Subject Lec. #6 1-25 (# slides) موضوع الدرس

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① mixer & splitter : $\boxed{\Delta H = 0}$

② Heat exchanger : $\boxed{\dot{Q} = \Delta H}$ idealized to be "isobaric"

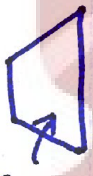
③ Throuttling process : $\boxed{\Delta H = 0}$ "isenthalpic"

: any kind of flow restricting devises that causes appreciable pressure drop in the fluid stream.

- to go to lower pressure (changing phase $l \rightarrow$ vapor)
- drop with P & so drop in Temp. (except ideal gas no Temp.).
- $l \rightarrow$ saturated wet $\rightarrow$ superheated

a. adjustable valves b. porous plugs.

compressor



Turbine

④ Turbine : $\boxed{\dot{W}_s = \Delta H}$ "isentropic" → reversible adiabatic

: produce work by ↓ pressure (drives the electric gen.)

:::: driving fluid & exhaust

- case # 1 : superheated → superheated
- case # 2 : wet → superheated
- case # 3 : saturated liquid → wet stream

max. shaft work $\dot{W}_s$ is isentropic (adiabatic turbine)

$\eta = \dot{W} / \dot{W}_s(\text{isentropic}) = \Delta H / \Delta H_s$ 0.7 - 0.8

حتى القوانين و التعاريف

⑤ Compressors : [same info. as turbine but opposite function]

:::: suction & discharge ↑ pressure of a gas stream.

compression ratio = Pdischarge / Psuction (3-5) value

to achieve; multistage operation with inter-cooling (3 for single stage)

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⑥ Fans, blowers : same as compressor but lower compression ratio.

: slighty increase in pressure of a gas stream, mainly to mobalize it.

∴ suction, discharge $W > 0$ (by the system)

⑦ Pumps : it is the counter part of a compressor for liquid.

: increase pressure of liquid stream +ve work

$$\dot{W}_s \text{ (isentropic)} = (\Delta h)_s = v(P_2 - P_1)$$

∴ A good approximation $\Delta h = c_p \Delta T + v \Delta P (1 - \beta T)$

$$\Delta S = c_p \ln \frac{T_2}{T_1} - \beta v \Delta P$$

$$x_2 = \frac{h_2 - h_f}{h_f - h_g}$$ $\left[\theta = x\theta_v + (1-x)\theta_l \quad x = \frac{\theta - \theta_l}{\theta_v - \theta_l} \text{ Generally} \right]$

$\dot{m} = \dot{W}_{out}$ ← extensive

w_{out} ← intensive

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

gas to be compressed is an ideal gas with constant heat capacity $\dot{W}_s = c_p(T_2' - T_1) = c_p T_1 \left[\left(\frac{P_2}{P_1} \right)^{R/c_p} - 1 \right]$

$$T_2' = T_1 \left(\frac{P_2}{P_1} \right)^{R/c_p}$$

→ For non isentropic gas $T_2 = T_1 + \frac{T_2' - T_1}{\eta}$

Lec. 15 : entropy & second law + Lec.16 دجمعها أملى الدكتور

∴ entropy is an intrinsic property (state function)

∴ $\boxed{ds = \frac{dQ_{rev.}}{T}}$

∴ Entropy does not change in a cyclic heat engine $\boxed{\frac{Q_H}{T_H} = -\frac{Q_c}{T_c}}$

∴ For an ideal gas
$$\boxed{\begin{aligned} \frac{dS}{R} &= \frac{C_P^{IG}}{R}\frac{dT}{T} - d\ln P \\ \frac{\Delta S}{R} &= \int_{T_o}^{T} \frac{C_P^{IG}}{R}\frac{dT}{T} - \ln\frac{P}{P_o} \end{aligned}}$$
applies to arbitrary entropy changes of ideal gas (relate prop.)

∴ For incompressible fluids (and solids)
$$\boxed{\begin{aligned} dS &= C_P\frac{dT}{T} \\ \Delta S &= \int_{T_o}^{T} \frac{C_P}{T}\,dT \end{aligned}}$$

∴ For incompressible liquids, isentropic process : isothermal & $\Delta h = V\Delta P$

∴ 1st law concerned with quantity of energy transformation, no constrains on process direction, necessary but not sufficient condition that process will occur.

∴ A process will not occur unless it satisfies both 1st & 2nd law.

∴ 2nd law $\boxed{\Delta S_{total} = \Delta S_{univers} = \Delta S_{system} + \Delta S_{surroundings} \geq 0}$

ΔS: 1. +ve ✓ 2. =0 reversible process 3. -ve ✗ impossible process

∴ Kelvin & Plank : impossible to construct a device in cycle the only effect to convert heat absorbed completely to work.

