Refrigeration and Air conditioning(BTME-4702)

Course Name: RAC

Semester: 7th

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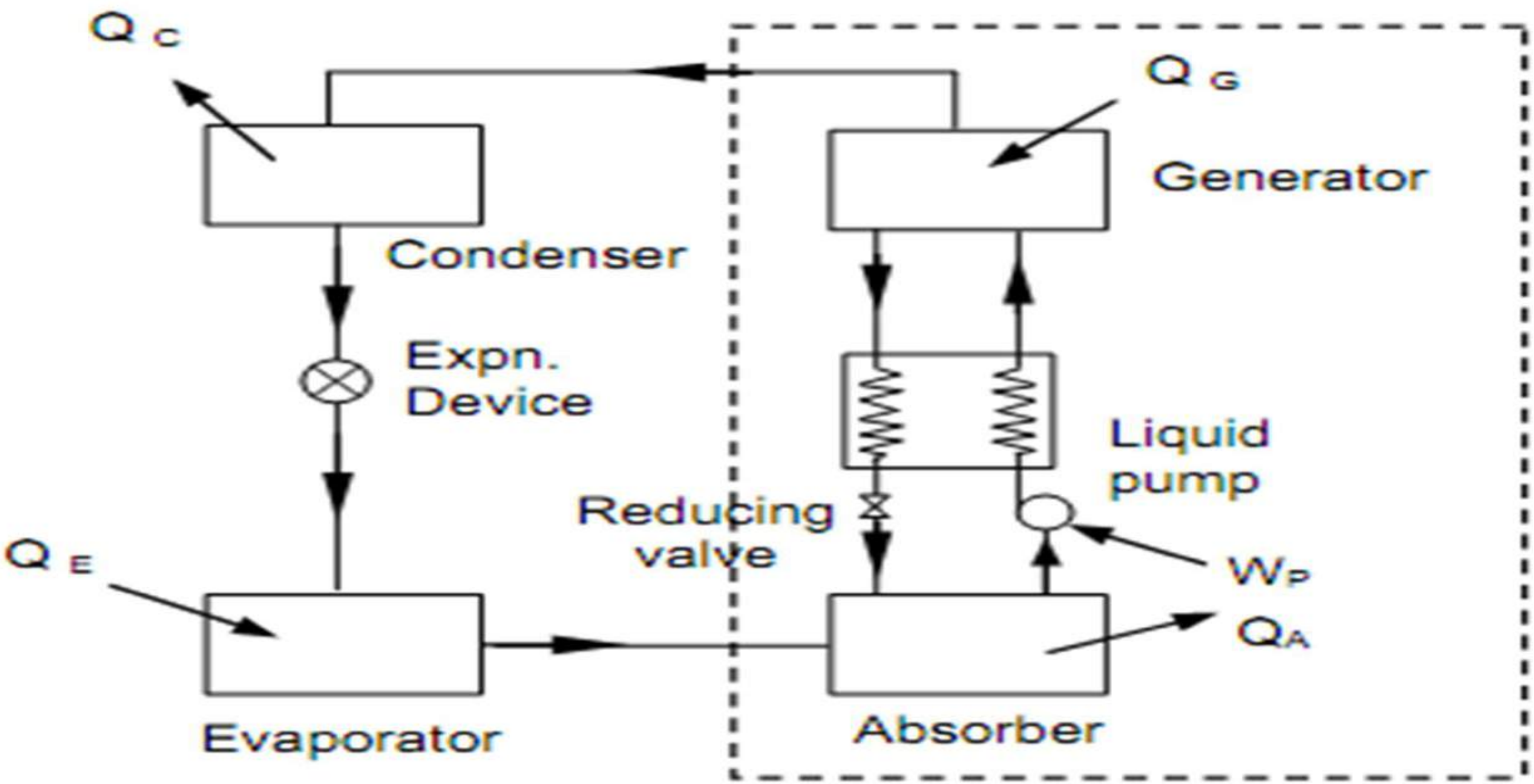
Refrigeration Systems

- Vapour compression refrigeration system
- Vapour absorption refrigeration system

