UNIT 3 HVAC&R
QB + Question papers Solution

Unit 3	Practical aspects of Vapor Compression and Advanced Refrigeration Systems

Major components of refrigeration cycle: Types of compressors, Characteristics of reciprocating and centrifugal compressors, Types of evaporators, Types of condensers and Types of expansion valves

Safety Controls: LP/HP cut-off, Low temperature control, Frost control, Motor overload control, Oil pressure failure control. Capacity control of different compressors

Advanced Refrigeration System: Transcritical cycle and their types, Simple ejector refrigeration system (analysis and numerical)

VPKBIET Baramati				
Mechanical Engineering Department				
Unit 3: Practical aspects of Vapor Compression and Advanced Refrigeration Systems (Theory Question Bank)				
Subject: Heating, Ventilation Air Conditioning & Refrigeration (402041) Class: BE Mech/Auto-2019 Course, Semester-II Chairman: Dr.P.R.Chitragar, +91-8050366105				
Sr. No.	**Question Statement**	**CO**	**BL**	**Marks**
1	Explain with a neat sketch Thermostatic Expansion Valve.	3	2	9
2	Explain with a neat sketch Low Pressure (LP) cut off used in VCR cycle.	3	2	9
3	Explain with neat sketch flooded type evaporator	3	2	9
4	Explain with neat schematic the frost control circuit used in VCR cycle	3	2	9
5	Explain with neat schematic CO2 transcritical cycle	3	3	9
6	Distinguish between the air cooled and water cooled condensers.	3	3	9
7	Explain with neat schematic Low temperature control in VCR cycle.	3	2	9
8	Explain with neat schematic Simple Ejector Refrigeration System.	3	2	9
9	Discuss the following terms used in analysis of Simple Ejector Refrigeration Cycle. a) Entrainment Ratio b) Entrainment efficiency c) Nozzle Efficiency	3	3	9

NOV - DEC 22

Q1) a) Explain with a neat sketch Thermostatic Expansion Valve. **[5]**

b) Discuss the following terms used in thermodynamic analysis of Simple Ejector Refrigeration Cycle. **[6]**

i) Entrainment Ratio

ii) Entrainment efficiency

iii) Nozzle efficiency

c) Explain with a neat sketch Low Pressure (LP) cut off used in VCR cycle. **[6]**

OR

Q2) a) Distinguish between the air cooled and water cooled condensers. **[4]**

b) Explain with neat schematic low temperature control in VCR cycle. **[6]**

c) Explain with neat schematic Simple Ejector Refrigeration System. **[7]**

MAY- JUN 23

Q1) a) Explain with neat sketch the flooded type evaporator. **[6]**

b) Explain with neat schematic diagram the frost control circuit used in VCR cycle. **[6]**

c) Explain with neat schematic CO_2 trans critical cycle. **[5]**

OR

Q2) a) Explain with a neat sketch Thermostatic Expansion Valve. **[5]**

b) Discuss the following terms used in thermodynamics analysis of Simple Ejector Refrigeration Cycle. **[6]**

i) Entrainment Ratio

ii) Entrainment efficiency

iii) Nozzle Efficiency

c) Explain with a neat sketch Low Pressure (LP) cut off used in VCR cycle. **[6]**

NOV - DEC 23

Q1) a) Explain with a neat sketch Thermostatic Expansion Valve. **[6]**

b) Explain with a neat sketch Low Pressure (LP) cut off used in VCR cycle. **[6]**

c) Distinguish between the air cooled and water cooled condensers. **[5]**

OR

Q2) a) Explain with neat sketch flooded type evaporator. **[6]**

b) Explain with neat schematic the frost control circuit used in VCR cycle. **[6]**

c) Explain with neat schematic CO_2 transcritical cycle. **[5]**

MAY - JUN 24

Q1) a) Explain with a neat sketch Thermostatic Expansion Valve. [6]

b) Explain with neat schematic Simple Ejector Refrigeration System. [5]

c) Discuss the following terms used in thermodynamics analysis of Simple Ejector Refrigeration Cycle. [6]

i) Entrainment Ratio

ii) Entrainment efficiency

iii) Nozzle Efficiency

OR

Q2) a) Explain with neat sketch flooded type evaporator. [6]

b) Explain with neat schematic the frost control circuit used in VCR cycle. [6]

c) Explain with neat schematic CO_2 trans critical cycle. [5]

NOV - DEC 24

Q1) a) Explain with neat sketch the flooded type evaporator. **[6]**

b) Explain with neat schematic diagram the frost control circuit used in VCR cycle. **[5]**

c) Explain with neat schematic CO_2 trans critical cycle. **[6]**

OR

Q2) a) Explain with a neat sketch Thermostatic Expansion Valve. **[6]**

b) Explain with neat schematic Simple Ejector Refrigeration System. **[5]**

c) Discuss the following terms used in thermodynamics analysis of Simple Ejector Refrigeration Cycle. **[6]**

i) Entrainment Ratio

ii) Entrainment efficiency

iii) Nozzle Efficiency

MAY - JUN 25

Q1) a) Discuss any one method of capacity controls of centrifugal compressor. **[6]**

b) Explain with neat sketch thermostatic expansion valve. **[6]**

c) Explain oil pressure failure control. **[5]**

OR

Q2) a) Explain with neat sketch evaporative condenser. **[6]**

b) Explain with neat sketch low temperature control. **[6]**

c) Explain with neat sketch transcritical cycle. **[5]**

ii) Thermostatic Expansion Valve (TXV) :

- It is the most commonly used expansion device in commercial and industrial refrigeration systems.
- It consists of a needle valve and seat a metallic diaphragm (bellows), a spring, an adjusting screw and a strainer. Refer Fig. Q.4.2.