· Rudolf clausius : no cyclic process consist solely heat transfer from temp. to higher one.

→ entropy creasted nor destroyed ($\Delta S = 0$ or +ve but not -ve)

∴ Entropy balance
$$\boxed{\frac{dS}{dt} = \sum_{K=1}^{K} \dot{m}_K S_K + \sum_{J=1}^{J} \frac{\dot{Q}_j}{T_j} + \dot{S}_{gen} \geq 0}$$
Flow terms

S_{gen} تساوي صفر اذا rev

حتى يصبح equality في المتباينة

∴ Control of high & low temp. sources is achieved using heat reservoirs

[Heat sources: supply energy in the form of heat / Heat sinks: absorbs ...] reservoirs

Heat reservoirs : imaginary bodies capable of absorbing or rejecting ∞ quantity of heat without any temp. change.

∴ Heat engine : device or machine that produce work from heat in a cyclic process.

· Pump, boiler, turbine, condenser $|W| = |Q_H| - |Q_c|$

Thermal efficiency $\boxed{\eta = \frac{\text{net W produced}}{(Q_H)\text{ heat absorbed}} = 1 - \frac{|Q_c|}{|Q_H|}}$ actually no engine with $|Q_c| = 0$ (Kelvin & plank).

· "Carnot's engine" 4 steps : rev. isoth. exp. → rev. adiabatic. exp. → rev. isoth. comp. → rev. adiabatic. comp.

boiler → turbine → condensor → pump

Q_1 T_H Q_2 T_c

work done on each step $-\int P dv$

- Carnot's theorem, for two given heat reservoirs; no engine can have a thermal efficiency higher than that of Carnot engine.
- $\eta = 1 - \frac{T_c}{T_H}$ $\left[\frac{|Q_H|}{|Q_c|} = \frac{T_H}{T_c} \right]$ it depends on temp. levels not upon the working substance of the engine.
- η 1. $> \eta_{carnot} \rightarrow$ impossible 2. $< \eta_{carnot} \rightarrow$ irreversible HE 3. $= \eta_{carnot} \rightarrow$ reversible

∴ "Carnot refrigerator" $|W| = |Q_H| - |Q_c|$

$COP_{winter} > COP_{summer}$

Coefficient of performance COP_R $\boxed{COP_R = \frac{|Q_c|}{|W|} = \frac{1}{|Q_H|/|Q_c| - 1} = \frac{1}{T_H/T_c - 1}}$ ≥ 0

∴ "Carnot heat pump" $|W| = |Q_H| - |Q_c|$

coefficient of performance COP_{HP} $\boxed{COP_{HP} = \frac{|Q_H|}{|W|} = \frac{|Q_H|}{|Q_H| - |Q_c|} = \frac{1}{1 - T_c/T_H}}$ ≥ 1

- Both refrigerator & heat pump transfer heat from low temp. medium to high temp. medium but objective ↓ ↓
  remove heat from cooled space | supply heat into warmer space $\boxed{COP_{HP} = COP_R + 1}$
- Most air conditioners or heat pump have energy efficiency rating

work per year device

$\boxed{EER = 3.412 \times COP_R}$ between 8-12 & COP_R between 2.3-3.5 8-12 Levels A there is A^+

low efficiency — ice cream the most cooled space, it's COP_R between 1.0-1.2

careful

- Remember: the unit of T_c / T_H is in Kelvin.
- Condition (AC): refrigirator (cooling) / heat pump (heating)
- 1 ton air to transfer = 12×10^3 Btu (Power) $Q = \dot{m} c_p \Delta T$ calculate $\dot{m}$

211 kJ/min
200 Btu/min

- Reversible & adiabatic → isentropic
- $W_{pump} = 0.1 W_{Turbine}$ process
- From — PV curve → work (area in the sha[...]
  — T.S curve → heat transfer (area[...]

Rankine

∴ Assumptions of power cycles :-

1. Frictionless cycle (no pressure drop of fluid)
3. Heat transfer from pipes to surroundings in negligible.

∴ Power generation cycle efficiency $\eta = \frac{W_{net,out}}{Q_{in}}$

* Pitfalls of Carnot engine for SPP (steam power plant).