Vapour Absorption System



Vapour Absorption System

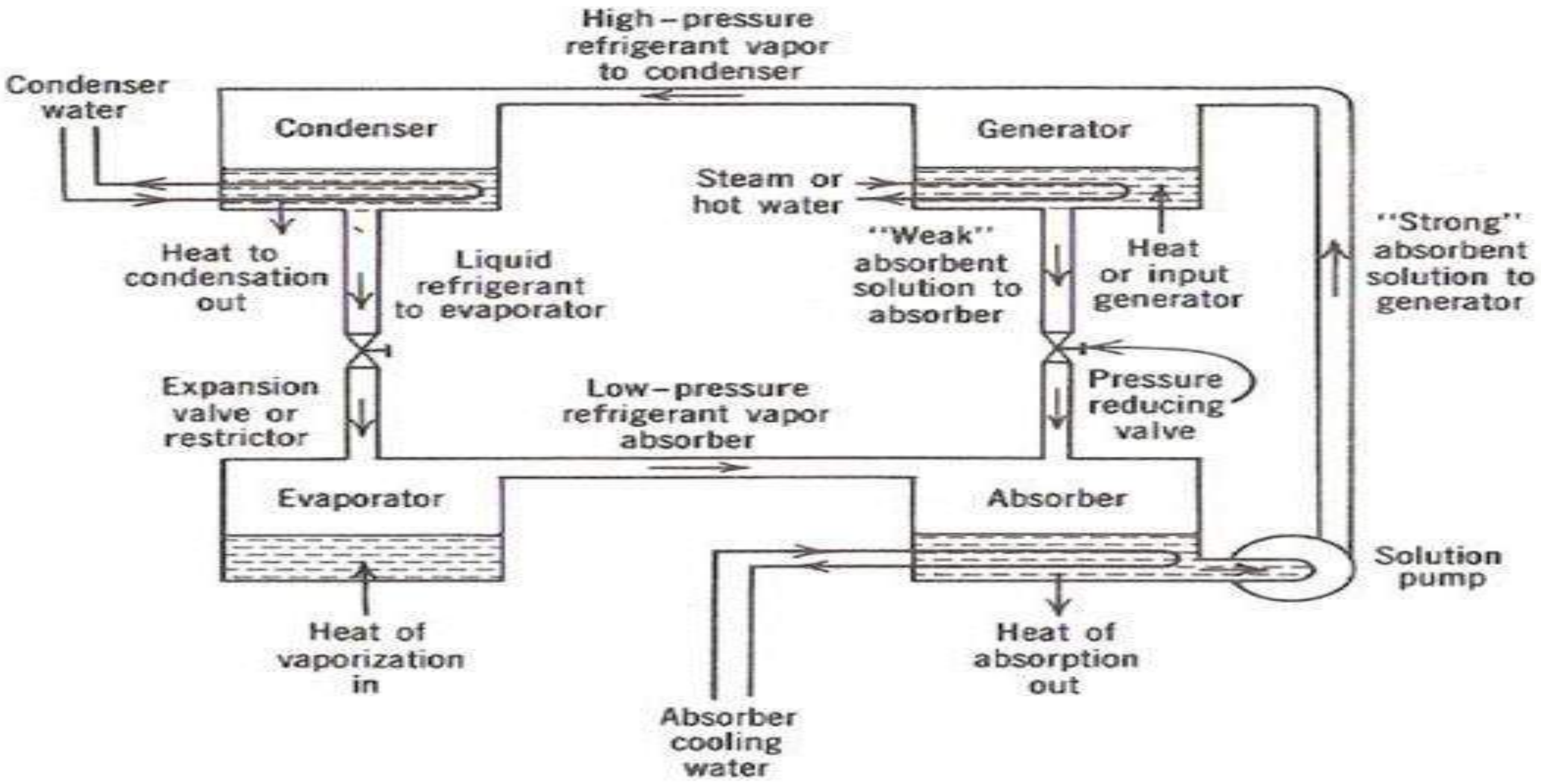


Fig. 20-21 Basic absorption refrigeration cycle.

Vapour Absorption System

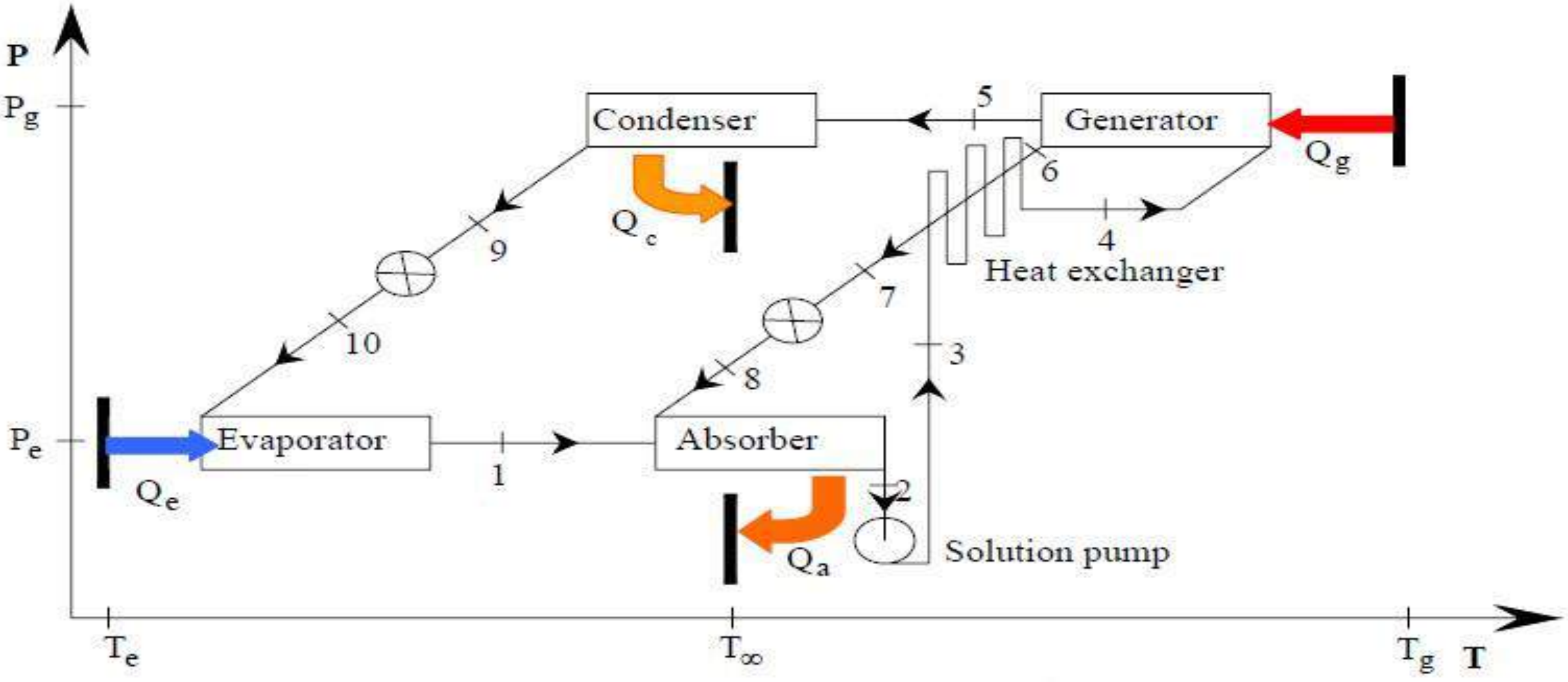


Fig.14.7: Basic vapour absorption refrigeration system with a solution heat exchanger on a pressure vs temperature diagram

