(V_2 - V_1)$

$= 800 (1.21515 - 1)$

$\boxed{_1W_2 = 172.15\ kJ}$

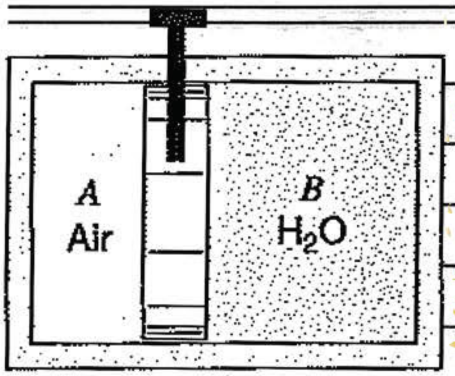


$_1Q_2 = m_2 u_2 - m_{A1} u_{A1} - m_{B1} u_{B1} + {_1W_2}$

$= (4.1363 * 2715.46) - (13 * 955.89) - (1.1363 * 2638.91) + 172.12$

$\Rightarrow \boxed{_1Q_2 = 5538\ kJ}$

A closed cylinder is divided into two rooms by a frictionless piston held in place by a pin, as shown in Fig. P5.138. Room *A* has 10 L of air at 100 kPa, 30°C, and room *B* has 300 L of saturated water vapor at 30°C. The pin is pulled, releasing the piston, and both rooms come to equilibrium at 30°C, and as the water is compressed it becomes two-phase. Considering a control mass of the air and water, determine the work done by the system and the heat transfer to the cylinder.



Solution

$_1W_2$ done by system $= 0.0$

$_1Q_2 = U_2 - U_1 + \cancel{_1W_2}^{0.0}$

w: water
a: air

$_1Q_2 = mu_2 - mu_1 \Rightarrow = \left((m_a u_a)_2 + (m_w u_w)_2\right) - \left((m_a u_a)_1 + (m_w u_w)_1\right)$

* هنا لدينا معطى في السؤال ان الكتلة ثابتة من الحالة ① — ② في الهواء
① — ② في الماء فيصبح القانون

$= m_a(\cancel{u_{a2} - u_{a1}})^{0.0} + m_w(u_{w2} - u_{w1})$

$u_{a1}\big|_{T=30} = u_{a2}\big|_{T=30} \Rightarrow (u_{a2} - u_{a1}) = 0$

$\frac{V}{m} = v$

$\boxed{v_{w1} = v_g\big|_{T=30} = 32.89}$

$_1Q_2 = m_w(u_{w2} - u_{w1})$

$\boxed{m_{w1} = m_{w2} = m_w}$

$m_w = \frac{V_{w1}}{v_{w1}} = \frac{0.3}{32.8932} \Rightarrow \boxed{m_w = 9.12 * 10^{-3} \text{ kg}}$

$\boxed{u_{w1} = u_g\big|_{T=30} = 2416.58 \text{ kJ/kg}}$

State② (water)

T = 30°C mix → P = P_s ⇒ $\boxed{u_2 = u_f + x\, u_{fg}}$

for water $v_2 = \frac{V_2}{m_2}$ $x = \frac{v_2 - v_f}{v_{fg}}$

$V_T = V_{w2} + V_{a2}$

$\underbrace{PV = mRT}_{constant} \Rightarrow PV = C$

$(P_1 V_1 = P_2 V_2)_{air}$

$V_{2a} = \frac{P_1 V_1}{P_2} = \frac{(100)(0.01)}{4.246}$

$\boxed{V_{2a} = 0.2355\, m^3}$

$V_T = 300 + 10$
$= 310 L$
$\boxed{V_T = 0.31\, m^3}$

$\Rightarrow V_T = V_{w2} + V_{a2}$

$V_{w2} = 0.31 - 0.2355 \Rightarrow \boxed{= 0.0745\, m^3}\ V_{w2}$

$\underset{water}{v_2} = \frac{V_{w2}}{m_2} = \frac{0.0745}{9.12*10^{-3}} \Rightarrow v_2 = 8.168$

$\Rightarrow x = \frac{v_2 - v_f}{v_{fg}} = \frac{8.168 - v_f}{v_{fg}}$

$x = 0.248$

Note
v_f, v_{fg}, u_f & u_{fg}
from Tables
@ T = 30°C

$u_2 = u_f + x\, u_{fg}$

$\boxed{u_2 = 694.6\, kJ/kg}$

${}_1Q_2 = m_w (u_{2w} - u_{1w}) \Rightarrow = (9.12*10^{-3})(694.6 - 2416.6)$

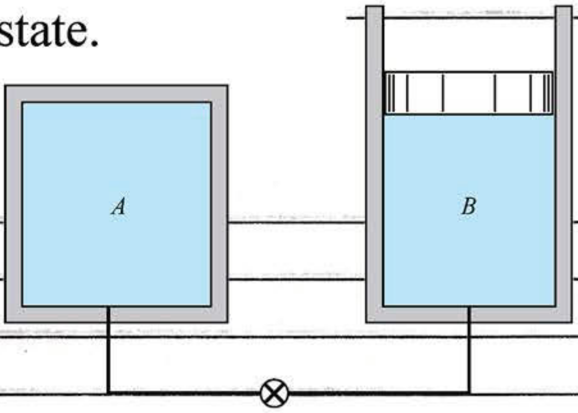
$\Rightarrow \boxed{{}_1Q_2 = -15.704\, kJ}$

5.171

A piston/cylinder arrangement *B* is connected to a 1-m^3 tank *A* by a line and valve, shown in Fig. P5.171. Initially both contain water, with *A* at 100 kPa, saturated vapor and *B* at 400°C, 300 kPa, 1 m^3. The valve is now opened, and the water in both *A* and *B* comes to a uniform state.

a. Find the initial mass in *A* and *B*.

b. If the process results in $T_2 = 200°C$, find the heat transfer and the work.



Solution.

a) Find m_{A1}, m_{B1}

$$m_{A1} = \frac{V_A}{v_A} = \frac{V_A}{v_g} = \frac{1}{1.694} \Rightarrow \boxed{m_{A1} = 0.5903 \text{ kg}}$$

$$m_{B2} = \frac{V_B}{v_B} = \frac{1}{1.03151} \Rightarrow \boxed{m_{B2} = 0.9695 \text{ kg}}$$

$\{(T_B, P_B)$ superheated vapor $\boxed{v = 1.03151}$

$\boxed{T_2 = 200°C}$

$$_1Q_2 = U_2 - U_1 + {_1W_2}$$

$$_1Q_2 = m_2 u_2 - (m_{A1} u_{A1} + m_{B1} u_{B1}) + {_1W_2}$$

* هنا في الحالة الثانية لا يوجد معنا سوى خاصية واحدة وهي T_2.
لذلك نستخدم الفرض.

اذا فرضنا ان الحجم النهائي أصبح ($1 m^3$) فقط فهذا يعني أن الكبس في الإسطوانة يجب ان يكون في قاع الإسطوانة . و يتحقق هذا اذا كان الضغط الناتج أقل من (300 kpa).
(لأن الضغط المعطى هو ضغط للكبس)

if (T_2, V_2) $V_2 = 1 m^3 \rightarrow P < 300$ (if true Ok if false no)

$V_2 = 1 m^3$ $m_2 = 1.5598$ kg $\Rightarrow v_2 = \frac{V_2}{m_2} = 0.641167$ m^3/kg

(T_2, V_2) superheated vapor $P = 341.26 > 300$

∴ الفرض خاطئ

P	v
300	0.7162
?	0.64116
400	0.5342

$\boxed{P = 341.26}$

نفرض فرض آخر إن الضغط الثاني هو (300kpa) ويترتب عليها هنا بما أن الضغط (300) يجعل المكبس يرتفع . لذلك الحجم الثاني يجب ان يكون أكبر من $1m^3$

Assume if $(T_2, P_2) \xrightarrow{P_2=300} V_2 \geq 1m^3$ if true <u>ok</u> if False <u>no</u>.

$(T_2, P_2) \rightarrow$ super heated vapor $\rightarrow v_2 = 0.71629 \, m^3/kg$

$\therefore V_2 = v_2 m_2 \Rightarrow = (0.71629)(1.5598)$

$\Rightarrow V_2 = 1.1172 \, m^3 > 1m^3$

∴ الفرض صحيح

$u_2 = 2650.65 \, kJ/kg$

$u_{A1} = 2506.06$

$u_{B1} = 2965.53$

للنظام كامل

$_1W_2 = \int P dV \Rightarrow = 300 \times (V_2 - V_1)$

$= 300(1.1172 - 21)$

$$\boxed{_1W_2 = -264.8 \, kJ}$$

$_1Q_2 = m_2 u_2 - m_{A1} u_{A1} - m_{B1} u_{B1} + {}_1W_2$

$$\Rightarrow \boxed{_1Q_2 = -484 \, kJ}$$

Two tanks, each with a volume of 1 m³, are connected by a valve and line, as shown in Fig. P5.62. Tank *A* is filled with R-134a at 20°C with a quality of 15%. Tank *B* is evacuated. The valve is opened and saturated vapor flows from *A* into *B* until the pressures become equal. The process occurs slowly enough that all temperatures stay at 20°C during the process. Find the total heat transfer to the R-134a during the process.

Tank (A) R-134a

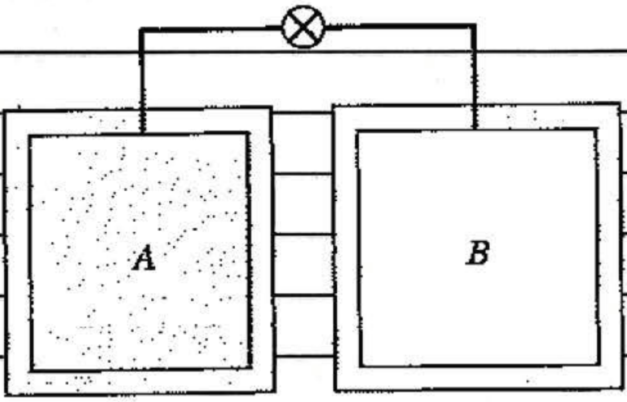
$V_A = 1 m^3$

$T_A = 20°C$

$X_A = 0.15$

Tank (B)

Evacuated (فارغ)



State (2) $T_2 = 20°C$

$1W_2 = 0.0$

$m_2 = m_A + m_B$

$1Q_2 = U_2 - U_1 + 1W_2 \Rightarrow 1Q_2 = m_2 u_2 - (m_A u_A + m_B u_B) + 0$

$\Rightarrow 1Q_2 = m_2 u_2 - m_A u_A - m_B u_B$

(A1) الخصائص عند T=20°C

$v_A = v_f + x\, v_{fg} \Rightarrow (0.000817) + (0.15 * 0.03524) \Rightarrow \boxed{v_A = 0.006103}$

$m_A = \frac{V_A}{v_A} = \frac{1}{0.006103} = \boxed{163.854 kg}$

$u_A = u_f + x\, u_{fg} \Rightarrow (227.03) + (0.15 * 162.16) \Rightarrow \boxed{u_A = 251.35 kJ/kg}$

الخصائص عند T=20°C

(B1)

no mass   no u_B

$\therefore \boxed{m_B = 0}$ $\boxed{u_{B1} = 0}$

State ②

$m_2 = m_A = 163.854\ kg$

$V_2 = 1+1 = 2\ m^3$

$v_2 = \frac{V_2}{m_2} = \frac{2}{163.854} = 0.0122059$

$(v_f < v_2 < v_g) \rightarrow$ mix.

$x = \frac{v - v_f}{v_{fg}} = \frac{0.0122059 - 0.000817}{0.03524} \Rightarrow \boxed{x = 0.3232}$

$u_2 = u_f + x u_{fg} \Rightarrow (227.03) + (0.3232 * 162.16) \Rightarrow \boxed{u_2 = 279.44}$

$_1Q_2 = m_2 u_2 - m_A u_A - m_B u_B$

$_1Q_2 = (163.85 * 279.44) - (163.854 * 251.35) - 0$

$\Rightarrow \boxed{_1Q_2 = 4602.65\ kJ}$

لا تنسو حل اكبر قدر من أسئلة الكتاب..

-أسئلة مقترحة من شابتر 5 (الكتاب الطبعة السابعة):

55، 64، 68، 70، 72، 109، 115، 119، 160،
161، 164، 165، 166، 167، 168، 169،
170، 172،

^_^

Chapter 6: First Law for control volume

في هذه الوحدة سنتعامل بشيء هو النسبة (Rate). أي ستكون القيم ثابتة أو متغيرة بالنسبة للزمن.

$m \rightarrow$ mass (الكتلة)

$\dot{m} \rightarrow$ mass flow rate (مقدار عبور الكتلة بالنسبة للزمن)

$$\dot{m} = \frac{\text{mass}}{\text{time}} \left[\frac{kg}{s}\right]$$

$\forall \rightarrow$ volume

$\dot{\forall} \rightarrow$ volume flow rat

$$\dot{\forall} = \frac{\text{volume}}{\text{time}} \left[\frac{m^3}{s}\right]$$

علاقة بين السرعة والكتلة والحجم

$$\boxed{\dot{m} = \frac{VA}{v}}$$

$V \rightarrow$ velocity سرعة

$A \rightarrow$ Area مساحة

$v \rightarrow$ specific volume حجم نوعي

$\dot{m} \rightarrow$ mass flow rate

أيها الميكانيكيةُ أنتمُ الأمراءُ بكم الأرضُ والسماءُ سواءُ
يا نجوماً تمشي على الأرضِ كلما أظلم القسم أضاؤوا

Ex. 6.1

Air is flowing in a 0.2-m-diameter pipe at a uniform velocity of 0.1 m/s. The temperature is 25°C and the pressure is 150 kPa. Determine the mass flow rate.

air. $d = 0.2\,m$ (pipe) $V = 0.1\,m/s$ $T = 25°C$

$P = 150\,kpa$ $\underline{\dot{m} = ?}$

$$\dot{m} = \frac{VA}{v}$$

$P\forall = mRT$ لأن المادة غاز (هواء)

$$\frac{\forall}{m} = \frac{RT}{P} \Rightarrow v = \frac{RT}{P} \Rightarrow = \frac{(0.287)(25+273)}{150} \Rightarrow \boxed{v = 0.5705\ m^3/kg}$$

$$\dot{m} = \frac{(0.1)(\frac{\pi}{4}\,0.2^2)}{0.5705} \Rightarrow \boxed{\dot{m} = 0.0055\ kg/s}$$

$i \rightarrow$ inlet مدخل

$e \rightarrow$ exist مخرج

Control volume

$$\boxed{\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e}$$ قانون عام

هذا القانون العام لـ chapter6 كاملاً حفظ

$$\boxed{\left(\frac{dE}{dt}\right) = \dot{Q} + \sum \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gZ_i\right) - \dot{W} - \sum \dot{m}_e \left(\frac{V_e^2}{2} + h_e + gZ_e\right)}$$

* steady state process (steady state steady flow)

steady state : it means no change with time. الخواص ثابتة لا تتغير مع الزمن

OR mathematically: $\frac{dm}{dt} = 0.0$

$$\overset{0.0}{\frac{dm}{dt}} = \sum \dot{m}_i - \sum \dot{m}_e \Rightarrow \boxed{\sum \dot{m}_i = \sum \dot{m}_e}$$

الكتلة الداخلة مساوية للكتلة الخارجة مهما كان عدد المداخل أو المخارج

$\frac{dE}{dt} = 0.0$ (الطاقة لا تتغير مع الزمن)

$$\boxed{\dot{Q} + \sum \dot{m}_i \left(h_i + \frac{v_i^2}{2} + g z_i\right) = \sum \dot{m}_e \left(h_e + \frac{v_e^2}{2} + g z_e\right) + \dot{W}}$$

هذا القانون يستخدم في حال كان النظام (SSSF)

مثل :

① Heat Exchanger
② Diffuser , Nozzle
③ Throttling
④ pump , compressor
⑤ Turbine
⑥ Mixing

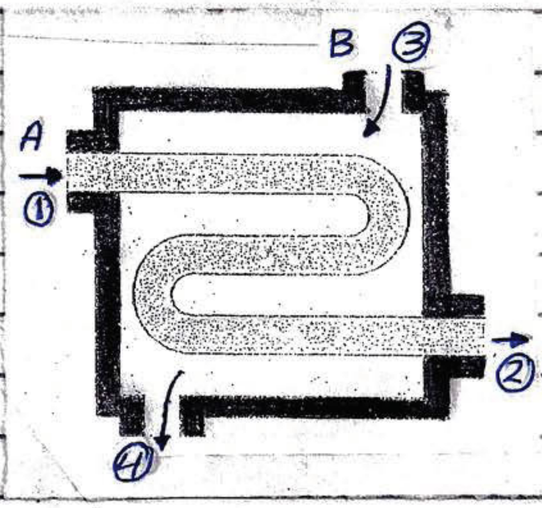
① Heat Exchanger المبادل الحراري

هو جهاز يستخدم لتبادل الحرارة بين مائعين؛ أحدهما بارد والآخر ساخن. يُراد إما تسخين البارد أو تبريد الساخن. ولا يوجد خلط للمائعين مع بعضها. وقد يكونا المائعين من نفس المادة.

