THERMODYNAMICS I

By :
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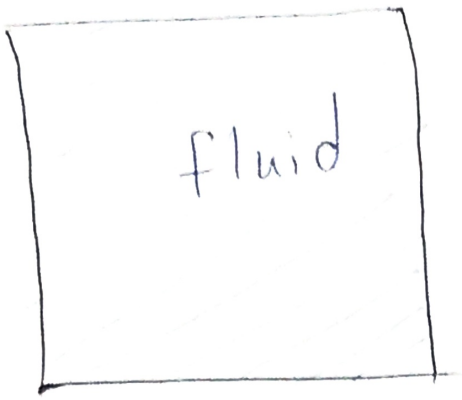
Mech Family

CHAPTER

1

INTRODUCTION AND BASIC CONCEPTS



*In thermodynamics, we study the fluid contained inside the system, we study it's states, it's properties in each state and the processes that happen to the fluid in their different types.

Fluid ← الماء

- liquid
- gas

properties of system at any state

- mass
- Pressure
- Temperature
- specific volume
- Internal energy

*We have also enthalpy and entropy but they will be discussed later.

Pressure (KPa) ≡ الضغط الذي يسببه المائع على جدران النظام

Internal energy (U) (KJ) ≡ الطاقة الداخلية لجزيئات المائع داخل النظام

Specific Volume (v) (m^3/kg) ≡ حجم الـ 1Kg من المائع داخل النظام

مثال توضيحي لمعنى الـ specific volume :-

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

v ← m^3/kg ، V ← m^3 ، m ← kg

Water
$v = 5m^3/kg$ ← $v = 5m^3/kg$

* يعني لو سحبنا 1Kg من الماء من هذا النظام سيكون عبارة عن $5m^3$

Specific energy (KJ/Kg) ≡ طاقة الـ 1Kg من المادة (او المائع) داخل النظام

مثال توضيحي :-

Water
10KJ/Kg

* يعني كل 1Kg من الماء تحوي طاقة مقدارها 10KJ

Density (kg/m^3) ≡ كتلة الـ $1 m^3$ من المادة او المائع داخل النظام

density → $\rho = \frac{1}{v}$ ← specific volume

$\rho = \frac{m}{V}$ (m ← kg, ρ ↑ kg/m^3, V ↑ m^3)

* All these properties can be classified as:-

Intensive

ρ — specific [energy / volume]

energy → kJ/kg, volume → m^3/kg

Extensive

Volume (m^3)

Energy (kJ)

mass (kg)

ملحوظة هامة :-

لا يمكن الجمع بين الـ intensive properties ، بينما يمكن في حالة الـ extensive

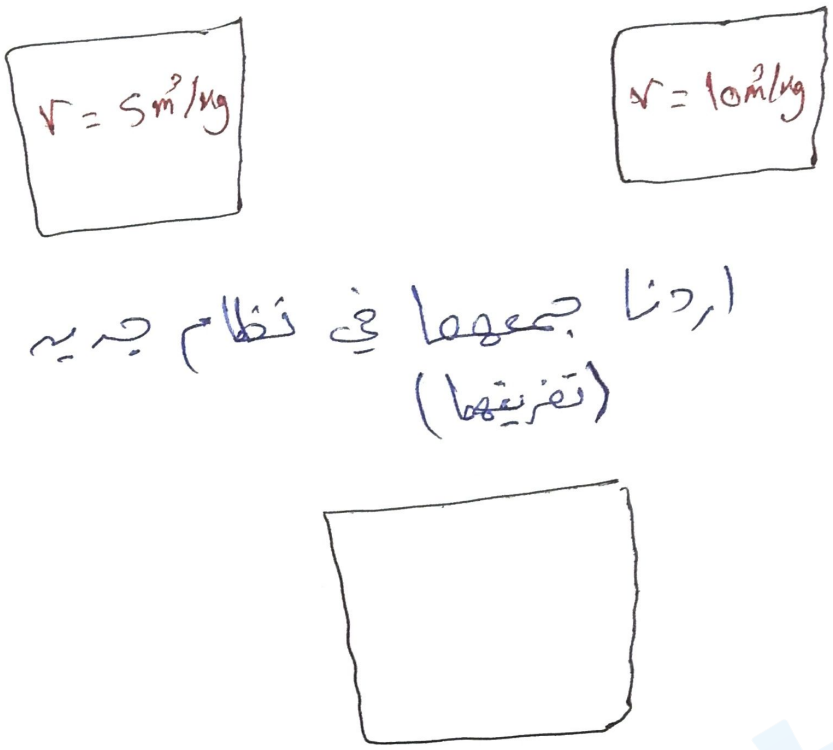
توضيح :-

نفرض ان لدينا نظامين & احدهما لديه

$v = 5 m^3/kg$

والاخر

$v = 10 m^3/kg$



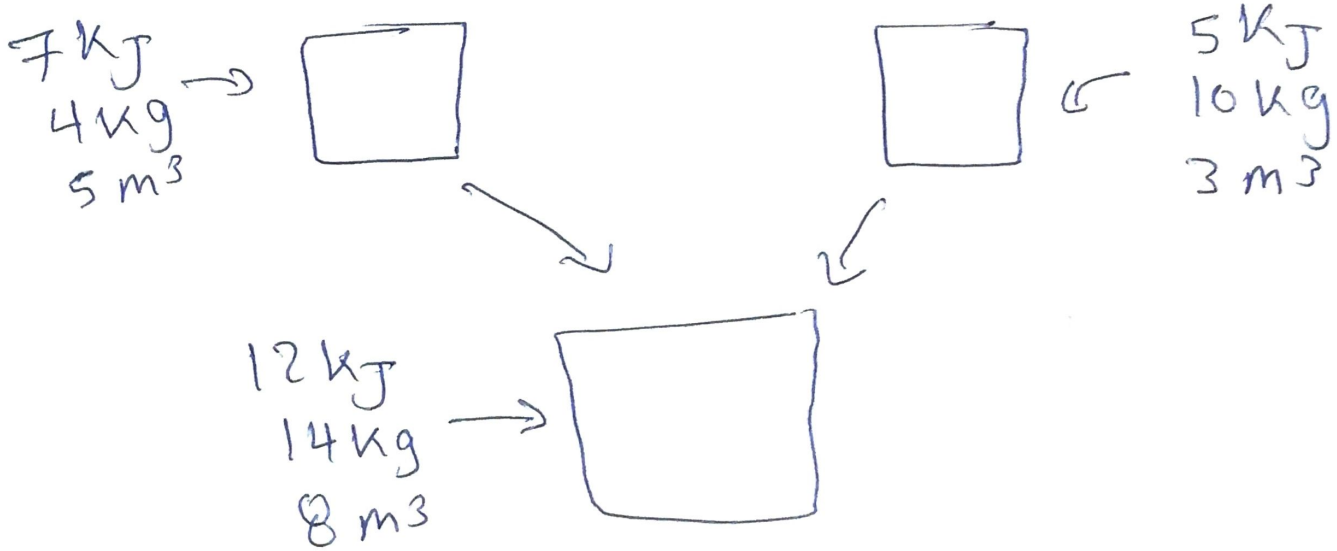
اردنا جمعهما في نظام جديد
(تفريغهما)

هل يكون الـ v للنظام الجديد $15 m^3/kg$ ؟

الاجابة: لا

وهذا ينطبق على جميع الـ intensive properties الاخرى ، بحيث لا يمكن جمع ضغطين او درجتي حراره .....

ولكن هذا ممكن في حالة الـ extensive



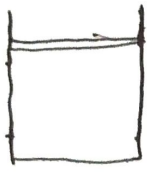
Types of systems

Closed system (control mass)

* No mass exchange

Ex:-

rigid tank ⇒ 

piston cylinder ⇒ 

open system (control volume)

* There is mass exchange

Ex:-

- Turbine
- compressor
- pump
- Nozzle

⋮

* Difference between isolated and insulated systems:-

Isolated system:- نظام منعزل عن المحيط ولا يتبادل الطاقة او الكتل مع النظام المحيط

Insulated system:- نظام معزول حراريا (No heat exchange)

$Q_{in} = Q_{out} = 0$

قد يتبادل الكتل وانواع الطاقة الاخرى مع النظام المحيط.

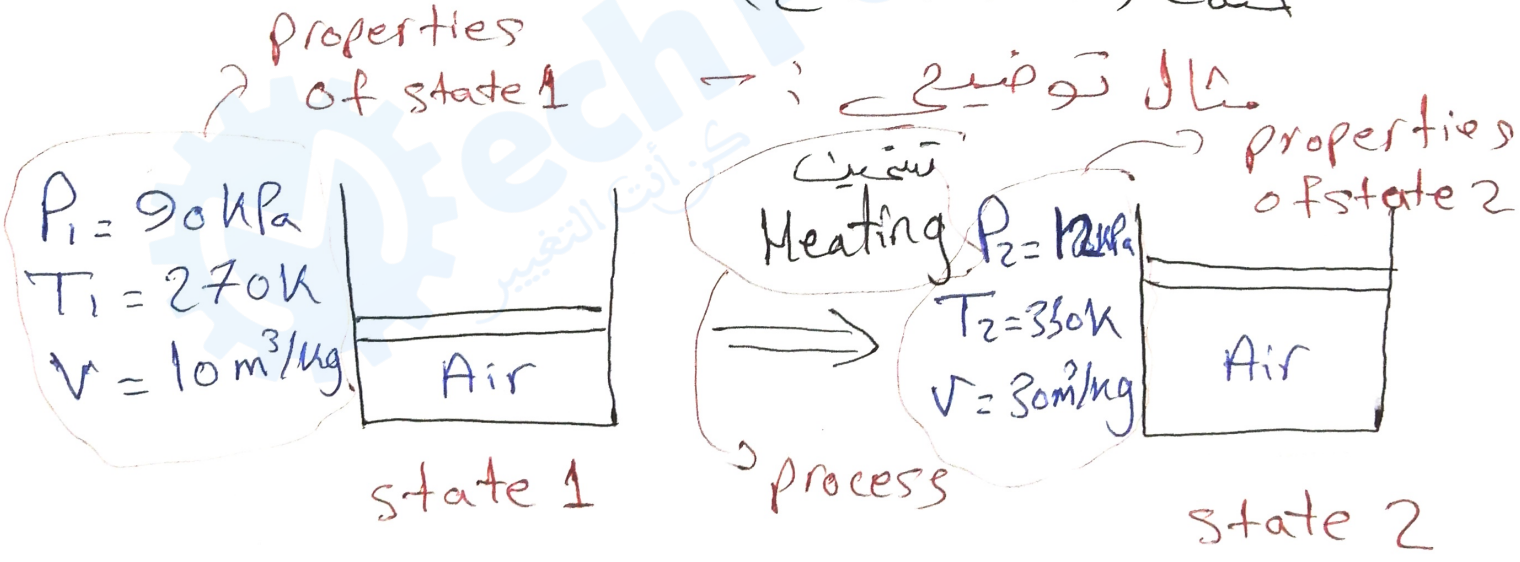
* النظام (system) في أي لحظة يكون في حالة (state) معينة، وفي هذه الحالة يحمل النظام خصائص (properties) معينة

(P, T, v, h, s)

حتى تحدث عملية (process) وتنقل هذا النظام من هذه الحالة الى حالة اخرى بخصائص جديدة

هذه العملية (process)، يمكن ان تتضمن تسخين، تشغيل (مروحة / مدفئة)، انتقال كتلة (دخول / خروج) .....

مثال توضيحي :-



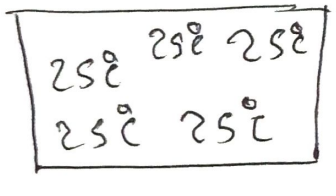
* الارقام غير دقيقة، فقط للتوضيح

Thermodynamic processes

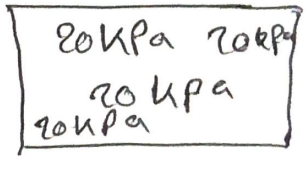
- **Isobaric process**
  Constant pressure process
  $P_1 = P_2$
- **isothermal process**
  constant temperature process
  $T_1 = T_2$
- **isochoric (isometric) process**
  constant specific volume process
  $v_1 = v_2$
- **polytropic process**
  It refers to the relation:-
  $PV^n = \text{constant}$
  $P_1 V_1^n = P_2 V_2^n$

Types of equilibrium

- **Thermal equilibrium**
  ⇓
  The temperature at each point on the system is the same



- **Mechanical equilibrium**
  The pressure at each point on the system is the same



وفي ماده الثيرمو ، على اي حاله (state) ، يكون النظام في حاله Thermal + Mechanical equilibrium

يعني اذا قال لك في المسأله ان $P_1 = 100kPa$:

يعني جميع النقاط لها نفس الضغط ، والذي هو 100kPa

وكذلك الامر بالنسبه للحراره على هذه الحاله

Pressure :-

Normal force exerted by a fluid per unit area.

$1\ bar = 100\ KPa$

$1\ atm = 101.325\ KPa$

$1\ MPa = 1000\ KPa$

- **Atmospheric pressure (P_{atm}):-**

ضغط الجو المحيط ، ويقاس بجهاز يسمى Barometer

- **Absolute pressure (P_{abs}):-**

ضغط موقع معين

- **Gage pressure (P_{gage}):-**

الفرق بين P_{abs} & P_{atm}

$$P_{gage} = P_{abs} - P_{atm}$$

وهناك جهاز يسمى (Pressure gage) يعطينا قراءه P_{gage} في tank معين

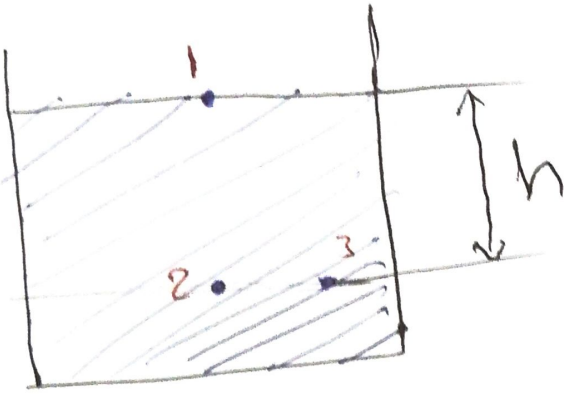
- **Vacuum pressure (P_{vac})**

فرق الضغط عندما يكون

$P_{atm} > P_{abs}$

$$P_{vac} = P_{atm} - P_{abs}$$

pressure + depth :-



* الضغط على سطح الماء (اعلى نقطة من الحوض) $\equiv P_{atm}$

so $P_1 = P_{atm}$

* النقاط الاعمق دائما ضغطها اعلى لنفس المائع وذلك لان المائع يتركز اكثر في الطبقات الاعمق

so $P_2 > P_1$

* الضغط يعتمد على الارتفاع (ضغط المائع) وبالتالي النقاط التي على نفس الارتفاع (على نفس الخط الافقي) يتساوى ضغطها

so $P_2 = P_3$

فرق الضغط بين اي نقطتين يملأ بينهما مائع في حالة سكون :-

$$\Delta P = \rho g h$$

ρ ← كثافة السائل الذي يملأ بين النقطتين

g ← 9.81

h ← الارتفاع بين النقطتين

ρ :- Kg/m^3

$g = 9.81\ m/s^2$ $\Rightarrow$ ΔP :- P_a

h :- m

so :-

$$P_{2 or 3} - P_1 = \rho g h$$

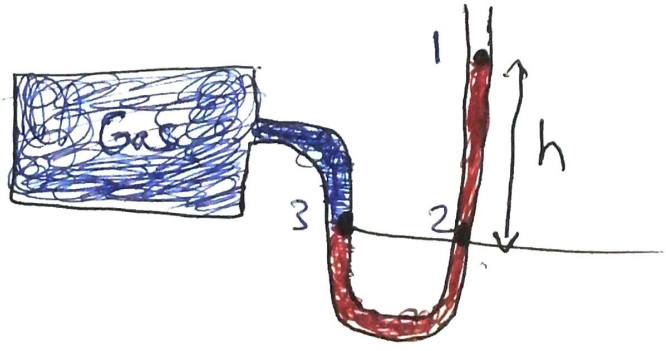
so the general equation is :-

$$P_{below} = P_{above} + \rho g h$$

Manometer :-

It's a device that measures the pressure in a tank

* It consists of U tube, which is made of plastic which contains one or more heavy fluid like oil, water, mercury .....