COP for Vapour Absorption System

- $\text{C.O.P} = \dfrac{\text{Heat absorbed in evaporator}}{\text{Work done by pump + Heat supplied in generator}}$
- According to first law of thermodynamics

$$Q_c = Q_g + Q_e$$

Q_c : Heat discharged to the atmosphere or cooling water from the condenser and absorber.

Q_g : Heat given to the refrigerant in the generator.

Q_e : Heat absorbed by the refrigerant in the evaporator.

T_g : Temperature at which heat(Q_g) is given to the generator.

T_c : Temperature at which heat (Q_c) is discharged to atmosphere

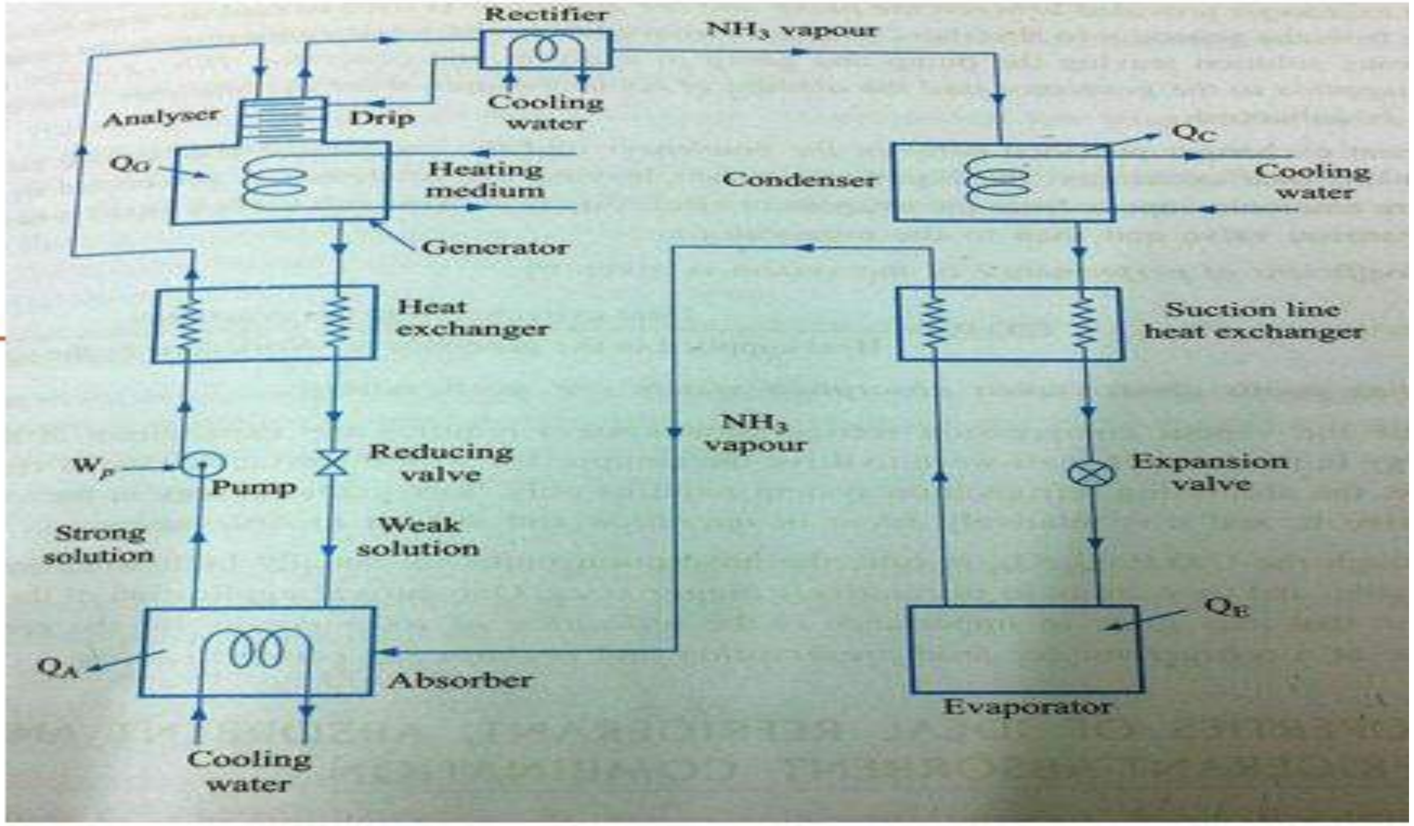
T_e : Temperature at which heat (Q_e) is absorbed in the evaporator.

Practical Vapour Absorption System

Analyser : Strong solution flows down the trays. Due to high saturation temperature water condenses down and NH_3 vapours escape through.