⊛ **ملاحظة** (المائع هنا يعني سائل أو غاز).

هنا للنظام كامل
لا يوجد W ولا يوجد Q

لكن اذا أخذنا كل نظام لوحده يصبح لدينا Q
مثلاً من (2-1) نظام
ومن (3-4) نظام آخر



⊛ هنا لا يوجد تغير في الطاقة الحركية أو طاقة الوضع $(\Delta KE = \Delta PE = 0)$
ما لم يقل في السؤال غير ذلك.

$$\boxed{\sum \dot{m}_i h_i = \sum \dot{m}_e h_e}$$

$$\dot{m}_1 h_1 + \dot{m}_3 h_3 = \dot{m}_2 h_2 + \dot{m}_4 h_4$$

$$\dot{m}_A h_1 + \dot{m}_B h_3 = \dot{m}_A h_2 + \dot{m}_B h_4$$

$$\boxed{\dot{m}_A (h_1 - h_2) = \dot{m}_B (h_4 - h_3)} \text{ --- } ⊛$$

$$\left.\begin{aligned} \dot{m}_A &= \dot{m}_1 = \dot{m}_2 \\ \dot{m}_B &= \dot{m}_3 = \dot{m}_4 \end{aligned}\right\}$$

لأن النظام SSSF

في حال أخذنا كل نظام لوحده

system Ⓐ

$\dot{Q}_A + \dot{m}_A h_1 = \dot{m}_A h_2$

$$\boxed{\dot{Q}_A = \dot{m}_A (h_2 - h_1)}$$

system Ⓑ

$\dot{Q}_B + \dot{m}_B h_3 = \dot{m}_B h_4$

$$\boxed{\dot{Q}_B = \dot{m}_B (h_4 - h_3)}$$

من المعادلة ⊛ ⇐ $Q_A = -Q_B$

هنا ما فقده Ⓐ كسبه Ⓑ

ملاحظات *

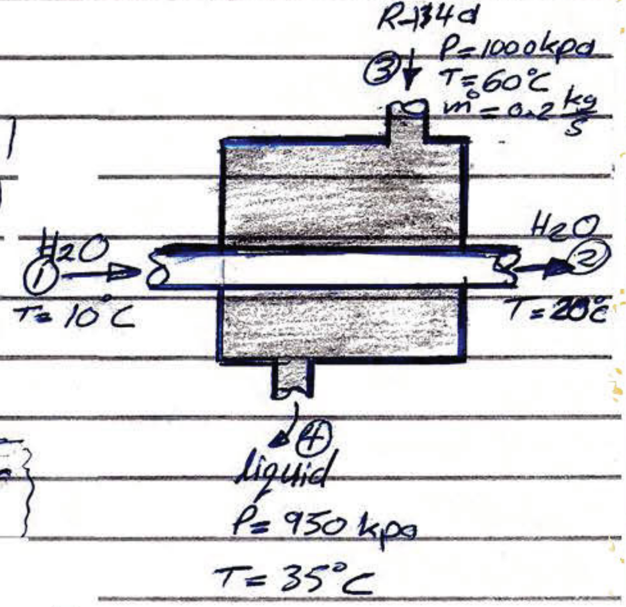
① في حال جاء السؤال وقال يكتب ماء مشبع وأعطانا درجة حرارة فقط يكون طور المادة سائل ، يعني ← $\boxed{h=h_f|}$ عند درجة الحرارة المعطاة.

② في الأنابيب (pipes) نعتبر الضغط ثابت عند المدخل والمخرج ما لم يكن هناك صمام (valve) يغير الضغط.

$$\boxed{P_{in} = P_{out}}$$

Ex: 6.3

Consider a water-cooled condenser in a large refrigeration system in which R-134a is the refrigerant fluid. The refrigerant enters the condenser at 1.0 MPa and 60°C, at the rate of 0.2 kg/s, and exits as a liquid at 0.95 MPa and 35°C. Cooling water enters the condenser at 10°C and exits at 20°C. Determine the rate at which cooling water flows through the condenser.



Solution

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

$\dot{m}_W h_1 + \dot{m}_R h_3 = \dot{m}_W h_2 + \dot{m}_R h_4$

$\dot{m}_W = \dot{m}_R \frac{(h_4 - h_3)}{(h_1 - h_2)}$

$\dot{m}_W = 0.2 \frac{(249.1 - 441.89)}{(41.99 - 83.94)}$

$$\boxed{\dot{m}_W = 0.919\ kg/s}$$

$h_1 = h_f|_{T=10°C}$

$\Rightarrow \boxed{h_1 = 41.99}$

$h_2 = h_f|_{T=20°C}$

$\boxed{h_2 = 83.94}$

h_3 : super heated vapor

$\boxed{h_3 = 441.89}$

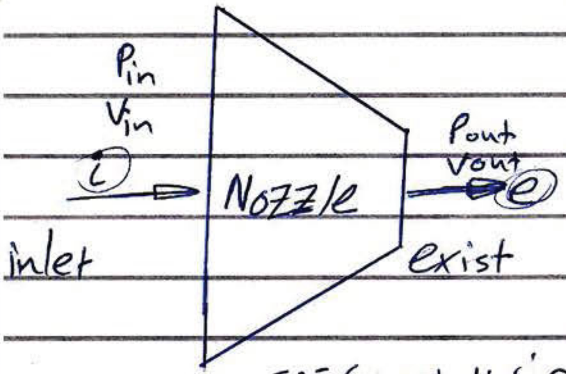
$h_4 = h_f|_{T=35} = \boxed{249.1}$

② Nozzle and Diffuser

يكثر استخدام هذين الجهازين في محركات الطائرات والمركبات الفضائية ومحركات الاحتراق الداخلي، وأيضاً في خراطيم المياه وغيرها من التطبيقات العملية الهامة في الحياة.

A) Nozzle

جهاز يزيد السرعة للسائل على حساب الضغط.



⊛ هنا الـ (area) تنقص

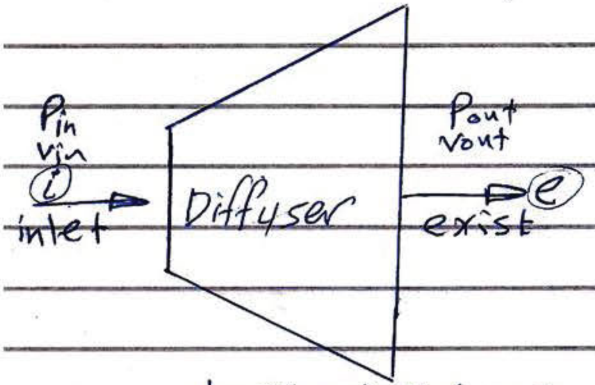
$V_e > V_i$

$P_e < P_i$

⊛ الضغط يقل عند المخرج والسرعة تزداد

B) Diffuser

جهاز يزيد من ضغط السائل عن طريق
تقليل سرعة السائل (عكس nozzle تماماً)



⊛ هنا الـ (area) تزداد

$V_e < V_i$

$P_e > P_i$

⊛ الضغط يزداد عند المخرج والسرعة تقل

⊛ ملاحظة هامة
في هذين الجهازين لا يوجد
انتقال للحرارة مع المحيط "$Q = 0.0$"
ولا يوجد شغل يبذل "$W = 0.0$"

إلا اذا جاء في نص السؤال
غير ذلك

أيضاً بالنسبة لـ (nozzle & diffuser) تكون الكتلة الخارجة مساوية للكتلة الداخلة. لأنه النظام (SSSF).

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

$$\boxed{h_i + \frac{V_i^2}{2} = h_e + \frac{V_e^2}{2}}$$

① هنا لا تنسى اذا إستخرجت قيمة h بـ kJ/kg (يعني من الجدول) يجب أن تقسم السرعة على (1000)

يصبح القانون ⇒ $$h_i + \frac{V_i^2}{2*1000} = h_e + \frac{V_e^2}{2*1000} \qquad \left.\begin{matrix} h_i \\ h_e \end{matrix}\right\} [kJ/kg]$$

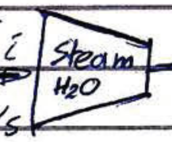
Ex 6-4

Steam at 0.6 MPa and 200°C enters an insulated nozzle with a velocity of 50 m/s. It leaves at a pressure of 0.15 MPa and a velocity of 600 m/s. Determine the final temperature if the steam is superheated in the final state and the quality if it is saturated.

If Phase superheated determine Te   IF phase sat. determine X.

Solution

$P_i = 600$ kpa
$T_i = 200°C$
$V_i = 50$ m/s



150 kpa
$V_e = 600$ m/s

(we must to know the h_e to know the phase)

$$h_i + \frac{V_i^2}{2} = h_e + \frac{V_e^2}{2}$$

$\{ h_i \Rightarrow (P_i, T_i)$ superheated vapor
$h_i = 2850.1$ kJ/kg

$$2850.1 + \frac{(50)^2}{2*1000} = h_e + \frac{(600)^2}{2*1000}$$

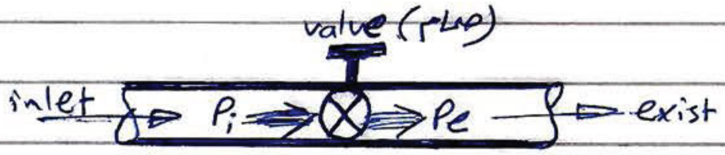
$$\Rightarrow \boxed{h_e = 2671.4 \text{ kJ/kg}}$$

$(h_e, P_e) \Rightarrow$ (mix.)

$$X = \frac{h - h_f}{h_{fg}} = \frac{2671.4 - 467.1}{2226.5} \Rightarrow \boxed{X = 0.99}$$

③ Throttling (Throttling valve)

تسمى عملية الخنق . وهي من أنواع الأنابيب ويكون فيها (valve) الهدف من
وجود الـ (valve) تخفيض الضغط بشكل كبير.



$P_e < P_i$ $\quad A_i = A_e$ $\quad h_i = h_e$

$V_i = V_e$

في هذا الجهاز: لا يوجد شغل يبذل ← $W = 0.0$

ولا 〃 في الارتفاع بين المدخل والمخرج ← $\Delta P.E = 0.0$

ولا 〃 تغير ملحوظ في الطاقة الحركية ← $\Delta K.E = 0.0$

ولا ينتج تبادل حراري (نعتبره دائماً "adiabatic") ← $Q = 0.0$

فيصبح الـ 1st law الخاص بهذا الجهاز: ← $\boxed{h_e = h_i}$ [kJ/kg]

See Example 6.5

④ Pump and Compressor

Pump ← رفع الضغط للسائل

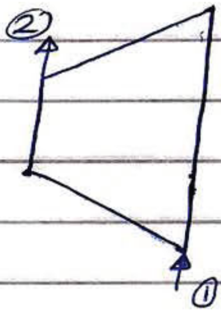
Compressor ← رفع الضغط للغاز

هذان الجهازان يحتاجان إلى power لتشغيلها (تحتاج W)

← هذا يعني أن قيمة الـ(W) سالبة. لأنه داخل النظام $W<0.0$

وغالباً لا يوجد Q إلا اذا ذكر في السؤال غير ذلك.

Pump



Compressor

المعادلة للجهازين هي $\dot m_i h_i = \dot W + \dot m_e h_e$

$\boxed{\dot m_i = \dot m_e = \dot m}$

$$\Rightarrow \boxed{\dot W = \dot m (h_i - h_e)}$$

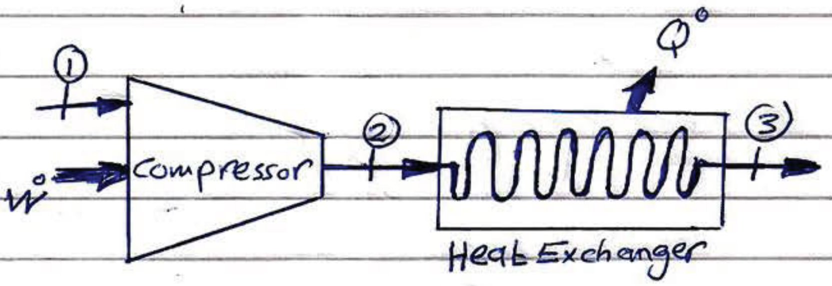
أحياناً قد يصاحب هذا القانون سرعة

$$\dot m_i \left(h_i + \frac{V_i^2}{2}\right) = \dot W + \dot m_e \left(h_e + \frac{V_e^2}{2}\right)$$

$$\Rightarrow \boxed{\dot W = \dot m_i \left(h_i + \frac{V_i^2}{2}\right) - \dot m_e \left(h_e + \frac{V_e^2}{2}\right)}$$

Ex: 6.7

The compressor in a plant (see Fig. 6.10) receives carbon dioxide at 100 kPa, 280 K, with a low velocity. At the compressor discharge, the carbon dioxide exits at 1100 kPa, 500 K, with velocity of 25 m/s and then flows into a constant-pressure aftercooler (heat exchanger) where it is cooled down to 350 K. The power input to the compressor is 50 kW. Determine the heat transfer rate in the aftercooler.