↳ step 2→3 Turbine (takes sat. steam & produce exhaust with high liquid content) severe erosion.
step 4→1 Pump (takes wet steam & discharge a sat. liquid)

$\dot{m} = \frac{\dot{W}_{net} \text{ (given)}}{W_{net} \text{ (calculated)}}$

FABER CASTELL

↓

cooled   supply heat into warmer space $\boxed{COP_{HP} = COP_R + 1}$

ners or heat pump have energy efficiency rating

$\boxed{COP_R}$ between 8-12 & COP_R between 2.3-3.5   8-12 Leve

e most cooled space, it's COP_R between 1.0-1.2   A there is A

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batic → isentropic

bine   Process [illegible]

→ work (area in the sha

→ heat transfer (area i

r cycles :-

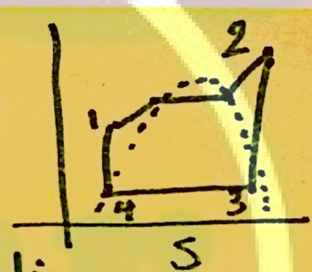
no pressure drop of fluid)

rom pipes to surroundings ir

le ellicieny $\eta = \dfrac{W_{net,out}}{Q_{in}}$

ine for SPP (steam power

Rankine cycle :



1→2 boiler isobaric T
- subcooled → T sat.
- isothermal isobaric vaporization
- superheating of vapor

2-3 isentropic exp. to $P_{con.}$ turbine

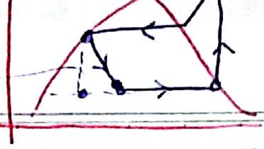
3-4 isothermal isobaric condens.

4-1 isentropic comp. of sat. ℓ to P boiler to get subcooled ℓ.

$$\eta_{Rankine} = \frac{|W_{s,Rankine}|}{Q_{boiler}}$$

$W_{s,Rankine} = Q_{con.} - Q_{biler} = W_{s,Pump} -$ $W_{s,turb.}$

Turbine



$\rho_{liquid} = 1000\, \rho_{vapor}$

Rankine refrigerator	Vapor compression refrigerator
isobaric condenser Q_C	isobaric condensor Q_C
W_T isentropic Turbine	0 isenthalpic Throttling valve
W_C isentropic Compressor	W_C isentropic Compressor
Q_H evaporator isothermal isobaric	Q_H evaporator isothermal isobaric

$$\boxed{COP_R = \frac{Q_{evaporator}}{W_{compressor} + W_{Turbine}} = \frac{|\Delta H|}{|\Delta H + \Delta H|}}$$

$$\boxed{COP_R = \frac{Q_{evaporator}}{W_{compressor}} = \frac{|\Delta H|}{|\Delta H|}}$$

- Not true for real refrigerants due to inherent irreversibilities.

- Choice of refrigerant, COP in carnot cycle is independent of the refrigerant type used.
  - constrains: corrosion, toxicity, Flammability, cost, vapor pressure.
  - Common refrigerants: Ammonia, methyl chloride, propane, CO_2, CFCs, HFCs

→ **Liquifaction:** The process by which gases are liquified.
applied in many areas, liquified natural gas (LNG) and refrigerant gases.

- Two approaches
  - cool the gas below B.P and the desired pressure not Practical
  - compress the gas to high P → cool at same P → expand to low P & T using Joule - Thompson expantion

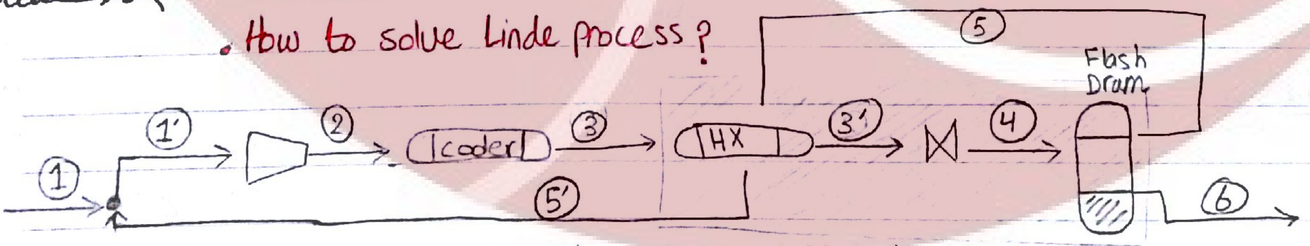
$$\boxed{\eta_{liquifaction} = \frac{\text{amount of liquified gas produced}}{\text{work done in the compressor}}}$$

- simple & Linde liquifaction (with recycle)

Feed → compressor (W_S) → cooler (Q_C) → throuttling valve → Flash drum < vapor / liquid

Feed → • → compressor → cooler → heat exchanger → throuttling valve → Flash drum < liquid / vapor

- How to solve Linde process?



- Use the heat exchanger, throttling valve and Flash drum as a system
  - $m_3 = m_6 + m_{5'}$
- Base the flow on 1 kg to the compressor
  - $m_{1'} = 1 \;/\; m_1 = x \;/\; m_{5'} = 1-x$