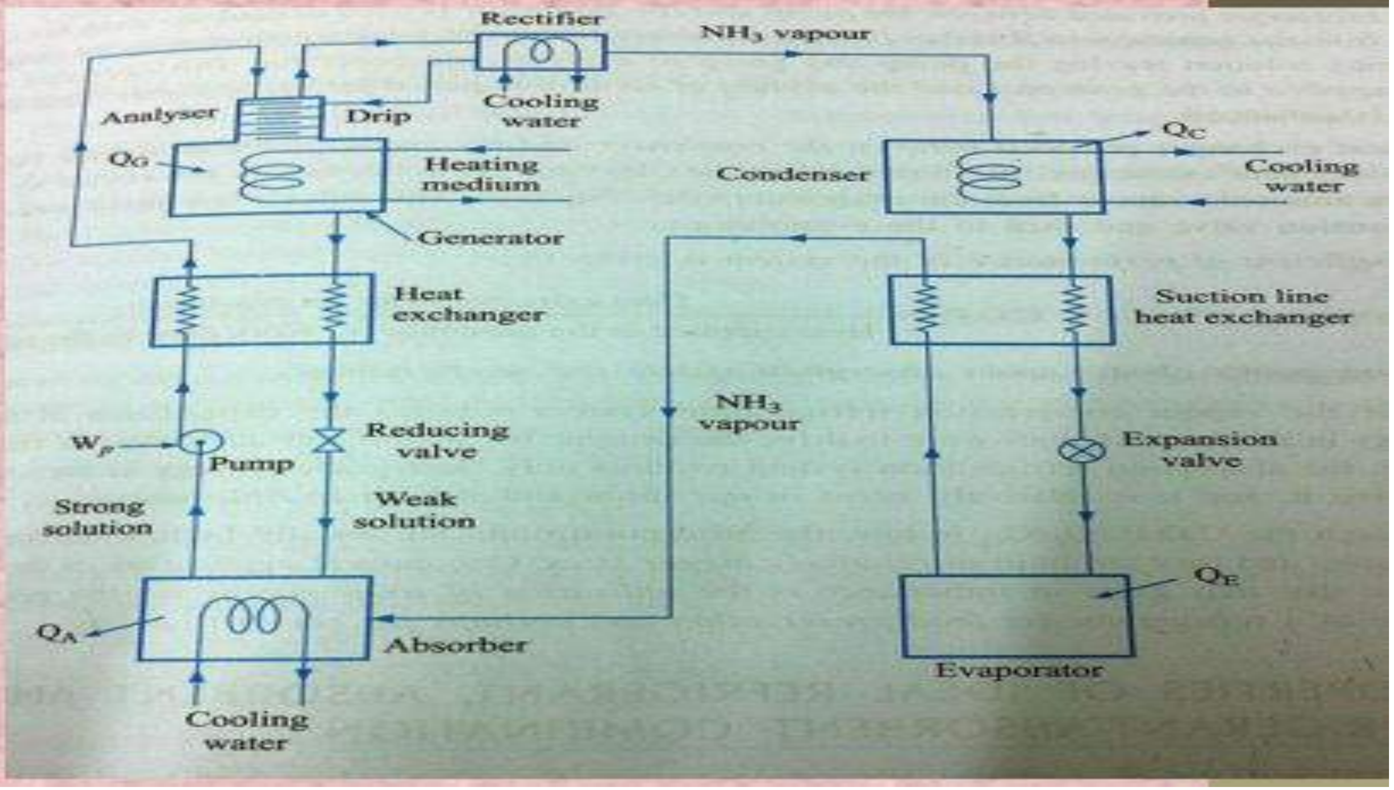
Rectifier : A water cooled heat exchanger which further condenses water vapour. (If any are left)

Heat Exchanger : Used to cool weak solution from generator. It also heats the strong solution coming from pump, thereby Reducing heat to be supplied at generator.