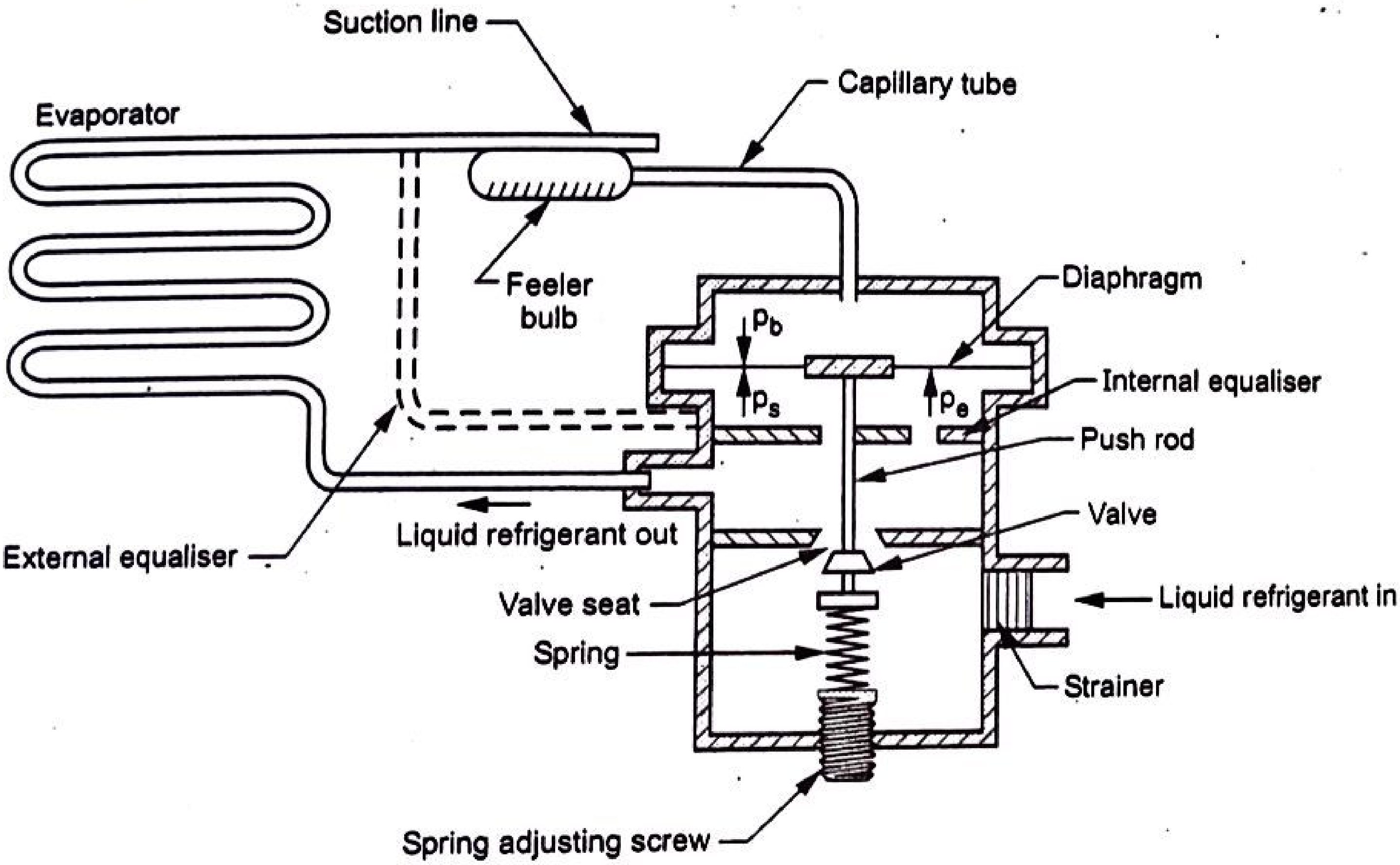


Fig. Q.4.2 Thermostatic expansion valve

- It also includes a feeler or thermal bulb which is mounted on the suction line (near the outlet of evaporator).
- This feeler or thermal bulb is partly filled with the same refrigerant as used in the system.
- The opening and closing of the valve depends upon the following forces acting on the diaphragm :

  i) Spring pressure (p_s) on the bottom of diaphragm (↑)

  ii) Evaporator pressure (p_e) on the bottom of diaphragm (↑)

  iii) Feeler bulb pressure (p_b) on the top of diaphragm (↓)

- As the feeler bulb is mounted on the suction line, it has the same temperature as the refrigerant of that point.
- If the temperature of refrigerant changes, the pressure in the feeler bulb changes and it is transmitted on the top of diaphragm.
- During the normal working condition, the value of p_b is balanced by p_s and p_e.
- The force required to close the valve depends upon the p_s and p_e which depends on the saturation temperature of refrigerant in the evaporator coil.
- The force required to open the valve depends upon the p_b which depends on the refrigerant temperature in the feeler bulb.
- It means, opening and closing of the valve depends on the difference in these two temperatures. This is called as **superheat.**
- TXV is also called as constant superheat valve because it maintains constant superheat of vapour refrigerant at the end of the evaporator.
- If the load on the evaporator increases, the liquid refrigerant boils faster in the evaporator coil. Hence, the temperature of feeler bulb increases and thus p_b also increases. This pressure is transmitted to the diaphragm and it moves downward. Thus, valve opens and more quantity of liquid refrigerant enters into the evaporator. It continues till the pressure equilibrium is obtained on the diaphragm.
- If the load on the evaporator decreases, less liquid refrigerant evaporates in the evaporator. Hence, the temperature of feeler bulb decreases and thus p_b also decreases. This pressure is transmitted to the diaphragm and it moves upward. Thus, opening of the valve reduces and the flow of liquid refrigerant to the evaporator also decreases. It continues till the pressure equilibrium is obtained on the diaphragm.

