UNIT-IV: Vapour Absorption System

Vapor Absorption System –

Calculation of max COP –

description and working of NH3 –

water system and Li Br –water (Two shell & Four shell) System.

Principle of operation Three Fluid absorption system, salient features.

Thermoelectric refrigerator

In 1821 *Thomas Seebeck,* a *German physicist,* observed the production of *emf* (*electromotive force*) if two dissimilar metals are joined together and their joints are kept at different temperatures. The magnitude of such *emf* is dependent upon the material combination and temperatures of junctions. However, he was unable to make use of his invention probably due to insignificant emf and electric power output.

Thereafter a *French scientist, Jean Peltier,* discovered a reversed phenomenon to that of Seebeck in 1834. He found that there is heating or cooling of a junction of a pair of dissimilar substances, if *direct current* is passed through them. However, he was not only unable to realize the utility of the same but also failed to correlate between his invention and that of Seeback.

In *1838 Lenz,* a *German Scientist,* applied a D.C. source to a pair of materials—*bismuth and antimony* connected together as shown in Fig. 8.1. He was *astonished* to see that the water droplet was frozen into ice. When the current was reversed, the ice melted. This led to the *concept of thermoelectric refrigeration.* However, the idea did not materialize into commercial products for about a century because of unavailability of suitable materials until 1930's when semiconductors were developed.
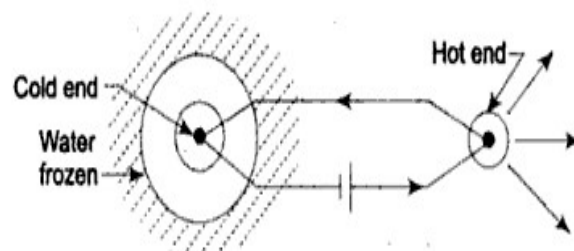

**Fig. 8.1** *Ice formation from thermoelectric refrigeration effect*

Thermoelectric Effects

Whenever direct current passes through a pair of thermocouples with junctions maintained at different temperatures, five effects are observed: *Seebeck effect, Peltier effect, Thomson effect, Joulean effect* and *conduction effect.*

   Seebeck effect: When the two junctions of a pair of dissimilar metals are maintained at different temperatures, there is the generation of emf (electromotive force) (Fig. 8.2 (a)). He conducted a series of tests by varying the temperatures of the junctions of various combinations of a set of materials. The emf output was found to be:

where ΔE and ΔT are the emf output and the temperature difference of the junctions. The phenomenon of generation of emf is called *Seebeck effect.*

$$\Delta E \propto \Delta T \tag{8.1}$$

(a) Seebeck effect.

(b) Peltier effect

(c) Thomson effect
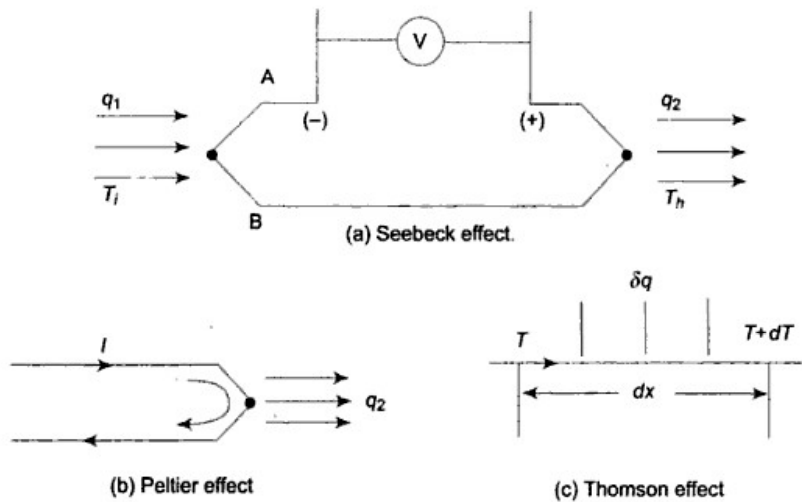
The proportionality constant of Eq. (8.1) is denoted by:

$$\alpha_{ab} = \Delta E / \Delta T \tag{8.2}$$

and is called *Seebeck coefficient* or the *thermoelectric power*. It is to be noted that $\alpha_{ab}(= \alpha_a - \alpha_b)$ is the coefficient for a pair of different metals (A and B or P and N or p and n).

Peltier effect: If direct current is passed through a pair of dissimilar metals (Fig. 8.2(b)), there is heating at one junction, cooling at the other depending upon material combinations. Peltier varied the current and observed the heating and cooling rate for different sets of elements. He found that:

$$q \propto I \tag{8.3}$$

where q is the cooling or heating rate. The proportionality constant of Eq. (8.3) is called as *Peltier coefficient*, π_{ab} (= volt) i.e.,

$$q = \pi_{ab} I \tag{8.4}$$

where $\pi_{ab} = \pi_a - \pi_b$ is the coefficient for two different metals.

Thomson effect: It is a reversible thermoelectric phenomenon. When a current passes through a single conductor having a temperature gradient as exhibited in Fig. 8.2c, heat transfer is given by:

$$\frac{\delta q}{dx} = \tau I \, (dT/dx) \tag{8.5}$$

where τ being *Thomson coefficient* (Volt/K) and $\delta q/dx$, the *Thomson heat transfer*.

Zemansky [1] using *first* and *second laws* of thermodynamics obtained the relation between *Seeback* and *Peltier* coefficients as:

$$\pi_{ab} = \alpha_{ab} T \tag{8.6}$$

Using Eq. (8.6) into Eq. (8.4), it is found:

$$q = \alpha_{ab} I T \tag{8.7}$$

It is evident from Eq. (8.7) that to get the high value of cooling or heating, α_{ab} should be high, otherwise large current would be required. But high current will render high heat generation due to Joulean effect.

Joulean effect: When the electrical current flows through a conductor, there is dissipation of electrical energy. According to *Joule* it is related as:

$$q_j = I^2 R \tag{8.8}$$

where I and R are the current and electrical resistance. This effect is called *Joulean effect*.

Conduction effect: If the ends of any element are maintained at different temperatures, there is heat transfer from the hot end to the cold end and is related by:

$$q_{cond} = U(T_h - T_l) \tag{8.9}$$

where U being overall conductance and T_h, T_l are the high and low temperatures, respectively. If there is only one conductor of cross-sectional area A, conductivity k and length L, the overall conductance is given by:

$$U = kA/L \tag{8.10}$$

We may well ask the same question about the vapor-compression refrigerator that we asked about the steam power plant—is it possible to accomplish our objective in a more direct manner? Is it possible, in the case of a refrigerator, to use the electrical energy (which goes to the electric motor that drives the compressor) to produce cooling in a more direct manner and thereby to avoid the cost of the compressor, condenser, evaporator, and all the related piping?

The thermoelectric refrigerator is such a device. This is shown schematically in Fig. 1.8a. The thermoelectric device, like the conventional thermocouple, uses two dissimilar materials. There are two junctions between these two materials in a thermoelectric refrigerator. One is located in the refrigerated space and the other in ambient surroundings. When a potential difference is applied, as indicated, the temperature of the junction located in the refrigerated space will decrease and the temperature of the other junction will
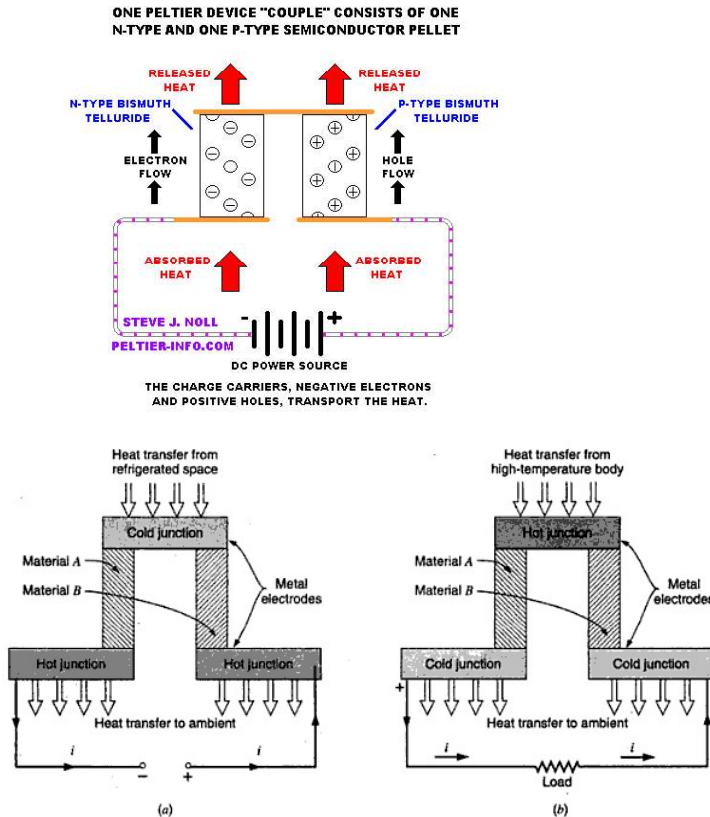
increase. Under steady-state operating conditions, heat will be transferred from the refrigerated space to the cold junction. The other junction will be at a temperature above the ambient, and heat will be transferred from the junction to the surroundings.

A thermoelectric device can also be used to generate power by replacing the refrigerated space with a body that is at a temperature above the ambient. Such a system is shown in Fig. 1.8b.