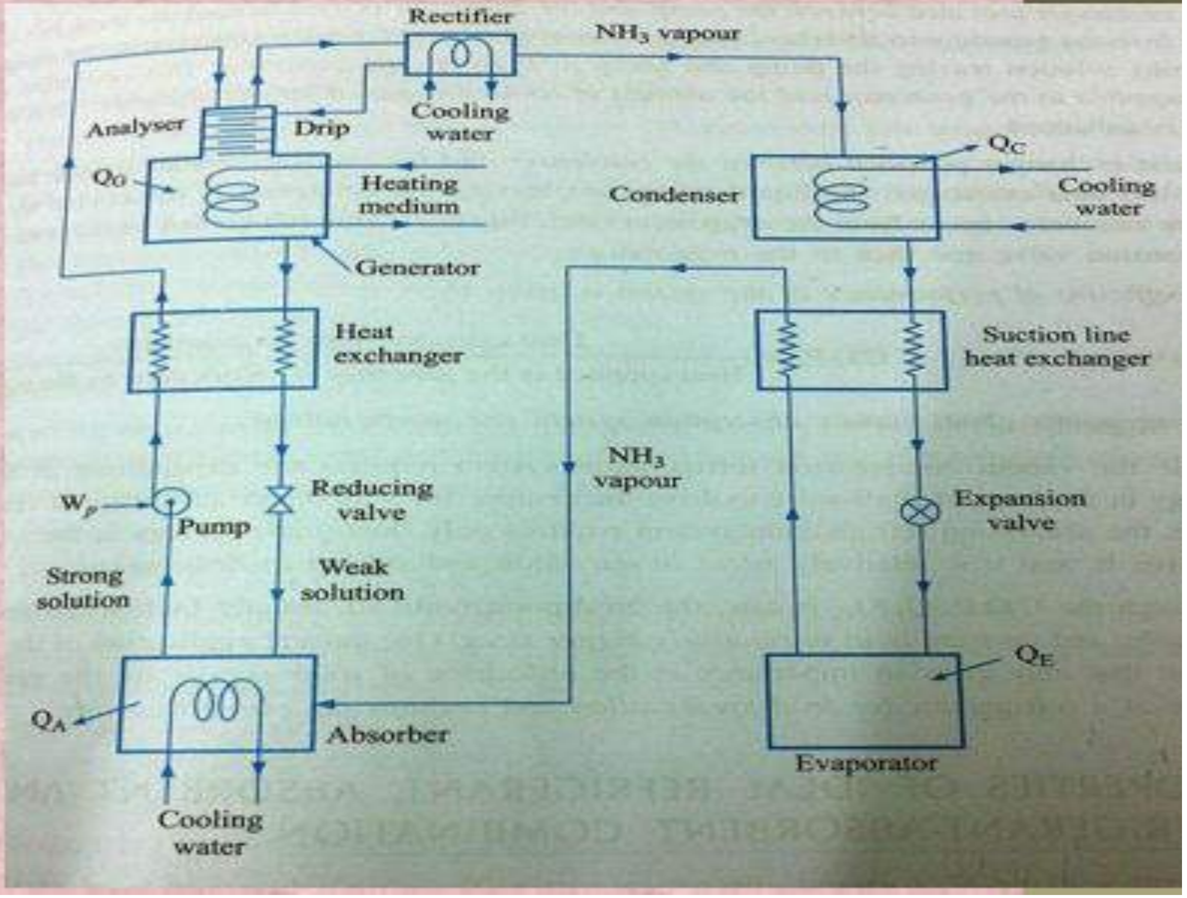
Vapour Absorption System

<u>Generator</u>: The strong solution of ammonia refrigerant and water absorbent are heated by the external source of heat such as steam or hot water. It can also be heated by other sources like natural gas, electric heater, waste exhaust heat etc.



Vapour Absorption System

Generator - Due to heating the refrigerant ammonia gets vaporized and it leaves the generator. However, since water has strong affinity for ammonia and its vaporization point is quite low some water particles also get carried away with ammonia refrigerant, so it is important to pass this refrigerant through analyzer.



Vapour Absorption System based on Li-Br

- Vapour absorption refrigeration systems using water-lithium bromide pair are extensively used in large capacity air conditioning systems.

- In these systems water is used as refrigerant and a solution of lithium bromide in water is used as absorbent.

- Since water is used as refrigerant, using these systems it is not possible to provide refrigeration at sub-zero temperatures. Hence it is used only in applications requiring refrigeration at temperatures above 0^oC.

- Hence these systems are used for air conditioning applications. The analysis of this system is relatively easy as the vapour generated in the generator is almost pure refrigerant (water), unlike ammonia-water systems where both ammonia and water vapour are generated in the generator.