$$P_2 = P_3$$

$$P_{2 or 3} = P_1 + \rho g h$$

$$SG = \frac{\rho_{fluid}}{\rho_{water}}$$

specific gravity

$\rho_{water} = 1000\ kg/m^3$

End of chapter 1

CHAPTER

3

PROPERTIES OF PURE SUBSTANCES

Mech Family

Substances that we deal with in thermodynamics

- pure substance
  - Water
  - R-134a
- Ideal gases
  - O_2
  - N_2
  - CO_2
  - He

pure substances behavior :-

سلوك المواد النقية :-

piston cylinder

* لنفترض أن لدينا ماء داخل تحت ظروف :-

$P = 1 atm$, $T = 20°C$

* تحت هذه الظروف ، يكون الماء بحالة تسمى :-

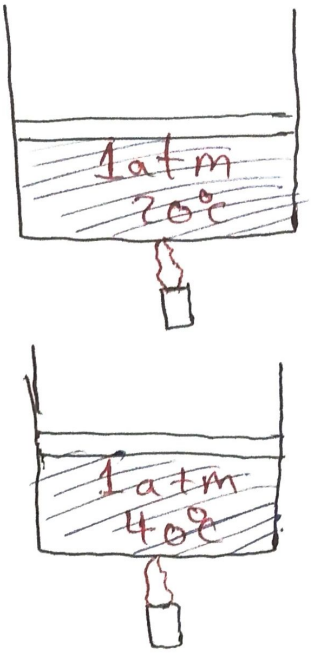
subcooled liquid

or

compressed liquid

ويجب التركيز على هذه المسميات جيداً

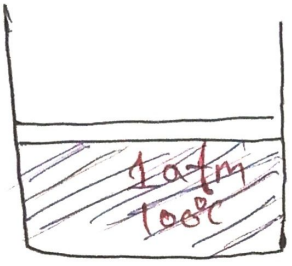
* ثم وضعنا شمعه (Heat source) اسفل الـ cylinder



* سوف ترتفع درجه الحراره بشكل تدريجي
، لنقل انها وصلت الى 40°c ، ويبقى الضغط ثابتاً
، حيث ان الضغط يعتمد على وزن المكبس بالاضافه
الى الضغط الخارجي (الضغط الجوي Patm)
، وفي هذه العمليه ، يكون المكبس حراً ، فيبقى
الضغط ثابتاً ، وخلال ارتفاع درجه الحراره التدريجي
، يرتفع المكبس ولكن بشكل بسيط ، حيث ان جزيئات
الماء تضغط على المكبس خلال حركتها الناتجه عن
الطاقه الحركيه المضافه لها بنتيجه التسخين

* تحت هذه الظروف التي وصلنا لها (1atm 40°c)
تبقى الماء في حاله :-
compressed or subcooled liquid

* خلال استمرارنا في التسخين (Heat addition)، تستمر درجة الحرارة في الارتفاع التدريجي ويبقى الضغط ثابتاً، حتى نصل الى (1atm, 100°C)



* عند هذه الظروف، نصل الى حالة تسمى saturated liquid

* saturated liquid:- It's a liquid that is about to vaporize

* حيث أن اي مقدار اضافي من الطاقة الحرارية (Q) سيؤدي الى بداية تبخير هذا السائل من الماء

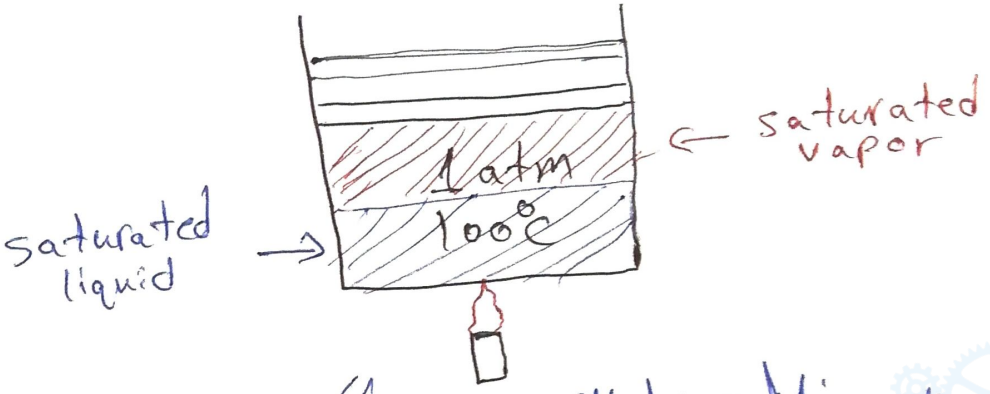
* نستمر في اضافة الطاقة الحرارية التي مصدرها الشمس، وهنا يبدأ السائل بالتبخر تدريجيا

* وخلال تحول السائل التدريجي الى بخار، تبقى درجة الحرارة ثابتة، لماذا؟

* لان الطاقة الحرارية المضافة (Heat) ستعمل على تفكيك الروابط بين جزيئات السائل لتحويله الى بخار، فلا يكون لهذه الطاقة القدرة على رفع درجة الحرارة

* وخلال التحول التدريجي من السائل الى البخار ، نحن نكون في حالة :-

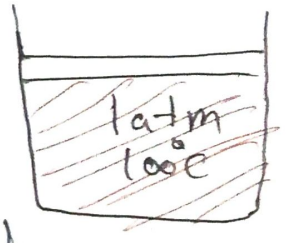
saturated liquid vapor mixture



* وخلال هذا التحول ايضاً ، يرتفع المكبس بشكل كبير بسبب وجود vapor بالداخل ، حيث انه من المعروف ان الطاقة الحركية للبخار او الغاز بشكل عام اكبر من السائل ، وبالتالي مع زيادة كمية البخار يزداد دفع المكبس لأعلى .

* تستمر هذه العملية حتى يتحول كل السائل الى بخار (100% vapor) ، ويكون هنا المائع في حالة تسمى :- saturated vapor

* ارتفاع المكبس ≡ زيادة الـ specific volume

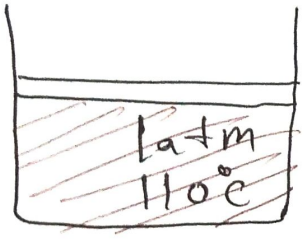


* saturated vapor :- A vapor that is about to condense

* بحيث ان اي تبريد (سحب للحرارة) من البخار سيؤدي مباشرة الى تكثيفه (تحوله الى سائل) تدريجيا

* ومع استمرار تسخين (اضافه طاقه حراريه) لهذا الـ saturated vapor ، سوف تستأنف درجه الحراره في ارتفاعها ، وطبعاً يبقى الضغط ثابت وذكرنا السبب قبل ذلك ، وسوف يرتفع المكبس بشكل اكبر واكبر.

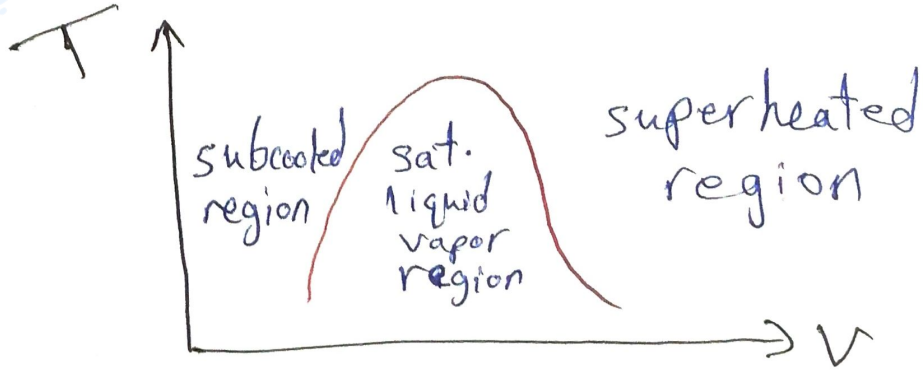
* وبارتفاع درجه حراره الـ sat. vapor ، يصل البخار (المائع) الى حاله تسمى :-
superheated vapor



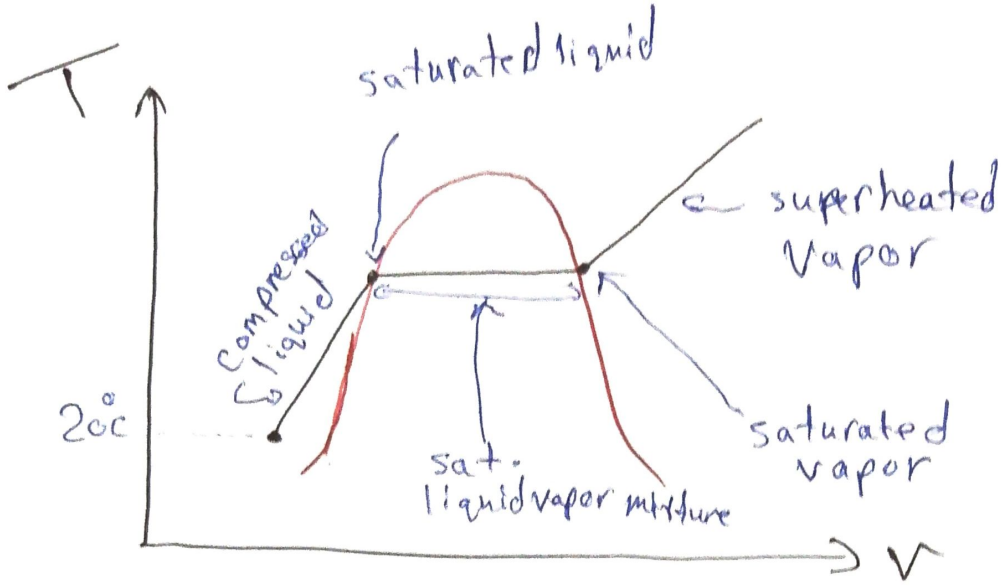
1 atm
110°c ⟹ ظروف يكون عندها المائع superheated vapor.

* هذه العمليات وهذا الـ procedure ينطبق على الـ pure substances

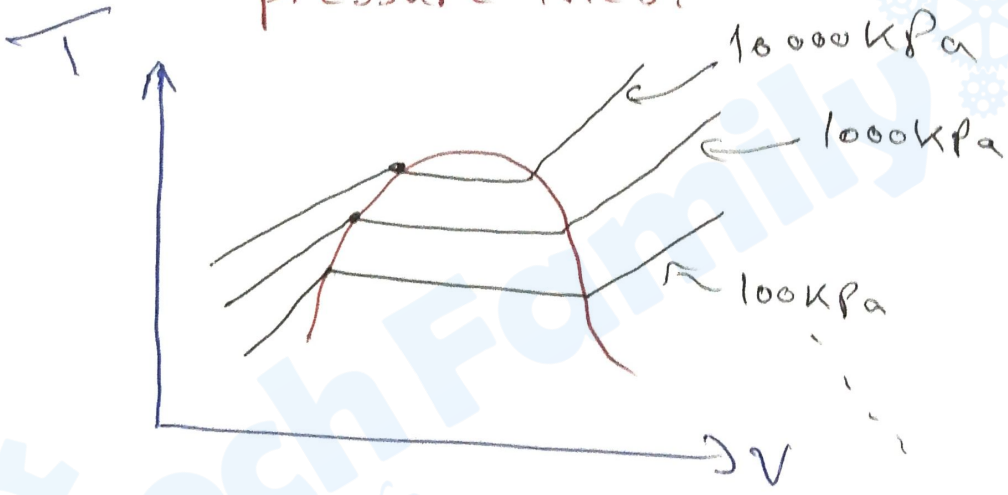
* ويمكن تمثيل ذلك على T - V diagram



Temperature - specific volume diagram with regions.

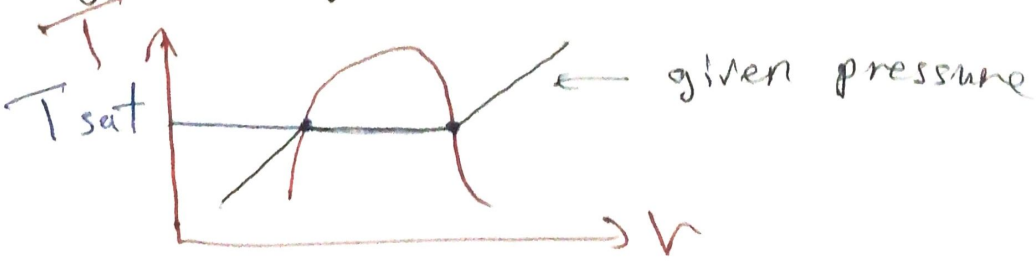


* In T-V diagram, constant pressure lines:-



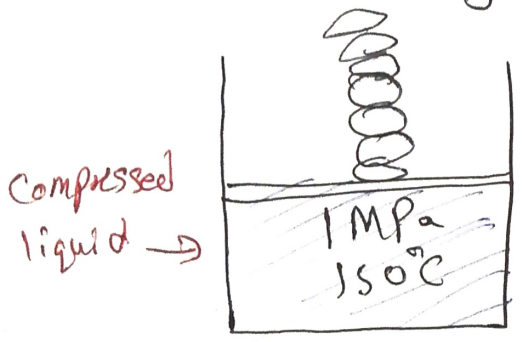
Saturation temperature
↑
saturation pressure
$P_{sat} + T_{sat}$.

saturation temperature:- It's a temperature at which a pure substance changes phase at a given pressure



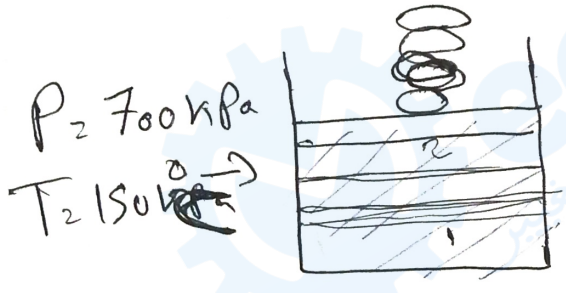
تجربة اخرى توضح تأثير وسلوك الضغط:-

لنفرض ان لدينا ماء داخل piston cylinder على ظروف $\left(\frac{P = 1MPa}{T = 150°C}\right)$، وطبعاً فوق المكبس توجد مجموعة من الاحجار التي هي مصدر هذا الضغط