State①	State②	State③
CO2	CO2	
100 kpa low vilocity ($v_i=0$)	1100 kpa $V_e=25$ m/s	$P_3=P_2$
280 K $\dot{W}$ (input) = -50 kw	500K	$T_3=350K$

$$\boxed{\sum \dot{m}_i h_i = \sum \dot{m}_e h_e + \dot{Q}}$$

$\dot{m}_2 h_2 = \dot{m}_3 h_3 + \dot{Q} \Rightarrow \boxed{\dot{Q} = \dot{m}(h_2 - h_3)}$ $\dot{m}_1 = \dot{m}_2 = \dot{m}_3 = \dot{m}$

لإيجاد $\dot{m}$ من الـ compr.

$$\boxed{\dot{W} = \dot{m}_i\left(h_i + \cancelto{zero}{\frac{V_i}{2}}\right) - \dot{m}_e\left(h_e + \frac{V_e^2}{2}\right)}$$

$\dot{m}_i = \dot{m}_e \Rightarrow \dot{W} = \dot{m}_i\left(h_1 - h_2 - \frac{V_2^2}{2}\right)$

$$\dot{m} = \frac{\dot{W}}{h_1 - h_2 - \frac{V_2^2}{2}}$$

$h_1 \rightarrow CO_2, 280K$

Table A-8

T	h
250	173.44
280	h
300	214.38

$\Rightarrow h_1 = 198.004$ kJ/kg

$h_2 \rightarrow CO_2, 500K$

Table A-8

$\Rightarrow h_2 = 401.52$ kJ/kg

$h_3 \rightarrow CO_2, 350K$

Table ---

$\Rightarrow h_3 = 257.9$ kJ/kg

$$\Rightarrow \dot{m} = \frac{-50}{(198.004) - (401.52) - \left(\frac{25^8}{2*1000}\right)} \Rightarrow \boxed{\dot{m} = 0.245 \text{ kg/s}}$$

For Heat Exchanger

$$Q = m(h_2 - h_3) \Rightarrow = 0.245(401.52 - 257.9)$$

$$\boxed{Q = 35.23 \text{ kw}}$$

⑤ Turbine

⊛ يستخدم هذا الجهاز في محطات الطاقة و يستخدم كمولد للطاقة وذلك عن طريق مرور غاز من خلاله بضغط مرتفع وحرارة مرتفعة جداً ، ويصطدم هذا الغاز مع شفرات "blades" موجودة بداخل "turbine" وتكون هذه الشفرات مربوطة مع عمود حركة "shaft" يولد شغل . ويخرج الغاز بضغط وحرارة منخفضين . و يستخدم أيضاً لانتاج الطاقة أسفل الشلالات .... وهكذا.

من أسمائه : (Hydro turbine , gas turbine , Steam turbine)

⊛ مبدأ عمله هو عكس مبدأ عمل الـ (compessor و pump). نتيج شغل $\Leftarrow W > 0.0$

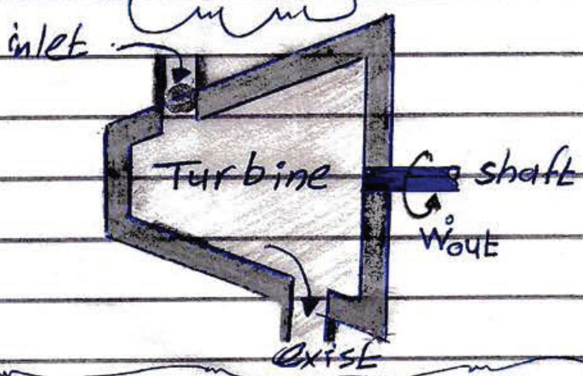
$$\sum \dot{m}_i h_i = W + \sum \dot{m}_e h_e$$

$$\Rightarrow \boxed{\dot{W} = \sum \dot{m}_i h_i - \sum \dot{m}_e h_e}$$

* قد يكون في التوربين عدة مداخل ومخارج

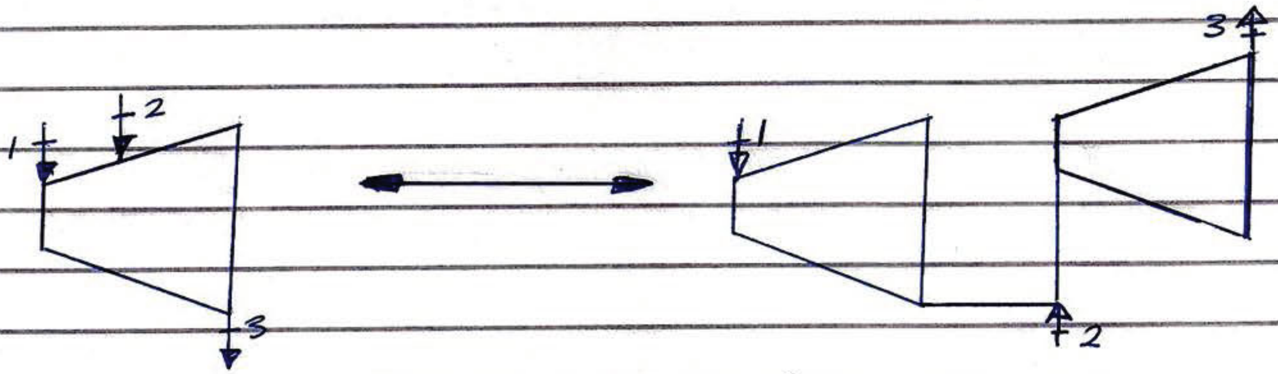
* في حال عدم وجود Q و KE و PE إلا اذا ذكر في السؤال غير ذلك

Turbine



أشكال أخرى لـ (Turbine):

A)

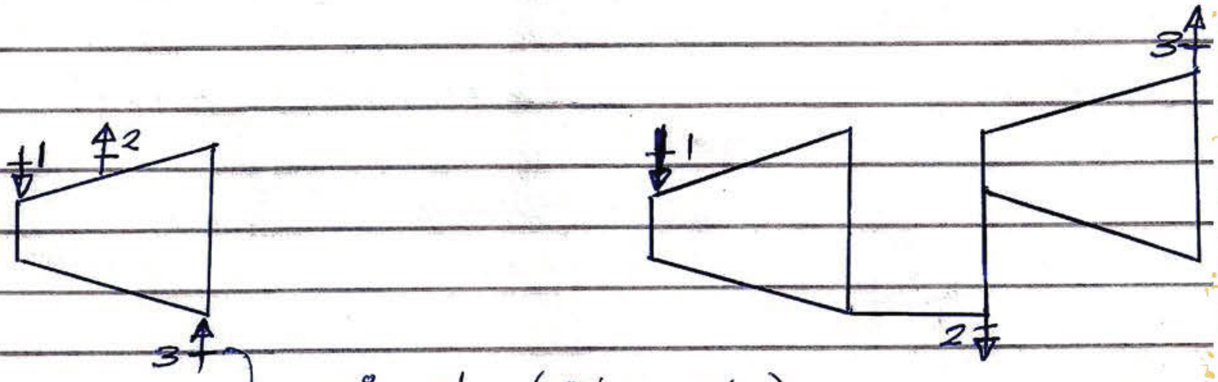


$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$

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

$\boxed{\dot{W} = \dot{m}_1 h_1 + \dot{m}_2 h_2 - (\dot{m}_1 + \dot{m}_2) h_3}$

B)



$\dot{W} = \dot{m}_1 h_1 - (\dot{m}_2 h_2 + \dot{m}_3 h_3)$

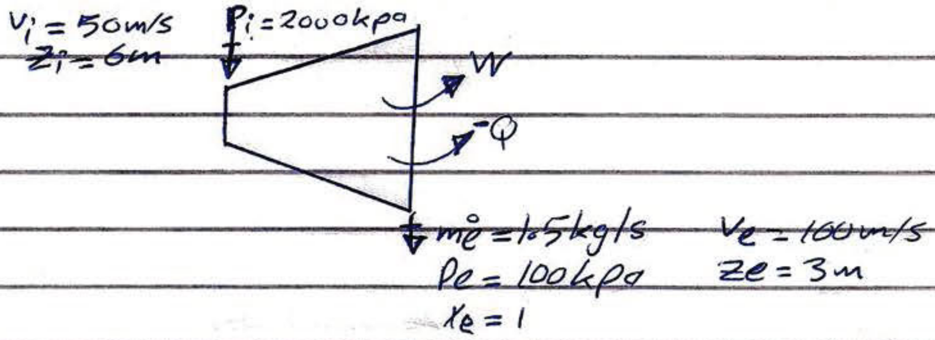
$\dot{m}_1 = \dot{m}_2 + \dot{m}_3$

$\dot{W} = (\dot{m}_2 + \dot{m}_3) h_1 - (\dot{m}_2 h_2 + \dot{m}_3 h_3)$

$\boxed{\dot{W} = (\dot{m}_2 + \dot{m}_3) h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3}$

Ex: 6.6

The mass rate of flow into a steam turbine is 1.5 kg/s, and the heat transfer from the turbine is 8.5 kW. The following data are known for the steam entering and leaving the turbine.



Solution

$P_i = 2000$ kpa } superheated vapor
$T_i = 350°C$ } $\Rightarrow \boxed{h_i = 3136.96}$

$x_e = 1 \Rightarrow (h_e = h_g), (v = v_g), (u = u_g)$

$\Rightarrow h_e = h_g|_{100kpa} \Rightarrow \boxed{h_e = 2675.5}$

$$\dot Q + \dot m_i\left(h_i + \frac{v_i^2}{2} + gz_i\right) = \dot W + \dot m_e\left(h_e + \frac{v_e^2}{2} + gz_e\right)$$

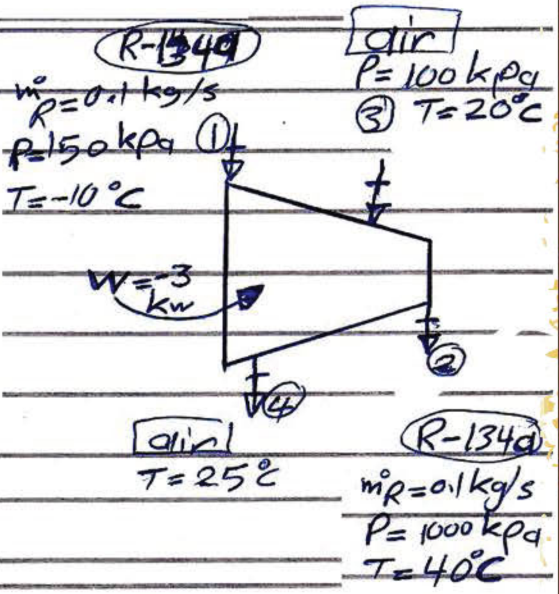
$$-8.5 + 1.5\left(3136.96 + \frac{(50)^2}{2*1000} + \frac{9.81*6}{1000}\right) = \dot W + 1.5\left(2675.5 + \frac{100^2}{2*1000} + \frac{9.81*3}{1000}\right)$$

$$\Rightarrow \boxed{\dot W = 678.2 kw}$$

⊕ لاحظ هنا أن $W > 0.0$ موجب
ولا تنسَ أن تقسم على (1000) في كل من PE و KE
للتحويل إلى (k كيلو).

Problem 6-81

A compressor receives 0.1 kg/s of R-134a at 150 kPa, −10°C and delivers it at 1000 kPa, 40°C. The power input is measured to be 3 kW. The compressor has heat transfer to air at 100 kPa coming in at 20°C and leaving at 25°C. What is the mass flow rate of air?



Solution

$h_1, h_2 \rightarrow$ Table B.5 | $h_2 \rightarrow$ Table B.5

$\left.\begin{matrix} T_1 = -10°C \\ P_1 = 150 kPa \end{matrix}\right\} \rightarrow \boxed{h_1 = 393.84}$ | $\left.\begin{matrix} T_2 = 40°C \\ P_2 = 1000 kPa \end{matrix}\right\} \rightarrow \boxed{h_2 = 420.25}$

$\boxed{h_4, h_3} \rightarrow$ Table A.7.1

① نحول درجات الحرارة بالكلفن

② اذا كانت درجات الحرارة 400K او أقل ⇐ فإن h مساوية لقيمة T (h=T) وتكون قيمة (T) بالكلفن.

$$h_4 = T_4 = 298.62$$
$$h_3 = T_3 = 293$$

هنا لا يوجد Q للنظامين معاً

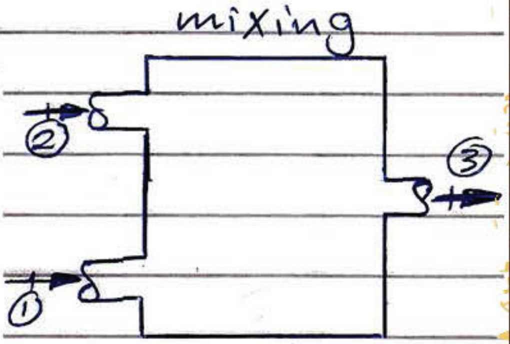
$$\overset{0.0}{\cancel{\dot Q}} + \Sigma \dot m_i h_i = \dot W + \Sigma \dot m_e h_e$$
$$\dot m_1 h_1 + \dot m_3 h_3 = \dot W + \dot m_2 h_2 + \dot m_4 h_4$$
$$\dot m_R h_1 + \dot m_a h_3 = \dot W + \dot m_R h_2 + \dot m_a h_4$$

$$\dot m_a = \frac{\dot m_R (h_1 - h_2) - \dot W}{(h_4 - h_3)} \Rightarrow = \frac{0.1(393.84 - 420.25) - (-3)}{(298.62 - 293)}$$

$$\Rightarrow \dot m_a = 0.0637 \text{ kg/s}$$

P: 6.98

An insulated mixing chamber receives 2 kg/s of R-134a at 1 MPa, 100°C in a line with low velocity. Another line with R-134a as saturated liquid at 60°C flows through a valve to the mixing chamber at 1 MPa after the valve, as shown in Fig. P6.97. The exit flow is saturated vapor at 1 MPa flowing at 20 m/s. Find the flow rate for the second line.