Q →

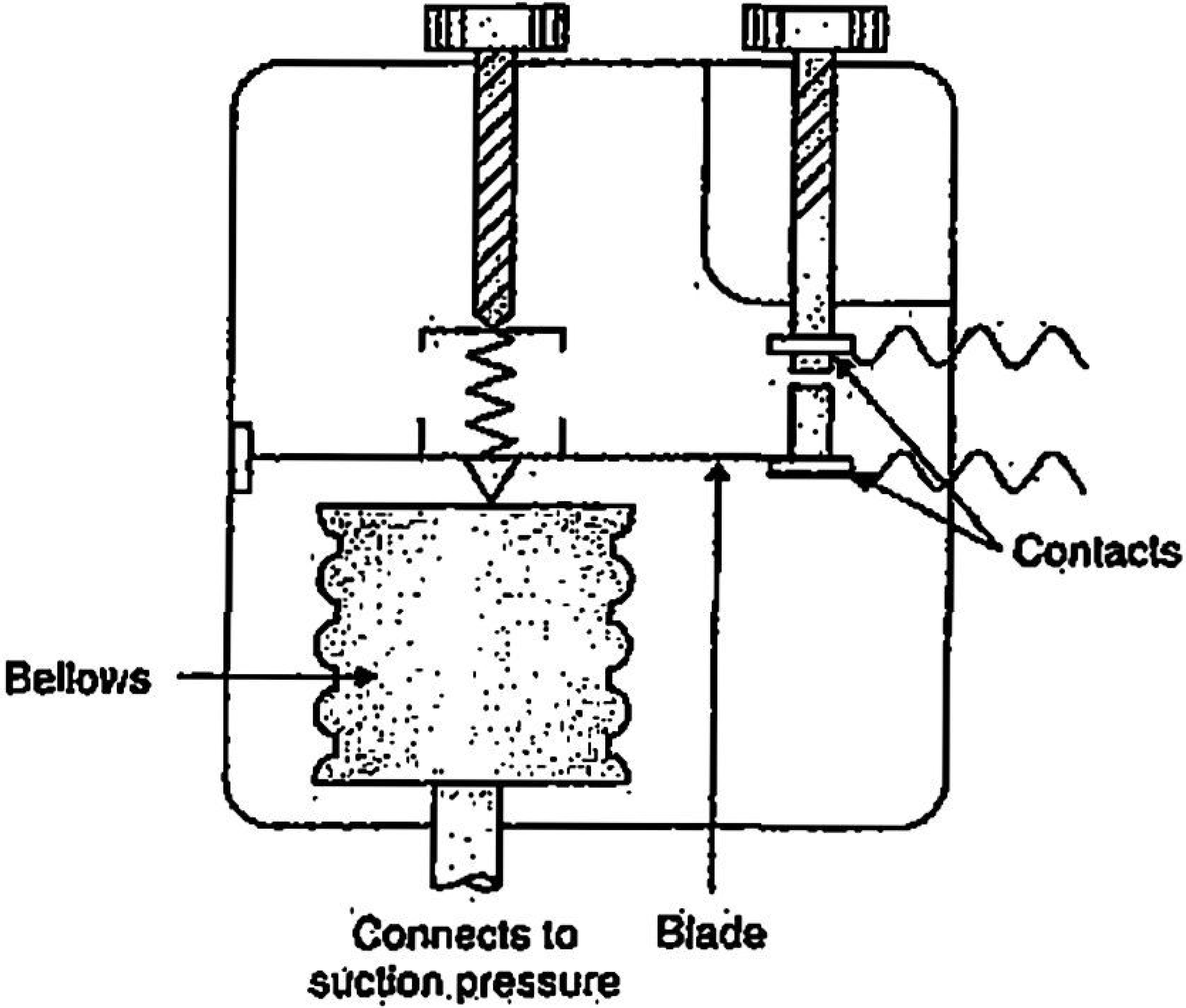


Fig. 3.19.1 : Low pressure control

(1) Low pressure control

- To protect the compressor against low pressure in the system and to avoid the negative pressure of air into the system if a vacuum is generated in the lines a low pressure cut out (control) is provided.

- When the refrigerated compartments are cut off by the solenoids and there is no return gas, the low pressure cut out is activated.
- When the solenoid of the refrigerated compartments open the return gas comes in the inlet of the compressor and the suction pressure rises and then the low pressure switch cuts in the compressor.
- Fig. 3.19.1 represents a mechanism for low pressure control.

Working principle

- As soon as the suction pressure falls below a certain limit the spring pushes the blade downward, opens the motor circuit and compressor is stopped.
- When the suction pressure increases the bellows get expanded, hence closing the contact of the motor circuit and restarting the compressor.
- The adjusting screws (2 Nos.) are utilised to set the cut-out and cut in pressures. Cut-out pressure is the pressure at which the compressor stops and cut in pressure is the pressure at which the compressor is getting started.

Q → **Flooded Type Evaporator**

RQ. Explain working of flooded type evaporator with neat sketch. (Ref. Q. 5(b), W-18, 4 Marks)

(1) In a Flooded type evaporator, a constant refrigerant liquid level is maintained.

(2) A float valve is used as throttling device, which maintains a constant liquid level in the evaporator. It consists of a shell into which, the refrigerant liquid is fed through the float valve.

(3) The shell is connected to the top and bottom of the coil. The liquid flows from the bottom of the shell by gravity to coil tubes, in which it evaporates by absorbing heat from the surrounding.

(4) The liquid vapour mixture from the coil returns to the shell. In the shell, the liquid and vapour are separated. The vapour is collected at the top of the shell (Flash chamber). From there it enters into the compressor through suction line.

(5) Flooded type evaporators provide rapid cooling and are used in large capacity equipment. It is shown in Fig. 3.4.1.