The thermoelectric refrigerator cannot yet compete economically with conventional vapor-compression units. However, in certain special applications, the thermoelectric refrigerator is already is use and, in view of research and development efforts under way in this field, it is quite possible that thermoelectric refrigerators will be much more extensively used in the future.

A **semiconductor** is a material with electrical conductivity due to electron flow (as opposed to ionic conductivity) intermediate in magnitude between that of a conductor and an insulator. Semiconductor materials are the foundation of modern electronics, including radio, computers, telephones, and many other devices. Such devices include transistors, solar cells, many kinds of diodes including the light-emitting diode, the silicon controlled rectifier, and digital and analog

integrated circuits. Similarly, semiconductor solar photovoltaic panels directly convert light energy into electrical energy.

In a metallic conductor, current is carried by the flow of electrons. In semiconductors, current is often schematized as being carried either by the flow of electrons or by the flow of positively charged "holes" in the electron structure of the material. Actually, however, in both cases only electron movements are involved.

Common semiconducting materials are crystalline solids, but amorphous and liquid semiconductors are known.

Silicon is used to create most semiconductors commercially. Dozens of other materials are used, including germanium, gallium arsenide, and silicon carbide. A pure semiconductor is often called an "intrinsic" semiconductor. The electronic properties and the conductivity of a semiconductor can be changed in a controlled manner by adding very small quantities of other elements, called "dopants", to the intrinsic material. In crystalline silicon typically this is achieved by adding impurities of boron or phosphorus to the melt and then allowing the melt to solidify into the crystal. This process is called "doping".

DEFINITION- A semiconductor is a substance, usually a solid chemical element or compound, that can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current. Its conductance varies depending on the current or voltage applied to a control electrode, or on the intensity of irradiation by infrared (IR), visible light, ultraviolet (UV), or X rays.

The specific properties of a semiconductor depend on the impurities, or *dopants*, added to it. An *N-type* semiconductor carries current mainly in the form of negatively-charged electrons, in a manner similar to the conduction of current in a wire. A *P-type* semiconductor carries current predominantly as electron deficiencies called holes. A hole has a positive electric charge, equal and opposite to the charge on an electron. In a semiconductor material, the flow of holes occurs in a direction opposite to the flow of electrons.

(i)   (ii) Vortex tube or Hilsch tube.
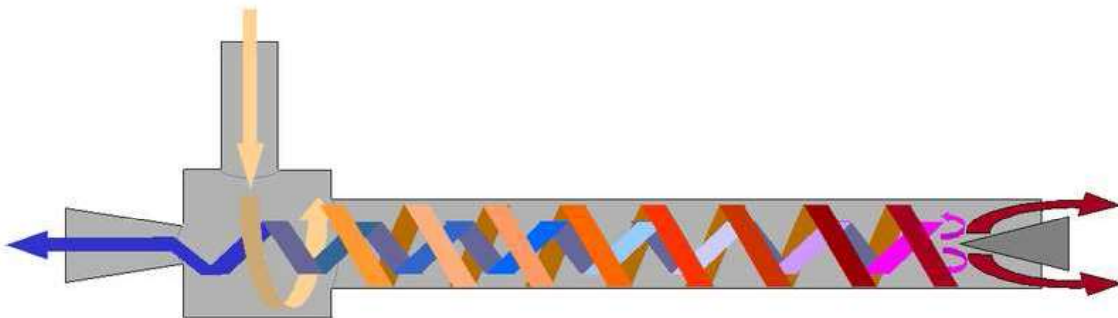
The **vortex tube**, also known as the **Ranque-Hilsch vortex tube**, is a mechanical device that separates a compressed gas into hot and cold streams. It has no moving parts.Pressurized gas is injected tangentially into a swirl chamber and accelerates to a high rate of rotation. Due to the conicalnozzle at the end of the tube, only the outer shell of the compressed gas is allowed to escape at that end. The remainder of the gas is forced to return in an inner vortex of reduced diameter within the outer vortex.

There are different explanations for the effect and there is debate on which explanation is best or correct.

What is usually agreed upon is that the air in the tube experiences mostly "solid body rotation", which simply means the rotation rate (angular velocity) of the inner gas is the same as that of the outer gas. This is different from what most consider standard vortex behaviour — where inner fluid spins at a higher rate than outer fluid. The (mostly) solid body rotation is probably due to the long time which each parcel of air remains in the vortex — allowing friction between the inner parcels and outer parcels to have a notable effect.

It is also usually agreed upon that there is a slight effect of hot air wanting to "rise" toward the center, but this effect is negligible — especially if turbulence is kept to a minimum.One simple explanation is that the outer air is under higher pressure than the inner air (because of centrifugal force). Therefore the temperature of the outer air is higher than that of the inner air.

Another explanation is that as both vortices rotate at the same angular velocity and direction, the inner vortex has lost angular momentum. The decrease of angular momentum is transferred as kinetic energy to the outer vortex, resulting in separated flows of hot and cold gas.

This is somewhat analogous to a Peltier effect device, which uses electrical pressure (voltage) to move heat to one side of a dissimilar metal junction, causing the other side to grow cold.When used to refrigerate, heat-sinking the whole vortex tube is helpful.

The vortex tube was invented in 1933 by French physicist Georges J. Ranque. German physicist Rudolf Hilsch improved the design and published a widely read paper in 1947 on the device, which he called a Wirbelrohr (literally, whirl pipe). The vortex tube was used to separate gas mixtures, oxygen and nitrogen, carbon dioxide and helium, carbon dioxide and air in 1967 by Linderstrom-Lang. Vortex tubes also seem to work with liquids to some extent. In 1988 R.T.Balmer applied liquid water as the working medium. It was found that when the inlet pressure is high, for instance 20-50 bar, the heat energy separation process exists in incompressible (liquids) vortex flow as well.

Efficiency

Vortex tubes have lower efficiency than traditional air conditioning equipment. They are commonly used for inexpensive spot cooling, when compressed air is available. Commercial models are designed for industrial applications to produce a temperature drop of about 45 °C (80 °F). With no moving parts, no electricity, and no Freon, a vortex tube can produce refrigeration up to 6000 BTU using only filtered compressed air at 100 PSI. A control valve in the hot air exhaust adjusts temperatures, flows and refrigeration over a wide range.

Proposed applications

Dave Williams, of dissigno, has proposed using vortex tubes to make ice in third-world countries. Although the technique is inefficient, Williams expressed hope that vortex tubes could yield helpful results in areas where using electricity to create ice is not an option.

There are industrial applications that result in unused pressurized gases. Using vortex tube energy separation may be a method to recover waste pressure energy from high and low pressure sources.[8]

<u>Vortex Tube/Hilsch Tube Advantages:</u>

1. No moving parts, reliable, maintenance free

2. No coolant
3. Compact and lightweight
4. Low cost application
5. Maintenance free units
6. Instant cold air in environmental chambers
7. No spark or explosion hazard
8. Interchangeable generators

The vortex tube was discovered in 1930 by French physicist Georges Ranque. Vortec was the first company to develop this phenomenon into practical, effective cooling solutions for industrial applications. Here's how it works.

Fluid that rotates about an axis -- like a tornado -- is called a vortex. A vortex tube creates a vortex from compressed air and separates it into two air streams -- one hot and one cold. Compressed air enters a cylindrical generator which is proportionately larger than the hot (long) tube where it causes the air to rotate. Then, the rotating air is forced down the inner walls of the hot tube at speeds reaching 1,000,000 rpm. At the end of the hot tube, a small portion of this air exits through a needle valve as hot air exhaust. The remaining air is forced back through the center of the incoming air stream at a slower speed. The heat in the slower moving air is transferred to the faster moving incoming air. This super-cooled air flows through the center of the generator and exits through the cold air exhaust port.

VAPOUR ABSORPTION SYSTEM

Simple Vapour Absorption system:
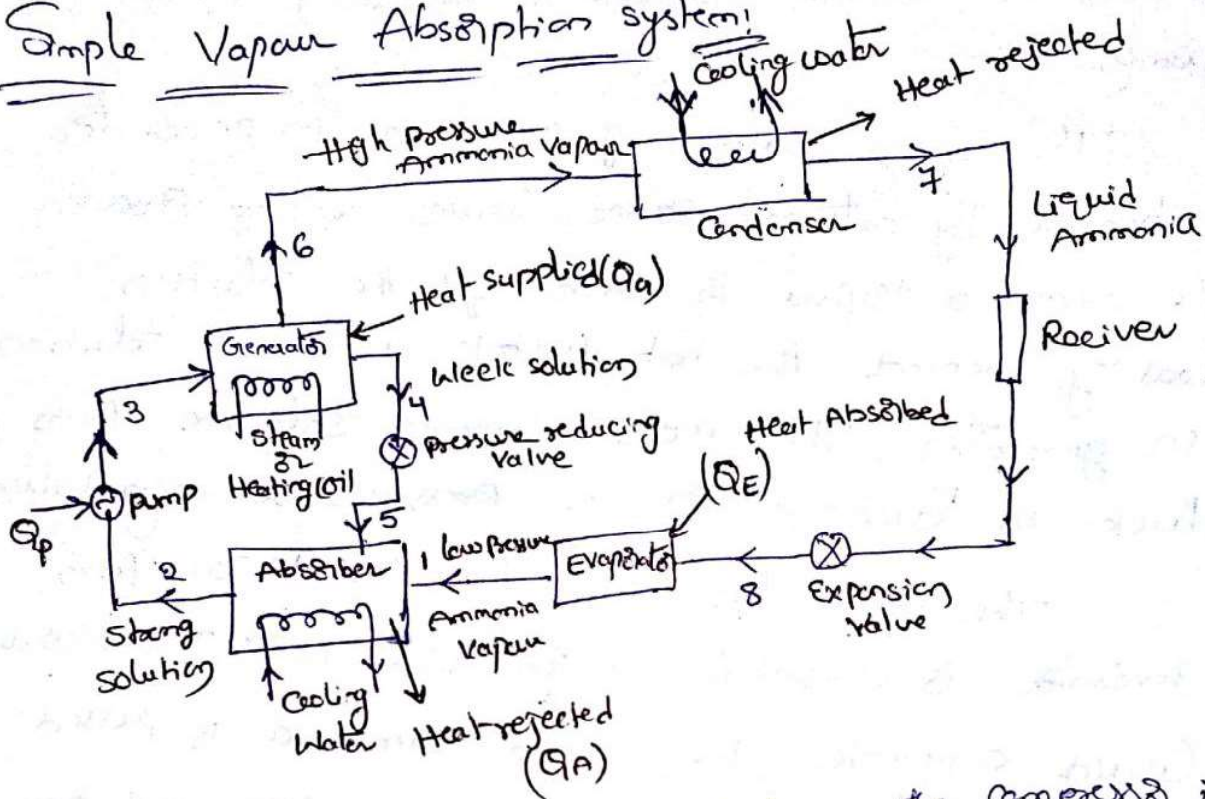
In Vapour Absorption System the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve. The Components of System are Condenser, receiver, Expansion valve and evaporator.