Solution

State① (R-134a)	State②	State③
$\dot{m}_1 = 2\,kg/s$	through a valve	sat. vap → $P = 1000$ kpa
$P_1 = 1000\,kpa$	sat. liq → $T = 60°C$	$V = 20\,m/s$
$T_1 = 1000\,°C$	after valve →	
low velocity $V_1 = 0.0$	$P = 1000\,kpa$	

$$\sum \dot{m}_i \left(h_i + \frac{V_i^2}{2} + g z_i\right) = \sum \dot{m}_e \left(h_e + \frac{V_e^2}{2} + g z_e\right)$$

$$\dot{m}_1\left(h_1 + \cancelto{0.0}{\frac{V_1^2}{2}} + \cancelto{0.0}{g z_1}\right) + \dot{m}_2\left(h_2 + \cancelto{0.0}{\frac{V_2^2}{2}} + \cancelto{0.0}{g z_2}\right) = \dot{m}_3\left(h_3 + \frac{V_3^2}{2} + \cancelto{0.0}{g z_3}\right)$$

$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3\left(h_3 + \frac{V_3^2}{2}\right)$$

$$\dot{m}_1 h_1 + \dot{m}_2 h_2 = (\dot{m}_1 + \dot{m}_2)\left(h_3 + \frac{V_3^2}{2}\right)$$

$h_1 = 483.36$ kJ/kg

$h_2 = h_f|_{T=60°C} \Rightarrow = 287.79$ kJ/kg

$$(2 * 483.36) + \dot{m}_2(287.79) = (2 + \dot{m}_2)\left(419.517 + \frac{20^2}{(2*1000)}\right)$$

لاتنس القسمة على 1000

$h_3 = h_g|_{P=1000}$

P	h = hg
887.6	417.52
1000	?
1017	419.82

$h_g = 419.517$ kJ/kg

$$\Rightarrow \boxed{\dot{m}_2 = 0.969}$$

The Transient Process (uniform state uniform flow)

uniform state uniform flow ⇒ (USUF)

عدم التغير مع المكان (Position) وهنالك تغير مع الزمن

control volume

$$\frac{dE}{dt} = 0.0 \quad \Big\} \quad \frac{dm}{dt} = 0.0$$

$$\frac{dm}{dt} = \sum \dot{m}_i - \sum \dot{m}_e$$

$$\boxed{(m_2 - m_1) = \sum m_i - \sum m_e}$$

①

m_1 ← الكتلة الأولى للنظام

m_2 ← الكتلة النهائية للنظام

m_i ← الكتلة الداخلة للنظام

m_e ← الكتلة الخارجة للنظام

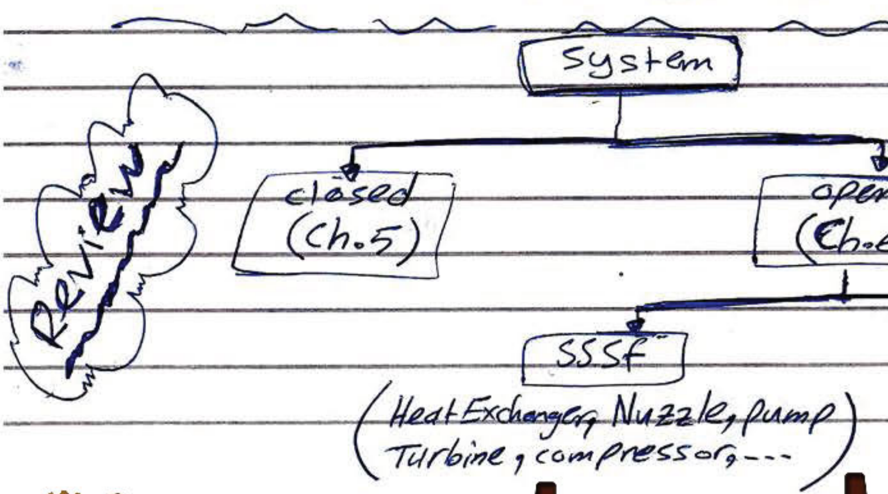
$$\frac{dE}{dt} = \dot{E}_{in} - \dot{E}_{out}$$

$$E_2 - E_1 = \dot{E}_{in} - \dot{E}_{out}$$

$$\boxed{m_2\left(u_2 + \frac{V_2^2}{2} + gz_2\right) - m_1\left(u_1 + \frac{V_1^2}{2} + gz_1\right) = \dot{Q} + \sum \dot{m}_i\left(h_i + \frac{V_i^2}{2} + gz_i\right) - W - \sum \dot{m}_e\left(h_e + \frac{V_e^2}{2} + gz_e\right)}$$

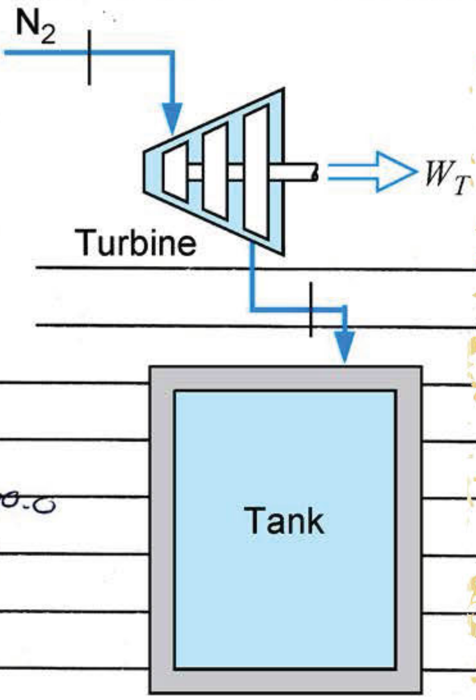
②

القانون العام لل (open system)



P 6.123

A nitrogen line at 300 K, 0.5 MPa, shown in Fig. P6.123, is connected to a turbine that exhausts to a closed, initially empty tank of 50 m^3. The turbine operates to a tank pressure of 0.5 MPa, at which point the temperature is 250 K. Assuming the entire process is adiabatic, determine the turbine work.



$m_2u_2 - \overset{0.0}{\underset{②}{m_1u_1}} = \overset{0.0}{\underset{①}{Q}} + \sum m_i h_i - W - \overset{0.0}{\underset{③}{\sum m_e h_e}}$

$\Rightarrow \boxed{m_2u_2 = m_i h_i - W}$

① adiabatic → $Q = 0.0$

② $\boxed{m_1 = 0.0}$ ⟵⟶ هنا التنك في الحالة الأولى مفرغ ⊛

③ $\boxed{m_e = 0.0}$ أيضاً لا يوجد كتلة تخرج للخارج ⊛

④ $\boxed{PE = 0.0}$ $\boxed{KE = 0.0}$ لم يذكر في السؤال أنهما (KE) او (PE) ⊛

State①

$h_i \rightarrow$ (300K, 500kpa) super heated $T > T_c$

P	h_i
400 →	310.5
500 →	h_i ?
600 →	310.6

$h_i = 310.28$

State②

$P = 500$ kPa

$T = 250$ K

To find u_2

$\boxed{400 \text{ kpa}}$

T	u_A
240 →	176.67
250 →	u_A ?
260 →	191.64

$u_A = \boxed{184.155}$

$\boxed{600 \text{ kpa}}$

T	u_B
240 →	176.11
250 →	u_B ?
260 →	191.13

$u_B = \boxed{183.62}$

$\boxed{T = 250}$

P	u_2
400 →	184.155
500 →	u_2 ?
600 →	183.62

$u_2 = 183.887$

$\boxed{u_2 = 183.887}$

To find m2

$$m_2 = \frac{V_2}{v_2}$$

$\boxed{400\,kpa}$

T	v_A
240	$\rightarrow$ 0.1773
250	$\rightarrow$ v_A ?
260	$\rightarrow$ 0.1924

$v_A = \boxed{0.1849}$

$\boxed{600\,kpa}$

T	v_B
240	$\rightarrow$ 0.1180
250	$\rightarrow$ v_B ?
260	$\rightarrow$ 0.1281

$v_B = \boxed{0.12308}$

$\boxed{T = 250}$

P	v_2
400	$\rightarrow$ 0.18496
500	$\rightarrow$ v_2
600	$\rightarrow$ 0.12308

$\boxed{v_2 = 0.15399}$

$$\Rightarrow m_2 = \frac{50}{0.15399} \Rightarrow \boxed{m_2 = 324.69\,kg}$$

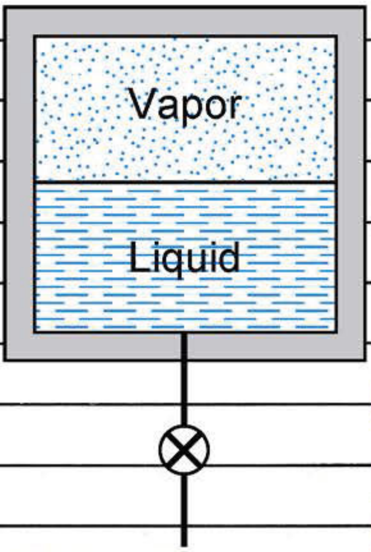
$$\dot{W} = m_2 (h_1 - h_2)$$

$$= 324.69 (310.28 - 183.88)$$

$$\boxed{\dot{W} = 41038.38038\ kJ}$$

P: 6.124

A 750-L rigid tank, shown in Fig. P6.124, initially contains water at 250°C, which is 50% liquid and 50% vapor by volume. A valve at the bottom of the tank is opened, and liquid is slowly withdrawn. Heat transfer takes place such that the temperature remains constant. Find the amount of heat transfer required to reach the state where half of the initial mass is withdrawn.



50% liq. by volume $\rightarrow V_{liq} = \frac{50}{100} * 0.75 = 0.375\ m^3$

50% vap. by volume $\rightarrow V_{vap} = \frac{50}{100} * 0.75 = 0.375\ m^3$

$\boxed{T_1 = 250°C}$

⊛ هنا درجة الحرارة ثابتة ، لأنه لم يحدث تسخين أو تبريد . فقط يتم فتح الـ (valve) (الصمام) ونزول الماء من خلاله . وهذا الأمر لا يتطلب زيادة أو نقصان حرارة .
ولا يتطلب أيضاً شغل .

⊛ الكتلة التي خرجت هي نصف الكتلة الأولى $\boxed{m_e = \frac{1}{2} m_1}$

∴ خرج النصف لـ وبقي أيضاً النصف $\boxed{m_1 = 2m_2} \Rightarrow \boxed{m_2 = \frac{1}{2} m_1}$

∴ $\boxed{m_2 = m_e}$ ∴

$$m_2 u_2 - m_1 u_1 = Q + \cancelto{0.0}{\sum m_i h_i} - \cancelto{0.0}{W} - \sum m_e h_e$$

$$m_2 u_2 - m_1 u_1 = Q - m_e h_e$$

$$Q = m_2 u_2 - m_1 u_1 + m_2 h_e$$

$$Q = m_2 u_2 - 2m_2 u_1 + m_2 h_e$$

$$\boxed{Q = m_2 (u_2 - 2u_1 + h_e)}$$

$\boxed{\text{State①}}$ (mix الحالة الأولى)

لإيجاد $\boxed{m2}$ نجيب $\boxed{m1}$

$$m_1 = m_{vap} + m_{liq}$$

$$= \left(\frac{V_g}{v_g}\Big|_{T=250}\right) + \left(\frac{V_f}{v_f}\Big|_{T=250}\right) \Rightarrow = \frac{0.375}{0.001251} + \frac{0.375}{0.05013} \Rightarrow \boxed{m_1 = 307.24\ kg}$$

$$m_2 = \frac{1}{2} m_1 \Rightarrow \boxed{m_2 = 153.62\ kg}$$

$$u_1 = u_f + x u_{fg}$$

$$x = \frac{v - v_f}{v_{fg}} \Rightarrow v: \text{مجهول}$$

$$x = \frac{m_{vap}}{m_{tot}} = \frac{7.48}{307.1} = \boxed{0.024}$$

$$\Rightarrow u_1 = (1081.3) + (0.024 * 1522) \Rightarrow \boxed{u_1 = 117.43\ kg/kJ}$$

$\boxed{\text{State②}}$ $T_2 = 250°C$

$$v_2 = \frac{V_2}{m_2} = \frac{0.75}{153.52} = 0.00488\ m^3/kg$$

(T_2, v_2) mix

$$\left\{ x = \frac{v - v_f}{v_g} = \boxed{0.07} \right.$$

$$u_2 = u_f + x u_{fg}$$

$$\boxed{u_2 = 1193.39\ kJ/kg}$$

$$h_e = h_f\Big|_{T=250°C} \Rightarrow \boxed{h_e = 1085.34\ kJ/kg}$$

$$Q_2 = m_2(u_2 + h_e - 241)$$

$$\Rightarrow \boxed{Q_2 = 6732\ kJ}$$

ملاحظات هامة

$\boxed{he}$ مساوية لـ (hf) عند درجة حرارة (250°C) لأنه الخروج يكون من ناحية (liq.)

* لو أن الصمام (valve) في الأعلى تكون (he) مساوية لـ (hg) عند درجة حرارة (250°C) لأنه بخار

بخار في الأعلى وماء في الأسفل

لا تنسو حل اكبر قدر من أسئلة الكتاب..

-أسئلة مقترحة من شابتر 6 (الكتاب الطبعة السابعة):

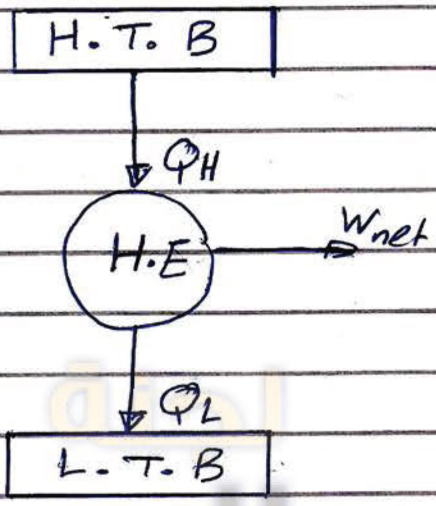
28، 46، 54، 58، 60، 76، 77، 78، 79، 80، 83، 93، 95، 97، 108، 110، 119، 120، 126، 127، 140.

^_^

Chapter 7: The second law of thermodynamics

القانون الثاني: لا يمكن أن تنتقل حرارة من جسم بارد إلى جسم ساخن إلا ببذل شغل من خارج النظام.

① Heat Engines (المحرك الحراري)



ع المحرك الحراري

$$\eta_{thermal} = \frac{\dot{W}_{net}}{\dot{Q}_H} = \frac{\dot{Q}_H - \dot{Q}_L}{\dot{Q}_H}$$

$$\Rightarrow \boxed{\eta_{th} = 1 - \frac{\dot{Q}_L}{\dot{Q}_H}}$$

$$\dot{Q}_H = \dot{W}_{net} + \dot{Q}_L$$

$$\boxed{\dot{W}_{net} = \dot{Q}_H - \dot{Q}_L}$$

ملاحظة: للتحويل من HP ← kw ⇐ نضرب ب 0.7355

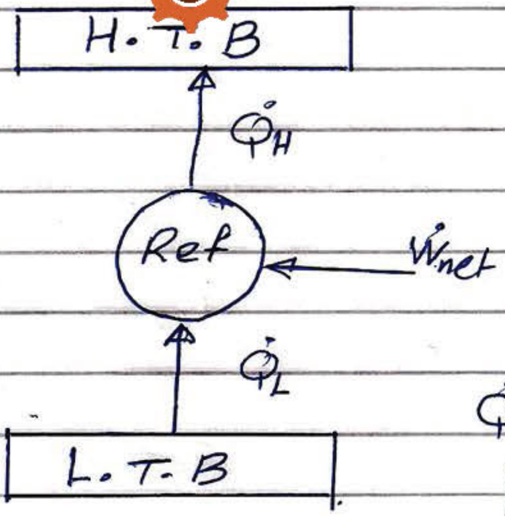
$$\frac{kw}{kg} \quad \boxed{\frac{\dot{Q}_H}{m} = q_H}$$

② Refrigerator (الثلاجة)

* كفاءة الثلاجة يطلق عليها (معامل الأداء) ← β: coefficient of performance

$$\beta = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L}$$

$$\Rightarrow \beta = \frac{1}{\frac{Q_H}{Q_L} - 1}$$



$\dot{Q}_L + \dot{W}_{net} = \dot{Q}_H$

$\boxed{\dot{W}_{net} = \dot{Q}_H - \dot{Q}_L}$

Ex: 7.1

An automobile engine produces 136 hp on the output shaft with a thermal efficiency of 30%. The fuel it burns gives 35 000 kJ/kg as energy release. Find the total rate of energy rejected to the ambient and the rate of fuel consumption in kg/s.