حيث اننا كما نعلم، ضغط المائع في الـ piston cylinder يعتمد على وزن المكبس والضغط الجوي، والاحجار هنا تزيد من الوزن الذي يحمله المكبس

ثم بدأنا بإزالة الاحجار بالتدريج، ما سيحدث ان الضغط على المائع سيقل، وسيبدأ المكبس بالارتفاع لكن بشكل بسيط جداً



وخلال هذه العملية ستثبت درجة الحرارة

وخلال الاستمرار، ينخفض الضغط تدريجياً وتبقى الماء على حالة compressed liquid حتى يصل الضغط الى 476.16kPa، فنكون قد وصلنا الى مرحلة الاشباع (saturated liquid)

ثم بعد ذلك نضع شمعة اسفل النظام لتسخين الماء بالـ heat

وفائدة هذه الهيت ، تحويل السائل الى بخار بالتدريج
دون احداث اي تغيير في درجة الحرارة او الضغط

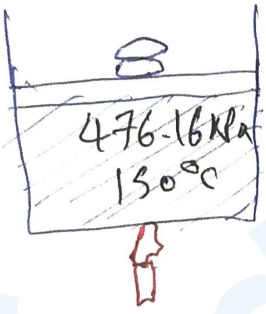
وخلال هذه العملية :-

يتحول السائل الى بخار تدريجيا

وتبقى P & T ثابتان

والحجم يرتفع اكثر بسبب بداية
تكون البخار

sat. liquid ⇒

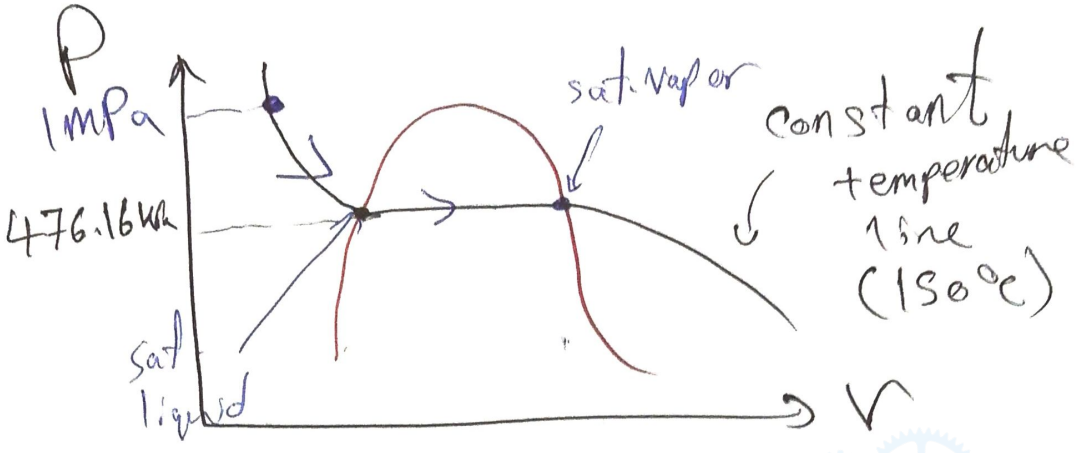


ويستمر ذلك حتى
تنتهي عملية التحول
فيصبح السائل كله
بخار

بعد التحول الى بخار ، نكون قد وصلنا الى حالة saturated vapor ، ثم طبعا تزيل الشمعة

ومع استئناف ازالة الاحجار ، يستمر الضغط في الهبوط
، حيث انه بمجرد ازالة اي مقدار من الوزن بعد
التحول الى sat. vapor ، نكون قد دخلنا في حالة الـ
super heated vapor

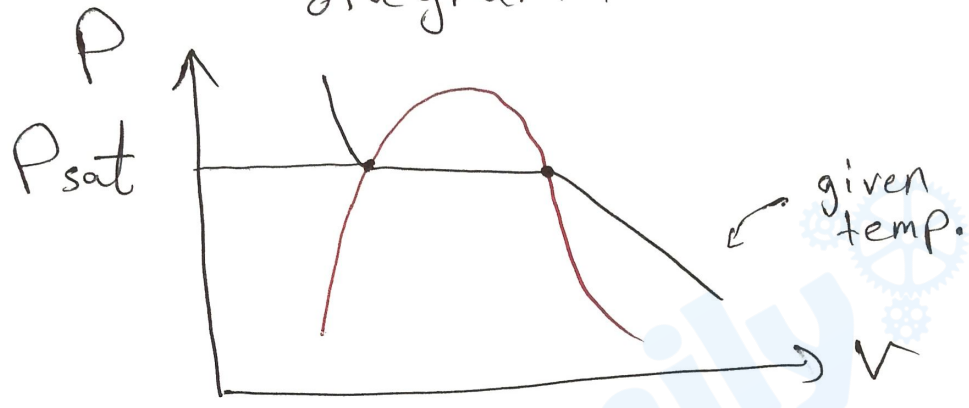
سلوك الماء داخل الـ piston cylinder يمكن
تمثيله من خلال الـ P-V diagram



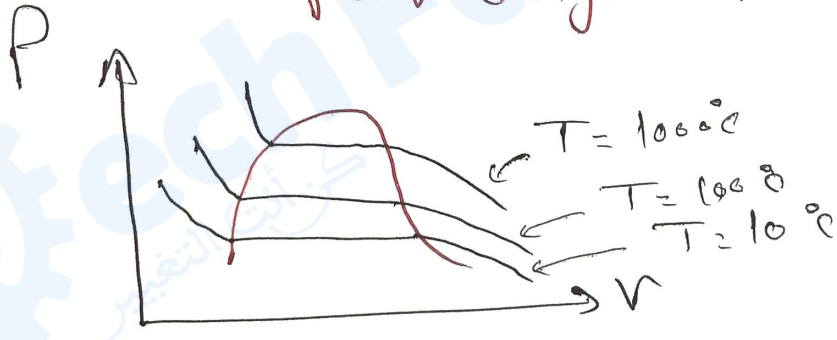
Saturation pressure :-

It's the pressure at which a pure substance changes phase at a given temperature

Pressure - specific volume diagram :-

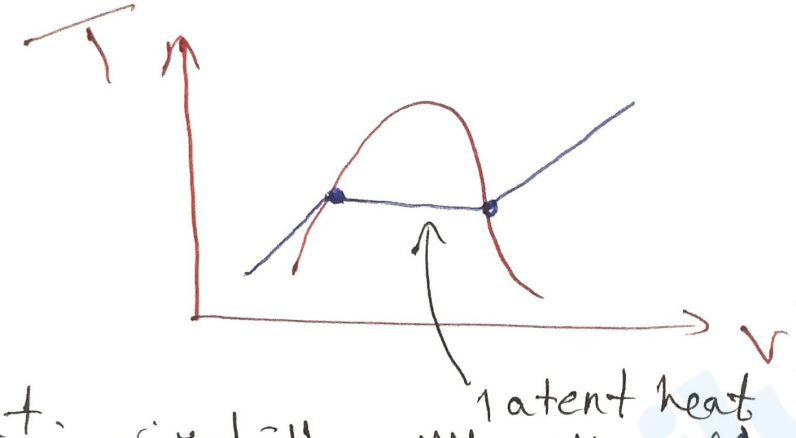


constant temp. lines on P-V diagram :-



sensible heat :- It's the heat that causes a change in the temperature

latent heat :- It's the heat that doesn't cause any change in the temperature, but it causes a change in the phase



(كمية الحرارة اللازمة للتحول من sat. liquid الى sat. vapor)

* كلما زاد الضغط، زادت Tsat وبالتالي قلّت الـ latent heat

* نلاحظ ان الخط يقل طوله بارتفاع Tsat & P

وينطبق ايضاً هذا الكلام على P-V diagram

$T \uparrow\uparrow$

$P_{sat} \uparrow\uparrow$

latent heat $\downarrow\downarrow$

Tables property:-

* أي مائع في أي حاله يكون له خصائص معينه
(لكل حاله خصائص)

* state postulate
(تحديد خصائص الحاله) :-

* The priciple of state postulation says:-
any two independent intensive property will be enough to determine the other properties.

يعني اي خاصيتين independent و intensive
سيحددوا باقي خصائص الماده في الحاله المراد
دراستها.

Intensive properties

P T v h u s

$h = Pv + u$

* h is enthapy and it has two meanings
* one is for closed system which is heat content
* The other is for open system and it will be discussed later.

Important note:-

* P + T are dependent in the mixture state

* At P we have Tsat and at T we have Psat

* So P + T are not enough to determine the other state's properties

---

* First, we will discuss state postulation of pure substances (water + R-134a)

* First step is to determine the state of the substance. (is it compressed liquid? mixture? or superheated vapor?)

لازم نحدد احنا بأي منطقة ⇒
(compressed, mixture, superheated, saturated...)

How does it done?

For water:-

we can go to table A-4 or A-5

For R-134a:-

we can go to table A-11 or A-12

* In these tables, we have many rows and columns contain these intensive properties

* And from these tables, we can know the state.

V_f = specific volume of saturated liquid

V_g = specific volume of saturated vapor

$V_{fg} = V_g - V_f$

h_f = enthalpy of saturated liquid

h_g = enthalpy of saturated vapor

h_{fg} = latent heat of vaporization.

$(h_g - h_f)$

u_f = internal energy of saturated liquid

u_g = internal energy of sat. vapor

$u_{fg} = u_g - u_f$

كيفية التدقيق ومعرفة الحالة :-

إذا اعطانا مثلا

P + T

لدينا طريقتين :-

إما تثبيت T او تثبيت P

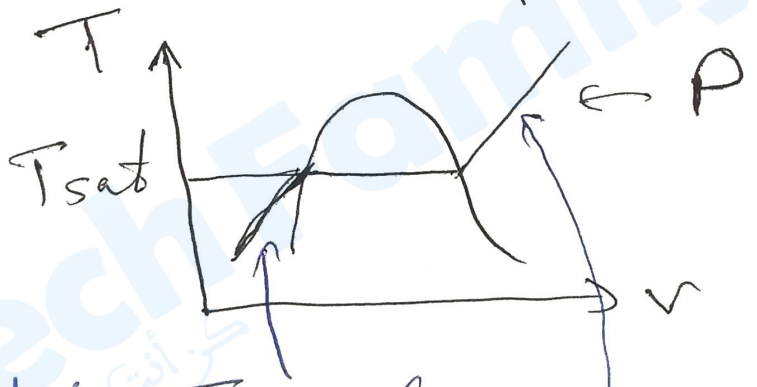
لو ثبتنا مثلا P رح علينا T-V diagram

والذهاب لجدول ال P

A-5 for water

or A-12 for R-134a

ثم نحدد ال P ونوجد Tsat من الجدول



اذا كانت T في السؤال اقل من Tsat

فنحن في حالة compressed liquid $(T < T_{sat})$

اذا كانت T اعلى من Tsat

فنحن في حالة super heated $(T > T_{sat})$

اذا $T = T_{sat}$

فنحن اما

sat. liquid or mixture or

sat. vapor

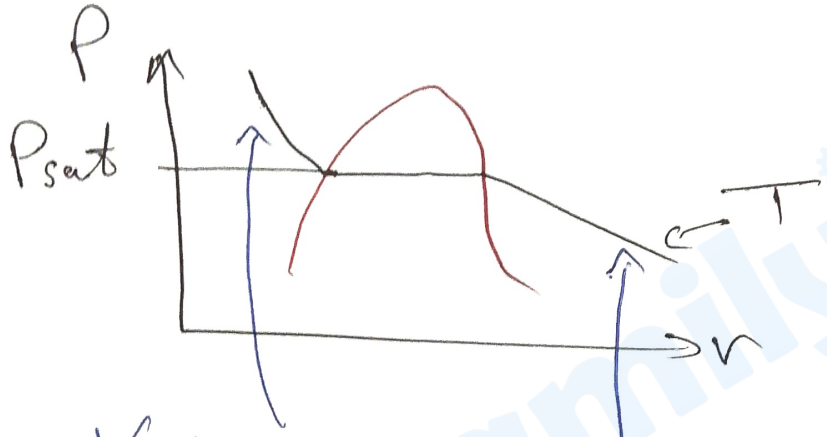
وإذا ثبتنا T ، فعلينا رسم P-V diagram

وعلينا استخدام جدول الـ T

A-4 for water

A-12 for R-134a

ثم نحدد الـ T في الجدول ونوجد Psat



اذا كان
$P > P_{sat}$
فنحن في الـ compressed

واذا كان
$P < P_{sat}$
فنحن في الـ superheated

وإذا كان $P = P_{sat}$
فنحن اما في الـ:-
sat. liquid or mixture or sat. vapor

* But if P or T is given with (v or u or s or h)

* If P then we have to use Pressure table

A-5 for water

A-12 for R-134

* If T then we have to use temperature table

A-4 for water

A-11 for R-134a

After determining the table and the T or P that is given in the question:-

we look at the other property (u, v, h, u)

u for example:-

* if $u < u_f$ @T or P

then we are at compressed

* if $u_f < u < u_g$

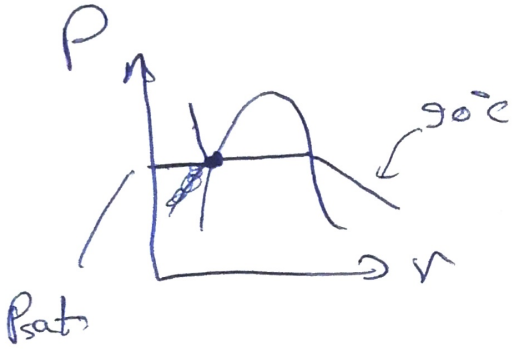
we are at mixture

* if $u > u_g$

we are at superheated

Some examples:- (saturated liquid or vapor)

1- A rigid tank contains 50 kg of saturated liquid water at 90°C. Find pressure and volume of the tank



It sat. liquid

so $v = v_f$

and $P = P_{sat}$ @ 90°C

+ It's water

so we can go to table A-4

P_{sat} @ 90 = 70.183 kPa

+ $v = v_f = 0.001036\ m^3/kg$

so $V = v * m$

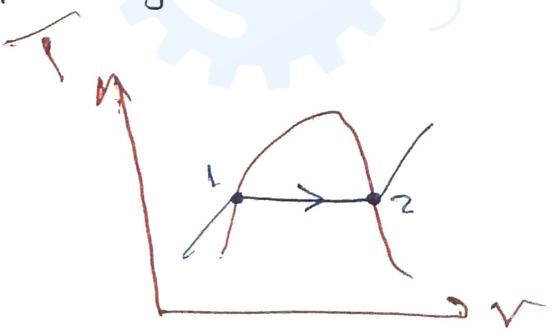
$= 0.001036 \times 50$

$= 0.0518\ m^3$

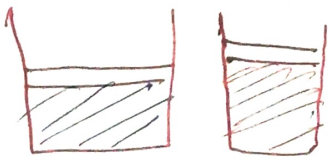
---

*we have to use table A-5 because P is given.