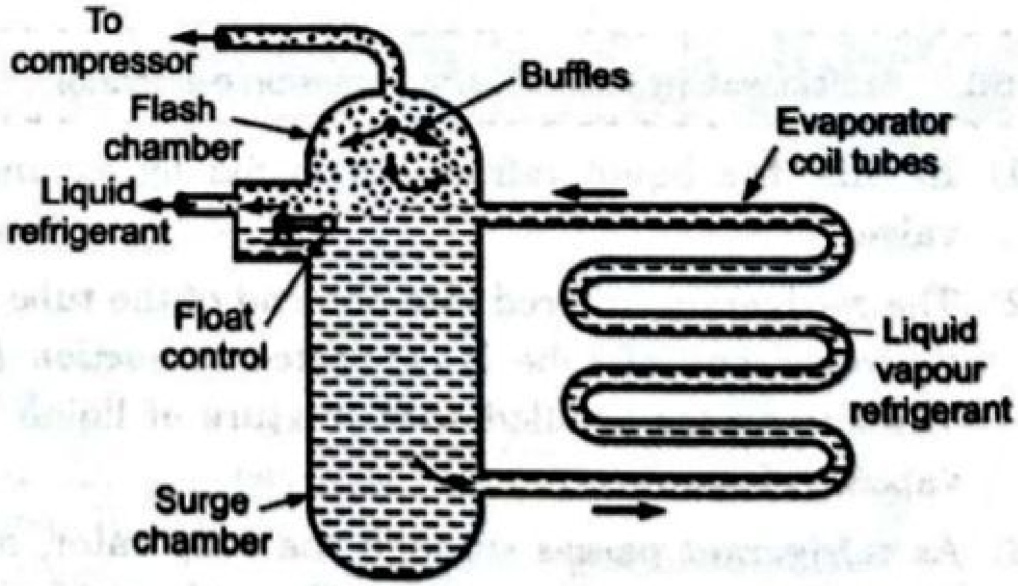


Fig. 3.4.1 : Flooded type evaporator

Q →

☞ **Frost control**

- Any evaporator that operates below the freezing point of water needs defrosting
- Develops a layer of frost and entrained air referred to as "hoar frost"
- Increased by humidity levels and air flow amounts
- Medium and low temperature range methods of defrosting
- Purpose-to prevent the formation of frost on the outer surface of the DX coil.
- Usually, a temperature sensor is used to sense the outer surface temperature of the DX coil.

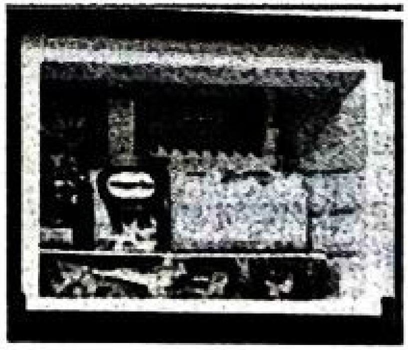


Fig. 3.5.6 : Frost-free

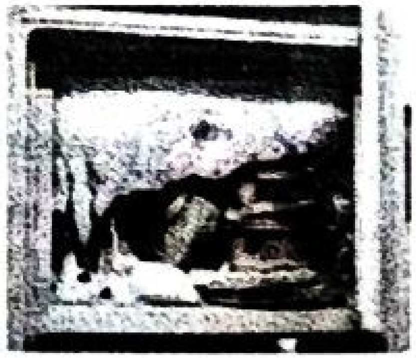


Fig. 3.5.7 : Direct cool

ii) Frost Control

- The purpose of frost control is to prevent the formation of frost on the outer surface of the DX coil.
- Usually, a temperature sensor is used to sense the outer surface temperature of the DX coil.
- When the temperature drops to 0° C, the controller actuates a relay, which opens the circuit and stops the compressor.

Q →

☞ **Transcritical cycle and their types**

- A **transcritical cycle** is a thermodynamic cycle where the working fluid goes through both Subcritical and supercritical states.
- **Transcritical CO_2 refrigeration** is a type of refrigeration cycle in which CO_2 is the sole refrigerant, evaporating in the subcritical region and rejecting heat at temperatures above the critical point in a gas cooler instead of a condenser.
- CO_2 transcritical systems require specialized controls and components to operate at necessary high pressures to accommodate CO_2's low critical temperature.