$et = 136\,hp = (136)*(0.7355) = 100\,kw$ $\qquad \eta_{th}\ 30\% = 0.3$

① $\dot{W}_{net} = \overset{?}{\dot{Q}_H} - \overset{?}{\dot{Q}_L}$

$\dot{Q}_H = \frac{\dot{W}_{net}}{\eta_{th}} = \frac{100}{0.3} = 333\,kw$

$\dot{Q}_L = \dot{Q}_H - \dot{W}_{net} \Rightarrow = 333 - 100 = \boxed{233\,kw}$ Ans.

$) \ \dot{m} = \frac{\dot{Q}_H}{q_H} = \frac{333\,kw}{35000\,kJ/kg} \Rightarrow = \boxed{0.0095\ kg/s}$ Ans

Ex: 7.2

The refrigerator in a kitchen shown in Fig. 7.7 receives electrical input power of 150 W to drive the system, and it rejects 400 W to the kitchen air. Find the rate of energy taken out of the cold space and the COP of the refrigerator.

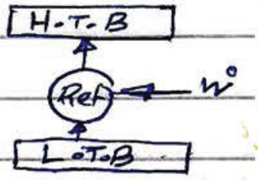
$\dot{W} = 150\,W \qquad \dot{Q}_H = 400\,W$

$\dot{W} + \dot{Q}_L = \dot{Q}_H$

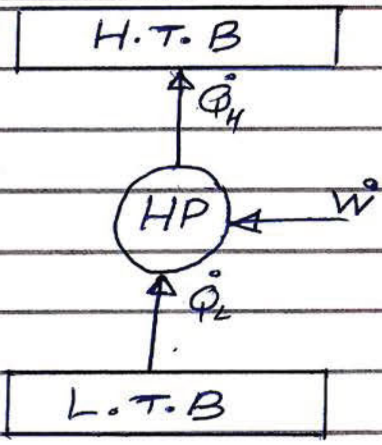
$\dot{Q}_L = 400 - 150$

$\dot{Q}_L = 250\,W$

$\beta = \frac{\dot{Q}_L}{\dot{W}} = \frac{250}{150} = 1.67$



For Heat pump



$$\beta = \frac{\dot{Q}_H}{\dot{W}} = \frac{\dot{Q}_H}{\dot{Q}_H - \dot{Q}_L}$$

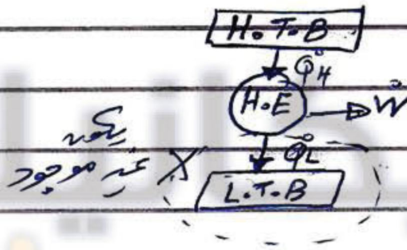
$$\Rightarrow \beta = \frac{1}{1 - \frac{\dot{Q}_L}{\dot{Q}_H}}$$

$$\dot{W} + \dot{Q}_L = \dot{Q}_H$$

$$\boxed{\dot{W} = \dot{Q}_H - \dot{Q}_L}$$

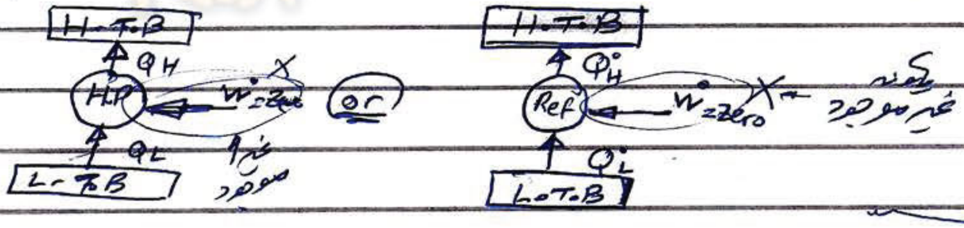
* Kelven-Planck statement (Heat Engine)

* لا يمكن انتاج (إنشاء) دورة لإنتاج شغل عن طريق خزان حراري واحد



* The Clausius statement (Ref, HP)

* لا يمكن نقل الحرارة من الخزان البارد إلى الخزان الساخن دون وجود شغل.



* Reversible and IRREVERSIBLE process.

اجراء قابل للإنعكاس

اجراء غير قابل للإنعكاس

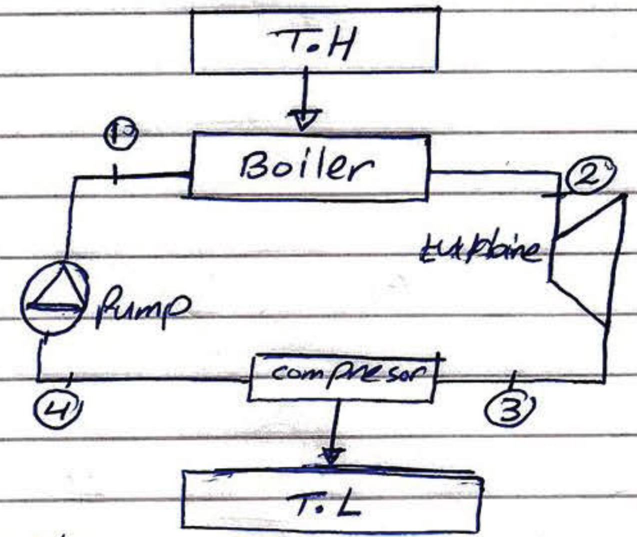
* factors that processes irreversible.

① friction (الإحتكاك)
② Heat transfer (انتقال الحرارة)
③ Unrestraind Expansion (تمدد غير مقيد)
④ Mixing (اذا حدث خلط بين مادتين) ← "يصبح النظام irr و يفقد النظام شغل"
⑤ other factors (مرور تيار كهربائي بمقاومة / الإحتراق / وجود صمام)

---

* Carnot – cycle

carnot cycle ≡ reversible heat engine



* The efficiency of carnot cycle

$$\eta = \frac{W_{net}}{Q_H} = \frac{Q_H - Q_L}{Q_L} = 1 - \frac{Q_L}{Q_H}$$

* for carnot H.E

$$\eta_c = 1 - \frac{T_L}{T_H}$$

for carnot

$$1 - \frac{T_L}{T_H} = 1 - \frac{Q_L}{Q_H} \Rightarrow \boxed{\frac{Q_L}{Q_H} = \frac{T_L}{T_H}}$$

* for carnot H.P

$$\beta' = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_L} \Rightarrow = \frac{T_H}{T_H - T_L} = \frac{1}{1 - \frac{T_L}{T_H}}$$

* for carnot Ref

$$\beta = \frac{Q_L}{W} = \frac{Q_L}{Q_H - Q_L} = \frac{T_L}{T_H - T_L} = \frac{1}{\frac{T_H}{T_L} - 1}$$

* دائماً كفاءة كارنوت أكبر من الكفاءة العادية

$$\eta_c \geq \eta_t$$

EXAMPLE 7.4

Let us consider the heat engine, shown schematically in Fig. 7.25, that receives a heat-transfer rate of 1 MW at a high temperature of 550°C and rejects energy to the ambient surroundings at 300 K. Work is produced at a rate of 450 kW. We would like to know how much energy is discarded to the ambient surroundings and the engine efficiency and compare both of these to a Carnot heat engine operating between the same two reservoirs.

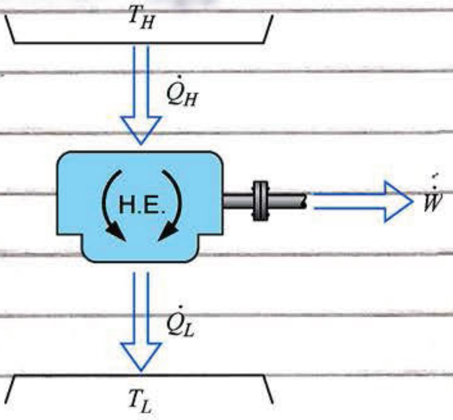
$\dot{Q}_H = 1Mw = 1000\ kw$

$T_H = 550°c$

$T_L = 300\ K$

$\dot{W}_{net} = 450\ kw$

find: Q_L, η_{th}
Q_L, η_c (carnot)



$$\eta_{th} = \frac{\dot{W}_{net}}{Q_H} = \frac{450}{1000} = 0.45$$

carnot (H.E)

$$\eta_c = 1 - \frac{T_H}{T_L} \Rightarrow 1 - \frac{300}{(550+273)} \Rightarrow \boxed{=0.635}$$

$$\dot{W} = \eta_c \dot{Q}_H \Rightarrow = (0.635)(1000) = \boxed{635\ kw}$$

$$\dot{Q}_L = 1000 - 635 \Rightarrow = \boxed{365\ kw}$$

P: 7.32 For each of the cases below, determine if the heat engine satisfies the first law (energy equation) and if it violates the second law.

a. $\dot{Q}_H = 6$ kW $\quad \dot{Q}_L = 4$ kW $\quad \dot{W} = 2$ kW
b. $\dot{Q}_H = 6$ kW $\quad \dot{Q}_L = 0$ kW $\quad \dot{W} = 6$ kW
c. $\dot{Q}_H = 6$ kW $\quad \dot{Q}_L = 2$ kW $\quad \dot{W} = 5$ kW
d. $\dot{Q}_H = 6$ kW $\quad \dot{Q}_L = 6$ kW $\quad \dot{W} = 0$ kW

a) ✓ ✓
b) ✓ × → (يحقق كلفن بلانك)
c) × ✓ but energy not conserved.
d) ✓ ✓ (irreversible)

ملاحظة
اذا كان HoP
فلا يحقق القانون الثاني

P: 7.35 In a steam power plant 1 MW is added in the boiler, 0.58 MW is taken out in the condenser, and the pump work is 0.02 MW. Find the plant's thermal efficiency. If everything could be reversed, find the COP as a refrigerator.

$Q_H = 1 \text{ Mw}$

$Q_L = 0.58 \text{ Mw}$

$\dot{W}_{Pump} = 0.02 \text{ Mw}$

① $Q_H + W_P = W_T + Q_L$

$W_T = Q_H + W_P - Q_L \Rightarrow 1 + 0.02 - 0.58 = 0.44 \text{ Mw}$

$W_{net} = 0.44 - 0.02 = 0.42 \text{ Mw}$

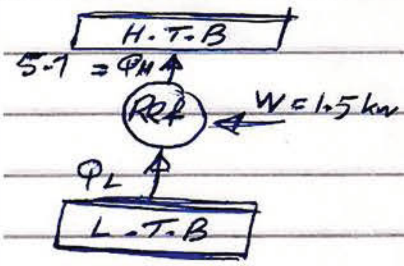
$\eta_{th} = \frac{W_{net}}{Q_H} = \frac{0.42}{1} = 0.42 = 42\%$

② $\beta = \frac{Q_L}{W_{net}} = \frac{0.58}{0.42} = 1.38$

P: 7.22 An air conditioner discards 5.1 kW to the ambient surroundings with a power input of 1.5 kW. Find the rate of cooling and the COP.

* Air conditioner (هواء بارد ← مكيف) *

$Q_H = 5.1 \text{ kw}$ Power input $= 1.5 \text{ kw}$ Q_L : rate of cooling



$\beta_{Ref} = \frac{\boxed{Q_L}}{W} = \frac{3.6}{1.5}$

$\beta_{Ref} = 2.4$

$Q_L + W = Q_H$

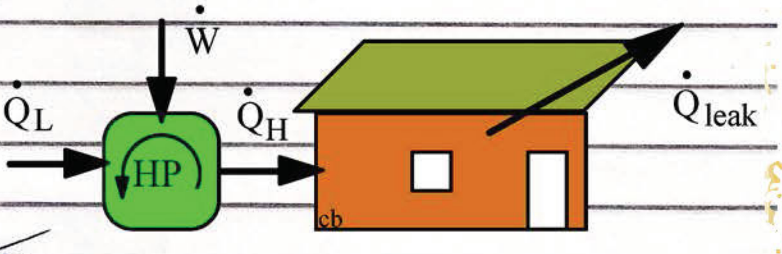
$Q_L = Q_H - W = 5.1 - 1.5$

$\Rightarrow \boxed{Q_L = 3.6 \text{ kw}}$

A house should be heated by a heat pump, $\beta' = 2.2$, and maintained at 20°C at all times. It is estimated that it looses 0.8 kW per degree the ambient is lower than the inside. Assume an outside temperature of –10°C and find the needed power to drive the heat pump?

(Heat pump) $\beta' = 2.2$ $\quad T_H = 20°C \quad T_L = -10°C$

$\dot{Q}_H = 0.8 \frac{kw}{degree}$ find power to drive the HP?



$\beta' = \frac{\dot{Q}_H}{\dot{W}}$

$\dot{Q}_H = 0.8 \frac{kw}{\cancel{degree}} (T_H - T_L) \cancel{degree}$

$\dot{Q}_H = 0.8(20-(-10)) = 24$

$\beta' = \frac{\dot{Q}_H}{\dot{W}} \Rightarrow \dot{W} = \frac{\dot{Q}_H}{\beta'} = \frac{24}{2.2} = \boxed{10.91 kw}$

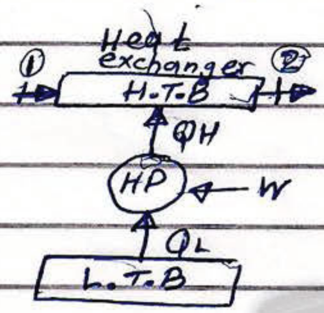
Refrigerant-12 at 95°C, $x = 0.1$ flowing at 2 kg/s is brought to saturated vapor in a constant-pressure heat exchanger. The energy is supplied by a heat pump with a coefficient of performance of $\beta' = 2.5$. Find the required power to drive the heat pump.

<u>R-12</u> $\left.\begin{matrix} T=95 \\ x=0.1 \end{matrix}\right\}$ mix $\dot{m} = 2\,kg/s$ $\beta' = 2.5$

* energy is supplied by H.P

find W (required power to drive H.P)

$\boxed{1}$



<u>from ch.6</u> Heat exchanger

$$Q \equiv Q_H$$

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

$$Q_H = \dot{m}(h_2 - h_1) \Rightarrow \boxed{Q_H = 129.08 \frac{kJ}{s} = kw}$$

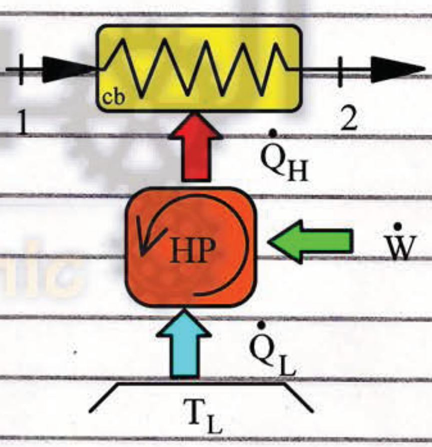
$\boxed{2}$ $(T, x) \rightarrow$ mix

$$h_1 = h_f + h_{fg}x$$

$$\Rightarrow h_1 = (140.23) + (0.1 * 71.71)$$

$$h_1 = 147.4 \ kJ/kg$$

$(T, sat.vap)$ $h_2 = h_g\Big|_{T=95°} = 211.94\,kJ/kg$



$\boxed{3}$ $\beta' = \frac{Q_H}{W}$

$$W = \frac{Q_H}{\beta} \Rightarrow = \frac{129.08}{2.5}$$

$$\Rightarrow W = 51.632\,kw$$

P. **7.44** Calculate the thermal efficiency of a Carnot-cycle heat engine operating between reservoirs at 300°C and 45°C. Compare the result to that of Problem 7.16.