In this system the low pressure ammonia Vapour leaving the evaporator enters the absorber where it is absorbed by Cold water in absorber. The water has ability to absorb very large quantities of Ammonia Vapour and solution thus formed is known as "aqua-ammonia". The absorption of ammonia Vapour in water lowers the pressure in absorber which draws more ammonia Vapour from evaporator and raises temperature of solution. The Cooling water is employed in absorber to remove heat

of solution. The cooling water is employed in absorber to remove heat of solution. The strong solution formed in absorber is pumped to generator by pump.

The strong solution of ammonia in generator is heated by external source. During heating process the ammonia vapour is driven off the solution, leaving behind the hot weak ammonia solution in generator. The weak ammonia solution flows back to absorber through pressure reducing value.

The High Pressure ammonia vapour from generator is condensed in condenser to a high pressure liquid ammonia. The liquid ammonia is passed to expansion value through the receiver and then to evaporator. Thus cycle completes.

In this system the net refrigerating effect is the heat absorbed by refrigerant in evaporator. The total energy supplied to system is sum of workdone by pump and heat supplied in generator.

$$\therefore C.O.P = \frac{\text{Heat absorbed in evaporator}}{\text{workdone by pump + Heat supplied in generator}}$$

⟹ The heat Q_G of Refrigerant in the generator

⟹ The heat Q_C is discharged to the atmosphere & Cooling water from the Condenser and absorber.

⟹ The heat Q_E is absorbed by the refrigerant in the Evaporator

⟹ The heat Q_P is added to the refrigerant due to pump work.

Neglecting pump work (Q_P), we have according to first law of thermodynamics

$$Q_C = Q_G + Q_E \longrightarrow ①$$

let T_G = Temperature at which heat (Q_G) is given to generator.

T_C = Temperature at which heat (Q_C) is discharged to atmosphere & Cooling water from the Condenser and absorber.

T_E = Temperature at which heat (Q_E) is absorbed in the Evaporator.

Since the vapour absorption System can be considered as a perfectly reversible System, therefore the initial entropy of the system must be equal to the entropy of the system after the change in its condition.

$$\therefore \quad \frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_C}{T_C} \longrightarrow ②$$

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} = \frac{Q_G + Q_E}{T_C} \quad \boxed{\because \text{from Eq } ①}$$

$$Q_{C1} \left[T_{C} - \right.$$

$$\frac{Q_{C1}}{T_{C1}} - \frac{Q_{C1}}{T_{C}} = \frac{Q_E}{T_C} - \frac{Q_E}{T_E}$$

$$Q_{C1} \left[\frac{T_C - T_{C1}}{T_C \, T_{C1}} \right] = Q_E \left[\frac{T_E - T_C}{T_C \times T_E} \right]$$

$$Q_{C1} = Q_E \left(\frac{T_E - T_C}{T_C \, T_E} \right) \left(\frac{T_{C1} \, T_C}{T_C - T_{C1}} \right)$$

$$= Q_E \left(\frac{T_C - T_E}{T_C \, T_E} \right) \left(\frac{T_{C1} \, T_C}{T_{C1} - T_C} \right)$$

$$\boxed{Q_{C1} = Q_E \left(\frac{T_C - T_E}{T_E} \right) \left(\frac{T_{C1}}{T_{C1} - T_C} \right)} = \quad ③$$

maximum Co-efficient of performance of the system

$$(C \cdot O \cdot P)_{max} = \frac{Q_E}{Q_{C1}} = \frac{Q_E}{Q_E \left(\frac{T_C - T_E}{T_E} \right) \left(\frac{T_{C1}}{T_{C1} - T_C} \right)}$$

$$\boxed{(C \cdot O \cdot P)_{max} = \left(\frac{T_E}{T_C - T_E} \right) \left(\frac{T_{C1} - T_C}{T_{C1}} \right)}$$

<u>Note:</u>

The Expression $\frac{T_E}{T_C - T_E}$ is the C.O.P. of a Carnot refrigerator working between the temperature limits of T_E and T_C

⇒ The Expression $\frac{T_{C1} - T_C}{T_{C1}}$ is the efficiency of a Carnot engine working between the temperature limits T_{C1} and T_C.

⇒ $(C \cdot O \cdot P)_{max} = (C \cdot O \cdot P)_{Carnot} \times \eta_{Carnot}$

⇒ In case the heat is discharged at different temperature in Condenser and absorber $(C \cdot O \cdot P)_{max} = \left(\frac{T_E}{T_C - T_E} \right) \left(\frac{T_{C1} - T_A}{T_{C1}} \right)$

⇒ Simple absorption refrigeration cycle does not Consider the rectification column and preheating Exchanger. In such aqua-ammonia cycle, evaporator, absorber, Condenser and generator temperatures are 233K, 303K, 313K and 373K respectively. The properties of aqua-ammonia are as follows.

Particulars	Concentration kg of NH₃ / kg solution	Enthalpy kJ/kg
Strong solution leaving absorber	0.421	30
weak solution leaving generator	0.375	340
vapour leaving generator	0.945	1870
Liquid leaving Condenser	0945	470
vapours leaving Evaporator	0.945	1388

1. Draw schematic diagram of the Systems
2. For 1TR Capacity, determine the mass flow rate of Solution in evaporator
3. Consider overall mass balance and material balance or partial mass balance of NH₃ in absorber. This will give two equations, solve them to determine mass flow rates of strong and weak Solutions.
4. Consider energy balance for absorber and generator to find absorber heat rejection

sol! G.D $T_E = 233 K$, $T_A = 303K$, $T_C = 313K$, $T_G = 373 K$.
$Q = Q_E = 1$

$x_2 = 0.421$, $h_2 = 30 kJ/kg$, $x_4 = x_5 = 0.375$, $h_4 = h_5 = 340 kJ/kg$
$x_6 = 0.945$; $h_6 = 1870 kJ/kg$, $x_7 = x_8 = 0.945$, $h_7 = h_8 = 470 kJ/kg$
$x_1 = 0.945$; $h_1 = 1388 kJ/kg$; $Q = Q_E = 1TR = 210 kJ/min$

R.T

$m_1 = ?$

$m_2 = ?$

$Q_A = ?$

$Q_{cr} = ?$

$Q_c = ?$

$C.O.P = ?$

F+0

$m_1 = \dfrac{210 \, Q_E}{h_1 - h_8}$

$m_2 = m_1 + m_4$

Condensing material balance $\quad m_1 x_1 + m_4 x_4 = m_2 x_2$

$Q_A = m_1 h_1 + m_4 h_4 - m_2 h_2$

$Q_{cr} = m_4 h_4 + m_6 h_6 - m_3 h_3$

$Q_c = m_6 (h_6 - h_7)$

$C.O.P = \dfrac{Q_E}{Q_{cr}}$

$\left(\begin{array}{l} Q_{cr} + Q_E = 1438 \cdot 852 \, \text{kJ/min} \\ Q_A + Q_c = 143889 \end{array} \right)$

Calculation

(i) mass flow rate in the evaporator $\quad m_1 = \dfrac{210 \, Q_E}{h_1 - h_8}$

$m_1 = \dfrac{210 \times 1}{h_1 - h_8} = \dfrac{210 \times 1}{1388 - 470} = 0.2288 \, \text{kg/min}$

$\boxed{\begin{array}{l} \text{w.r.t} \quad C.O.P = \dfrac{Q_E}{Q_{cr}} \\ = \dfrac{1 \times 210}{1228 \cdot 852} = \\ = 0.171 \end{array}}$

(ii) $m_1 x_1 + m_4 x_4 = m_2 x_2 = (m_1 + m_4) \, x_2$

$0.2288 \times 0.945 + m_4 \times 0.375 = (0.2288 + m_4) \, 0.421$

$m_4 = \dfrac{0.1199}{0.046} = 2.606 \, \text{kg/min}$

$m_2 = m_1 + m_4 = 0.2288 + 2.606 = 2.8348 \, \text{kg/min}$

(iv) $Q_A = m_1 h_1 + m_4 h_4 - m_2 h_2$

$= 0.2288 \times 1388 + 2.606 \times 340 - 2.8348 \times 30$

$= 317.574 + 886.04 - 85.044$

$= 1118.57 \, \text{kJ/min}$

$\left(\begin{array}{l} m_6 = m_1, \ m_3 = m_2 \text{ and} \\ h_3 = h_2 \end{array} \right)$

$Q_{cr} = m_4 h_4 + m_6 h_6 - m_3 h_3$

$= 2.606 \times 340 + 0.2288 \times 1870 - 2.8348 \times 30$

$= 886.04 + 427.856 - 85.044 = 1228.852 \, \text{kg/min}$

$Q_c = m_6 (h_6 - h_7) = 0.2288 (1870 - 470) = 320.32 \, \text{kJ/min}$

(v) Considering the overall energy balance, the heat absorbed by the generator and evaporator must be equal to the heat rejected from the absorber and condenser.