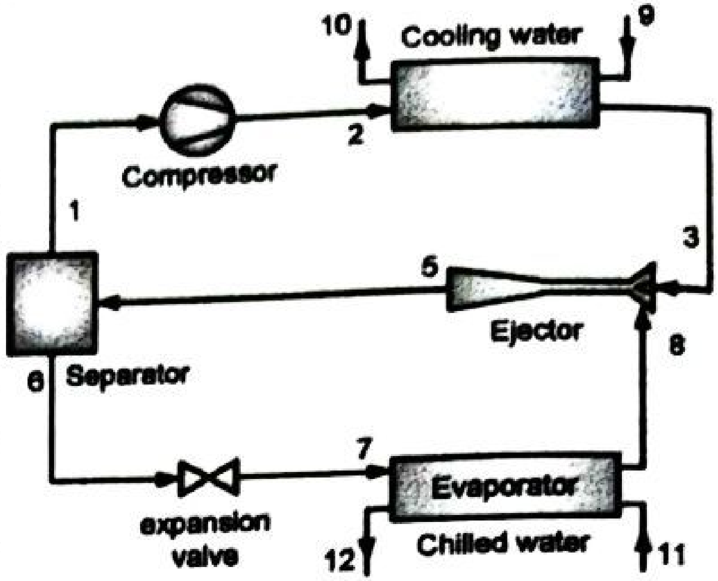


Fig. 3.5.13

- A transcriptical cycle is a closed thermodynamic cycle where the working fluid goes through both subcritical and supercritical states. In particular, for power cycles the working fluid is kept in the liquid region during the compression phase and in vapour and/or supercritical conditions during the expansion phase.
- The ultra-supercritical steam Rankine cycle represents a widespread transcritical cycle in the electricity generation field from fossil fuels, where water is used as working fluid.
- Other typical applications of transcritical cycles to the purpose of power generation are represented by organic Rankine cycles, which are especially suitable to exploit low temperature heat sources, such as geothermal energy, heat recovery applications or waste to energy plants. With respect to subcritical cycles, the transcritical cycle exploits by definition higher pressure ratios, a feature that ultimately yields higher efficiencies for the majority of the working fluids.
- Considering then also supercritical cycles as a valid alternative to the transcritical ones, the latter cycles are capable of achieving higher specific works due to the limited relative importance of the work of compression work.
- While in single level supercritical cycles both pressure levels are above the critical pressure of the working fluid, in transcritical cycles one pressure level is above the critical pressure and the other is below.
- In the refrigeration field carbon dioxide, CO_2, is increasingly considered of interest as refrigerant.

Q **Compare air cooled and water cooled condenser.**

Ans. : →

Sr. No.	Air Cooled Condenser	Water Cooled Condenser
1)	Its construction is simple hence initial cost and maintenance cost is low.	Its construction is complicated hence initial cost and maintenance cost is high.
2)	For carrying the piping arrangement is not required.	For carrying the water piping arrangement is required.
3)	There is no problem of disposal of used air.	If waste water system is used then there is problem of disposal of used water.
4)	Because of air there is no corrosion problem.	Corrosion occurs inside the tubes carrying the water.
5)	They are used for small capacity plants.	They are used for large capacity plants.
6)	Air distribution on condenser surface is not uniform.	There is even distribution of water on the condensing surface.
7)	These condensers have high flexibility.	These condensers have low flexibility.
8)	Power is required to drive the fan and there is problem of fan noise.	There is no fan noise.
9)	They have low heat transfer capacity.	They have high heat transfer capacity.

Q →

Low Temperature Control

Low temperature control is used to prevent the temperature of chilled water in the liquid cooler from falling below a certain limit to protect the water from freezing.

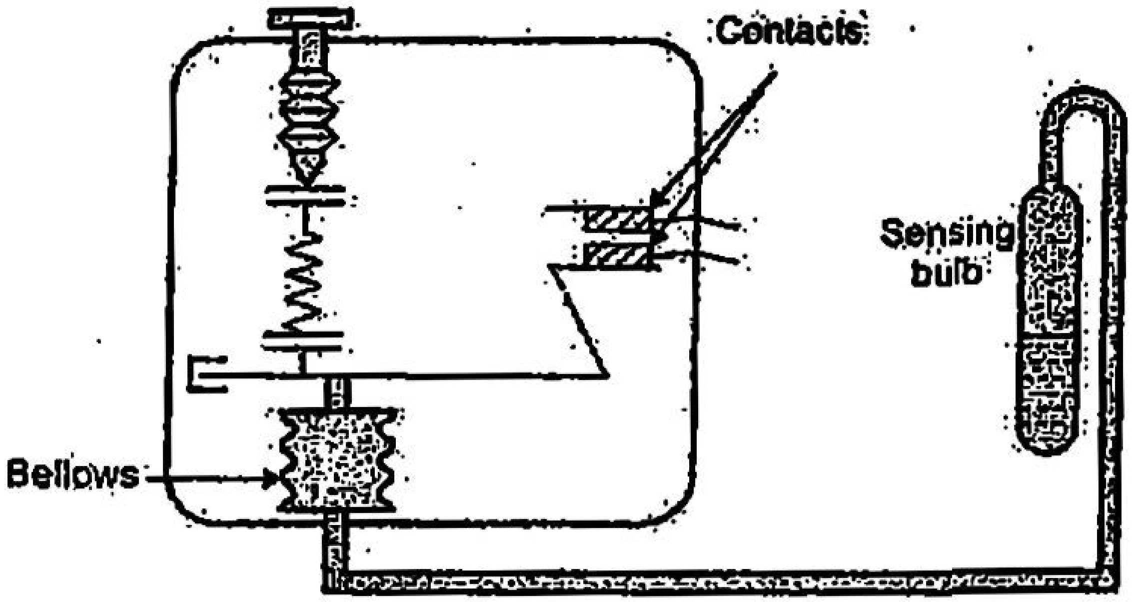


Fig. 3.20.1 : Schematic diagram of Low temperature control

Fig. 3.20.1 shows schematic diagram of low temperature control.

Important components of low temperature control are listed below :

(a) Sensing bulb

(b) Bellow

(c) Contact

(d) Adjusting screw

Freezing water is responsible for damaging of the liquid cooler.

Working principle

Sensing bulb used in low temperature control unit is sensing the chilled water leaving temperature.

- As soon as the temperature falls below certain limit contraction of the bellow opens the motor circuit and and stops the compressor.

- As soon as the chilled water temperature rises above the limit the expansion of bellow closes the circuit and the compressor is getting started.

Q →

- Working fluid is then acceleratea to a high velocity and entrains motive steam from the evaporator, resulting in a cooling effect. After that, mixed vapour steams are discharged from the nozzle to the condenser where they are cooled down and condensed to liquid fluids.
- A part of the liquid refrigerant returns to the evaporator through an expansion valve whereas the other part is pumped to the generator.
- Ejector cooling technology can be used for air conditioning in trains and large buildings. However, ejector refrigeration systems always have a smaller coefficient of performance (COP) compared with that of vapour compression systems, but it can be more practical and economical when waste heat, solar energy, or exhaust heat are used to provide heat to the generator of an ejector system.