Carnot cycles and absolute temp.

$$\eta_c = 1 - \frac{T_L}{T_H} \Rightarrow 1 - \frac{(45+273)}{(300+273)} \Rightarrow \boxed{\eta_c = 0.445}$$

يجب أن تكون بالكلفن ^^

Calculate the coefficient of performance of a Carnot-cycle heat pump operating between reservoirs at 0°C and 45°C.

$T_L = 0°C = 273 K$ $\qquad T_H = 45°C = 318 K$

$$\beta_c = \frac{T_H}{T_H - T_L} = \frac{318}{318-273} = 7.0667$$

7.46 Find the power output and the low *T* heat rejection rate for a Carnot-cycle heat engine that receives 6 kW at 250°C and rejects heat at 30°C, as in Problem 7.38.

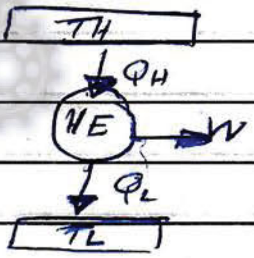
$Q_H = 6 kw$ $\qquad T_H = 250°C = 523 K$ $\qquad T_L = 30°C = 303 K$

Carnot cycle find output power (W)

solution

$$\eta_c = \frac{W}{Q_H} = 1 - \frac{T_L}{T_H} \Rightarrow = 1 - \frac{303}{523} \Rightarrow 0.42$$

$$W = \eta_c * Q_H \Rightarrow (0.42)(6) \Rightarrow 2.52 kw$$



$$Q_L = Q_H - W$$

$$\therefore Q_L = 6 - 2.52 = 3.48 \ kw$$

7.51 A car engine burns 5 kg of fuel (equivalent to adding Q_H) at 1500 K and rejects energy to the radiator and exhaust at an average temperature of 750 K. Assume the fuel has a heating value of 40 000 kJ/kg and find the maximum amount of work the engine can provide.

$m = 5 kg$ (fuel) $T_H = 1500 K$ $T_L = 750 K$

q = heating value $= 40000 kJ/kg$

$$q \frac{kJ}{kg} m . kg = Q_H kJ$$

$$\Rightarrow Q_H = (40000)(5) = 200000 kJ$$

maximum work (??) ≡ carnot work

$$\eta_c = 1 - \frac{T_L}{T_H} = 1 - \frac{750}{1500}$$

$$\boxed{\eta_c = 0.5}$$

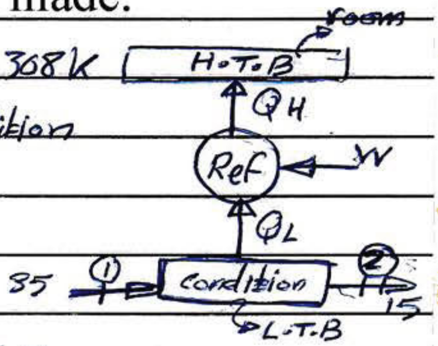
$$W = Q_H * \eta_c \Rightarrow W = (0.5)(200000)$$

$$\Rightarrow \boxed{W = 100000 kJ}$$

7.53 An air conditioner provides 1 kg/s of air at 15°C cooled from outside atmospheric air at 35°C. Estimate the amount of power needed to operate the air conditioner. Clearly state all assumptions made.

$\dot{m} = 1 kg/s$ (Air) $T_L = 15°C = 288 K$ $T_H = 35°C = 308 K$

find power (W) needed to operate the Air condition



solution Assume carnot cycle

$$\beta = \frac{Q_L}{W} \Rightarrow W = \frac{Q_L}{\beta}$$

$$\beta = \frac{T_L}{T_H - T_L} = \frac{288}{(308-288)} = 14.4$$

$$W = \frac{20}{14.4} = \boxed{1.388 kw}$$

$$\dot{m}_i h_1 = Q_L + \dot{m}_e h_2$$

$$Q_L = \dot{m}(h_1 - h_2)$$

$[h_1, h_2]$ from table A-7

$$\Rightarrow Q_L = 1(288 - 30)$$

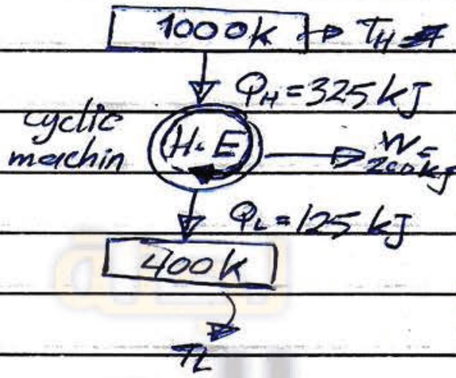
$$\Rightarrow \boxed{Q_L = 20 kw}$$

7.54 A cyclic machine, shown in Fig. P7.54, receives 325 kJ from a 1000 K energy reservoir. It rejects 125 kJ to a 400 K energy reservoir, and the cycle produces 200 kJ of work as output. Is this cycle reversible, irreversible, or impossible?

is this cycle reversible, irreversible or impossible?

(أولاً) نتأكد إن كان possible أم لا.

$\eta_{th} \leq \eta_c$



Hedt engine. $\eta_{th} = \frac{W}{Q_H} = \frac{200}{325} \Rightarrow = 0.615$

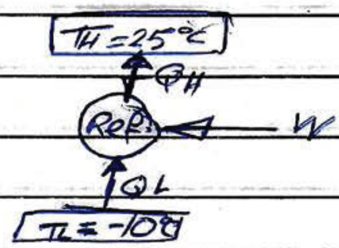
$\eta_c = 1 - \frac{T_L}{T_H} \Rightarrow 1 - \frac{400}{100} = 0.6$

$\therefore \eta_c < \eta_{th} \Rightarrow$ that's impossible

7.58 An inventor has developed a refrigeration unit that maintains the cold space at −10°C while operating in a 25°C room. A COP of 8.5 is claimed. How do you evaluate this?

Refrigeration $\beta = 8.5$

How doyou evalute this? OR find β_{carnot} and coment in Result?



$\beta_c = \frac{T_L}{T_H - T_L} = \frac{263}{298-263}$

$\Rightarrow \beta_c = 7.51428$

$\beta_c < \beta \Rightarrow$ that's impossible

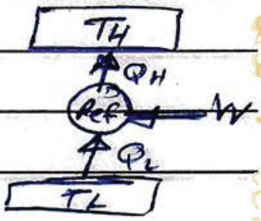
$T_L = -10+273 = 263\,K$

$T_H = 25+273 = 298\,K$

7.64 Helium has the lowest normal boiling point of any element at 4.2 K. At this temperature the enthalpy of evaporation is 83.3 kJ/kmol. A Carnot refrigeration cycle is analyzed for the production of 1 kmol of liquid helium at 4.2 K from saturated vapor at the same temperature. What is the work input to the refrigerator and the COP for the cycle with an ambient temperature at 300 K?

$T_L = 4.2 K$ $T_H = 300 K$ $Q_L = 83.3 \,(kJ/kmol) * 1 kmol = 83.3 kJ$

Carnot . find W



$$\beta_c = \frac{T_L}{T_H - T_L} \Rightarrow = \frac{4.2}{300 - 4.2} = 0.01419878$$

$$\beta_c = \frac{Q_L}{W} \Rightarrow W = \frac{83.3}{0.01419878} = \boxed{5866.7}$$

$Q_L + W = Q_H$

$\boxed{W = Q_H - Q_L}$

for carnot $\frac{Q_H}{Q_L} = \frac{T_H}{T_L} \Rightarrow Q_H = 5950 kJ$

$$W = 5950 - 83.3 = \boxed{5866.7 kJ}$$

7.71 A heat engine has a solar collector receiving 0.2 kW/m^2, inside of which a transfer medium is heated to 450 K. The collected energy powers a heat engine that rejects heat at 40°C. If the heat engine should deliver 2.5 kW, what is the minimum size (area) of the solar collector?

receiving 0.2 kw per square meter that's mean $Q_H = 0.2 \frac{kw}{m^2} * A$

$Q_H = 0.2 \frac{kw}{m^2} * A$. find A ? $Q_H \Rightarrow$ معطى؟

solution $\eta_c = 1 - \frac{T_L}{T_H} = 1 - \frac{313}{450} \Rightarrow \boxed{= 0.304}$

$\eta_c = \frac{W}{Q_H} \Rightarrow Q_H = \frac{2.5}{0.304} \Rightarrow \boxed{8.224 \text{ kw}}$

$Q_H = 0.2 * A \Rightarrow A = \frac{8.224}{0.2} \Rightarrow \boxed{A = 41.12 m^2}$

Ideal gas carnot cycles

$q_L = \frac{Q_L}{m} \left[\frac{kJ}{kg}\right]$

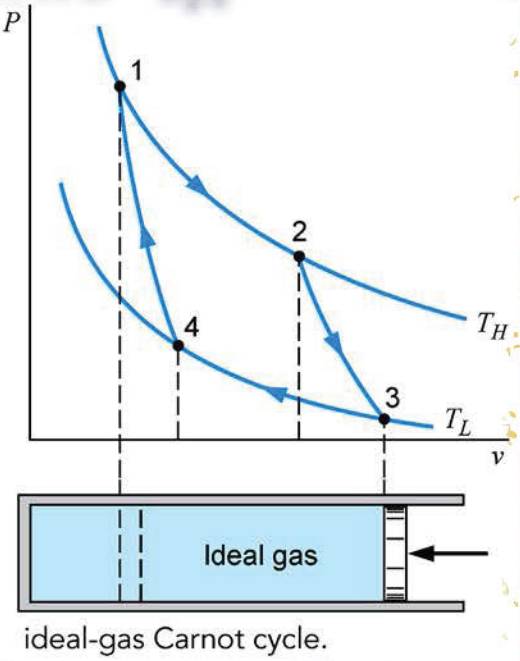
تذكر *

ideal gas

$PV = RT$

$\boxed{q_L = R T_L \ln \frac{v_3}{v_4}}$ → during heat rejection

$\boxed{q_H = R T_H \ln \frac{v_2}{v_1}}$ → during heat addition



ideal-gas Carnot cycle.

$\frac{W}{m} = w \; [kJ/kg]$

$\boxed{T_3 = T_4 = T_L}$ q_L: low temp heat transfer

$\boxed{T_1 = T_2 = T_H}$ q_H: high temp heat tranfer

7.92 Hydrogen gas is used in a Carnot cycle having an efficiency of 60% with a low temperature of 300 K. During the heat rejection the pressure changes from 90 kPa to 120 kPa. Find the high- and low-temperature heat transfer and the net cycle work per unit mass of hydrogen.

carnot cycle (Hydrogen gas $R = 4.1243$)

$\eta = 0.6$ $T_L = 300K$ $P_3 = 40 kpa$ $P_4 = 120 kpa$

find q_L, q_H, W

solution

$T_3 = T_4 = T_L$

$\boxed{P_3 V_3 = R_3 T_3}$ $\boxed{P_4 V_4 = R_4 T_4}$

$q_L = R T_L \ln \frac{V_3}{V_4}$

$\frac{P_3 V_3}{\cancel{R_3 T_3}} = \frac{P_4 V_4}{\cancel{R_4 T_4}}$

$q_L = (4.1243)(300)(\ln 1.333)$

$\Rightarrow \boxed{q_L = 355.63679 kJ/kg}$ Ans

$\frac{V_3}{V_4} = \frac{P_4}{P_3} \Rightarrow = \frac{120}{90} \Rightarrow \boxed{= 1.333}$

$\eta = 0.6 = 1 - \frac{T_L}{T_H} \Rightarrow 0.6 = 1 - \frac{300}{T_H} \Rightarrow \boxed{T_H = 750K}$

$\frac{T_H}{T_L} = \frac{q_H}{q_L} \Rightarrow q_H = q_L \cdot \frac{T_H}{T_L} \Rightarrow q_H = 889.09 kJ/kg$

$W = q_H - q_L \Rightarrow = 889.09 - 355.636 \Rightarrow \boxed{W = 533.45 kJ/kg}$

7.94 An ideal-gas Carnot cycle with air in a piston cylinder has a high temperature of 1200 K and a heat rejection at 400 K. During the heat addition, the volume triples. Find the two specific heat transfers (q) in the cycle and the overall cycle efficiency.

(Air $R = 0.287$) $T_H = 1200\,K$ $T = 400\,K$

During the heat addition . the volume triples

$V_2 = 3V_1 \rightarrow \boxed{v_2 = 3v_1}$

m=constant find the specific heat transfer q_L, q_H and η_c

$q_H = R\,T_H \ln \frac{v_2}{v_1} = (0.287)(1200)\left(\ln \frac{3v_1}{v_1}\right) \Rightarrow \boxed{q_H = 378.36\ kJ/kg}$

$\frac{T_H}{T_L} = \frac{q_H}{q_L} \Rightarrow \boxed{q_L = 1261.12\ kJ/kg}$

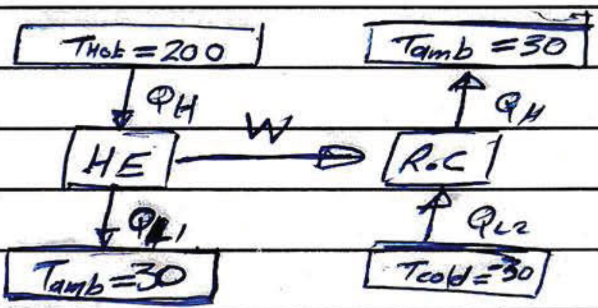
$\eta_c = 1 - \frac{T_L}{T_H} \Rightarrow = 1 - \frac{400}{1200} \Rightarrow \boxed{\eta_c = 0.667}$

7.101 We wish to produce refrigeration at −30°C. A reservoir, shown in Fig. P7.101, is available at 200°C, and the ambient temperature is 30°C. Thus, work can be done by a cyclic heat engine operating between the 200°C reservoir and the ambient surroundings. This work is used to drive the refrigerator. Determine the ratio of the heat transferred from the 200°C reservoir to the heat transferred from the −30°C reservoir, assuming all processes are reversible.

for H.E

$$\eta = \frac{W}{Q_{H_1}} = \frac{T_{Hot} - T_{amb}}{T_{Hot}}$$

$$\Rightarrow W = Q_{H_1}\left(\frac{T_{Hot} - T_{amb}}{T_{Hot}}\right)$$



for Ref

$$\beta = \frac{Q_{L_2}}{W} = \frac{T_{cold}}{T_{amb} - T_{cold}}$$

$$\Rightarrow W = Q_{L_2}\left(\frac{T_{amb} - T_{cold}}{T_{cold}}\right)$$

مفتاح الحل
الشغل مشترك

$$W = W$$

$$Q_{H_1}\left(\frac{T_{Hot} - T_{amb}}{T_{Hot}}\right) = Q_{L_2}\left(\frac{T_{amb} - T_{cold}}{T_{cold}}\right)$$

THot = 473.15 K
Tamb = 303.15 K
Tcold = 243.15 K

$$\frac{Q_{H_1}}{Q_{L_2}} = \frac{\left(\frac{303.15 - 243.15}{243.15}\right)}{\left(\frac{473.15 - 303.15}{473.15}\right)}$$

$$\Rightarrow \boxed{\frac{Q_{H_1}}{Q_{L_2}} = 0.68679}$$

*Chapter 8: Entropy

Inequality of clausius

$$\oint \frac{\delta Q}{T} \leq 0$$

for reversible process ($T \rightarrow$ constant)

$$\int_1^2 \frac{\delta Q}{T} = S_2 - S_1 \longrightarrow \boxed{\frac{{}_1Q_2}{T} = m(s_2 - s_1)}$$

بالكلفن

ملاحظة = $S \leftarrow$ تعامل معاملة (u , h) من ناحية استخراج الخصائص من الجدول

$$\boxed{S = S_f + X S_{fg}} \rightarrow \text{mix}$$

Ex:

A cylinder/piston setup contains 1 L of saturate liquid refrigerant R-12 at 20°C. The piston now slowly expands, maintaining constant temperature to a final pressure of 400 kPa in a reversible process. Calculate the required work and heat transfer to accomplish this process.