∴ Heat absorbed by the generator and evaporator

$= Q_{cr} + Q_E = 1228.852 + 210 = 1438.852 \, \text{kJ/min}$

Heat Rejected from the absorber and evaporator

$= Q_A + Q_c = 1118.57 + 320.32 = 1438.89 \, \text{kJ/min}$

Since the heat absorbed and heat rejected are very close therefore the overall energy balance is checked.

Domestic Electrolux (Ammonia Hydrogen) Refrigerator:

This type of Refrigerator is also called Three-fluid absorption System. The main Purpose of this system is to Eliminate the Pump so that in the absence of moving parts, the machine becomes Noiseless.
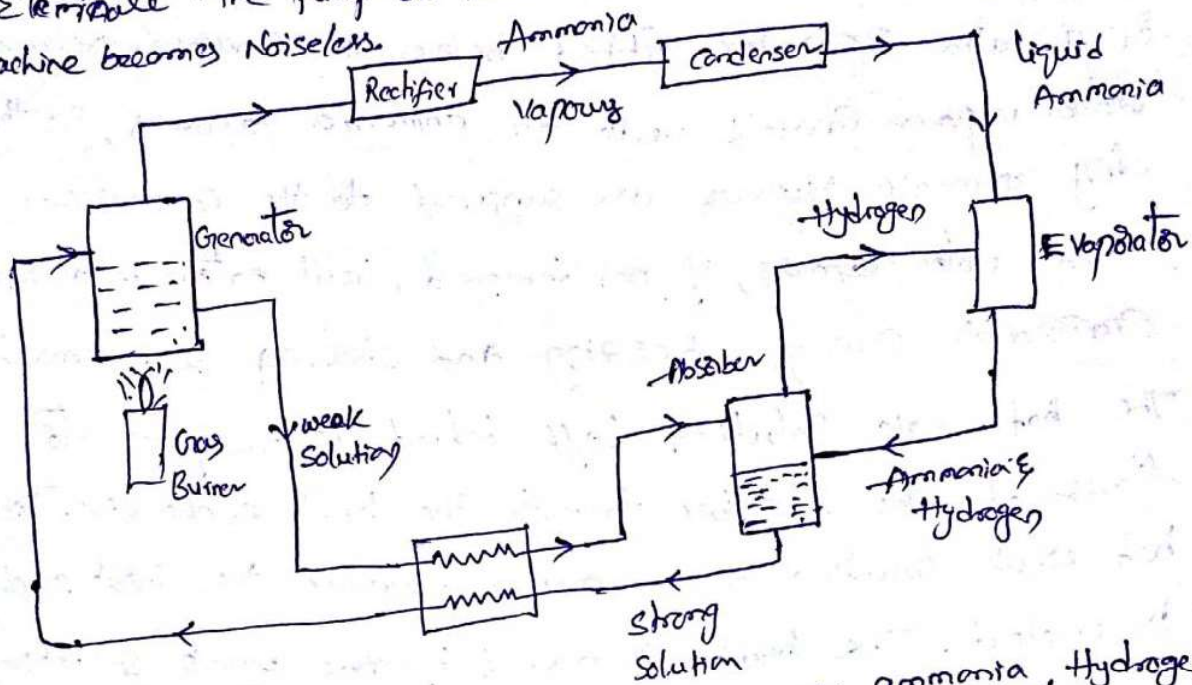
The three fluids Used in this system are ammonia, Hydrogen and water.

⇒ The ammonia is used as a refrigerant because it possesses most of the desirable properties. It is toxic but due to absence of moving parts there is very little chance for the leakage and the total amount of refrigerant used small.

⇒ The Hydrogen being the lightest gas, is used to increase the rate of evaporation of the liquid Ammonia Passing through the Evaporator, The Hydrogen is also non-corrosive and insoluble in water. This is used in the low pressure side of the system.

→ The water is used as a solvent because it has the ability to absorb ammonia readily.

The strong Ammonia solution from the absorber through heat exchanger is heated in the generator by applying heat from an external source, usually a gas Burner. During this heating process Ammonia Vapours are removed from the solution and passed to the Condenser. A rectifier or a water separator fitted before the condenser removes water vapour carried with the ammonia Vapours, so that dry ammonia Vapours are supplied to the Condenser. These water vapours, if not removed, will enter into the evaporator causing freezing and choking of the machine. The hot weak solution left behind in the generator flows to the absorber through the heat exchanger. This hot weak solution while passing through the heat exchanger is cooled. The heat removed by the weak solution is utilised in raising the temperature of strong solution passing through the Heat exchanger. In this way the absorption is accelerated and the improvement in the Performance of a plant is achieved.

The ammonia Vapours in the Condenser are condensed by using external cooling source. The liquid refrigerant leaving the Condenser flows under gravity to the evaporator where it meets the hydrogen gas. The hydrogen gas which is being fed to the evaporator permits the liquid ammonia to evaporate at a low pressure and temperature according to Dalton's Principle. During the process of evaporation the ammonia absorbs latent heat from the refrigerated space and thus produces cooling effect. The mixture of ammonia Vapour and hydrogen is passed to the absorber where ammonia is absorbed in water while the hydrogen rises to the top and flows back to evaporator. Thus cycle is completed.

Description and working of NH_3-water system.

Description and working of LiBr-water (2 shell and 4 shell) system.
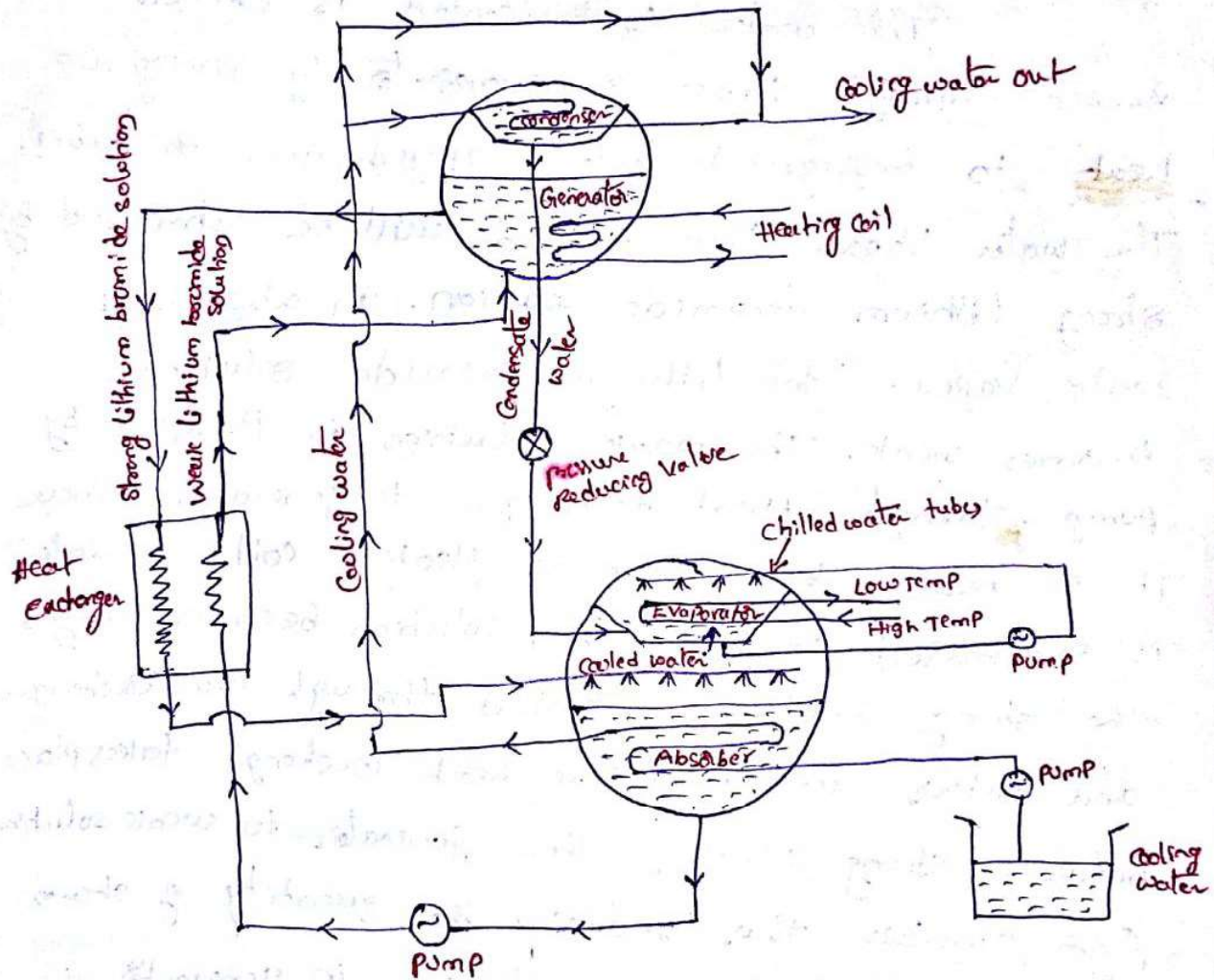
The Lithium bromide absorption refrigeration system uses as a solution Lithium bromide in water. In this system, water is used as refrigerant where as Lithium bromide as an absorbent. The Lithium bromide solution has strong affinity for water vapour. ~~as water is used as~~ refrigerant, the temperatures must be kept above 0°C. This system is very popular for air conditioning in which low refrigeration temperatures are required.