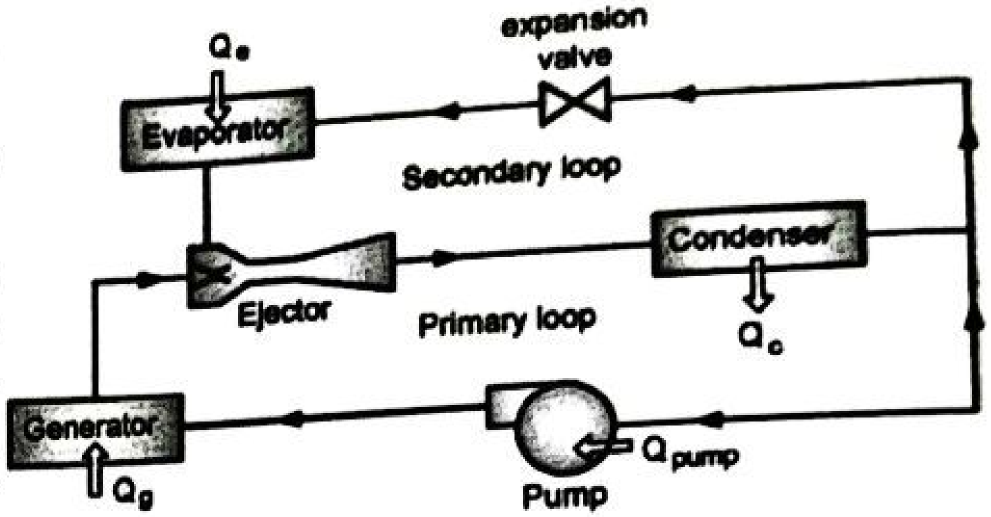


Fig. 3.5.16 : Schematic of an ejector refrigeration system

Application of an Simple ejector refrigeration system

(1) The removal of ash from flue gases

(2) desalination plants

(3) solid oxide fuel cells

(4) refrigeration machines

(5) fueling of hydrogen vehicles

(6) power generation cycle

(7) Ejectors could be integrated into various energy conversion processes to improve the energy efficiency

Q →

Discuss the following terms used in analysis of Simple Ejector Refrigeration Cycle. a) Entrainment Ratio b) Entrainment efficiency c) Nozzle Efficiency

The terms requested are key performance parameters for the ejector component within an Ejector Refrigeration Cycle.

a) Entrainment Ratio

- **Definition:** The entrainment ratio (μ) is defined as the ratio of the mass flow rate of the low-pressure refrigerant vapor drawn from the evaporator (secondary fluid, $\dot{m}_s$) to the mass flow rate of the high-pressure refrigerant vapor supplied from the generator (primary or motive fluid, $\dot{m}_p$ or $\dot{m}_m$).
- **Formula:** $\mu = \dot{m}_s/\dot{m}_p$.
- **Significance:** It quantifies the ejector's ability to pump the secondary fluid using the energy of the primary fluid. A higher entrainment ratio generally indicates better performance of the ejector and a higher overall Coefficient of Performance (COP) for the refrigeration cycle, as it means more cooling effect (more refrigerant circulated through the evaporator) per unit of primary fluid input.

b) Ejector Efficiency

- **Definition:** Ejector efficiency is a more comprehensive metric than the entrainment ratio alone. It accounts for both the mass entrainment and the pressure lift (compression) that the ejector provides to the secondary fluid. Various definitions exist in the literature, often relating the actual performance to an ideal (reversible or isentropic) process.
- **Significance:** It provides a single parameter to quantify the performance of the entire ejector by comparing the actual work recovered by the ejector to the maximum possible work recovery potential. A higher ejector efficiency directly enhances the overall cycle's COP.

c) Nozzle Efficiency

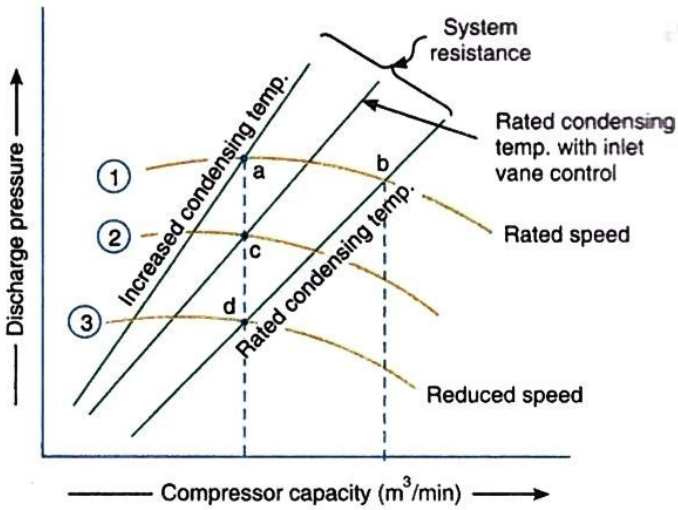
- **Definition:** Nozzle efficiency (η_{nozzle}) is a measure of how effectively the high-pressure primary fluid's enthalpy (or pressure energy) is converted into kinetic energy as it expands through the primary nozzle.
- **Formula:** It is typically defined as the ratio of the actual kinetic energy of the fluid exiting the nozzle to the theoretical kinetic energy if the process were ideal (isentropic).
- **Significance:** High nozzle efficiency (typical values range from 0.85 to 0.95) is crucial for the ejector's performance because the high-velocity jet created by the nozzle is what drives the entrainment and compression of the secondary fluid. Irreversibilities in the nozzle reduce the velocity and kinetic energy of the primary stream, which negatively impacts the entrainment ratio and the overall cycle efficiency.