2- A mass of 200 g of sat. liquid water is completely vaporized at a constant pressure of 100 kPa find change of volume and the amount of energy transferred to the water



It was sat. liquid and it's completely vaporized! so in state 2, it's sat. vapor



at 100 kPa

state 1:-

$V_1 = v_{f_1} m = 0.001043 \times 0.2$

$= 0.0002086\ m^3$

state 2:-

$V_2 = v_{g_2} m = 1.6941 \times 0.2$

$= 0.33882\ m^3$

So

$\Delta V = V_2 - V_1 = 0.33882 - 0.002086$

$= 0.3386\ m^3$

Amount of energy = latent heat

$\equiv h_{fg}$

$\equiv h_{fg} m = 0.2 \times 2257.5$

$= 451.5\ kJ$

at 100 kPa

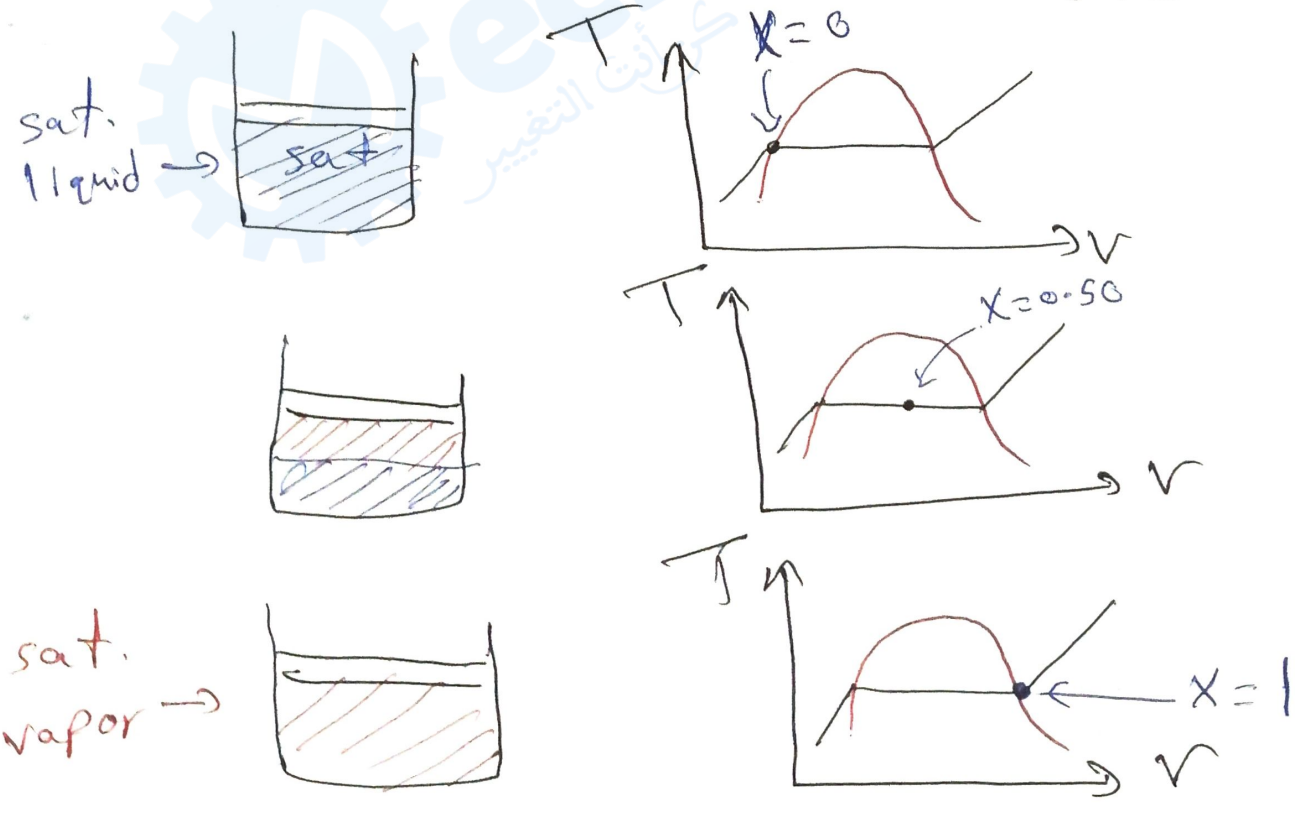
Quality (x):-

It's the fraction of vapor contained in the system (mixture)

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

m_v ← mass of vapor

m_f ← mass of liquid



For mixtures :-

$$h = h_f + x h_{fg}$$

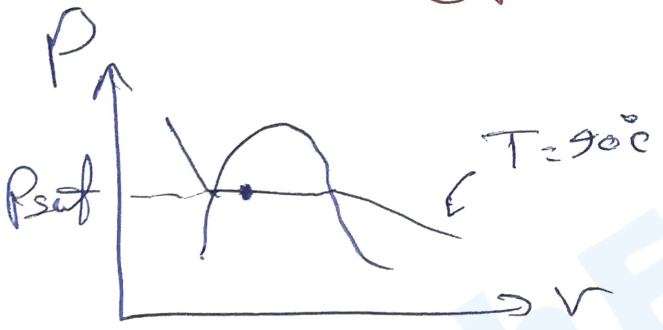
$$u = u_f + x u_{fg}$$

$$v = v_f + x v_{fg}$$

Some examples :-

1- A rigid tank contains 10kg of water at 90°c, if 8kg is in the liquid form and the rest is vapor find :-

① pressure ② volume of the tank



$P = P_{sat}$ @ 90°c because it's mixture

so $P = 70.183$ kPa (from table A-4)

$m_f = 8$ kg

$m_v = 10 - 8 = 2$ kg

$$x = \frac{m_v}{m_f + m_v} = \frac{2}{8+2} = 0.2$$

$$v = v_f + 0.2(v_{fg})$$

$$v = 0.001036 + 0.2(2.3593)$$

$$= 0.47322 \ m^3/kg$$

$$V = m v = 4.7322 \ m^3$$

2- An 80L vessel contains 4Kg of R-134a at a pressure of 160kPa

find:-

1. Temperature
2. quality
3. Enthalpy
4. volume occupied by the vapor.

First, we have to fix the state:-

given

$P = 160 kPa$, $V = 80 \times 10^{-3} = 0.08 m^3$

$$v = \frac{V}{m} = \frac{0.08 m^3}{4 kg}$$

$$= 0.02 m^3/kg$$

For R-134a

∵ P is given, then we have to go to table A-12

At $P = 160 kPa$ $(T = -15.6°C)$

$v_f = 0.0007435 m^3/kg$

$v_g = 0.12355 m^3/kg$

$v = 0.02 m^3/kg$

$v_f < v < v_g$

so we are in mixture

so we have to apply:-

$$0.02 = 0.0007435 + x(0.12355 - 0.0007435) \Leftarrow v = v_f + x v_{fg}$$

$$\Rightarrow x = 0.157$$

$$h = h_f + x h_{fg}$$

$h_f + h_{fg}$ is found from table A-12 at $P = 160 kPa$

$h = 64.1 kJ/kg$

For volume of the vapor:-

$$V_g = m_g v_g$$

$$m_g = x\, m_{total} = 4 \times 0.157$$

$$= 0.628\,kg$$

$$V_g = 0.628 \times 0.12355 = 0.0776\,m^3$$

For compressed or subcooled liquid:-

If the state was compressed:-

For water

if $P \geq 5\,MPa$

we have to use table A-7

if $P < 5\,MPa$

we have to use table A-4

A-4 & not A-5 !!!

just A-4, okay?

so that

$h = h_f$

$v = v_f$

$u = u_f$

$s = s_f$

For R-134a

we have always to use A-11 (not A-12)

so that

$h = h_f$

$v = v_f$

$s = s_f$

$u = u_f$

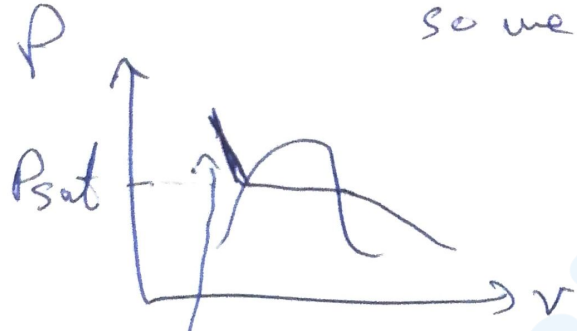
Example :-

Determine the internal energy of water at 5MPa and 80°c

First, we have to fix the state

we can fix T

so we have to use table A-4



$P_{sat} = 47.416$ KPa

$P > P_{sat}$

so it's compressed liquid

$\because P = 5MPa$

so we can use table A-7

At 5MPa and 80°c

$u = 333.82$ kJ/kg.

If the state is superheated:-

we have to transfer to:-

Table A-6 for water

Table A-13 for R-134a

Example:-

Determine the internal energy of water at 200 kPa and 300°C

First, we have to fix the state

we can fix $P = 200\ kPa$

from pressure table:-
(A-5)

$T_{sat} = 120.21°C$
at 200kPa

$T > T_{sat}$

so the water is superheated vapor
so we have to move to table A-6

$u @ 200kPa, 300°C = 2808.8\ kJ/kg$.

Ideal gas :-

الغاز المثالي هو غاز يميل الى ان يكون ضغطه منخفض ودرجه حرارته عاليه وتكون جزيئاته منتشره في الفراغ وبعيده عن بعضها وبالتالي كلما زادت درجه حراره الغاز وضغطه زادت مثاليته

reduced pressure $\rightarrow P_r = \dfrac{P}{P_{cr}}$

reduced temperature $\rightarrow T_r = \dfrac{T}{T_{cr}}$

P_{cr} & T_{cr} are in table A-1 for different gases

شروط الغاز المثالي :-

1- $P_r < 1$

2- $T_r > 2$

* In thermodynamics 1, we assume that the gas is ideal in all problems and questions.

Ideal gas equations:-

$$Pv = RT$$

m^3/kg

$$PV = mRT$$

m^3

$$PV = NR_uT$$

kmol

$R_u = 8.31447\ kJ/kmol.K$

$$N = \frac{m}{M}$$

moles

mass

molar mass, it's found it table A-1 for different gases

R is the gas constant and it's found in table A-1 for different gases

End of chapter 3

CHAPTER

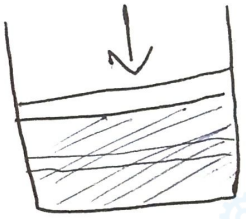
4

ENERGY ANALYSIS OF CLOSED SYSTEMS

Moving boundary work :-

It's the work associated with the moving of piston in piston cylinder device.

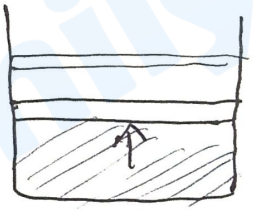
* بحيث ان حركه المكبس للأسفل (compression) ، تضيف للمائع طاقه تختزن فيه



(Win)

(work done on system by surrounding)

* وحركه المكبس للأعلى (expansion) تنتج من استخدام المائع لطاقته الداخليه لتتمكن جزيئاته من دفع المكبس للاعلى



(Wout)

(work done by system on surrounding)

Moving boundary work (Wb):-

$$W_b = \int_{V_1}^{V_2} P\,dv \quad (kJ/kg)$$

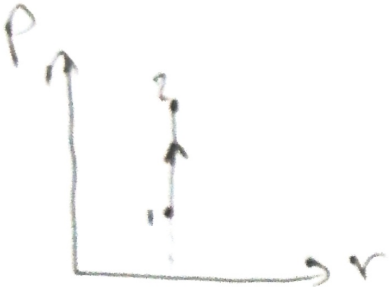
$W_b \equiv$ Area under P-V diagram.

Moving boundary work for different processes:-

1- isochoric (isometric) process:-

$v_1 = v_2$

so $$W_b = \int_{v_1}^{v_2} P\,dv = 0$$



so $W_b = 0$ for isochoric process (piston is fixed)

2- isobaric process:-

$$W_b = \int_{v_1}^{v_2} P\,dv$$

$P = \text{constant}$

so $$W_b = P \int_{v_1}^{v_2} dv = P(v_2 - v_1)$$

so $W_b = P\Delta v$ for isobaric process

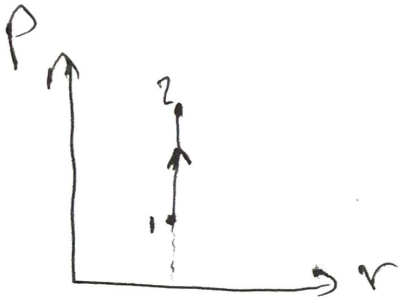
Moving boundary work for different processes:-

1- isochoric (isometric) process:-

$v_1 = v_2$

so

$$W_b = \int_{v_1}^{v_2} P\,dv = 0$$



so $W_b = 0$ for isochoric process (piston is fixed)

2- isobaric process:-

$$W_b = \int_{v_1}^{v_2} P\,dv$$

$P \equiv$ constant

so

$$W_b = P \int_{v_1}^{v_2} dv = P(v_2 - v_1)$$

so $W_b = P\Delta v$ for isobaric process

3- Isothermal process of an ideal gas:-

for ideal gas when T is constant:-

$$P_1 V_1 = P_2 V_2$$

so

$$PV = C \quad \text{(constant)}$$

$= P_1 V_1$ OR $P_2 V_2$

$$W_b = \int_{V_1}^{V_2} P \, dV$$

$$P = \frac{C}{V}$$

$$W_b = \int_{V_1}^{V_2} \frac{C}{V} dV = C \int_{V_1}^{V_2} \frac{1}{V} dV$$

$$W_b = C \ln \frac{V_2}{V_1}$$

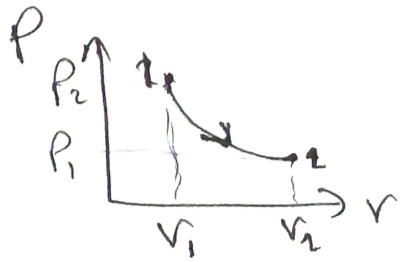
so that $C = P_1 V_1$ OR $C = P_2 V_2$

4- Polytropic process:-

$$P V^n = \text{constant}$$

$$P_1 V_1^n = P_2 V_2^n$$

$$W_b = \frac{P_2 V_2 - P_1 V_1}{1 - n} = \frac{mR(T_2 - T_1)}{1 - n}$$



First law of thermodynamics:-

* Energy can be converted from one form to another, but the total amount of energy remains constant.

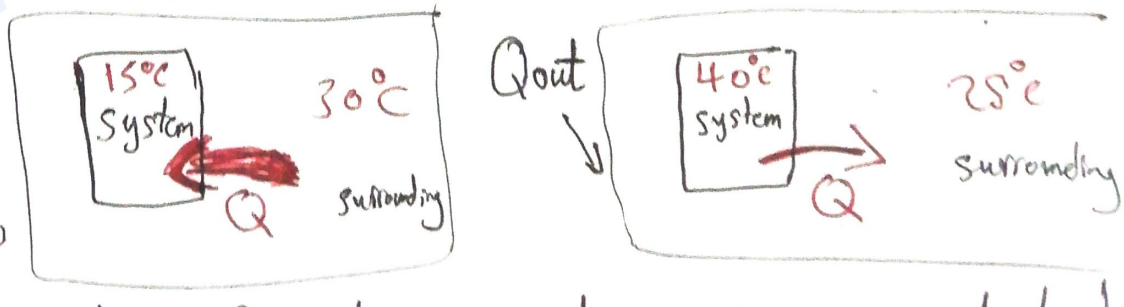
Forms of energy interactions

- Heat
- Work
- Mass

1- Heat:-

* When there is a temperature difference between the system and the surrounding, there will be heat transfer from the hot medium to the cold one

* Heat is a form of energy and it's represented by Q



Qin

* If the system is insulated, so there will not be heat transfer ($Q = 0$)

2- Work

Work types

Boundary work

* Just if the system is piston cylinder
* if expansion it's Wout
* if compression it's Win

Others

- Electric work (like heater)
- shaft work
- Paddle work

* They are all Win if the system is closed

$$W_{electric} = I v t$$

* Win if the work is done on system
* Wout if the work is done by system.