Vapour Absorption System

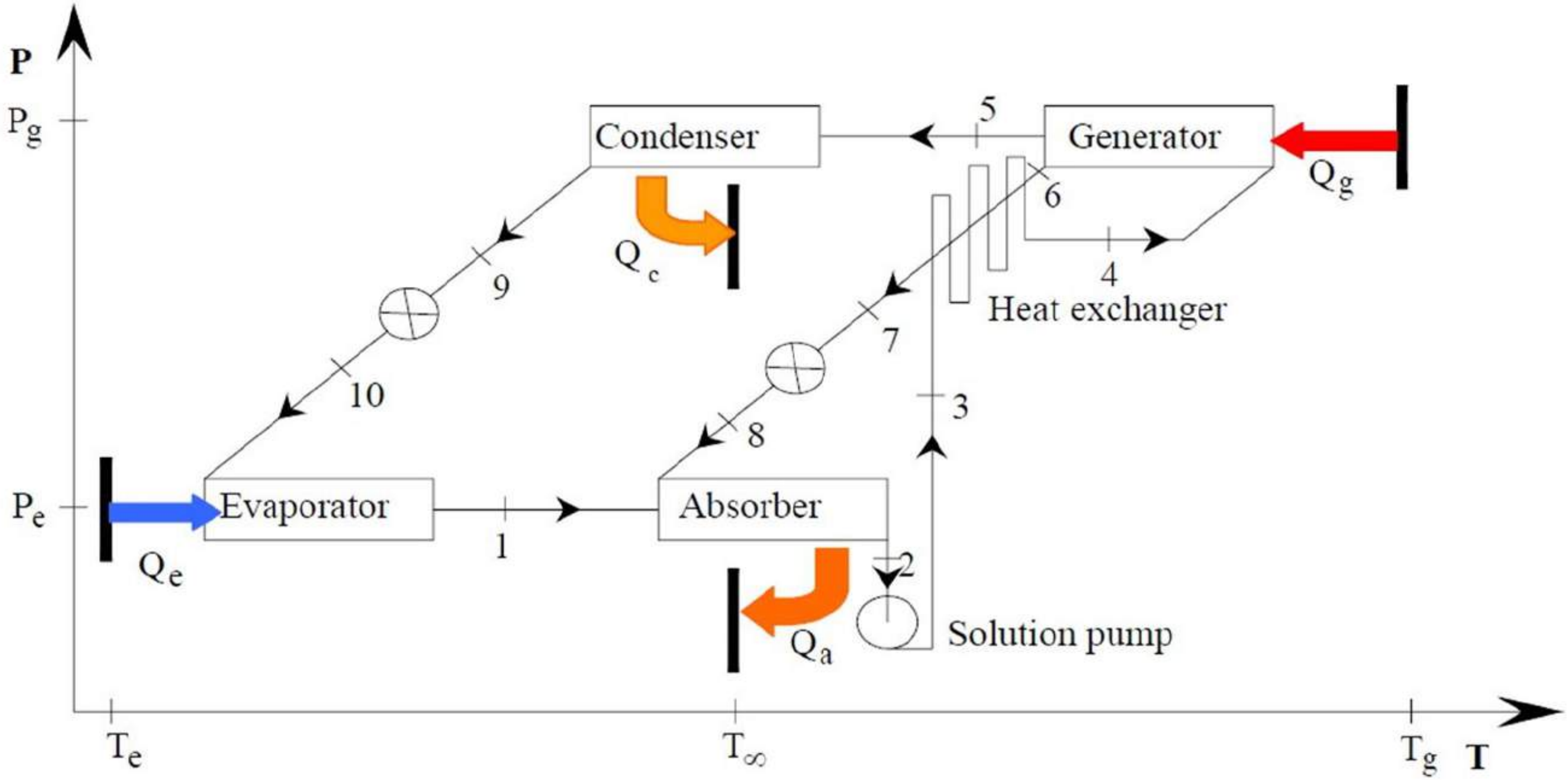


Fig.15.2: H_2O-LiBr system with a solution heat exchanger on Dühring plot

Vapour Absorption System

Numerical Problem:

The operating temperatures of a single stage vapour absorption refrigeration system are: generator: **90°C**; condenser and absorber: **40°C**; evaporator: **0°C**. The system has a refrigeration capacity of **100 kW** and the heat input to the system is **160 kW**. The solution pump work is negligible.

- a) Find the COP of the system and the total heat rejection rate from the system.
- b) An inventor claims that by improving the design of all the components of the system he could reduce the heat input to the system to **80 kW** while keeping the refrigeration capacity and operating temperatures same as before. Examine the validity of the claim.

Vapour Absorption System

a) $COP = Q_e/Q_g = 100/160 = \mathbf{0.625}$ **(Ans.)**

Total heat rejection rate $= Q_a + Q_c = Q_e + Q_g = 100 + 160 = \mathbf{260\ kW}$ **(Ans.)**

b) According to the inventor's claim, the COP_{claim} is given by:

$$COP_{claim} = Q_e/Q_g = 100/80 = \mathbf{1.25}$$

However, for the given temperatures, the maximum possible COP is given by:

$$COP_{ideal\ VARS} = \left(\frac{Q_e}{Q_g}\right)_{max} = \left(\frac{T_e}{T_o - T_e}\right)\left(\frac{T_g - T_o}{T_g}\right)$$

Substituting the values of operating temperatures, we find that:

$$COP_{max} = \left(\frac{T_e}{T_o - T_e}\right)\left(\frac{T_g - T_o}{T_g}\right) = \left(\frac{273}{313 - 273}\right)\left(\frac{50}{363}\right) = 0.94$$

Since $COP_{claim} > COP_{max} \Rightarrow$ Inventor's claim is FALSE **(Ans.)**

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Comparing Vapour Compression and Vapour Absorption Systems

Comparison between Vapour compression & Vapour Absorption refrigeration systems

S.No.	Vapour Compression System	Vapour Absorption System
1	This system has more wear and tear and produces more noise due to the moving parts of the compressor.	Only moving part in this system is an aqua pump. Hence the quieter in operation and less wear and tear
2.	Electric power is needed to drive the system	Waste of exhaust steam may be used. No need of electric power
3.	COP is more	COP is less
4.	At partial loads performance is poor.	At partial loads performance is not affected.
5.	Mechanical energy is supplied through compressor	Heat energy is utilised
6.	Energy supplied is ¼ to ½ of the refrigerating effect (less)	Energy supplied is about one and half times the refrigerating effect (more)

S.No.	Vapour Compression System	Vapour Absorption System
7.	Charging of the refrigerating to the system is easy	Charging of refrigerant is difficult
8.	Preventive measure is needed, since liquid refrigerant accumulated in the cylinder may damage to the cylinder	Liquid refrigerant has no bad effect on the system.

Refrigerants

Most evidence indicate that the Chinese were the first to store natural ice and snow to cool wine and other delicacies. Ancient people of India and Egypt cooled liquids in porous earthen jars.

In 1834, Jacob Perkins, an American, developed a closed refrigeration system using liquid expansion and then compression to produce cooling. He used Ether as refrigerant, in a hand-operated compressor, a water-cooled condenser and an evaporator in liquid cooler.

- **1850's – 1870's**: ammonia, ammonia/water, CO_2
- **Early 1900's**: SO_2, methyl chloride used for domestic refrigerators
- **1930's**: halocarbon refrigerants (R-12, R-22, R-114, R-22)
  Halocarbon advantages – stable compounds, favorable thermodynamic properties, safer than existing refrigerants.

Refrigerants

- Modern refrigeration and air-conditioning equipment is dominated by vapour compression refrigeration technology built upon the thermodynamic principles of the reverse Carnot cycle.

- **Refrigerant Changes phase during cooling and used again and again.** The **thermodynamic efficiency** of a refrigeration system depends mainly on its operating temperatures.

- However, **important practical issues** such as the system design, size, initial and operating costs, safety, reliability, and serviceability etc. **depend** very much on the type of refrigerant selected for a given application.

- Due to **several environmental issues** such as ozone layer depletion and global warming and their relation to the various refrigerants used, the selection of suitable refrigerant has become **one of the most important issues in recent times.**

Refrigerants

Working substances:

- **Primary** and **Secondary** refrigerants.

- **Primary refrigerants** are those fluids, which are used directly as working fluids. Ex.-refrigerant used in VCC and VAR systems. These fluids provide refrigeration by undergoing a phase change process in the evaporator.