Q→ **Capacity Control of Centrifugal Compressors**

The discharge pressure *versus* capacity relationship for a centrifugal compressor is very useful for capacity control. Generally, an impeller with backward curve blades is used because it gives a fairly flat pressure capacity characteristic. Fig. 9.18 shows the graph between discharge pressure and capacity in m^3/min, for an impeller with backward curve blades, running at two different constant speeds. The graph also shows the different system resistances. It may be noted that the capacity of a centrifugal compressor can be reduced by increasing the system resistance. This may be done by using the following methods :

MAY - JUN 25 SPPU Question

1. ***Condenser water control system.*** The capacity of a centrifugal compressor may be controlled by increasing the condensing pressure and temperature. This is done by reducing the quantity of condenser cooling water. It may be noted that when the cooling water passing through the condenser is reduced, the rate of condensate also reduces. This gives rise in condenser pressure and temperature, thereby forcing the compressor to self-adjust to the new part load capacity as shown by point *a* in Fig. 9.18.

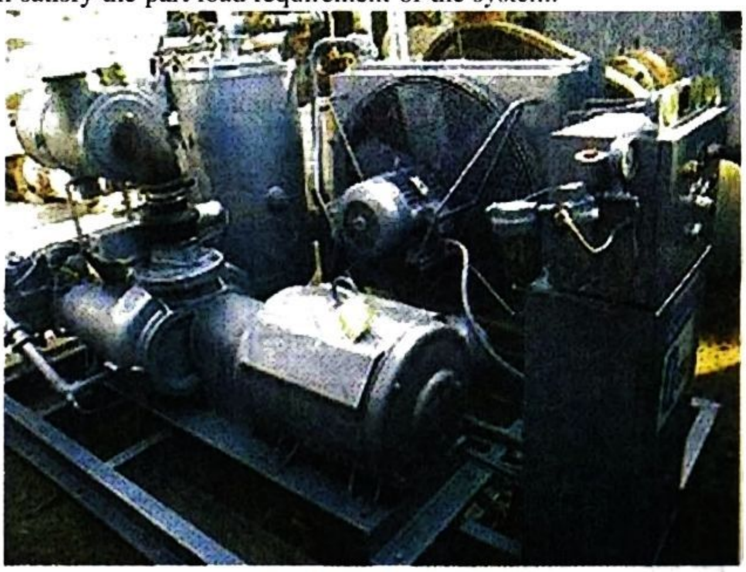


Curve 1 — Discharge pressure at constant speed.
Curve 2 — Discharge pressure, at same speed as that of curve 1, with inlet vane control.
Curve 3 — Discharge pressure at constant speed.

Fig. 9.18. Graph between discharge pressure and compressor capacity for a centrifugal compressor.

2. ***Inlet vane control system.*** The capacity of a centrifugal compressor may be controlled by the inlet vane which throttles the flow at inlet and reduces the inlet pressure. The discharge pressure at the same speed of compressor gets reduced. The curve 2 in Fig. 9.18 shows the performance with inlet vane control. Due to throttling at inlet, the system resistance increases at the same speed with the same condensing temperature as for the rated capacity shown by point *b*. The new operating point *c* will satisfy the part load requirement of the system.

3. ***Speed control system.*** The capacity of a centrifugal compressor may be controlled by varying the speed of the compressor as the discharge pressure is a function of the compressor speed. The variation in compressor speed changes system resistance due to the change in velocity of flow. The point *d*, as shown in Fig. 9.18, satisfies the part load requirements.



Centrifugal compressor.

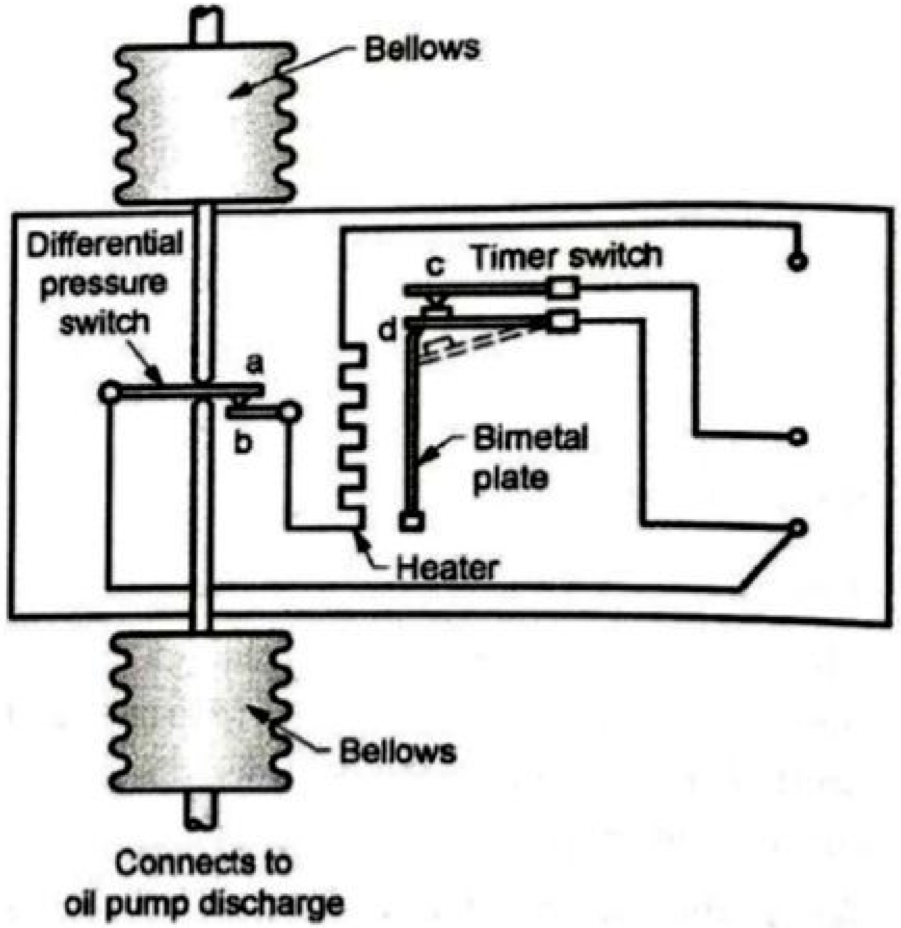
Out of all the three methods discussed above, the speed control system is most efficient but it is expensive. The inlet vane control system is cheaper and less efficient than speed control system. The condenser water control system is the cheapest among all the systems, but it is least efficient.