$V = 1L = 0.001m^3$ ① sat. liq (R-12) $T = 20°c$ = constant * صراحة من السؤال

② $P = 400$ kpa $T = 20°c$

Reversible process find Q and W.

solution

$\frac{Q}{T} = m(s_2 - s_1) \Rightarrow Q = mT(s_2 - s_1)$

state ①

$S = S_f)_{T=20°c} = 0.278$ kJ/kgK $v_1 = 0.000752$

state ② $(T_2, P_2) \rightarrow$ super heated vapor $\boxed{S_2 = 0.7204 \text{ kJ/kg K}}$

$_1Q_2 = m T (S_2 - S_1) \Rightarrow = (1.33)(20+273.15)(0.7204-0.2078)$

$\Rightarrow \boxed{_1Q_2 = 200 \text{ kJ}}$

To find work

$\left\{ \begin{array}{l} u_1 = 54.45 \\ u_2 = 180.57 \end{array} \right.$

$_1Q_2 = m(u_2 - u_1) + {}_1W_2$

$\therefore {}_1W_2 = {}_1Q_2 - m(u_2 - u_1) \Rightarrow = 200 - 1.33(180.57 - 54.45)$

$\Rightarrow \boxed{_1W_2 = 32.26 \text{ kJ}}$

8.50 Water in a piston/cylinder device at 400°C and 2000 kPa is expanded in a reversible adiabatic process. The specific work is measured to be 415.72 kJ/kg out. Find the final *P* and *T* and show the *P*–*v* and the *T*–*s* diagrams for the process.

state ① (400°C, 2000 kg)

rev. (adiabatic process) $\rightarrow {}_1Q_2 = 0$ $\qquad \frac{_1W_2}{m} = 415.72$ kJ/kg out

find. P_2, T_2, (show P-V diagram and T-S digram) ?

Rev. نحتاج لخاصيتين

$\frac{\overset{0.0}{_1Q_2}}{T} = m(S_2 - S_1) \Rightarrow m(S_2 - S_1) = 0 \overset{\div m}{\Rightarrow} (S_2 - S_1) = 0 \Rightarrow \boxed{S_2 = S_1}$

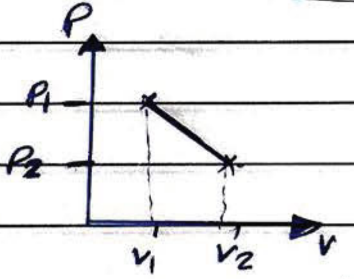
$\boxed{S_1 = 7.127 \text{ kJ/kg.K}} = S_2$

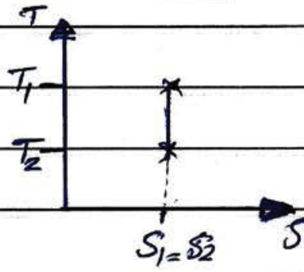
$\frac{\overset{0.0}{_1Q_2}}{m} = \frac{m}{m}(u_2 - u_1) + \frac{_1W_2}{m} \Rightarrow 0 = u_2 - u_1 + {}_1W_2$

$\boxed{u_1 = 2945.21 \text{ kJ/kg}}$

$u_2 = u_1 - {}_1W_2 \Rightarrow = 2945.21 - 415.72 \Rightarrow \boxed{= 2529.49 \text{ kJ/kg}}$

$\left. \begin{array}{l} u_2 \\ S_2 \end{array} \right\} \rightarrow \begin{array}{l} P_2 = 200 \text{ kPa} \\ T_2 = 120°\text{C} \end{array}$





8.59 A heavily insulated cylinder fitted with a frictionless piston, as shown in Fig. P8.59, contains ammonia at 5°C and 92.9% quality, at which point the volume is 200 L. The external force on the piston is now increased slowly, compressing the ammonia

(NH_3) insulated

$${}_1\overset{0.0}{\cancel{Q}}_2 = m(u_2-u_1) + {}_1W_2 \Rightarrow \boxed{{}_1W_2 = -m(u_2-u_1)}$$

State ① 5°C $x = 0.929$ $V_1 = 0.2\,m^3$ $m = $ constant (cylinder)

$(T, x) \rightarrow$ mix

$$m = \frac{V_1}{\underset{?}{v_1}} \quad , \quad v_1 = v_f + x\,v_{fg}$$

$$\Rightarrow \boxed{v_1 = 0.2258}$$

$$u_1 = u_f + x\,u_{fg} \Rightarrow \boxed{u_1 = 1242.5}$$

$$\Rightarrow \therefore m = \frac{0.2}{0.2258} = 0.886\ kg$$

State ② $T_2 = 50°C$

$$\frac{{}_1\overset{0}{\cancel{Q}}_2}{T} = m(s_2 - s_1) \Rightarrow \boxed{s_2 = s_1}$$

$$s_1 = s_f + x\,s_{fg} \Rightarrow \boxed{s_1 = 4.9491\ kJ/kg\,K}$$

$(T_2, s_2) \rightarrow \boxed{u_2 = 1364.9\ kJ/kg}$ ← interpolation

$${}_1W_2 = -0.886 * (1364.9 - 1242.5) \Rightarrow \boxed{{}_1W_2 = -108.4\ kJ}$$

Extra

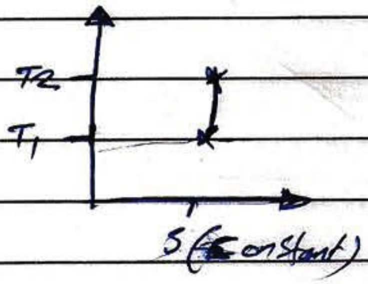
إذا طلب P_2

تستخرجها بنفس طريقة

u_2

$\Rightarrow P_2 = 1600\ kpa$

By interpolation



IRREVERSIBLE PROCESS

(Entropy generation)

المتولدة

$$\boxed{\frac{{}_1Q_2}{T} = m(s_2 - s_1) - {}_1S_2\,(\text{generation})}$$ Entropy Equation

درجة حرارة [illegible]

الصيغة العامة

A mass and atmosphere loaded piston/cylinder contains 2 kg of water at 5 MPa, 100°C. Heat is added from a reservoir at 700°C to the water until it reaches 700°C. Find the work, heat transfer, and total entropy production for the system and surroundings.

$m = 2\text{ kg}\ (H_2O)$ (piston cylinder $P = C$)

$P_1 = 5000\text{ kpa}$ $T_1 = 100°C$ $P_2 = 5000\text{ kpa}$ $T_2 = 700°C$

find Q, W, S_{gen}

$${}_1W_2 = P(V_2 - V_1)$$

so $v = \frac{V}{m} \Rightarrow {}_1W_2 = Pm(v_2 - v_1)$

$$\Rightarrow {}_1W_2 = (5000)(2)(0.08849 - 0.00104)$$

$$\Rightarrow \boxed{{}_1W_2 = 874.6\text{ kJ}}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2$$

$$= 2(3457.6 - 417.52) + 874.6$$

$$\Rightarrow \boxed{= 6954.76\text{ kJ}}$$

OR ${}_1Q_2 = m(h_2 - h_1) \Rightarrow \boxed{= 6954.76\text{ kJ}}$

$${}_1S_{2\,gen} = m(s_2 - s_1) - \frac{{}_1Q_2}{T_2} \Rightarrow = 2(7.5122 - 1.303) - \frac{6954.76}{(700+273)}$$

$$\Rightarrow \boxed{{}_1S_{2\,gen} = 5.27\text{ kJ/K}}$$

$(T_1, P_1) \to$ compressed liquid

Table (B.1.4)

$s_1 = 1.303$ $v_1 = 0.00104$

$u_1 = 417.52$ $h_1 = 422.72$

$(T_2, P_2) \to$ superheated vapor

Table (B.1.3)

$s_2 = 7.5122$ $v_2 = 0.08849$

$u_2 = 3457.6$ $h_2 = 3900.1$

$${}_1S_2\,gen = \Delta S_{cim} + \Delta S_{surr}$$

توضيح

$$\Delta S_{cm} = S_2 - S_1$$

$$\boxed{\Delta S_{surr} = \frac{-{}_1Q_2}{T_{surr}}}$$

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

$$\boxed{{}_1S_2\,gen = m(s_2 - s_1) - \frac{{}_1Q_2}{T_{surr}}}$$

نفس المعادلات السابقة

فقط هنا قسّم الـ S إلى داخلية وخارجية

① إذا كان الـ ${}_1S_2\,gen = 0 \Leftarrow$ يرجع لقانون rev.

A cylinder/piston contains water at 200 kPa, 200°C with a volume of 20 L. The piston is moved slowly, compressing the water to a pressure of 800 kPa. The loading on the piston is such that the product *PV* is a constant. Assuming that the room temperature is 20°C, show that this process does not violate the second law.

(H_2O) state① $P_1 = 200$ kpa $T_1 = 200°c$

$V = 0.02 m^3$ state② $P_2 = 800$ kpa

$PV =$ constant

$n = 1$

مدار السؤال

اثبت أن $S_{gen} > 0$

$$\frac{S_{gen}}{m} = s_2 - s_1 - \frac{{}_1q_2}{T_{surr}}$$

$$\frac{{}_1W_2}{m} = P_1 v_1 \ln\frac{v_2}{v_1}$$

$(T_1, P_1) \rightarrow \boxed{v_1 = 1.0803}$

$P_1 v_1 = P_2 v_2 \Rightarrow v_2 = \frac{P_1 v_1}{P_2} \Rightarrow \boxed{v_2 = 0.2701}$

$$\Rightarrow {}_1w_2 = (200)(1.0803)\ln\left(\frac{0.2701}{1.0803}\right) \Rightarrow \boxed{{}_1w_2 = -294.5\ kJ/kg}$$

$$\frac{{}_1Q_2}{m} = \frac{m}{m}(u_2-u_1) + \frac{{}_1W_2}{m}$$

$$\Rightarrow {}_1q_2 = (u_2-u_1) + {}_1w_2$$ → small letter

$u_1 = 2654.4$ kJ/kg

$s_1 = 7.5066$

state ② (v_2, P_2) → superheat vapor

$u_2 = 2655$

$s_2 = 6.8822$

$${}_1q_2 = (2655 - 2654.4) - 299.5$$
$$= -298.9$$

$$\frac{{}_1S_{2gen}}{m} = \frac{m}{m}(s_2-s_1) - \frac{{}_1Q_2}{T_{surr}*m}$$

$$\Rightarrow {}_1s_{2gen} = s_2 - s_1 - \frac{{}_1q_2}{T_{surr}} \Rightarrow = 6.8822 - 7.5066 - \frac{(-298.9)}{(20+273.15)}$$

$$\Rightarrow \boxed{{}_1s_{2gen} = 0.395 \text{ kJ/kg.K}}$$

$\therefore {}_1s_{2gen} > 0$

$\therefore$ satisfy 2nd law

هنا حسب القانون الثاني للديناميكا الحرارية يجب أن يكون الـ S_{gen} أكبر من صفر حتى يتحقق القانون الثاني

Entropy Change of a solid or liquid

Assuming constant specific heat

$$s_2 - s_1 = C \ln\frac{T_2}{T_1}$$

$C \equiv c_p$

* جداول الـ solid & liquid

A.3   A.4

بالكلفن ← T_1, T_2

EXAMPLE 8.3

One kilogram of liquid water is heated from 20°C to 90°C. Calculate the entropy change, assuming constant specific heat, and compare the result with that found when using the steam tables.

(liquid water) $T_1 = 20 + 273.2 = 293.2\,K$ $T_2 = 90 + 273.2 = 363.2\,K$

constant specific heat.

$$s_2 - s_1 = c_p \ln \frac{T_2}{T_1} \Rightarrow = 4.18 \ln \left(\frac{363.3}{293.2}\right) \Rightarrow \boxed{s_2 - s_1 = 0.8954\ kJ/k}$$

* في حال لم يقل constant specific heat

$$s_2 - s_1 = \underset{T=90}{s_f} - \underset{T=20}{s_f} = 1.1925 - 0.2966 \Leftarrow$$

$$= 0.8959\ kJ/kg.K$$

(Entrop Change of an ideal gas)

①

$$\boxed{s_2 - s_1 = C_{p0} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}} \rightarrow \text{constant } c_p, c_v$$

R from Table A.5

$$\boxed{s_2 - s_1 = C_{v0} \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}} \rightarrow \text{constant } c_p, c_v$$

② $$\boxed{s_2 - s_1 = s^\circ_{T_2} - s^\circ_{T_1} - R \ln \left(\frac{P_2}{P_1}\right)} \rightarrow \text{using table A.7 or A.8}$$

في حال وجود T2 & T1

③ empirical equation from Table A.6 $\theta = \frac{T}{1000}$, T (kelvin)

$$s_2 - s_1 = \int_{T_1}^{T_2} c_{p0} \frac{dT}{T} - R \ln \left(\frac{P_2}{P_1}\right)$$

$$s_2 - s_1 = \left[c_0 \ln \theta + c_1 \theta + \frac{1}{2} c_2 \theta^2 + \frac{1}{3} c_3 \theta^3 \right]_{\theta_1}^{\theta_2} - R \ln \left(\frac{P_2}{P_1}\right)$$

④ Avg. Temp ($\bar{T}$)

$\bar{T} = \frac{T_1+T_2}{2}$ $\qquad \theta = \frac{T}{1000}$

$C_{P_0} = C_0 + C_1\bar{\theta} +$

EXAMPLE 8.4

Consider Example 5.7, in which oxygen is heated from 300 to 1500 K. Assume that during this process the pressure dropped from 200 to 150 kPa. Calculate the change in entropy per kilogram.

$T_1 = 300\,K$ $\qquad T_2 = 1500\,K$ $\qquad P_1 = 200\,kPa$ $\qquad P_2 = 150\,kPa$

(O_2) calculate change in entropy.

① Table A.8

$s_2 - s_1 = (s^{o}_{T_2} - s^{o}_{T_1}) - R\ln\left(\frac{P_2}{P_1}\right) \Rightarrow = (8.04649 - 6.4168) - 0.2598\ln\left(\frac{150}{200}\right)$

$\Rightarrow \boxed{s_2 - s_1 = 1.7228\ kg/kg\,K}$

② Assume constant specific heat

هنالك، معادلتين .. نختار المعادلات ذات المعلومات المتوفرة.