- **Secondary refrigerants** are those liquids, which are used for **transporting thermal energy from one location to other.**
- Secondary refrigerants are also known under the name **brines or antifreezes.**

Refrigerants

Primary Refrigerants:

The refrigerants which are **directly used** to **obtain the cooling effect in evaporator** by undergoing a phase change process are referred as **Primary refrigerants.**

- **Halocarbon Refrigerants**
- **Azeotropes Refrigerants**
- **Inorganic Refrigerants**
- **Hydro-carbon Refrigerants**

Secondary Refrigerants:

- Used for **transporting thermal energy** from one location to other.
- **Does not undergo phase change process.**
- Used when refrigeration is required at sub-zero temperatures.
- Known as **Brines or Antifreezes.**
- Used in **large refrigeration units.**
- **Commonly used secondary refrigerants are:-**
  Solution of water & ethylene glycol, propylene glycol etc.

Refrigerants

Secondary Refrigerants

- If **working temperature is above 3^0C**, Water is used as SR.
- **Brine** is aqueous solution of **NaCl** and **CaCl2** in water and used at temperature below freezing point of water 0^0C. **Used in cooling of fish, meat & ice plant.**
- **Ethylene glycol** & **Propylene glycol** mixes with water and gives colorless & odourless solutions.

  These have capacity to lower freezing temperatures and hence used as antifreeze mixtures for **I.C. engine cooling systems.**

  These solutions become corrosive after some use, hence corrosive treatment is necessary.

Advantages

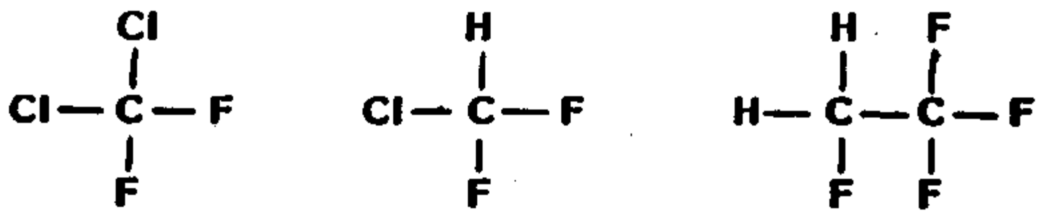
- Different rooms of building can be cooled up to different temperatures **by adjusting the flow rates** of secondary refrigerants.
- SR can be **easily handled.**
- SR can be **easily controlled.**
- **Eliminates** long refrigeration lines and thus reduces pressure drops.

Refrigerants

Desirable properties

- **Low** freezing point.
- **High** heat transfer coefficients.
- **High** specific heat.
- **Low** vapour pressure.
- **Good** stability.
- **Non**-flammable and **non**-toxic

Primary Refrigerants



CFC (R-12) (a) | HCFC (R-22) (b) | HFC (R-134a) (c)

CFC –Chlorofluorocarbons (Freon‘s)
HCFC -Hydrochlorofluorocarbon
HFC -Hydrofluorocarbon

Primary Refrigerants

- **CFC's**
  - First developed by **General Motor's researchers in the 1920's** and commercialized as **Freon's.**
  - **Most stable** – remain in atmosphere for many years, allowing them to diffuse to high altitudes
  - Contains Chlorine, Fluorine, Carbon.
  - CFC's break down, and Cl combines with and consumes some ozone
- **HCFC's**
  - **Hydrogenated**
  - **Not as stable** – most of it breaks down before reaching high altitudes
  - Contains Hydrogen, Chlorine, Fluorine, Carbon.
  - Less damaging to ozone
- **HFC's**
  - Contains Hydrogen, Fluorine, Carbon.
  - **Contains no Cl (Chlorine)**
  - **Causes no depletion of ozone**

Halocarbon Refrigerants

- Synthetically produced (Derived from Methane , Ethane) and were developed as the Freon family of refrigerants.
- Commonly used in Domestic, Commercial and Industrial Purposes due to their wide range of boiling points at atmospheric pressure.
- Presence of fluorine makes it Non-toxic.
- Ozone unfriendly refrigerants.

Examples :

– **CFC's (CHLOROFLUROCARBONS):**
  R11 (CCl3F) Trichloromonofluoromethane
  R12 (CCl2F2) Dichlorodifluoromethane
  R40 (CH3Cl) Methyl Chloride
  R13, R21, R22,R113, R114, R115

- **HCFC's(HYDROCHLOROFLUROCARBONS):**
  R22 (CHClF)2 Monochlorodiflurومethane
  R123 ($C_2HCl_2F_3$) Dichlorodifluoromethane

- **HFC's (HYDROFLUROCARBONS):**
- R134a (CH_2FCF_3)Tetrafluoroethene
- R404a, R407C,
- R410a mixture of Difluoromethane (CH_2F_2, called R-32) and Tetrafluoroethene (CHF_2CF_3, called R-125)

Azeotrope Refrigerants

- A **stable mixture** of **two or several refrigerants** whose vapour and liquid phases retain identical compositions over a wide range of temperatures. **Thermodynamic properties** remains fixed.
- **Code starts with** digit 5.

Examples

R500 – mixture of 73.8% of R12 and 26.2% of R152

R502 – Mixture of 49% of R22 and 51% of R115

- A zeotropic **mixture** is one whose composition in liquid phase differs to that in vapour phase.

- Zeotropic refrigerants therefore do not boil at constant temperatures unlike azeotropic refrigerants.