In this system the absorber and the evaporator are placed in one shell which operates at low pressure of the system. The generator and condenser are placed in another shell which operates at high pressure of the system.

The water to be cooled is chilled when pumped through tubes in evaporator by giving up heat to refrigerant water sprayed over the tubes. The water vapour thus formed will be absorbed by strong Lithium bromide solution. (In absorbing water vapour, the lithium bromide solution becomes weak. The weak solution is pumped by pump through Heat exchanger to generator where it is heated by steam in Heating coil. As water is evaporated in generator, solution becomes strong, the strong solution is passed through heat exchanger and enters absorber. The heat exchange takes place between strong solution from generator to weak solution from absorber thus reducing the quantity of steam required to heat weak solution in generator.

The refrigerant water vapour formed in generator is passed to Condenser where it is cooled by cooling water flowing through the Condenser water tubes. The Condensate from Condenser is supplied to evaporator to compensate the water vapour formed in evaporator. The Pressure reducing the value reduces the pressure of condensate from the Condenser pressure to the evaporator pressure. The cooled water from evaporator is pumped to evaporator to cool water for process requirements. Thus completes the cycle.

⟹ The temperature of generator, Condenser and Evaporator of a vapour absorption system are 100°C, 30°C and -5°C respectively. Find its maximum COP. If the respective temperatures of generator, Condenser and Evaporator are changed to 180°C, 30°C and -35°C respectively, find the new COP and the percentage change in COP.

Given Data:-

$T_g = 100°C = 100 + 273 = 373K$

$T_e = 30°C = 30 + 273 = 303K$

$T_e = -5°C = -5 + 273 = 268K$

Temp changes

$T_{G_1} = 180°C = 180 + 273 = 453K$

$T_E = 30°C = 30 + 273 = 303K$

$T_E = -35°C = -35 + 273 = 238K$

Required Terms:-

$$COP_{max} = ?$$

$$COP_{new} = ?$$

$$\% \ of \ COP = ?$$

Formulas used:-

$$COP_{max} = \left(\frac{T_e}{T_c - T_e}\right)\left(\frac{T_g - T_c}{T_g}\right)$$

$$COP_{new} = \left(\frac{T_E}{T_c - T_E}\right)\left(\frac{T_{G_1} - T_c}{T_{G_1}}\right)$$

$$\% \cdot COP = \frac{COP_{max} - COP_{new}}{COP_{max}}$$

Calculations:-

$$(COP)_{max} = \left(\frac{T_e}{T_c - T_e}\right)\left(\frac{T_g - T_c}{T_g}\right)$$

$$= \left(\frac{268}{303 - 268}\right)\left(\frac{373 - 303}{373}\right)$$

$$\boxed{(COP)_{max} = 1.437}$$

$$(COP)_{new} = \left(\frac{T_E}{T_c - T_E}\right)\left(\frac{T_{G_1} - T_c}{T_{G_1}}\right)$$

$$= \left(\frac{238}{303 - 238}\right)\left(\frac{453 - 303}{453}\right)$$

$$\boxed{(COP)_{new} = 1.212}$$

$$\% \ of \ COP = \frac{(COP)_{max} - (COP)_{new}}{(COP)_{max}}$$

$$= \frac{1.437 - 1.212}{1.437}$$

$$= 0.1565$$

$$\boxed{\% \ of \ COP = 15.65\%}$$

Steam Jet Refrigeration System:-

The steamjet Refrigeration system also known as ejector refrigeration system is one of the oldest methods of producing refrigerationg effect.

Principle:- To boil the water below 100°c at under the reduced temperature condition. When atmospheric pressure is reduced and high vaccum is created. If pressure is reduced to 6.5cm of water the water boiling temperature is 10°c and if it is further reduced to 5cm of water water may be boiled at 6°c.

Working:-
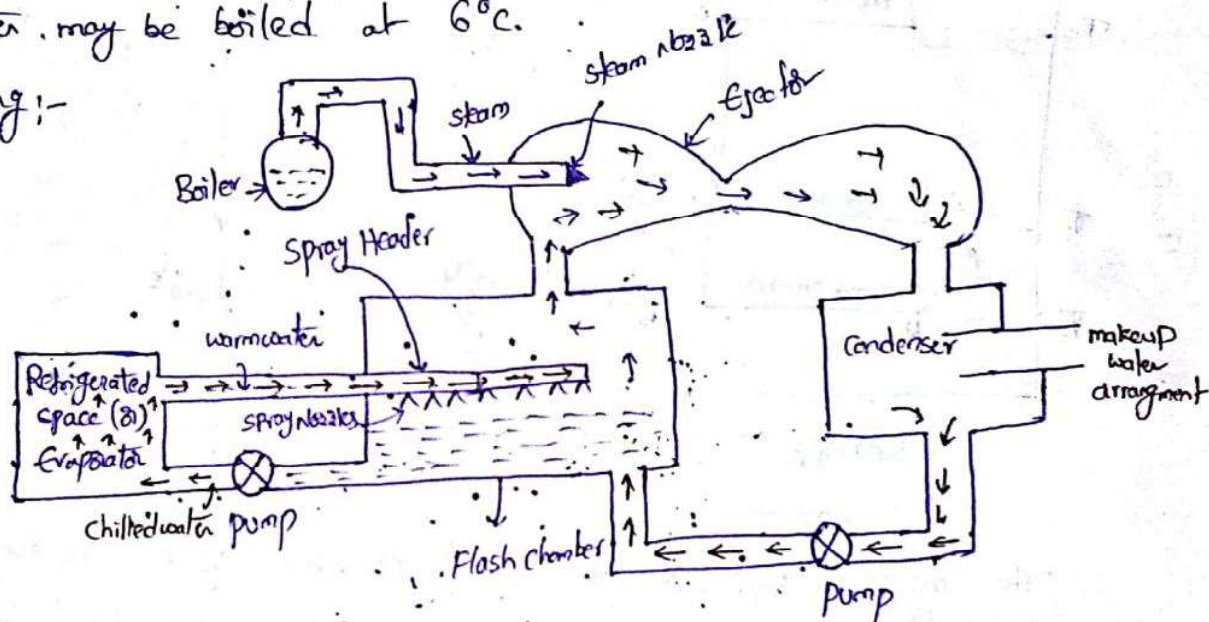
The main Components of the steam jet refrigeration systems, are the flash chamber, evaporator, steam Nozale, Ejector & Condenser. The flash chamber is a large vessel and is heavily insulated to avoid the rise in temperature of water due to high ambient temperature. It is fitted with perforated pipes for spraying water. The warm water coming out of the refrigerated space is sprayed into the flash chamber where some of which is converted into vapour after absorbing the latent heat, there by cooling the rest of water.

The high pressure steam from the boiler is passed through the steam nozzles there by increasing its velocity. This high velocity steam in the ejector would entrain the water vapours

form the flash chamber which would result in further form
of vapours. The mixture of steam and water vapours passes through
the Venturi tube of the ejector and gets compressed. The temperature
and pressure of the mixture rises considerably and fed to the
water cooled condenser where it gets condensed. The condensate
is again fed to the boiler as feed water. A constant water
level is maintained in the flash chamber and any loss of water
due to evaporation is made up from the make-up water line.
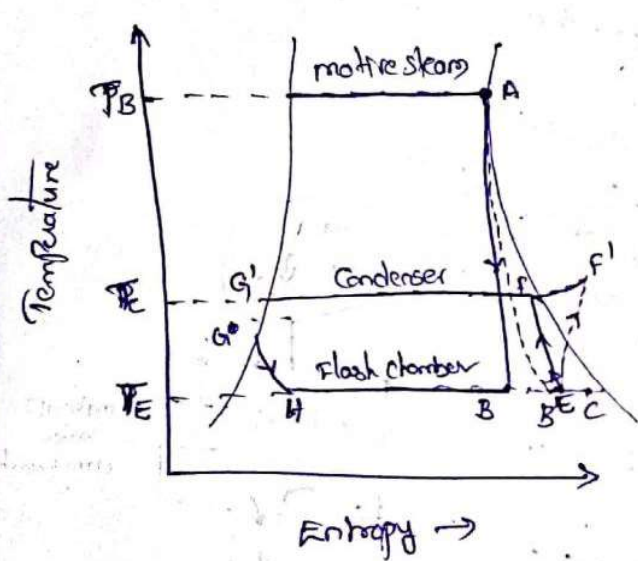
T-S Diagram
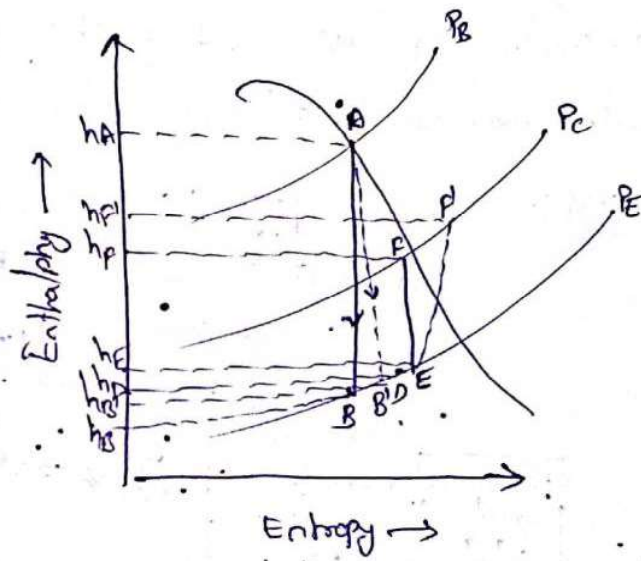
h-s-Diagram.