3- Mass

* When an amount of mass transfers to or from a system, an amount of energy will be tranferred to or from the system

* If the system is closed, so no mass can transfer to or from it, so no energy will be added or removed from the system by mass

---

Energy balance equation (first law formula):-

energy entered the system → $E_{in} - E_{out} = \Delta E_{system}$

E_{out}: energy leaved the system

ΔE_{system}: The change in the energy content of the system

* If ΔE_{system} is $\oplus \Rightarrow E_{in} > E_{out}$

$\Rightarrow$ Means energy added to the system

* If ΔE_{system} is $\ominus$ $\Rightarrow E_{in} < E_{out}$

$\Rightarrow$ Means that energy is lost.

$$\Delta E_{system} = \Delta U + \Delta P.E + \Delta K.E$$

Changes in Kinetic and potential energies.

so

$$E_{in} - E_{out} = \Delta U + \Delta P.E + \Delta K.E$$

* In thermodynamics, we always deal with stationary systems (الثابتة), so $\Delta P.E$ & $\Delta K.E \equiv 0$

$$E_{in} - E_{out} = \Delta U$$

$$\underbrace{\left(W_{in} + Q_{in} + \sum (\text{Energy by mass})_{in}\right)}_{E_{in}} - \underbrace{\left(W_{out} + Q_{out} + \sum (\text{Energy by mass})_{out}\right)}_{E_{out}} = \Delta U$$

If the system is closed :-

$$\sum(\text{Energy by mass})_{in} - \sum(\text{Energy by mass})_{out} = 0$$

So the energy balance equation of closed systems becomes:-

$$\boxed{(Q_{in} + W_{in}) - (Q_{out} + W_{out}) = \Delta U}$$

Specific Heats :-

specific heat :- It's the amount of heat needed to raise the temperature of 1kg of the substance by 1 Kelvin

السعه الحراريه :- كميه الحراره اللازمه لرفع درجه حراره كيلو جرام واحد من ماده معينه درجه واحده.

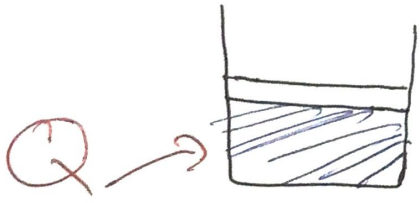
* كل ماده لها سعه حراريه معينه

* We have two types of specific heat :-

C_p C_v

C_p:- It represents the amount of heat that we have to add at constant pressure to increase the T by 1 K

كمية الحرارة اللازم اضافتها على ضغط ثابت لرفع درجة حرارة المادة درجة واحدة

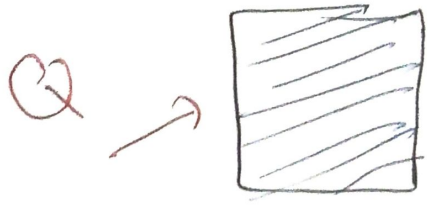


P ≡ constant

because P_{atm} and the weight of the piston are constant....

C_v:- It represents the amount of heat that we have to add at constant volume to increase the T by 1 K

كمية الحرارة اللازم اضافتها على حجم ثابت لرفع درجة الحرارة درجة واحدة



V ≡ constant

[C_p and C_v] = KJ/Kg.K

* C_p and C_v are function of T and they can be found in table A-2 b at different temperatures for different gases and in table A-2 a just at 300 K.

Enthalpy and Internal energy of ideal gases

* First, we have to know that enthalpy and internal energy are function of temperature only for ideal gases

$$\boxed{c_p = R + c_v}$$

$$\boxed{k = \frac{c_p}{c_v}}$$

$$\boxed{c_p > c_v}$$

$$h = h(T) \quad u = u(T)$$

for ideal gases.

$$h = c_p T \qquad u = c_v T$$

for ideal gases

$$\Delta h = c_p \Delta T \qquad \Delta u = c_v \Delta T$$

which c_v & c_p that we have to use in these equations??

It depends on the question

يعتمد على السؤال

ممكن يطلب فرض ان c_p و c_v ثابتان عند درجة الحرارة في الحالة ① (T_1)

فنوجدها من الجدول

وفي بعض الاسئله يطلبها عند 300K

، فنوجدها من جدول A-2a

وفي بعض الاسئله (الغالب) علينا ايجاد Cpavrage

يعني إما نوجد

$$T_{average} = \frac{T_1 + T_2}{2}$$

ثم نوجد Cp و Cv عندها من

جدول A-2b

او نوجد Cv و Cp عند T_1 وعند T_2

ثم

$$C_{v\,average} = \frac{C_{v1} + C_{v2}}{2}$$

$$C_{p\,average} = \frac{C_{p1} + C_{p2}}{2}$$

الطريقه الادق لإيجاد h او U عند

اي حراره هي من جداول الغازات

A-17 To A-22

فهذه الجداول تحوي U و h عند

كل حراره

لكن ننتبه ان من A-18 الى A-22

، تكون U و h بوحدة $\boxed{KJ/Kmol}$

فعلينا ان نقسم على ال
لتحويلها الى KJ/Kg

molar mass

$\Downarrow$

At A-1

End of chapter 4

CHAPTER

5

MASS AND ENERGY ANALYSIS OF CONTROL VOLUMES

Mass and volume flow rates:-

Mass flow rate:- The amount of mass flowing through a cross section per unit time

عدد الكيلوجرامات التي تقطع (تمر) خلال مقطع معين خلال مده معينه

لو فرضنا ان لدينا ماسوره لها مساحه مقطعيه معينه A_c ، وكان هناك مائع له كثافه ρ تدفق خلال هذه الماسوره بسرعه متوسطه V_{avg}

يكون المعدل الزمني لتدفق هذا المائع (mass flow rate) :-

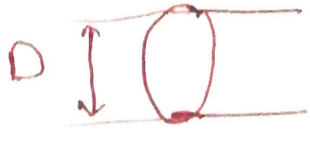
mass flow rate $\longrightarrow$ $\dot{m} = \rho \, V_{avg} \, A_c$

ρ : kg/m^3 ، V_{avg} : m/s ، A_c : m^2

$$[\dot{m}] = kg/s$$

كم kg يمر كل ثانيه

If we have a circular cross section:-



$$A_c = \frac{\pi}{4} D^2$$

Volume flow rate:-

It's the volume of the fluid flowing through a cross section per unit time

كم m^3 تخترق المقطع خلال زمن معين

$m^3/s \rightarrow \dot{V} = V_{avg} A_c$

V_{avg}: m/s , A_c: m^2

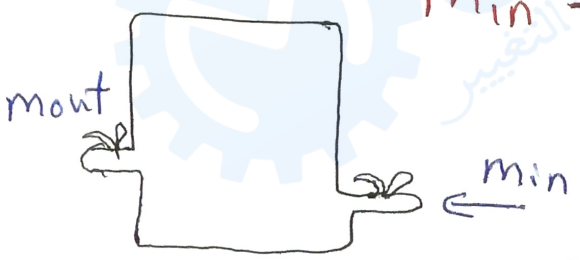
so

$$\dot{m} = \rho V_{avg} A_c$$

$$\dot{m} = \rho \dot{V}$$

Conservation of mass principle:-

$$m_{in} - m_{out} = \Delta m_{system}$$



$$\dot{m}_{in} - \dot{m}_{out} = \Delta \dot{m}_{system}$$

معدل الدخول

معدل الخروج

معدل تغير كتلة النظام

(مثلا كل ثانية بيزيد بمقدار — او بيقل)

Mass balance of steady flow devices:-

Steady flow devices:-

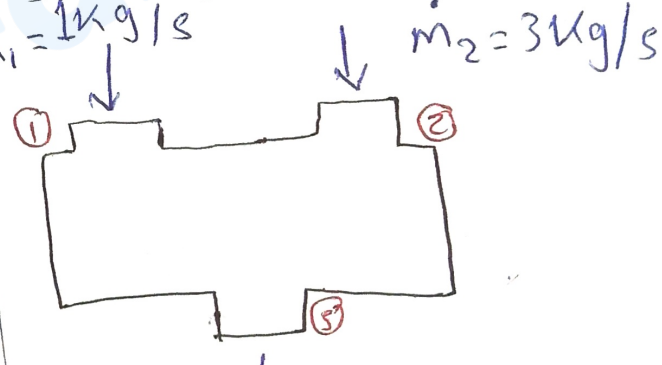
هي احد انواع الـ control volumes والتي تتميز بالعديد من الخصائص منها :-

$$\sum_{in} \dot{m} = \sum_{out} \dot{m}$$

$$\dot{m}_{in} = \dot{m}_{out} \qquad \Delta \dot{m}_{system} = 0$$

* في هذه الاجهزه ، هناك كتل تدخل و تخرج بنفس الوقت ، و مجموع الكتل الداخله = مجموع الكتل الخارجه

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$



$$\dot{m}_3 = \dot{m}_1 + \dot{m}_2 = 1 + 3 = 4 Kg/s$$

$$\boxed{\begin{aligned} \dot{m}_{in} &= \dot{m}_{out} \\ \rho_1 V_1 A_1 &= \rho_2 V_2 A_2 \end{aligned}}$$

single stream (مدخل واحد و مخرج واحد)

$$\left(\rho_1 \cdot V_1 \cdot A_1 + \rho_2 \cdot V_2 \cdot A_2 + \rho_3 V_3 A_3 \cdots\right)_{in} = \left(\rho_1 V_1 A_1 + \rho_2 V_2 A_2 + \cdots\right)_{out}$$

Special case (Incompressible flow)

* The incompressible fluids like liquids, have constant densities.

$$\rho \approx \text{constant}$$

so if an incompressible fluid flows through a steady flow device:-

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

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

$$\rho_1 \approx \rho_2$$

$$V_1 A_1 = V_2 A_2$$

$$\dot{V}_1 = \dot{V}_2$$

$$\sum \dot{V}_{in} = \sum \dot{V}_{out}$$

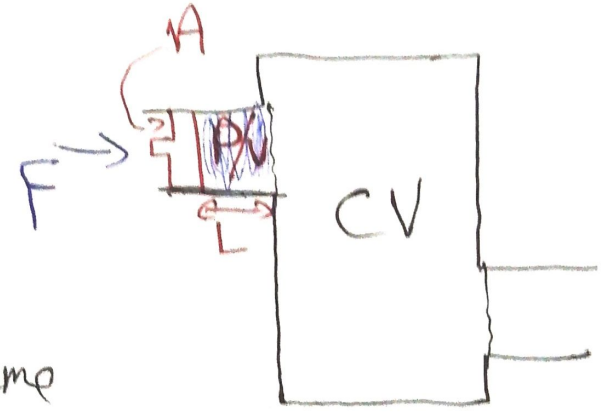
Flow work :-

$W = FL$

$W = PAL$

$W = PV$

flow work — Pressure — volume



Any flowing fluid carries a type of energy called flow energy

---

Total energy carried by any flowing fluid :-

$$E_{mass\,(fluid)} = W_{flow} + U + K.E + P.E$$

$$E_{mass\,(fluid)} = PV + U + \frac{1}{2}mV^2 + mgh$$

$$PV + U = h$$

$$\boxed{E_{mass\,(fluid)} = h + K.E + P.E}$$

$$\dot{E}_{mass} = \dot{m}\,(h + P.E + K.E)$$

rate of energy tranferred to or from a system by mass (Power)

h : KJ/kg, $P.E$: KJ/kg, $K.E$: KJ/kg

$P.E = gh$

$K.E = \frac{1}{2}V^2$

$(KJ/s = KW)$

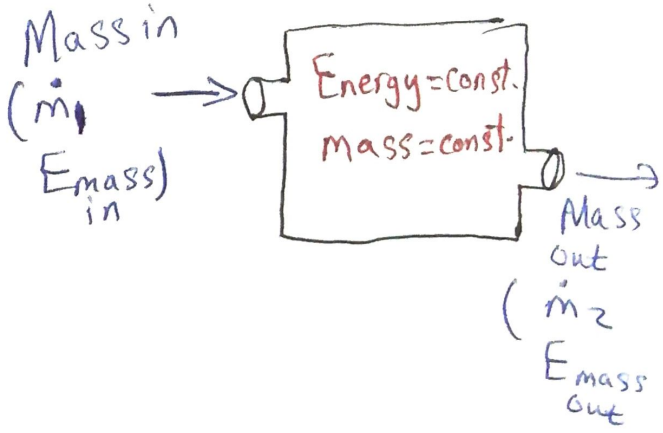
Open systems (control volumes)

- Steady flow systems
- unsteady flow systems

1 – steady flow systems:–

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

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$



$$\Delta \dot{E}_{system} = 0$$

$$\dot{E}_{in} - \dot{E}_{out} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$(\dot{Q}_{in} + \dot{W}_{in} + \sum \dot{E}_{mass\,in}) = (\dot{Q}_{out} + \dot{W}_{out} + \sum \dot{E}_{mass\,out})$$

$$\sum \dot{E}_{mass\,in} = \dot{m}_1 \left(h_{in} + K.E_{in} + P.E_{in} \right)$$

$$\dot{Q}_{in} + \dot{W}_{in} + \sum \dot{m} \left(h_{in} + K.E_{in} + P.E_{in} \right)$$

$$= \dot{Q}_{out} + \dot{W}_{out} + \sum \dot{m} \left(h_{out} + K.E_{out} + P.E_{out} \right)$$

$$\boxed{\left(\dot{Q}_{in} + \dot{W}_{in} \right) - \left(\dot{Q}_{out} + \dot{W}_{out} \right) = \dot{m} \left(\Delta h + \Delta P.E + \Delta K.E \right)}$$

for steady flow systems (single inlet and outlet)

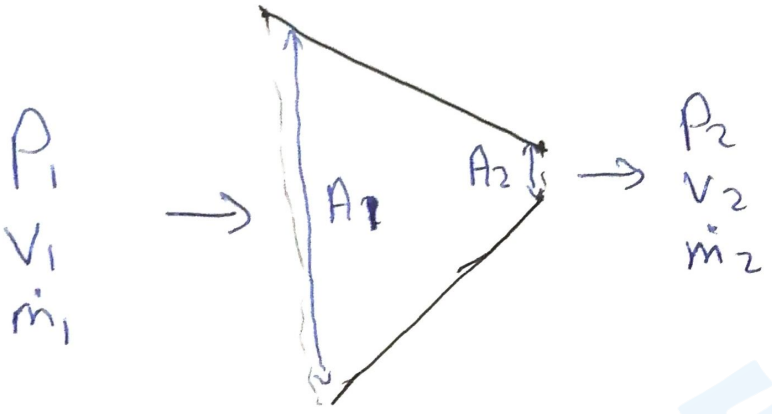
Types of engineering steady flow devices

- Turbine
- Pump
- compressor
- mixing chamber
- Nozzle
- Diffuser
- Throttling Valve
- Heat exchanger
- pipe and Duct

1- Nozzle and Diffuser :-

Nozzle :-

It's a steady flow device used to increase the velocity of the fluid by decreasing it's pressure.