Examples :

R404a : R125/143a/134a (44%,52%,4%)

R407c : R32/125/134a (23%, 25%, 52%)

R410a : R32/125 (50%, 50%)

R413a : R600a/218/134a (3%, 9%, 88%)

Hydro carbon Refrigerants

- **Satisfactory** Thermodynamic properties.
- **Extraordinary reliability-** The most convincing argument is the reliability of the hydrocarbon system because of fewer compressor failures.
- Virtually **no refrigerant losses.**
- Hydrocarbons have been **used since the beginning of the century** and now being considered as long term solutions to environmental problems.
- But most of the hydrocarbons are highly flammable and require additional safety precaution during its use as refrigerants
- Not used in Industry and commercial installations.
- **Dominant** in **domestic market** like household refrigerators and freezers
- **Growing use** in **very small commercial systems** like car air-conditioning system.

Examples:

R170 – Ethane (C_2H_6)
R600 – Butane (C_4H_{10})
R600a – Isobutane (C_4H_{10})

Present/Futuristic Refrigerants

- **R-134a** has emerged as the primary substitution for many CFC's.
- **HCFC-22** and **HCFC–123** are viable alternatives for now but will eventually be phased out.
- In Europe, natural refrigerants such as ammonia, CO_2, propane, and water are being used more.
- Our legal system makes flammable refrigerants questionable in the US.

Applications of New Refrigerants

Application	HFCs used	Possible Eco-friendly refrigerant
Domestic refrigeration	R134a,R152a	HC600a and blends
Commercial refrigeration	R134a,R404A,R407C	HC blends,NH_3 ,CO_2 **
Cold storage ,food processing		
And industrial refrigeration	R134a,R404A,R507A	NH_3 ,HCs,CO_2 **
Unitary air conditioners	R410A,R407C	CO_2 , HC s
Centralized AC (chillers)	R134a,R410A,R407C	NH_3 ,HCs,$CO_{2,}$ water **
Transport refrigeration	R134a,R404A	CO $_{2,}$
Mobile air conditioner	R134a	CO_2 ,HCs
Heat pumps	R134a,R152a,R404A	NH_3 ,HCs,$CO_{2,}$ water **
	R407C,R410A	

Refrigerants

Global warming :

Refrigerants directly contributing to global warming when released to the atmosphere.

Indirect contribution based on the energy consumption of among others the compressors (CO_2 produced by power stations).

Ozone Depletion:

- Ozone (O3) is an **isotope of oxygen** with three atoms instead of normal two.
- It is **naturally occurring gas** which is created by high energy radiation from the Sun.
- The greatest concentration of ozone are found from **12 km to 50 km above the earth** forming a layer in the stratosphere which is called the ozone layer.
- This layer, which forms a semi-permeable blanket, **protects the earth** by **reducing the intensity of harmful ultra-violet (UV) radiation from the sun.**

Ozone layer depletion

N0RMAL REACTION

$O_2 = O + O$

$O_2 + O = O_3$

- **But CFC refrigerants** leaked during the **manufacturing** and **normal operation** or at the **time of servicing or repair, mix with surrounding air and** rise to troposphere and then into stratosphere due to normal wind or storm.

- The Ultraviolet rays act on CFC releasing Cl atom, which retards the normal reaction:

RETARDED REACTION:

$O_3 = O_2 + O$

$CCL_2F_2 = CCLF_2 + CL$

$O_3 + CL = CLO + O_2$

Harmful effects of ozone depletion

- **For Humans**
  - Increase in **skin cancer**
  - slow blindness
  - Cataracts
- **Less immunity to**
  - infectious diseases - malaria -herpes
- **For plants**
  - smaller size -lower yield -increased toxicity
  - altered form

For marine life
  - Reduced plankton -juvenile fish
  - larval crabs and shrimps

Refrigerants

- Refrigerant selection is also based on several factors:
  - ►Performance: provides adequate cooling capacity cost-effectively.
  - ►Safety: avoids hazards (i.e., toxicity).
  - ►Environmental impact: minimizes harm to stratospheric ozone layer and reduces negative impact to global climate change.

Refrigerants

Refrigerant Data Including Global Warming Potential (GWP)

Refrigerant Number	Type	Chemical Formula	Approx. GWP[a]
R-12	CFC	CCl_2F_2	10900
R-11	CFC	CCl_3F	4750
R-114	CFC	$CClF_2CClF_2$	10000
R-113	CFC	CCl_2FCClF_2	6130
R-22	HCFC	$CHClF_2$	1810
R-134a	HFC	CH_2FCF_3	1430
R-1234yf	HFC	$CF_3CF{=}CH_2$	4
R-410A	HFC blend	R-32, R-125 (50/50 Weight %)	1725
R-407C	HFC blend	R-32, R-125, R-134a (23/25/52 Weight %)	1526
R-744 (carbon dioxide)	Natural	CO_2	1
R-717 (ammonia)	Natural	NH_3	0
R-290 (propane)	Natural	C_3H_8	10
R-50 (methane)	Natural	CH_4	25
R-600 (butane)	Natural	C_4H_{10}	10

Global Warming Potential (GWP) is a simplified index that estimates the ***potential future influence on global warming*** associated with different gases when released to the atmosphere.

Summary

- In this chapter, Vapour absorption systems are described for their applications in various fields
- Comparing Vapour absorption with vapour compression systems
- Refrigerants and their classification
- Different types of refrigerants are discussed with filed of their importance

Topics to be Discussed in Next Lecture

- In the next chapter, the science of psychometry will be studied.
- Different types of air will be depicted under varied ambient conditions
- Differentiating between window and split air conditioning
- Calculation of the cooling load for the different conditionsp
- Central air conditioning in various industrial applications.