The point A represents the intial condition of the motive steam before
passing through the nozzle and the point B is the final condition
of the steam, assuming Isentropic expansion. The point 'c' represents
the intial conditions of the water vapour in the flash chamber or
evaporator and the point E is the condition of the mixture of high velocity
steam nozzle and the entrained water vapour before compression.
Assuming Isentropic compression the final condition of the mixture
discharged to the condenser is represented by point 'F'. The condition of
motive steam just before mixing with the water vapour is shown at
point D. The make up water supplied at point G whose temperature
is slightly lower than the condenser temperature and is throttled to
point H in the flash chamber.

P_B = Pressure of steam suplied from water

P_C = Pressure in the Condenser

P_E = Pressure in the Evaporator

AB = Isentropic Eapansion of steam through nozzle

AB_1 = Actual Eapansion of steam through nozzle

A = Initial Condition of motive steam before Eaponding in the nozzle

B = Condition of steam assuming isentropic Exporsion

B_1 = Actual Condition of steam after Exponsion.

C = Intial Condition of water vapour in the Evaporator

D = The condition of steam before mixing with water vapour

E = Condition of steam & water vapour mixture at the begining of the compression process

F = Final Condition of the mixture assuming isentropic compression

F_1 = Actual condition of the mixture after Exponsion

G_1 = Condition of the make up water being supplied before throttling process

H = Final condition of the make-up water in the flash chamber

EF = Isentropic Compression in booster ejector

EF_1 = Actual Compression in Booster ejector

Nozzle Efficiency:- It is the ratio of Actual enthalpy drop to the isentropic Enthalpy drop of the motive steam passing through the nozzle. Mathematically nozzle Efficiency

$$\eta_N = \frac{Actual\ Enthalpy\ drop}{Isentropic\ Enthalpy\ drop} = \frac{AB'}{AB} = \frac{h_A - h_{B'}}{h_A - h_B}$$

Nozzle Efficiency vary from 55 to 90 percentage.

Entrainment Efficiency:- The water vapour formed in the flash chamber or evaporator comes out with a very low velocity as compared to the velocity of the steam (V) coming out of the nozzle which is given by $V = \sqrt{2000(h_A - h_{B'})} = 44.72\sqrt{h_A - h_{B'}}$

The Expansion $(h_A - h_{B'})$ represents the kinetic energy of the motive steam. This kinetic energy gives the required momentum to the water vapour coming out of the flash chamber or evaporator. The process of giving the momentum to the water vapour formed in the flash chamber by the high velocity steam is called Entrainment of vapour. During the entrainment of water vapour from the flash chamber, the motive steam losses some of its kinetic energy. This process of entrainment is inefficient and part of the original motive force available for compression is reduced. This is taken into consideration by a factor known as entrainment efficiency. Mathematically entrainment efficiency $\eta_E = \dfrac{h_A - h_D}{h_A - h_{B'}}$, The Entrainment efficiency may be taken as 65 Percent.

Compression Efficiency :- It is defined as the ratio of the isentropic Enthalpy increase to the actual Enthalpy increase required for the compression of the mixture of motive steam and the water vapour, in the diffuser. Mathematically

$$\eta_c = \frac{\text{Isentropic enthalpy increase}}{\text{Actual enthalpy increase}}$$

$$= \frac{h_F - h_E}{h_{F'} - h_E}$$

→ the Compression Efficiency may be taken as 75 to 80 percent. It is also known as diffuser Efficiency

Mass of motive Steam Required :-

According to law of Conservation of Energy, the available Energy for compression must be equal to the energy required for compression.

Let m_s = Mass of motive steam suplied in kg/min

m_v = Mass of water vapour formed from the flash Chamber in kg/min

m = Mass of the mixture for compression in kg/min

$ = m_s + m_v$

we know that available Energy for Compression $= m_S(h_A - h_D) \rightarrow$ ①

Energy Required for compression $= m(h_{F'} - h_E) = (m_S + m_v)(h_{F'} - h_E) \rightarrow$ ②

According to law of Conservation of energy

$$m_S(h_A - h_D) = (m_S + m_v)(h_{F'} - h_E) \longrightarrow ③$$

W.K.T.

$$\eta_N = \frac{h_A - h_{B'}}{h_A - h_B} \Rightarrow h_A - h_{B'} = \eta_N(h_A - h_B) \longrightarrow ④$$

$$\eta_E = \frac{h_A - h_D}{h_A - h_{B'}} \Rightarrow h_A - h_D = \eta_E(h_A - h_{B'}) \longrightarrow ⑤$$

$$\eta_C = \frac{h_F - h_E}{h_{F'} - h_E} \Rightarrow h_{F'} - h_E = \frac{h_F - h_E}{\eta_C} \longrightarrow ⑥$$

from eq ③ $\quad m_S(h_A - h_D) = (m_S + m_v)(h_{F'} - h_B)$

$$m_S \cdot \eta_E(h_A - h_{B'}) = (m_S + m_v)\frac{(h_F - h_E)}{\eta_C}$$

$$m_S \cdot \eta_E \, \eta_N \, \eta_C (h_A - h_B) = m_S(h_F - h_E) + m_v(h_F - h_E)$$

$$m_S\left[(h_A - h_B)\eta_E \, \eta_N \, \eta_C - (h_F - h_E)\right] = m_v(h_F - h_E)$$

$$\frac{m_S}{m_v} = \frac{h_F - h_E}{(h_A - h_B)\eta_E \, \eta_N \, \eta_C - (h_F - h_E)}$$

$\frac{m_S}{m_v} =$ mass of motive steam required per kg of water vapour
produced in the flash chamber.

∴ Refrigeration Effect $R_E = m_v(h_C - h_{f8})$ kJ/min

$$R_E = 210 \, Q \text{ kJ/min}$$

∴ $m_v = \dfrac{210 \, Q}{h_c - h_{f8}}$ kg/min ; Mass of motive steam required
per Q tonne of refrigeration load

$= m_S \times m_v$

$\boxed{∴ \text{COP} = \dfrac{m_v(h_c - h_{fa})}{m_S(h_a - h_{fa})}}$

$= \dfrac{210 \, Q}{} \times m_S$

we know that available Energy for Compression $= m_s(h_A - h_D) \rightarrow$ ①

Energy Required for Compression $= m(h_{F1} - h_E) = (m_s + m_v)(h_{F1} - h_E) \rightarrow$ ②

According to law of Conservation of Energy

$$m_s(h_A - h_D) = (m_s + m_v)(h_{F1} - h_E) \longrightarrow ③$$

W.K.T

$$\eta_N = \frac{h_A - h_{B1}}{h_A - h_B} \Rightarrow h_A - h_{B1} = \eta_N(h_A - h_B) \longrightarrow ④$$

$$\eta_E = \frac{h_A - h_D}{h_A - h_{B1}} \Rightarrow h_A - h_D = \eta_E(h_A - h_{B1}) \longrightarrow ⑤$$

$$\eta_c = \frac{h_F - h_E}{h_{F1} - h_E} \Rightarrow h_{F1} - h_E = \frac{h_F - h_E}{\eta_c} \longrightarrow ⑥$$

from Eq ③ $m_s(h_A - h_D) = (m_s + m_v)(h_{F1} - h_E)$

$$m_s \cdot \eta_E (h_A - h_{B1}) = (m_s + m_v) \frac{(h_F - h_E)}{\eta_c}$$

$$m_s \cdot \eta_E \, \eta_N \, \eta_c \, (h_A - h_B) = m_s(h_F - h_E) + m_v(h_F - h_E)$$

$$m_s\left[(h_A - h_B)\,\eta_E\,\eta_N\,\eta_c - (h_F - h_E)\right] = m_v(h_F - h_E)$$

$$\frac{m_s}{m_v} = \frac{h_F - h_E}{(h_A - h_B)\,\eta_E\,\eta_N\,\eta_c - (h_F - h_E)}$$

$\frac{m_s}{m_v}$ = mass of motive Steam required per kg of water vapour Produced in the flash chamber.

∴ Refrigeration Effect $R_E = m_v(h_c - h_{f8})$ kJ/min

$$R_E = 210Q \text{ kJ/min}$$

∴ $m_v = \frac{210Q}{h_c - h_{f8}}$ kg/min ;   Mass of motive steam required Per Q tonne of refrigeration load

$= m_s \times m_v$

$$\boxed{∴ COP = \frac{m_v(h_c - h_{f8})}{m_s(h_A - h_{fG})}}$$

$= \frac{210Q}{h_c - h_{fG}} \times m_s$

→ A steam ejector refrigerator system is supplied with motive steam at 7 bar saturated with the water in the flash chamber at 4.5°C. The make-up water is supplied to the cooling system at 18°C and the condenser is operated at 0.058 bar. The nozzle efficiency is 88%. the entrainment efficiency is 65% and the compression efficiency is 80%. The quality of steam and flash chamber vapour at the begining of compression is 92%. Determine 1. mass of motive steam required per kg of flash chamber vapour. 2. Quality of vapour flashed from the flash chamber. 3. Refrigerating effect per kg of flash vapour. 4. mass of motive steam required per hour per ton of refrigeration. 5. Volume of vapour removed from the flash chamber per hour per tonne of refrigeration. 6. Co-efficient of Performance of the system.