$P_2 < P_1$

$V_2 > V_1$

$A_2 < A_1$

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

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

First law :-

$$(\dot{Q}_{in} + \dot{W}_{in}) - (\dot{Q}_{out} + \dot{W}_{out}) = \dot{m}\,(\Delta h + \Delta P.E + \Delta K.E)$$

mainly

$$\begin{cases} Q_{in} = Q_{out} = 0 \\ W_{in} = W_{out} = 0 \\ \Delta P.E = 0 \end{cases}$$

$$0 = \dot{m}\,(\Delta h + \Delta K.E)$$

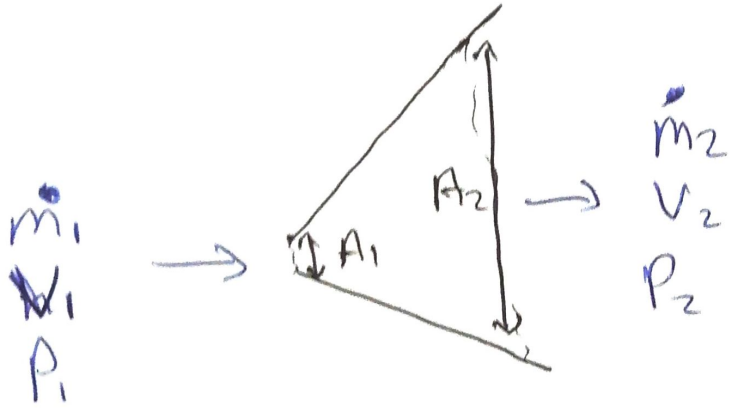
$$\dot{m}\,(-h_2 + h_1) = \dot{m}\,(K.E_2 - K.E_1)$$

$$-\dot{m}h_2 + \dot{m}h_1 = \dot{m}\,K.E_2 - \dot{m}\,K.E_1$$

$$\dot{m}\,(h_{in} + \tfrac{1}{2}V_{in}^2) = \dot{m}\,(h_{out} + \tfrac{1}{2}V_{out}^2$$

Diffuser :-

It's a steady flow device that increases the pressure of the fluid by decreasing it's velocity



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

$P_2 > P_1$

$V_2 < V_1$

$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$

First law :-

$E_{in} = E_{out}$

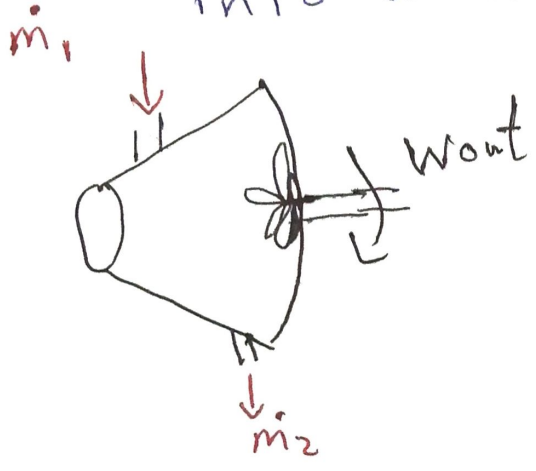
$$\cancel{\dot{Q}_{in}} + \cancel{\dot{W}_{in}} + \dot{m}(h_{in} + K.E_{in} + \cancel{P.E_{in}}) = \cancel{\dot{Q}_{out}} + \cancel{\dot{W}_{out}} + \dot{m}(h_{out} + K.E_{out} + \cancel{P.E_{out}})$$

$$\dot{m} h_{in} + \dot{m} K.E_{in} = \dot{m} h_{out} + \dot{m} K.E_{out}$$

$$\dot{m} h_{in} + \frac{1}{2} \dot{m} V_{in}^2 = \dot{m} h_{out} + \frac{1}{2} \dot{m} V_{out}^2$$

2- Turbine:-

It's a steady flow device that converts the energy of the fluid into a shaft work



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

First law analysis:-

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\cancel{\dot{Q}_{in}} + \cancel{\dot{W}_{in}} + \dot{m}(\cancel{K.E_{in}} + h_{in} + \cancel{P.E_{in}})$$

$$= \dot{W}_{out} + \cancel{\dot{Q}_{out}} + \dot{m}(\cancel{K.E_{out}} + h_{out} + \cancel{P.E_{out}})$$

$$\boxed{\dot{m}(h_{in}) = \dot{W}_{out} + \dot{m}(h_{out})}$$

We have many types of turbines

- Steam turbine
- gas turbine
- Hydraulic turbine
- Wind turbine

In thermodynamics, we just study steam and gas turbines.

3- Compressor and pump

Compressor :-

It's a device that is used to compress (increase the pressure) of gases by consuming work

$$\dot{E}_{in} = \dot{E}_{out}$$

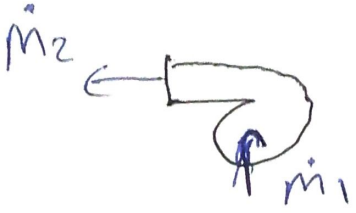
$$\cancel{\dot{Q}_{in}} + \dot{W}_{in} + \dot{m}(\cancel{P.E_{in}} + \cancel{K.E_{in}} + h_{in}) \quad W_{in}$$

$$= \cancel{\dot{Q}_{out}} + \cancel{W_{out}} + \dot{m}(\cancel{P.E_{out}} + \cancel{K.E_{out}} + h_{out})$$

$$\dot{W}_{in} + \dot{m} h_{in} = \dot{m} h_{out}$$

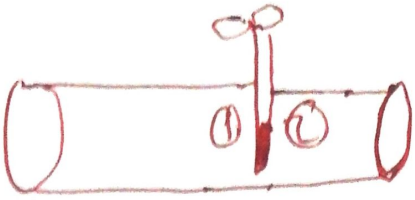
pump :-

It's a device that is used to compress (increase the pressure) of liquids by consuming work



$$W_{in} + \dot{m} h_{in} = \dot{m} h_{out}$$

4_ Throttling valve



It's a device that decreases the pressure of the fluid and contains a constant enthalpy process

Energy analysis

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\cancel{\dot{Q}_{in}} + \cancel{\dot{W}_{in}} + \dot{m}(h_{in} + \cancel{P.E_{in}} + \cancel{K.E_{in}})$$
$$= \cancel{\dot{Q}_{out}} + \cancel{\dot{W}_{out}} \; \dot{m}(h_{out} + \cancel{P.E_{in}} + \cancel{K.E_{out}})$$

$$h_{in} = h_{out}$$

$P =$ constant

so $T_2 < T_1$

* It's mainly used in air conditioning applications

In ideal gases:-

$h(T)$

$h_1 = h_2$

so

$T_1 = T_2$

Some types

- Adjastable valve

- Porous plug

- Capillary tube

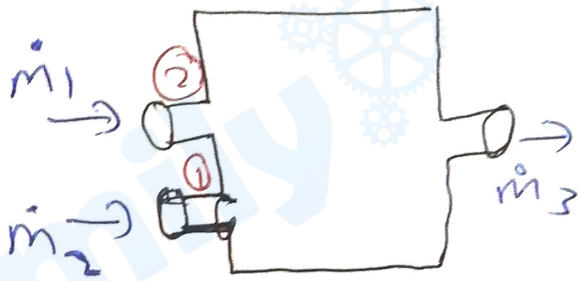
5- Mixing chamber

It's a device that is used to mix fluids.

* An important example is <u>shower</u>

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

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



$$\dot{E}_{in} = \dot{E}_{out}$$

$$\cancel{\dot{Q}_{in}} + \cancel{\dot{W}_{in}} + \sum \dot{m}_{in}(h_{in} + \cancel{P.\mathcal{E}_{in}} + \cancel{K.\mathcal{E}_{in}})$$

$$= \cancel{\dot{Q}_{out}} + \cancel{\dot{W}_{out}} + \sum \dot{m}_{out}(h_{out} + \cancel{P.\mathcal{E}_{out}} + \cancel{K.\mathcal{E}_{out}})$$

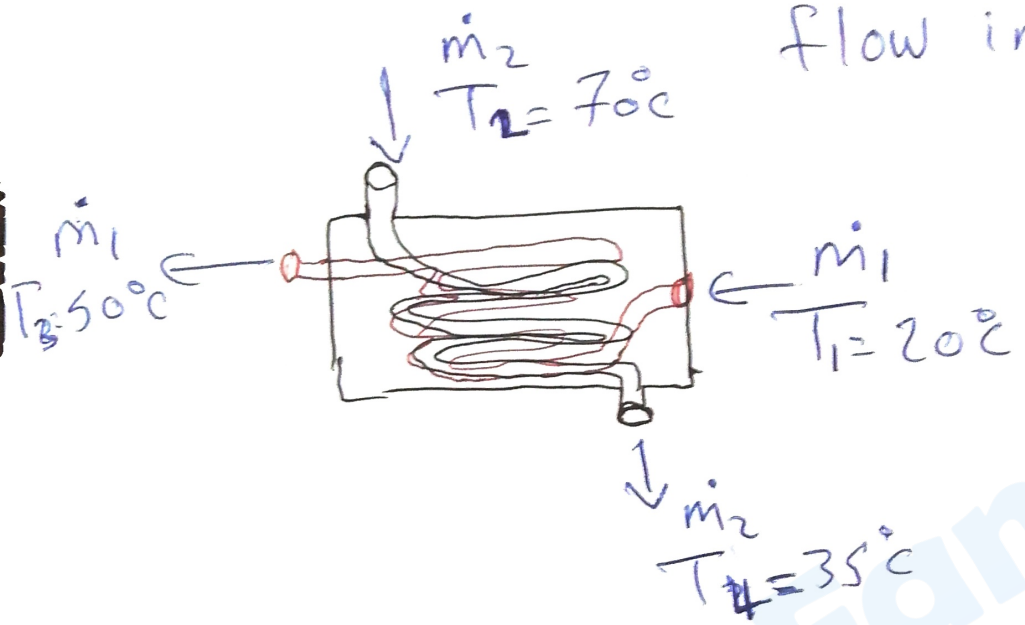
$P_1 \approx P_2 \approx P_3$

$$\sum \dot{m}_{in} h_{in} = \sum \dot{m}_{out} h_{out}$$

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

6- Heat exchanger :-

It's a device that is used to tranfer heat between two fluids flow in two streams



$$\dot{m}_1 = \dot{m}_1$$

$$\dot{m}_2 = \dot{m}_2$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\cancel{\dot{Q}_{in}} + \cancel{\dot{W}_{in}} + \sum \dot{m}\left(\cancel{KE_{in}} + h_{in} + \cancel{PE_{in}}\right) = \cancel{\dot{Q}_{out}} + \cancel{\dot{W}_{out}} + \sum \dot{m}\left(\cancel{KE_{out}} + \cancel{PE_{out}} + h_{out}\right)$$

$$\sum_{in} \dot{m}\,(h_{in}) = \sum_{out} \dot{m}\,(h_{out})$$

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

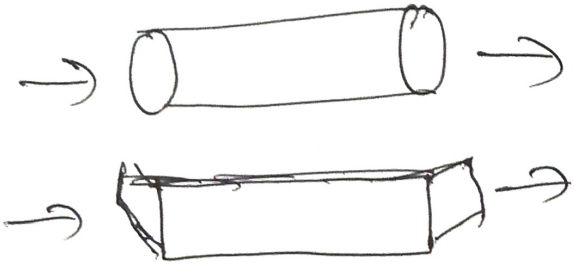
$\dot{Q}$ between two stream

$$= \dot{m}_1 (h_3 - h_1) = \dot{m}_2 (h_4 - h_2)$$

7- Pipe and duct

They are used to transport fluids.

* The difference between them is that the pipe has a circular cross section, while duct has rectangular cross section



* They can contain any type of energy interactions

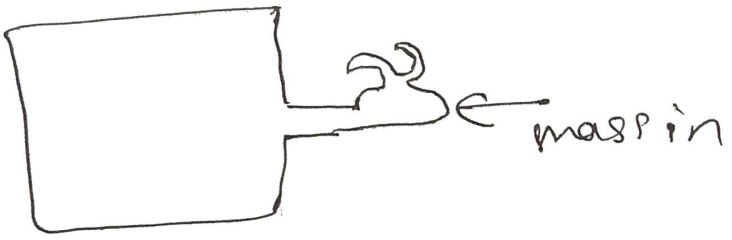
$$\dot{E}_{in} = \dot{E}_{out}$$

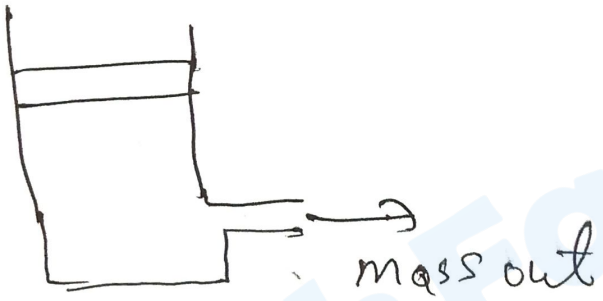
$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m}(h_{in} + K.E_{in} + P.E_{in})$$

$$= \dot{Q}_{out} + \dot{W}_{out} + \dot{m}(h_{out} + K.E_{out} + P.E_{out})$$

Unsteady flow system:-

It just contains either mass in or mass out





$U_2 - U_1$

$$E_{in} - E_{out} = E_2 - E_1$$

$$m_{in} - m_{out} = \Delta m_{system}$$

$m_2 - m_1$

End of chapter 5

CHAPTER

6

THE SECOND LAW OF THERMODYNAMICS

Mech Family

Efficiency الكفاءه

$$\eta = \frac{\text{output}}{\text{input}}$$

output ← الناتج

input ← المصروف

تعبر عن النسبه المستفاده
من الشيء المصروف

كفاءه المدفأه ⇒ $\eta = \frac{\text{Heat}}{\text{electrical energy}}$

Reservior:-

They are systems that have very large thermal energy capacity (mass X Specific heat) or heat capacity

هي انظمه لها سعه حراريه كبيره جدا
KJ/K
بحيث ان مقدار الطاقه الحراريه اللازم لرفع درجه حرارتها درجه واحده تكون كبيره جدا جدا ، وهذه السعه الحراريه الكبيره ناتجه من كتلتها او كميتها الضخمه

Some examples of reservior:-

- River
- Ocean
- Atmosphere

* مثلا تشغيل ولاعه في الجو لن تزيد من درجه حرارته ابدا

* اي كوب شاي ساخن في نهر لن يؤثر على درجه حرارته

(It's just a latent heat)

Second law of thermodynamics :-

1 - Any process occur in a certain direction and not in the reverse direction.

Ex: Heat transfers from the hotter medium to the colder one, not the opposite.

2 - Higher quality (like work) energy can be converted totally to lower quality (like heat), but part of lower quality can be converted to higher quality.