Q →

MAY - JUN 25 SPPU Question

Oil pressure failure control

- Purpose-to stop the compressor when the oil pressure drops below a certain limit and fails to lubricate the main bearings and other components.
- When the compressor starts, points a & b of the differential pressure switch and points c &d of the timer switch are in contact
- The differential pressure switch is affected by the differential pressure between oil pump discharge pressure & crankcase suction pressure.
- If the pressure of oil discharged from the oil pump does not reach a predetermined level within a certain time interval, the low oil pressure keeps the differential pressure switch a and b in a close contact position.



Q → **Evaporative Condenser** MAY - JUN 25 SPPU Question

GQ. Explain with neat sketch an 'Evaporative Condenser'.

The schematic diagram shown in Fig. 3.3.6.

☞ **Working Principle**

1. In an evaporative condenser, both air and water are employed as a condensing medium to condense vapour refrigerant to liquid refrigerant.
2. Water is pumped from the sump of the evaporative condenser to spray over the condenser coil. At the same time, a fan draws air from bottom side of the condenser and discharges out at the top of the condenser. An eliminator is provided above the sprayed holder to stop the particles of water escaping from along with the discharge air.
3. The sprayed water coming in contact with condenser surface, evaporates into the air stream, the amount of heat vaporising the water being taken from the refrigerant, thereby condensing the gas.
4. The cold water that drops down into a sump is circulated. In order to make up the deficiency caused by the evaporator water, additional water in supplied to the sump. The make- up supply is controlled by a float valve.

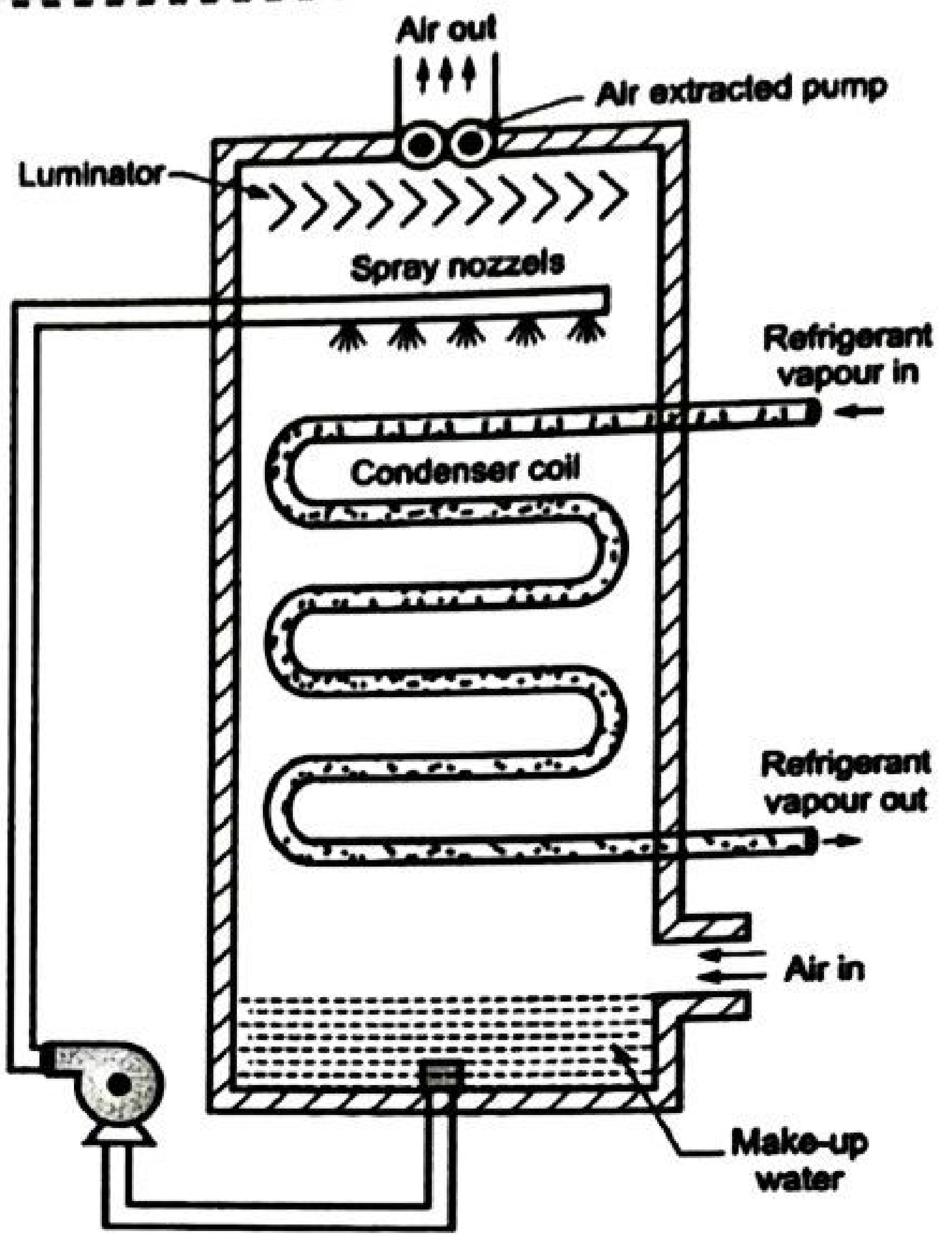


Fig. 3.3.6 : Evaporative Condenser