Sol:- Given Data:

$P_B = 7 \text{ bar}$

$t_w = 4.5°C$

$t_{mw} = 18°C$

$P_C = 0.058 \text{ bar}$

$\eta_N = 0.88$

$\eta_E = 0.65$

$\eta_C = 0.8$

$x_E = 92\% = 0.92$

R.T:-

$\dfrac{m_S}{m_V} = ?$

$x_C = ?$

$R_E = ?$

$M = ?$

$V_C = ?$

$C.O.P = ?$

Formulas Used:-

$$\dfrac{m_S}{m_V} = \dfrac{h_F - h_E}{(h_A - h_B)\,\eta_N\,\eta_E\,\eta_C - (h_F - h_E)}$$

$$h_C = h_{fC} + x_C \cdot h_{fgC} \qquad \boxed{\therefore h_{fc} = h_{fB} \ \& \ h_{fgc} = h_{fgB}}$$

$x_C = 0.96$

$$m_V h_C + m_S h_D = (m_S + m_V) h_E$$

$$R_E = h_C - h_{fcr} \ \text{kJ/kg}$$

$$M = \dfrac{210\,Q}{h_C - h_{fcr}} \times \dfrac{m_S}{m_V}$$

$$V = V_C \times 210 d$$
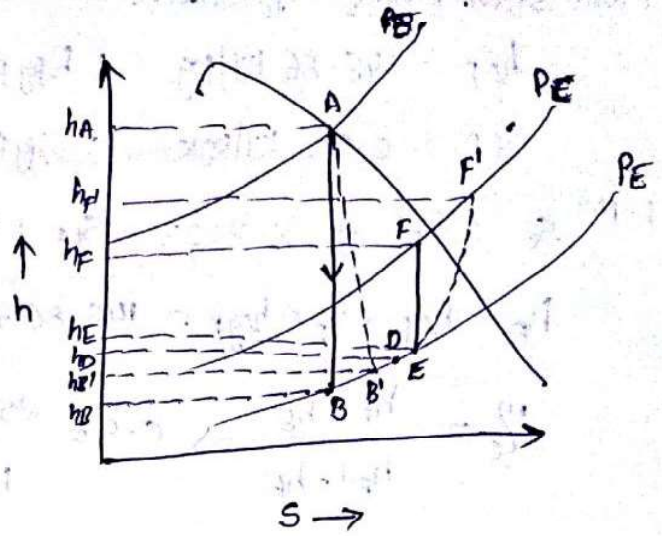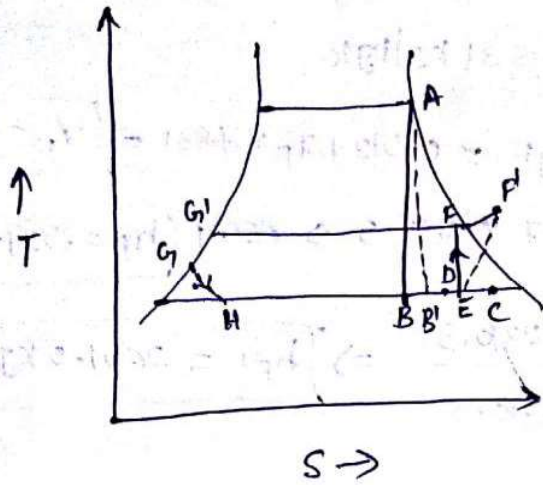
$V_C = \text{Volume of liquid at C} + x_C \text{(Volume of saturated vapour - Volume of liquid)}$

$= 1 + 0.96\,[152.22) - 1]$

$$C.O.P = \dfrac{m_V (h_C - h_{fcr})}{m_S (h_A - h_{fcr})}$$

↓ at 4.5°C → V = 152.22 m³/kg

- Calculations:-

from steam tables of dry saturated steam, corresponding to a pressure of 7 bar

$$h_A = 2762 \text{ KJ/kg} \quad ; \quad S_A = 6.705 \text{ KJ/kgk} \quad ; \quad t_A = 165°C$$

at $t_w = 4.5°C \rightarrow h_{fB} = 18.9 \text{ KJ/kg} : h_{fgB} = 2490.9 \text{ KJ/kg}$
$$S_{fB} = 0.0685 \text{ KJ/kgk} ; \quad S_{fgB} = 8.9715 \text{ KJ/kgk}$$

W.K.T $\quad S_A = S_B$
$$6.705 = S_{fB} + x_B \cdot S_{fgB} = 0.0685 + x_B \cdot (8.9715) \Rightarrow \boxed{x_B = 0.74}$$

$$h_B = h_{fB} + x_B \, h_{fgB} = 18.9 + 0.74 \,(2490.9) \Rightarrow \boxed{h_B = 1862.16 \text{ KJ/kg}}$$

$$\eta_N = \frac{h_A - h_{B'}}{h_A - h_B} \Rightarrow 0.88 = \frac{2762 - h_{B'}}{2762 - 1862.16} \Rightarrow \boxed{h_{B'} = 1970.14 \text{ KJ/kg}}$$

Since the points B, B', D and E lie on the same Pressure lines (4.5°C)

$$h_{fB} = h_{fB'} = h_{fD} = h_{fE} = 18.9 \text{ KJ/kg} :$$

$$h_{fgB} = h_{fgB'} = h_{fgD} = h_{fgE} = 2490.9 \text{ KJ/kg}$$

W.N.T $h_{B'} = h_{fB'} + x_{B'} \cdot h_{fgB'} \Rightarrow 1970.14 = 18.9 + x_{B'}(2490.9) \Rightarrow \boxed{x_{B'} = 0.78}$

$$\eta_E = \frac{h_A - h_D}{h_A - h_{B'}} \Rightarrow 0.65 = \frac{2762 - h_D}{2762 - 1970.14} \Rightarrow \boxed{h_D = 2247.3 \text{ KJ/kg}}$$

$$h_D = h_{fD} + x_D \cdot h_{fgD} \Rightarrow 2247.3 = 18.9 + x_D (2490.9) \Rightarrow \boxed{x_D = 0.894}$$

$$h_E = h_{fE} + x_E \cdot h_{fgE} = 18.9 + 0.92 \times 2490.9 \Rightarrow \boxed{h_E = 2310.5 \text{ KJ/kg}}$$

$$S_E = S_{fE} + x_E \cdot S_{fgE} = 0.0685 + 0.92 \times 8.9715 \Rightarrow \boxed{S_E = 8.3223 \text{ KJ/kgk}}$$

From steam tables $P_c = 0.058$ bar

$$h_{fF} = 148.86 \text{ kJ/kg} \quad \& \quad h_{fgF} = 2417.5 \text{ kJ/kg}$$

$$s_{fF} = 0.512 \text{ kJ/kgK} \quad ; \quad s_{gF} = 7.831 \text{ kJ/kgk}$$

W.N.T $S_E = S_F \Rightarrow 8.3223 = s_{fF} + x_F \times s_{fgF} = 0.512 + x_F \times 7.831 \Rightarrow \boxed{x_F = 0.997}$

$$h_F = h_{fF} + x_F \times h_{fgF} = 148.86 + 0.997 \times 2417.5 \geq 2559 \quad \boxed{h_F = 2559.1 \text{ kJ/kg}}$$

$$\eta_c = \frac{h_F' - h_E}{h_{F'} - h_E} \Rightarrow 0.8 = \frac{2559.1 - 2310.5}{h_{F'} - 2310.5} \Rightarrow \boxed{h_{F'} = 2621.2 \text{ kJ/kg}}$$

1. mass of motive steam required per kg of the flash chamber

$$\frac{m_s}{m_v} = \frac{h_F - h_E}{(h_A - h_B)\, \eta_E\, \eta_N\, \eta_c - (h_F - h_E)}$$

$$= \frac{2559.1 - 2310.5}{(2762 - 1862.16)\,0.88 \times 0.65 \times 0.5 - (2559.1 - 2310.5)}$$

$$= \frac{248.6}{-411.8 - 248.6} = 1.523 \text{ kg/kg of flash vapour}$$

2. Quality of vapour flashed from the flash chamber

$$x_c =$$

$$m_v h_c + m_s h_D = (m_s + m_v) h_E$$

$$h_c + \frac{m_s}{m_v} h_D = \left(\frac{m_s}{m_v} + 1\right) h_E$$

$$h_c + 1.523 \times 2247.3 = (1.523 + 1)\, 2310.5$$

$$\boxed{h_c = 2406.8 \text{ kJ/kg}}$$

$$h_c = h_{fc} \cdot + x_c \cdot h_{fgc}$$

$$2406.8 = 18.9 + x_c \times 2490.9$$

$$x_c = \frac{2406.8 - 18.9}{2490.9}$$

$$\boxed{x_c = 0.96}$$

③ Refrigeration effect per kg of flash vapour

$$\therefore \text{ at } 18°C \\ h_{fc_1} = 75.5 \text{ kJ/kg}$$

$$R_E = h_c - h_{fc_1}$$

$$= 2406.8 - 75.5$$

$$\boxed{R_E = 2331.3 \text{ kJ/kg}}$$

④ mass of motive steam

$$M = \frac{210Q}{h_c - h_{fc_1}} \times \frac{m_s}{m_v}$$

$$= \frac{210 \times 1}{2406.8 - 75.5} \times 1.523$$

$$= 0.133 \text{ kg/min/TR}$$

$$= 0.133 \times 60$$

$$\boxed{M = 7.98 \text{ kg/h/TR}}$$

i) volume of vapour removed from flash chamber per hour per tonne of refrigeration.