Ex:-

Electric heater
(input = electric work
output = heat
so it's efficiency $\approx 100\%$)

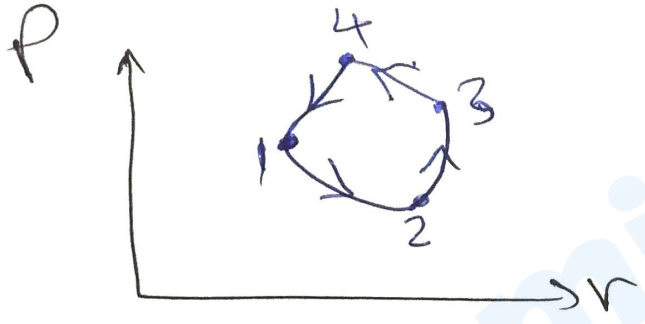
Car engine
(input = heat
output = electric work
so it's efficiency $< 100\%$)

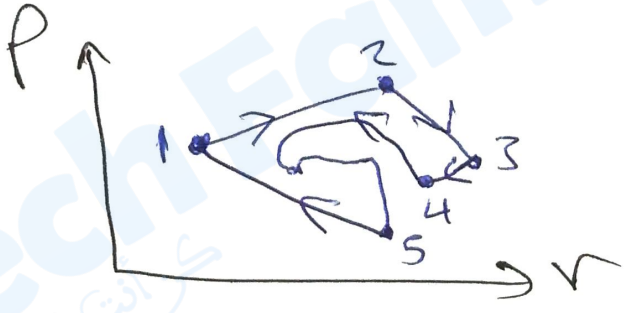
3 - No heat engine with $\eta = 100\%$

Cycle:-

It represents a set of processes done that the first state = final state

تعبر عن عمليات مختلفة تحدث بحيث الحالة النهائية
≡ الحالة الابتدائية





Cycles

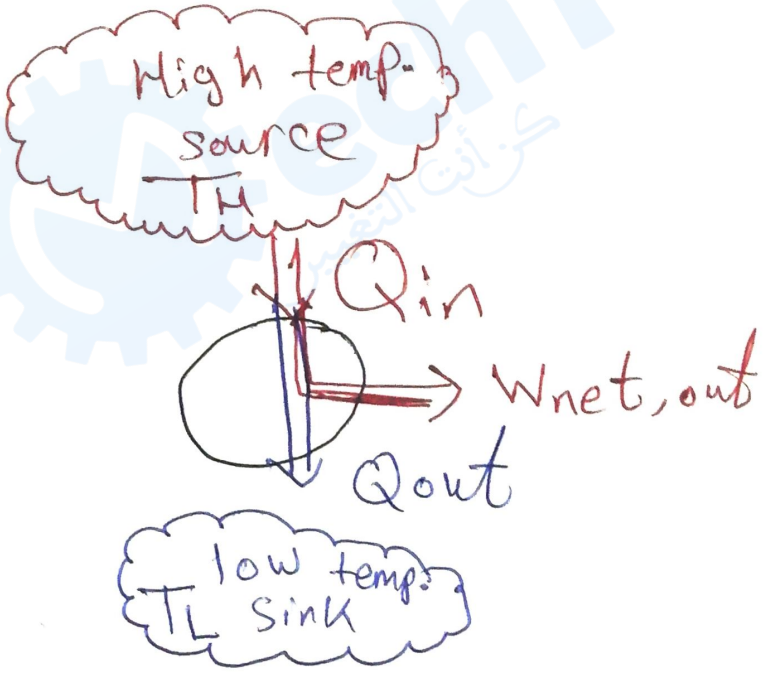
- **Thermodynamic cycles**
  The working fluid is recycled in each cycle (same fluid)
- **Mechanical cycles**
  The working fluid is rejected at the end of the cycle and a new fluid enters the cycle when a new cycle starts

Heat engine :-

It's a device that recieves heat from a heat source and converts part of it into work and the other part is rejected to a heat sink.

* Heat engine works on thermodynamic cycle

جهاز يستقبل حرارة (طاقة حرارية Q Heat) من مصدر ذو درجة حرارة عالية ويحول جزء من هذه الطاقة الى شغل والجزء الاخر يتم التخلص منه.



* Car engine is not a heat engine because it works on a mechanical cycle

* Steam power plant is an example of heat engines.

Steam powerplant :-

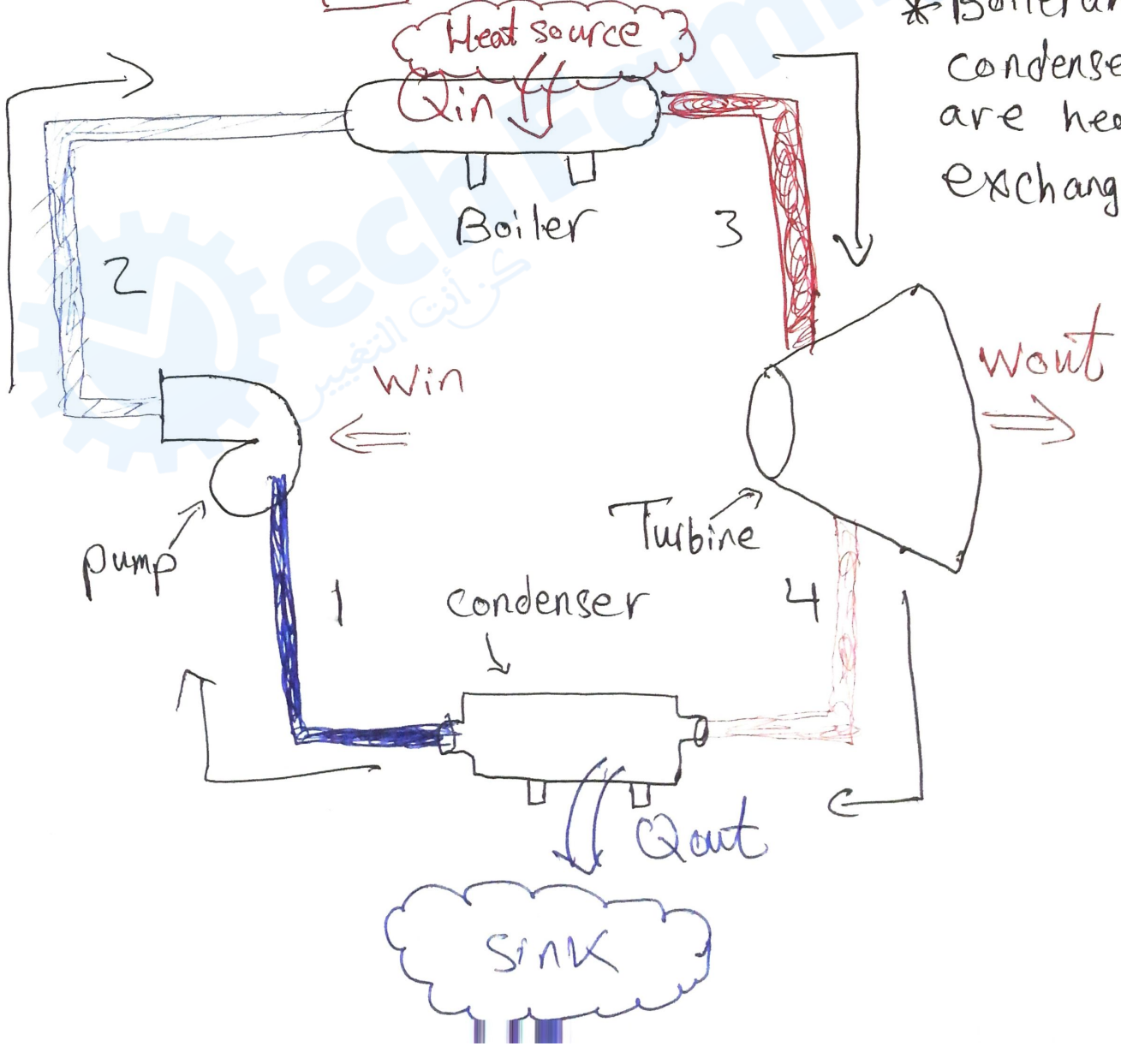
محطة تعمل على cycle مكونة من (4processes) هدفها انتاج الطاقة الكهربائية

الدوره مكونة من (4 components) :-

1. pump
2. Boiler
3. Turbine
4. condenser

* The working fluid is water.

* Boiler and condenser are heat exchangers



processes :-

(1 - 2): Compression of a liquid by a pump (W_{in})

(2 - 3): Heat addition in a boiler (Q_{in})

(3 - 4): The steam do a work in side the turbine (W_{out})

(4 - 1): Heat is rejected by a codenser.

---

the cycle is considered as a closed system :-

$$(Q_{in} + W_{in}) - (Q_{out} + W_{out}) = \Delta U$$

Through a complete cycle :- $\Delta U = 0$

$$Q_{in} + W_{in} - Q_{out} - W_{out} = 0$$

$$Q_{in} - Q_{out} = W_{out} - W_{in}$$

$$\boxed{Q_{in} - Q_{out} = W_{net}}$$

Thermal efficiency:-

$$\eta_{th} = \frac{\text{output}}{\text{input}}$$

output ← الناتج

input ← المصروف

$$\eta_{th} = \frac{W_{net}}{Q_{in}}$$

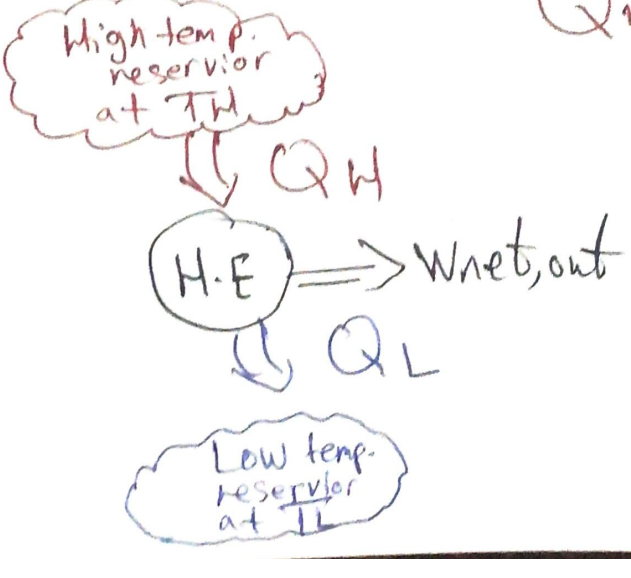
$$\eta_{th} = \frac{Q_{in} - Q_{out}}{Q_{in}}$$

$$\eta_{th} = 1 - \frac{Q_{out}}{Q_{in}}$$

* η_{th} تعبر عن كم بالمية من الحرارة اللي صرفناها تحول الى work

$$Q_{in} = Q_H$$

$$Q_{out} = Q_L$$



$$W_{net,out} = Q_H - Q_L$$

$$\eta_{th} = 1 - \frac{Q_L}{Q_H}$$

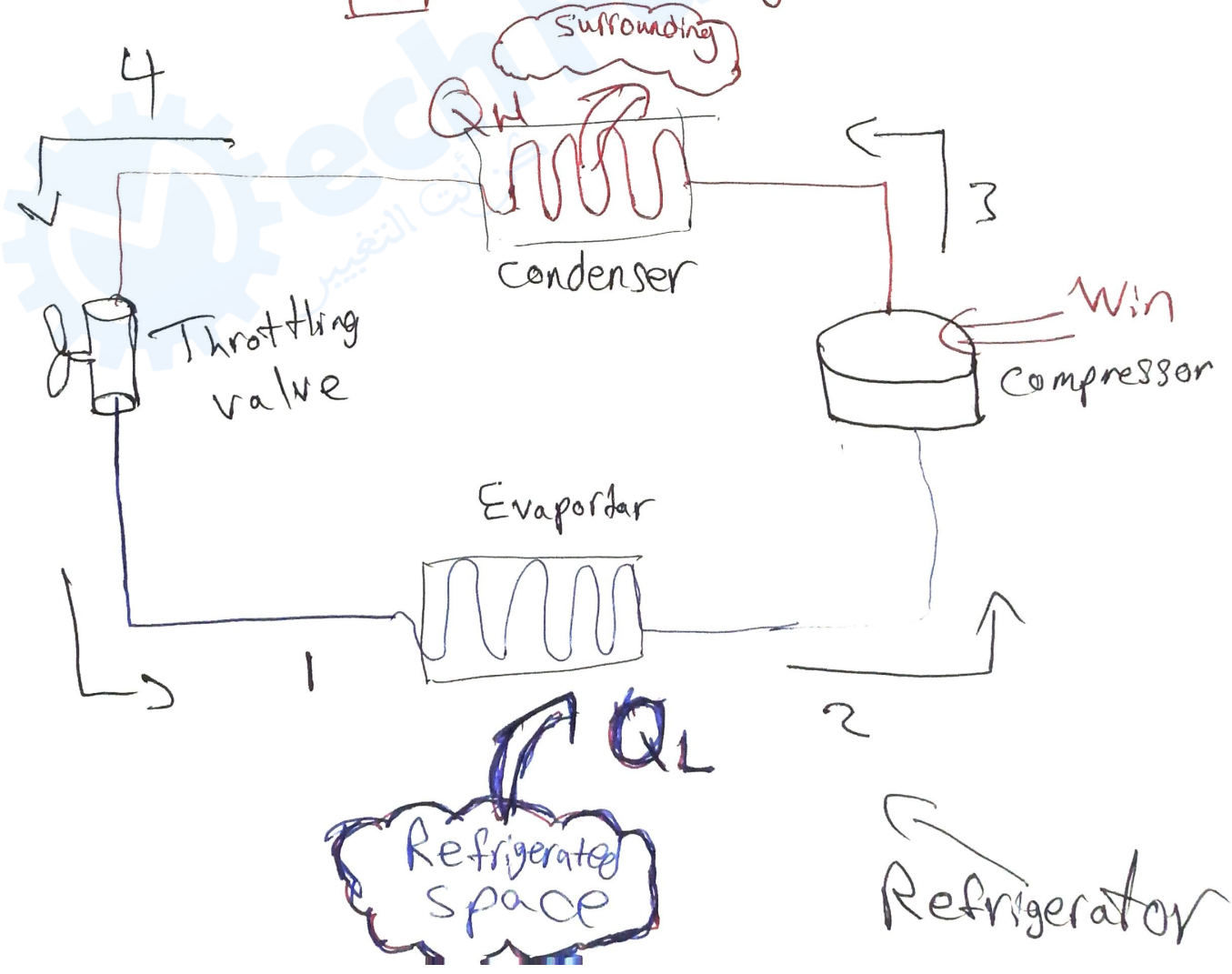
Refrigerators and Heat Pumps :-

* اجهزة التكييف والتبريد والتدفئة بشكل عام تعمل على cycles

* The cycle contains :-

* R-134a is used as a working fluid

1. Evaportor
2. compressor
3. Condenser
4. Throttling valve



Processes:-

(1-2) Absorbing heat from the refrigerated space (Q_L)

(2-3) compressing the fluid by consuming work (W_{in})

(3-4) rejecting the absorbed heat to the surrounding (Q_H)