$s_2 - s_1 = C_{P_0}\ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right) \Rightarrow = 0.922\ln\left(\frac{1500}{300}\right) - 0.2598\ln\left(\frac{150}{200}\right)$

$\Rightarrow \boxed{s_2 - s_1 = 1.5586\ kJ/kg.K}$

③ Avg. Temp

$T_{avg} = \frac{300+1500}{2} = 900\,K$ $\qquad \theta = \frac{T}{1000} \Rightarrow = \frac{900}{1000} = 0.9$

$C_{P_0} = 0.88 - (0.0001 * 0.9) + (0.54 * 0.9^2) - (0.33 * 0.9^3)$

$\Rightarrow \boxed{C_{P_0} = 1.07676}$

8.81 A piston/cylinder setup containing air at 100 kPa, 400 K is compressed to a final pressure of 1000 kPa. Consider two different processes: (1) a reversible adiabatic process and (2) a reversible isothermal process. Show both processes in a *P–v* diagram and a *T–s* diagram. Find the final temperature and the specific work for both processes.

(Air) $P_1 = 100\ kpa$ $T_1 = 400K$ $P_2 = 1000\ kpa$

① rev. adiabatic

$$\frac{\cancel{{}_1Q_2}^{0.0}}{T} = m(s_2 - s_1) - \cancel{{}_1S_{2gen}}^{0.0}$$

$$\Rightarrow s_2 = s_1$$

لأنه هواء لا نستطيع استخدام أحد الجداول المسبقة، لذلك نستخدم قوانين Ideal gas

وبما أن S ثابتة $\boxed{S = const.} \Rightarrow \boxed{n = k}$

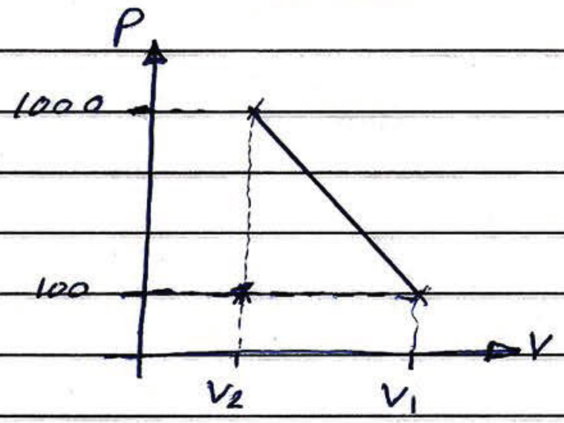
$$k = \frac{C_{p_0}}{C_{v_0}} = \frac{1.004}{0.717} = 1.4$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \longrightarrow \frac{T_2}{400} = \left(\frac{1000}{100}\right)^{\left(\frac{1.4-1}{1.4}\right)} \Rightarrow \boxed{T_2 = 772\,K}$$

$k = n \neq 1$

$${}_1W_2 = \frac{mR(T_2 - T_1)}{1-n} \Rightarrow {}_1w_2 = \frac{R(T_2 - T_1)}{1-n} = \frac{0.287\,(772 - 400)}{1 - 1.4}$$

$$\Rightarrow \boxed{{}_1w_2 = -266.91\ kJ/kg}$$



هنا الشغل سالب

$\therefore V_2 < V_1$

$${}_1w_2 = \frac{1}{2}(V_2 - V_1)(P_1 + P_2) \Rightarrow = -ve$$ قيمة سالبة

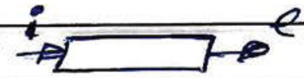
Chapter 9: Second law. Anyalsis for a control volume

$$\boxed{\frac{dS_{c.v}}{dt} = \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \sum \frac{\dot{Q}_{c.v}}{T} + \dot{S}_{gen}}$$ ← القانون العام

sssf (steady state process)

$$\frac{dS_{c.v}}{dt} = 0 \Rightarrow \sum \dot{m}_e s_e - \sum \dot{m}_i s_i = \sum \frac{\dot{Q}_{c.v}}{T} + \dot{S}_{gen}$$

①



$$\dot{m}(s_e - s_i) = \sum \frac{\dot{Q}_{c.v}}{T} + \dot{S}_{gen}$$

② Adiabatic

$$\dot{m}(s_e - s_i) = \dot{S}_{gen} \qquad > 0.0$$

حتى لا نهدم القانون الثاني $\boxed{s_e > s_i \quad \text{دائماً}}$

③ rev. Adiabatic

$$m(s_e - s_i) = 0$$

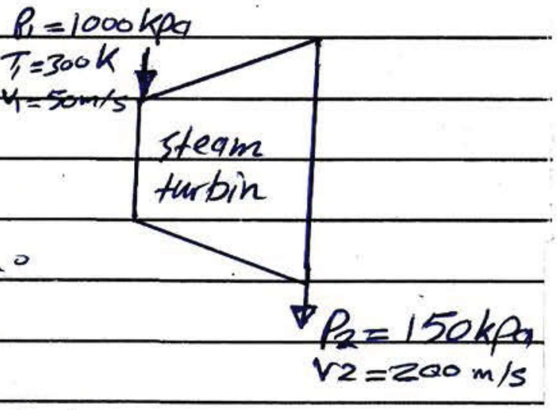
$$\boxed{s_e = s_i}$$

EXAMPLE 9.1

Steam enters a steam turbine at a pressure of 1 MPa, a temperature of 300°C, and a velocity of 50 m/s. The steam leaves the turbine at a pressure of 150 kPa and a velocity of 200 m/s. Determine the work per kilogram of steam flowing through the turbine, assuming the process to be reversible and adiabatic.

(steam turbin) rev.+adiabatic

find w → specific



2nd

SSSf (turbin)

$$\sum \dot{m}_e s_e - \sum \dot{m}_i s_i = \sum \overset{0.0}{\cancel{\frac{\dot{Q}_{c.s}}{T}}} + \overset{0.0}{\cancel{S_{gen}}}$$

$$m_e s_e = m_i s_i$$

$$\boxed{s_e = s_i}$$

$s_i = 7.1228$ kJ/kg.K

$s_e = 7.1228$ kJ/kg.K

1st

$$\overset{0.0}{\cancel{Q}} + \frac{\cancel{\dot{m}}}{\cancel{\dot{m}}}\left(h_i + \frac{V_i^2}{2} + \overset{0.0}{\cancel{gz_i}}\right) = \frac{\cancel{\dot{m}}}{\cancel{\dot{m}}}\left(h_e + \frac{V_e^2}{2} + \overset{0.0}{\cancel{gz_e}}\right) + \frac{{}_1W_2}{\dot{m}}$$

$$\Rightarrow h_i + \frac{V_i^2}{2} = h_e + \frac{V_e^2}{2} + {}_1w_2$$

$h_1 = 3051.2$

$${}_1w_2 = h_i - h_e + \frac{V_i^2}{2} - \frac{V_e^2}{2}$$

$$= 3051.2 - 2655 + \frac{(50)^2}{2*1000} - \frac{(200)^2}{2*1000}$$

$h_2 \rightarrow (P_2, S_2)$ mix

$h_2 = h_f + x h_{fg}$

$S_e = S_f + x S_{fg}$

$$\Rightarrow \boxed{{}_1w_2 = 377.5 \text{ kJ/kg}}$$

$$x = \frac{s_e - s_f}{s_{fg}} = \frac{7.1228 - 1.433}{5.7897}$$

$$\Rightarrow \boxed{x = 0.9827}$$

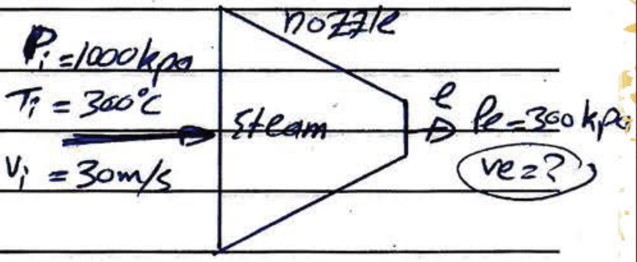
$h_e = 467.1 + 0.927(2226.5)$

$$\boxed{h_e = h_2 = 2655 \text{ kJ/kg}}$$

EXAMPLE 9.2

Consider the reversible adiabatic flow of steam through a nozzle. Steam enters the nozzle at 1 MPa and 300°C, with a velocity of 30 m/s. The pressure of the steam at the nozzle exit is 0.3 MPa. Determine the exit velocity of the steam from the nozzle, assuming a reversible, adiabatic, steady-state process.

(rev + adiabatic) (Nozzle)



2nd $\sum \dot{m}_e s_e - \sum \dot{m}_i s_i = \overset{0.0}{\cancel{\sum \frac{\dot{Q}_{c.v}}{T}}} + \overset{0.0}{\cancel{S_{gen}}}$

$\dot{m} s_e = \dot{m} s_e$

$\boxed{s_e = s_i}$

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

$(P_i, T_i) \to s_i = 7.1228$ kJ/kg.K

$s_e = 7.1228$ kJ/kg.K

$\overset{0.0}{\cancel{Q}} + \dot{m}(h_i + \frac{v_i^2}{2} + \overset{0.0}{\cancel{g z_i}}) = \dot{m}(h_e + \frac{v_e^2}{2} + \overset{0.0}{\cancel{g z_e}}) + \overset{0.0}{\cancel{W}}$

$h_i + \frac{v_i^2}{2g} = h_e + \frac{v_e^2}{2}$

$(P_i, T_i) \to \boxed{h_i = 3051.2}$ kg/kg

$(s_e, P_e) \to \boxed{h_e = 2780.2}$ kJ/kg

$v_e = \sqrt{2(h_i - h_e + \frac{v_i^2}{2})}$

$\Rightarrow \boxed{v_e = 737 \text{ m/s}}$

$v_e > v_i$

USUf (Transient process)

$$(m_2 s_2 - m_1 s_1)_{cv} = \sum m_i s_i - \sum m_e s_e + \int_0^t \frac{\dot{Q}_{cv}}{T} dt + {}_1S_{2gen}$$

EXAMPLE 9.6

Assume an air tank has 40 L of 100 kPa air at ambient temperature 17°C. The adiabatic and reversible compressor is started so that it charges the tank up to a pressure of 1000 kPa and then it shuts off. We want to know how hot the air in the tank gets and the total amount of work required to fill the tank.

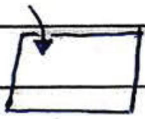
(Air) $V = 40L = 0.04 m^3$

state ① $P_1 = 1000$ kpa $T_1 = 17°C$

state ② $P_2 = 1000$ kpa

$$m_2 u_2 - m_1 u_1 = \overset{0}{\cancel{{}_1Q_2}} - {}_1W_2 + m_i h_i - \overset{0}{\cancel{m_e h_e}}$$

$$s_1 = s_i$$



مدخل ولا يوجد مخرج

$T_1 = 290 K$

$u_1 = 207.19$ $h_1 = 290.43$

$$m_1 = \frac{P_1 V_1}{R T_1} = \frac{(100)(0.04)}{(0.287)(555.7)} = 0.04806 \text{ kg}$$

$$m_2 = \frac{P_2 V_2}{R T_2} = \frac{(1000)(0.04)}{(0.287)(555.7)} = 0.2508 \text{ kg}$$

s_{T_2}	T_2
7.46642	540
7.4905	T_2 ?
7.507	560

$\Rightarrow T_2 = 555.7 K$

$m_1 + m_i = m_2$

$m_2 - m_1 = m_i$

$\Rightarrow \boxed{m_i = 0.2027 \text{ kg}}$

$$m_2 s_2 - m_1 s_1 = \sum m_i s_i - \cancelto{0}{\sum m_e s_e} + \cancelto{0}{\int \frac{Q\,dT}{T}} + \cancelto{0}{S_{gen}}$$

$$m_2 s_2 = m_i s_i + m_1 s_1$$

$$m_2 s_2 = (m_i + m_1) s_1$$

$$\boxed{s_2 = s_1}$$

هلأ لحل السؤال بيجب احضار خاصية للحالة الثانية من جدول A-7 وهي $\dot{S}_{T_2}$

$$s_2 - s_1 = s^\circ_{T_2} - s^\circ_{T_1} - R\ln\left(\frac{P_2}{P_1}\right)$$

$$s^\circ_{T_2} = s^\circ_{T_1} + R\ln\left(\frac{P_2}{P_1}\right) \Rightarrow s^\circ_{T_2} = 7.49605 \text{ kJ/kg.K}$$

$s^\circ_{T_2}$	u
7.4664	389.69
7.4905	u_2?
7.5042	404.74

$$\boxed{u_2 = 401.49} \Leftarrow$$

$$_1W_2 = m_i h_i - m_2 u_2 + m_1 u_1$$

$$\Rightarrow = (0.2027 * 290.43) - (0.2508 * 401.49) + (0.04806 * 207.19)$$

$$\Rightarrow \boxed{_1W_2 = -31.9 \text{ kJ}}$$

Polytropic Process

$$Pv^n = C$$

$n \neq$ $$w = \frac{-n(P_e v_e - P_i v_i)}{n-1} = \frac{-n R (T_e - T_i)}{n-1}$$

$n = 1$ $$w = -P_i v_i \ln\left(\frac{P_e}{P_i}\right) = -R T_i \ln\left(\frac{P_e}{P_i}\right) = R T_i \ln\left(\frac{v_e}{v_i}\right)$$

(Effiein cy)

$$\eta_{th} = \frac{W_{net}}{Q_H}$$

الداخل

$$\eta_{turbin} = \frac{W_a}{W_s} = \frac{h_i - h_e}{h_i - h_{es}}$$

$$\eta_{comp} = \frac{W_s}{W} = \frac{h_i - h_{es}}{h_i - h_e}$$

$$\eta_{pump} = \frac{W_T}{W}$$

$$\eta_{nozzle} = \frac{(V_e^2/2)}{(V_{es}^2/2)}$$

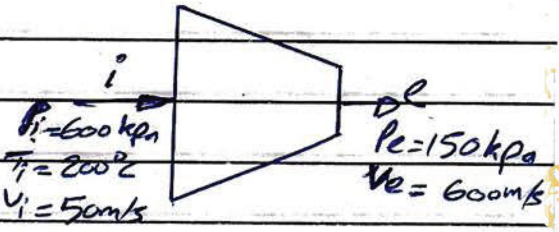
Steam at 0.6 MPa and 200°C enters an insulated nozzle with a velocity of 50 m/s. It leaves at a pressure of 0.15 MPa and a velocity of 600 m/s. Determine the final temperature if the steam is superheated in the final state and the quality if it is saturated.

Find the isentropic efficiency of the nozzle in example

find η_{nozzle}

① $(P_i, T_i) \rightarrow h_i = 2850.1 \text{ kJ/kg}$

$\rightarrow s_i = 6.9665 \text{ kJ/kg}$



$s_i = s_{es} = 6.9665 \text{ kJ/kg}$

$\text{to } x_{es} = \frac{s_{es} - s_f}{s_{fg}} = \frac{6.9665 - 1.4735}{5.7847} = 0.95\cancel{5}7.$

$h_i + \frac{V_i^2}{2*1000} = h_{es} + \frac{V_{es}^2}{2*1000}$

$\left\{ h_{es} = h_f + x_{es} h_{fg} \right.$

$\Rightarrow h_{es} = 2594.9 \text{ kJ/kg}$

$2850.1 + \frac{(50)^2}{2000} = 2594.9 + \frac{V_{es}^2}{2000}$

$\Rightarrow \boxed{V_{es} = 716.2 \text{ m/s}}$

$\eta_{noz} = \frac{(600^2/2)}{(716^2/2)} = \frac{180}{256.45} = 0.7$