$$V_C = \text{Volume of liquid at } C + x_C \text{ (volume of saturated vapour} - \text{volume of liquid)}$$

$$= 1 + 0.95 \, (152.22 - 1) \qquad \boxed{\because \text{at } 4.5°C \Rightarrow v = 152.22 \, m^3/kg}$$

$$V_C = 144.66 \, m^3/kg$$

$$V = V_C \times \frac{210Q}{h_C - h_{fg}} = 144.66 \times \frac{210 \times 1}{2406.8 - 75.5} \times 60 = 782 \, m^3/h/TR$$

$$\boxed{V = 782 \, m^3/h/TR}$$

⑥ coefficient of Performance of the system.

at $P_C = 0.058 \, bar$ $\quad h_{fG'} = 148.8 \, kJ/kg$

$$C.O.P = \frac{m_v(h_C - h_{fG})}{m_s(h_A - h_{fG'})} = \frac{1(2406.8 - 75.5)}{1.523(2762 - 148.8)} = 0.586$$

— x —

→ An ejector Refrigeration unit is to be designed to deliver 150 kg per minute of chilled water at 4°C from supply water at 22°C. water vapour entering the ejector has a quality of 0.97. Determine (i) volume of flashed vapour removed per minute from flash chamber (ii) Refrigeration Capacity of the unit.

Sol⁻ Given Data :-

$m_v = 150 \, kg/min = \frac{150}{60} = 2.5 \, kg/s$

$t_w = 4°C$

$t_s = 22°C$

$x_e = 0.97$

R.T :-

$V = ?$

$R_E = ?$

Formulas Used

$$V = V_e \times \frac{210Q}{h_{\bar{c}} - h_{f \text{ cn}}}$$

$$R_E = m_v(h_c - h_{f \text{ cn}})$$

V_e = volume of liquid flash chamber + x (vol of saturated vapour — vol of liquid)

Calculations:-

from steam tables $t_w = 4°C$

$h_{fc} = 16.78$ kJ/kg, $h_{fgc} = 2491.9$ kJ/kg, $V_{gc} = 157.232$ m³/kg

$$h_c = h_{fc} + x_c \cdot h_{fgc}$$

$$= 16.78 + 0.97 \times 2491.9 \Rightarrow \boxed{h_c = 2433.923 \text{ kJ/kg}}$$

at $t_s = 22°C$ from steam tables $\boxed{h_{fc_1} = 92.332 \text{ kJ/kg}}$

V_c = volume of liquid at flash chamber + x (vol of satured vapour
vol of liquid)

$$= 1 + 0.97 (157.232 - 1)$$

$$V_c = 152.545 \text{ m}^3/kg$$

(i) Volume of vapour removed $\quad V = V_c \times \dfrac{2100}{h_c - h_{fc_1}}$ $\quad \boxed{\because Q = 1TR}$

$$V = 152.545 \times \frac{210 \times 1}{2433.923 + 92.332}$$

$$\boxed{V = 13.681 \text{ m}^3/\min/TR}$$

(ii) Refrigeration Capacity per kg of flash chamber

$$R_E = m_v (h_c - h_{fc_1})$$

$$= 2.5 (2433.923 - 92.332)$$

$$\boxed{R_E = 5853.978 \text{ kJ/kg}}$$

→ The following data refer to a LiBr + H_2O absorption system. Generator temp = 80°C, Condenser Temp = Absorber Temp = 30°C, Evaporator temp = 10°C, Condensate temp = 25°C. Steam enters the generator heating coil at 120°C (dry-saturated state steam) and leaves at 100°C as condensate. The concentration of liquid leaving the generator is 0.65 and its enthalpy is −75 kJ/kg. The concentration of liquid leaving the absorber is 0.51 and its enthalpy is −170 kJ/kg. The enthalpy of vapour leaving the generator is 2620 kJ/kg. The flow rate through the evaporator is 0.4 kg/s. Find ① Pressure in generator, Condenser, evaporator and absorber in mm of mercury head. ② Tonnage ③ Heat rejection to condenser and absorber ④ C.O.P and ⑤ Relative C.O.P.

Sol:

G→① $T_G = 80°C = 80 + 273 = 353 K$

$T_C = T_A = 30°C = 30 + 273 = 303 K$

③ = $T_E = 10°C = 10 + 273 = 283 K$

$T_2 = 25°C =$

$T_H = 120°C$

$T_L = 100°C$

$x_5 = 0.65$, $h_5 = -75$ kJ/kg

$x_4 = 0.51$, $h_4 = -170$ kJ/kg

$h_1 = -170$ kJ/kg , $h_1 = 2620$ kJ/kg ; $m_1 = m_2 = m_3 = 0.4$ kg/s
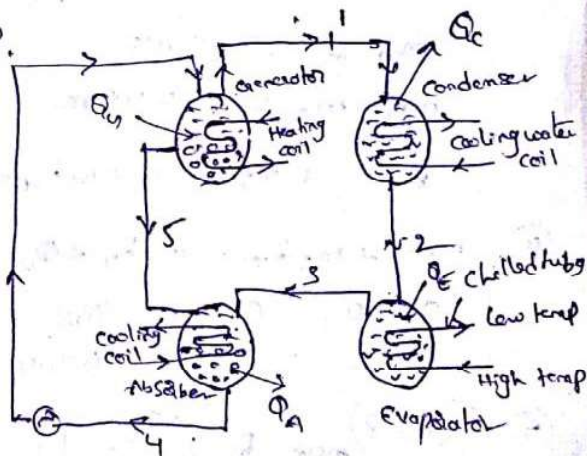
R.T: ① $P_G = ?$ ④ C.O.P = ?

$P_C = ?$ ⑤ $(C.O.P)_{max} = ?$

$P_E = ?$

$P_A = ?$

② $Q_E = ?$

③ $Q_C = ?$
  $Q_A = ?$

F.O

① From steam tables dry saturated steam at corresponding temp

② $Q_E = m_2(h_3 - h_2)$ (∵ h_3, h_2 from ①)

③ $Q_C = m_2(h_1 - h_2)$

mass balance absorber ⟹ $m_3 + m_5 = m_4$

Lithium bromide solution in absorber $m_4 x_4 = m_5 x_5$

Energy balance for absorber

$m_3 h_3 + m_5 h_5 = m_4 h_4 + Q_A$

④ $C.O.P = \dfrac{Q_E}{Q_{gr}}$; Considering the energy balance for the generator $m_1 h_1 + m_5 h_5 = m_4 h_4 + Q_{gr}$

⑥ $Q_{gr} = Q_C + Q_A - Q_E$

⑧ $(C.O.P)_{max} = \left(\dfrac{T_E}{T_C - T_E}\right)\left(\dfrac{T_{gr} - T_A}{T_{gr}}\right)$ $\boxed{\therefore 1.013\ bar = 760\ mm\ of\ Hg}$

Calculations:

① at $T_G = 80°C$, $P_G = 0.4736\ bar = 0.4736 \times \dfrac{760}{1.013} = 355.3\ mm\ of\ Hg$

at $T_C = 30°C$, $P_C = 0.04242\ bar = 0.04242 \times \dfrac{760}{1.013} = 31.82\ mm\ of\ Hg$

at $T_E = 10°C$, $P_E = 0.01227\ bar = 0.01227 \times \dfrac{760}{1.013} \approx 9.2\ mm\ of\ Hg$

at $T_A = 30°C$, $P_A = 0.04242\ bar = 0.04242 \times \dfrac{760}{1.013} = 31.82\ mm\ of\ Hg$

② at $T_C = 25°C$, $h_2 = 104.75\ kJ/kg$

$T_E = 10°C$, $h_3 = 2519.9\ kJ/kg$

$Q_E = m_2(h_3 - h_2) = 0.4(2519.9 - 104.75) = 966\ kJ/s$

$= \dfrac{966}{3.5} = 276\ TR$ ($1\ TR = 3.5\ kJ/s$)

③ $Q_C = m_2(h_1 - h_2) = 0.4(2620 - 104.75) = 1006\ kJ/s$

$m_4 x_4 = m_5 x_5 \Rightarrow \dfrac{m_4}{m_5} = \dfrac{x_5}{x_4} = \dfrac{0.65}{0.51} = 1.2745$

$m_4 = 1.2745\ m_5$:

$m_3 + m_5 = 1.2745\ m_5 \Rightarrow$ $m_5 = 1.4572\ kg/s$
                                        $m_4 = 1.8572\ kg/s$

$m_3 h_3 + m_5 h_5 = m_4 h_4 + Q_A \Rightarrow Q_A = 1214.36\ kJ/s$

④ $m_1 h_1 + m_5 h_5 = m_4 h_4 + Q_{gr} \Rightarrow Q_{gr} = 1254.4\ kJ/s$

$C.O.P = \dfrac{Q_E}{Q_{gr}} = \dfrac{966}{1254.4} = 0.77$

⑤ $(C.O.P)_{max} = \left(\dfrac{T_E}{T_C - T_E}\right)\left(\dfrac{T_n - T_A}{T_n}\right) = \cancel{0.384}\ 2.004$

$=$

Relative $C.O.P = \dfrac{C.O.P}{(C.O.P)_{max}} = \dfrac{0.77}{2.004} = 0.384$

$\longleftarrow$ 0 $\longrightarrow$