(4-1) Expansion by a throttle valve

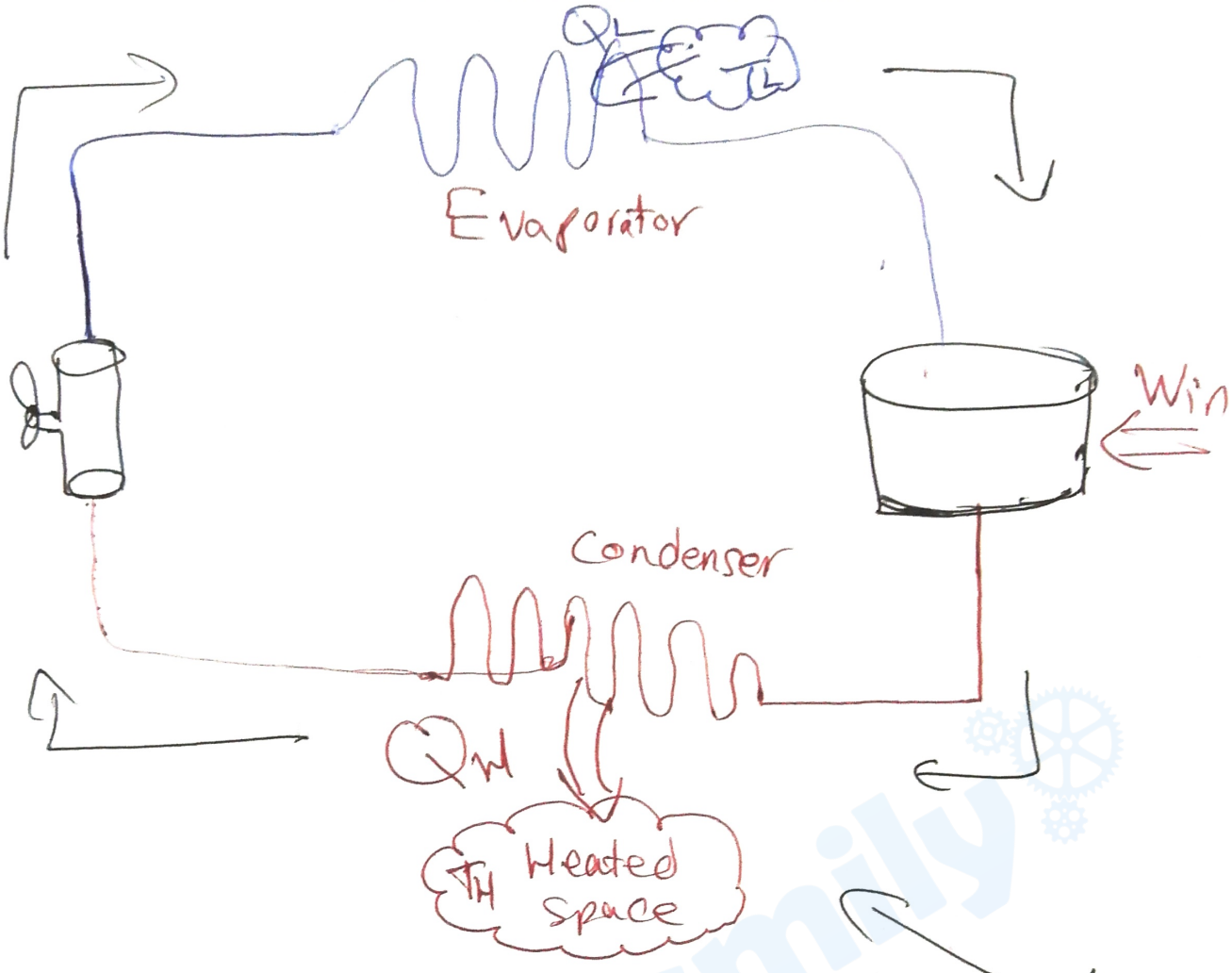
$$(Q_{in} + W_{in}) - (\cancel{W_{out}} + Q_{out}) = 0$$

$$Q_L + W_{in} - Q_H = 0$$

$$W_{in} = Q_H - Q_L$$

* The efficiency of the cycle is expressed by coefficient of performance

$$COP_R = \frac{Q_L}{W_{in}}$$



Heat pump

$$COP_{HP} = \frac{Q_H}{W_{in}}$$

* فكرة عمل ال HP وال R ، انه
يتم ضخ حراره من المكان الابرد الى ال
المكان الاسخن بطريقه منطقيه
ولا تخالف قوانين الـ Thermodynamics
وباستهلاك شغل

* Pumping Heat from low temperature medium (T_L) To high temperature medium (T_H)

$$COP_{HP} = COP_R + 1$$

$$COP_{HP} > COP_R$$

Reversible and irreversibilities:-

العوائق والمثالية

Reversible process:-

It's a process that doesn't contain any irreversibilities

عملية ليس فيها عوائق

Irreversibilities

- Friction
- Heat transfer due to temperature difference
- Fast processes

Reversibility

- Internally reversible
  - ⇓
  - No friction
  - Slow process
  - Heat transfer is allowed
- Externally reversible
  - Heat transfer is very low
  - there is friction
  - + the process is

$$COP_{HP} = COP_R + 1$$

$$COP_{HP} > COP_R$$

Reversible and irreversibilities:-

العوائق والمثالية

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It's a process that doesn't contain any irreversibilities

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Reversibility

- Internally reversible
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- Externally reversible
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  - there is friction
  - + the process is

Externally reversible + Internally reversible = Totally reversible

* كلما كانت الـ irreversibilities اقل
كلما زادت كفاءة العملية

Carnot cycle :-

هي دورة مثالية وخالية تماماً من
العوائق
(Totally reversible)

Carnot heat engine :-

النموذج المثالي والأعلى كفاءة لأي
Heat engine

- No friction
- No temperature difference
  (it's so low)
- slow processes

Carnot heat engine processes :-

1-2 reversible isothermal heat addition (expansion)

2-3 reversible adiabatic expansion

3-4 reversible isothermal heat rejection (compression)

4-1 reversible adiabatic compression.

In carnot (reversible) :-

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

$$\eta_{th,\,carnot} = 1 - \frac{T_L}{T_H}$$

T_L = Temperature of heat sink in Kelvin

T_H = Temperature of heat source.

* لا يوجد اي Heat engine كفاءته تتعدى كفاءة η_{carnot}

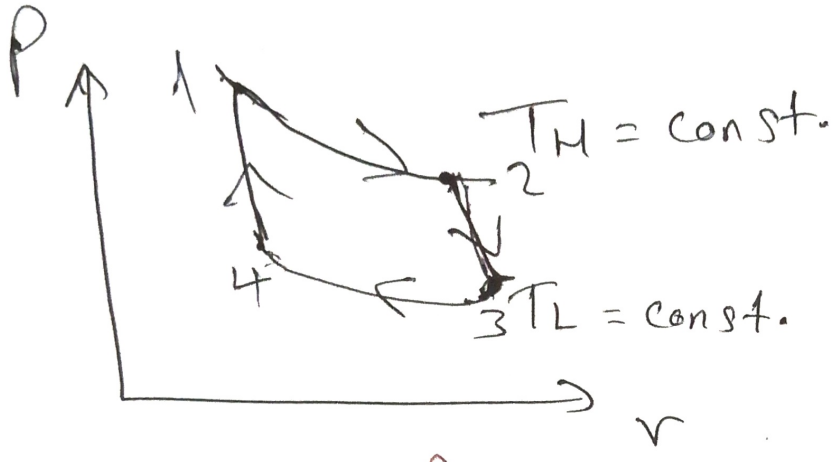
* كارنوت يعبّر عن افضل اداء يمكن ان يصله اي Heat engine

* لا يمكن تطبيق كارنوت في الواقع

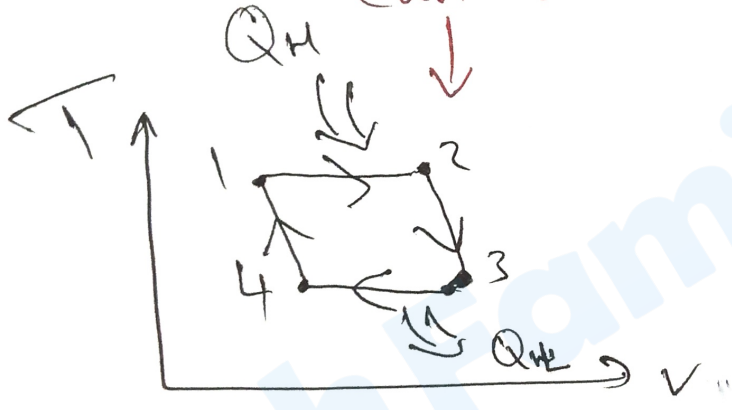
* يعني لو لدينا مثلاً steam power plant ، نستطيع ايجاد اعلى كفاءه يمكن ان تصلها المحطه من خلال معرفه درجه حراره مصدر الحراره (T_H) ودرجه حراره طارد الحراره (المبرد) (T_L)

$$\eta_{carnot} = 1 - \frac{T_L}{T_H}$$

نحن لا نستطيع ان نصل الى الاداء المثالي (carnot) ، لكن يمكننا محاوله الاقتراب منه



carnot



* We have to know that, if we increase T_H (temp. of heat source), the η_{th} increases

Carnot refrigerator & Heat pump

$$COP_R = \frac{Q_L}{W_{in}} = \frac{Q_L}{Q_H - Q_L}$$

$$= \frac{1}{Q_H/Q_L - 1}$$

$$COP_{R,\,carnot} = \frac{1}{T_H/T_L - 1}$$

$$COP_{HP,\,carnot} = \frac{1}{1 - T_L/T_H}$$

COP carnot is the highest possible of any refrigeration cycle.

* It represents the best performance

End of chapter 6

CHAPTER

7

ENTROPY

Mech Family

Entropy :-

It's a measure of molecular disorder or molecular randomness.

مقياس لمقدار العشوائية او الاضطراب داخل النظام

* كلما كانت الـ entropy (العشوائية) اعلى ، كانت كفاءة الجهاز او العملية اقل ، فنحاول دائماً التقليل منه

How does entropy change (tranfer)?

- By heat tranfer
- By irreversibilities (friction)
- By mass

* The work doesn't produce entropy.

$$S_{in} - S_{out} + S_{gen} = \Delta S_{system}$$

Entropy balance equation

$$\Delta S_{system} = S_2 - S_1$$

S_2: Entropy at the end of the process (final state)

S_1: Entropy before the process starts

$$S_{in} = \frac{Q_{in}}{T_H} + m\,S_{in}$$

$\frac{Q_{in}}{T_H}$: Entropy transfered by heat

$m\,S_{in}$: Entropy transfered by mass

$$S_{out} = \frac{Q_{out}}{T_L} + m\,S_{out}$$

$S_{gen} \equiv$ Entropy generated by friction

Entropy calculations:-

1- For closed systems:-

$$\frac{Q_{in}}{T_H} - \frac{Q_{out}}{T_L} + S_{gen} = \Delta S_{system}$$

$$\Delta S_{system} = S_2 - S_1$$

* S at any state for any pure substance (R-134a/water) can be found from their tables.

$S_2 - S_1$ For ideal gases:-

$$\Delta S_{system} = C_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1}$$

OR

$$\Delta S_{system} = C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

For constant specific heats

$$\Delta S_{system} = s_2^\circ - s_1^\circ - R \ln \frac{P_2}{P_1}$$

for variable specific heat

s° can be found from ideal gas tables (A-17 ----)

$* \; s^\circ (T)$

For steady flow system:-

$$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = dS/dt$$

In steady flow systems, there is no change in entropy.

$$\left(\frac{\dot{Q}_{in}}{T_H} + \dot{m} s_{in}\right) - \left(\frac{\dot{Q}_{out}}{T_L} + \dot{m} s_{out}\right) + \dot{S}_{gen} = 0$$

$$\frac{\dot{Q}_{in}}{T_H} - \frac{\dot{Q}_{out}}{T_L} + \dot{m}(s_{in} - s_{out}) + \dot{S}_{gen} = 0$$

* S_{in} & S_{out} for pure substances can be found from their tables.

For ideal gases

$$S_{in} - S_{out} = S^{\circ}_{in} - S^{\circ}_{out} - R \ln \frac{P_{in}}{P_{out}}$$

variable specific heats

$$S_{in} - S_{out} = C_v \ln \frac{T_{in}}{T_{out}} + R \ln \frac{V_{in}}{V_{out}}$$

Isentropic process :-

It's a constant entropy process.

$$S_1 = S_2$$

If we have a reversible adiabatic process, then we have to know that it's an isentropic process

reversible $\Rightarrow$ $S_{gen} = 0$

adiabatic $\Rightarrow$ $S_{heat} = 0$

isentropic $\Rightarrow$ $\Delta S_{system} = 0$

Minimizing compressor's work :-

$$W_{rev,in} = \int v\,dP$$ (Area under v-P diagram)

Isentropic :- $(Pv^k = C)$

$$W_{comp,in} = \frac{kR(T_2 - T_1)}{k-1} = \frac{kRT_1}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k} - 1\right]$$

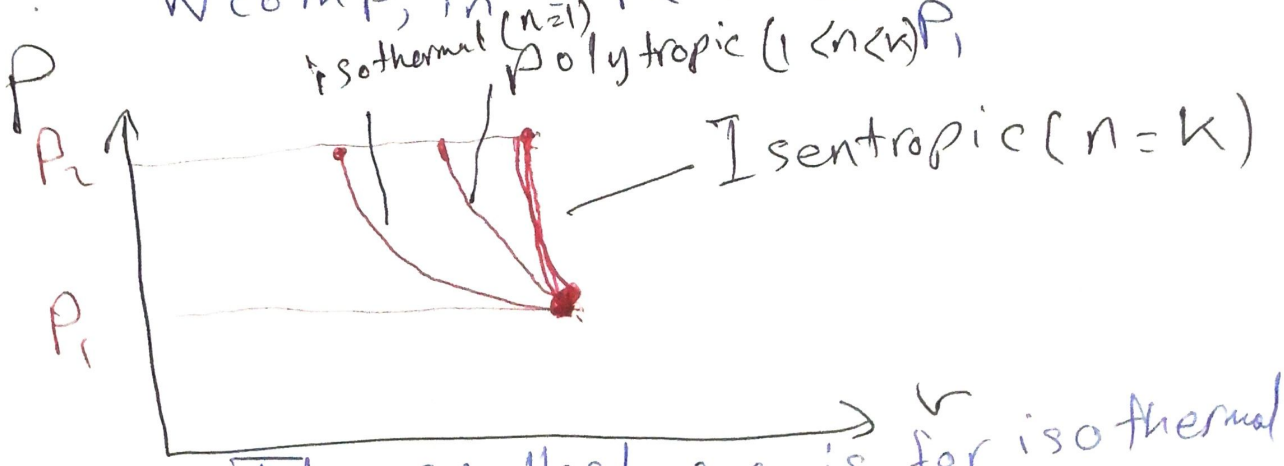
Polytropic :- $(Pv^n = C)$

$$W_{comp,in} = \frac{nR(T_2 - T_1)}{n-1}$$

$$= \frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{n-1/n} - 1\right]$$

Isothermal :- $(Pv = C)$

$$W_{comp,in} = RT \ln \frac{P_2}{P_1}$$



The smallest area is for isothermal, so Win of isothermal is the minimum one

Isentropic efficiencies of steady flow systems:-

تعبر عن نسبه الاستفاده من الحاله المثاليه .

$$\eta_{Turbine,is.} = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}}$$

$$= \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

$s_{in} = s_{out}$

$$\eta_{compressor,is} = \frac{\text{Isentropic compressor work}}{\text{Actual compressor work}}$$

$$= \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

$$\eta_{Nozzle,is} = \frac{\text{Actual K.E at the exit}}{\text{Isentropic K.E at the exit}}$$

$$= \frac{V_{2a}^2}{V_{2s}^2}$$

$$h_1 = h_{2a} + \frac{V_{2a}^2}{2}$$

$$h_1 = h_{2s} + \frac{V_{2s}^2}{2}$$

End of chapter 7