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Department of PHYSICS

III B.Sc. SEMESTER-VI

PAPER 6B: LOW TEMPERATURE PHYSICS & REFRIGERATION

STUDY MATERIAL

Name of the Student : ______________________________

Roll Number : ______________________________

Group : ______________________________

Academic Year : ______________________________

Production of low temperature

Introduction

- For a long time it was considered that nothing could be colder than Ice and hence the temperature of ice was chosen as zero of the scale in all earlier systems of temperature measurement.
- About 150 years ago scientists began to realize that the temperatures well below the ice point were possible and that temperature scale had other lower limit.
- With the knowledge of gas laws the lowest temperature attainable theoretically, was 273^{o}C well below the melting point of ice, which is used as the zero of the absolute scale of thermometry and hence called the absolute zero temperature.
- Since then scientists all over the world have been attempting to achieve this low temperature. This attempt to reach towards absolute zero makes a fascinating study and has given rise to a new branch of Physics known as the low temperature physics.

Freezing mixtures

A freezing Mixture is a mix of salt and ice. It is used to lower the temperature.

A freezing mixture is a composite of two or more elements. It is used to obtain a temperature below the freezing point of a solvent. The principle behind it is the depression in freezing point.

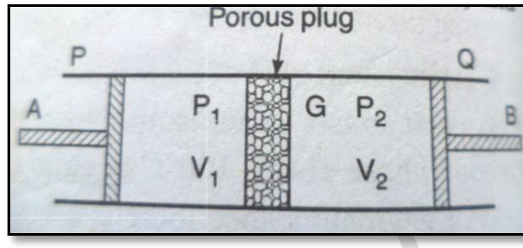
(1) Temperature lower than 0^{o}C can be produced by mixing certain salts with ice. When salt is mixed with ice it gives some heat to the ice causing a little of ice to melt.
(2) Now salt gets dissolved in the water produced by the melting of ice. The heat required for this process i.e. i) the heat which salt absorbs while dissolving (heat of solution) and ii) the heat of fusion which ice absorbs while melting (latent heat) is extracted from the mixture itself and consequently the temperature of mixture falls below zero.
(3) This process cannot go indefinitely. The lowest temperature that can be obtained by this method is fixed depending upon the salt and is called the eutectic temperature.
(4) When this temperature is reached the salt will not absorbed into the solution and hence there is no further fall of temperature. Thus no purpose will be served by adding more salt.

The lowest temperatures reached are different by mixing different salts to ice

S.No.	Salt	Lowest temp (^{o}C)
1.	NaCl	- 21.2
2.	KOH	- 65

Joule-Kelvin effect (OR) Joule – Thomson effect (Porous plug experiment)

❖ Joule-Kelvin experiment is as shown in figure.



❖ PQ is the thermally insulated hallow cylinder. The porous plug G,(Wool or cotton having porous) divides the cylinder in to two parts.

❖ A and B are two non-conducting pistons on both sides.

❖ The gas in left compartment is at higher constant pressure P_1 and in right compartment the gas has lower constant pressure P_2.

❖ When the gas in left compartment at higher pressure P_1 is compressed, then the gas passed through the porous plug and goes in to right compartment of lower constant pressure P_2. Then the distance between the molecules increase and the gas suffers change in temperature.

<u>Statement</u>:- When a gas is passed through a porous plug from a high constant pressure region to a low constant pressure region, the gas suffers a change in temperature. This effect is called <u>Joule-Kelvin effect or Joule-Thomson effect</u>.

<u>Results</u> :-

➢ All the gases suffer a change in temperature.

➢ At room temperature Hydrogen and Helium show heating effect, all other gases show cooling effect.

➢ The change in temperature is directly proportional to the change in pressure

i.e. $dT \propto (P_1 - P_2)$ (or) $\frac{dT}{(P_1 - P_2)} = Constant$

➢ The fall of temperature per unit pressure difference decreases as initial temperature increases. i.e. $\frac{dT}{(P_1 - P_2)}$ *decreases as initial temperature increses.*

<u>Temperature of inversion</u> :- The temperature at which the gas shows no Joule-Kelvin effect is called the inversion temperature of that gas.

➢ The temperature of inversion is different for different gases.

<u>Explanation</u> :- Let P_1, V_1, T_1 and P_2, V_2, T_2 be the pressures, volumes and temperatures of the gas on left and right compartments respectively ($P_1 > P_2$). Let unit mass of gas passed through the porous plug & U_1, U_2 be the internal energies before and after passing through the porous plug.

Work done on the gas by the piston A = P_1V_1

Work done by the gas on the piston B = P_2V_2

Net work done by the gas = $(P_2V_2 - P_1V_1)$

The system is thermally isolated, so, the work is done by utilizing its internal energy.

i.e. Work done = Decrease in internal energy

$(P_2V_2 - P_1V_1) = (U_1 - U_2)$

$P_2V_2 + U_2 = P_1V_1 + U_1$ (or) $PV + U = Constant$

This is enthalpy. So, Joule-Kelvin effect follows the law of conservation of enthalpy.

Regenerative cooling

Joule – Thomson effect shows very small cooling effect in most of the gases. This draw back is removed by the principle of regenerative cooling.

In regenerative cooling, the gases already suffered Joule – Thomson cooling is made to flow back over the tube containing the incoming gas. The out going gas cools the incoming gas and it again suffer Joule – Thomson effect becomes still more cooled. In this way, the out going cooled gas cools the incoming gas and this incoming gas further cooled by Joule – Thomson expansion. By continuing this process, ultimately a temperature is reached at which the gas is liquefied under the pressure available there. This is called regenerative cooling.

Definition :- Regenerative cooling is the process that the incoming gas cooled by the gas which is already cooled by Joule – Thomson expansion.

Different methods of liquefaction of gases

In general, gases can be liquefied by one of three general methods:

(1) By compressing the gas at temperatures less than its critical temperature.

In this approach, the application of pressure alone is sufficient to cause a gas to change to liquid. For example, ammonia has a critical temperature of 406K (133°C). This temperature is well above room temperature, so it is simple to convert ammonia gas into the liquid state simply by applying sufficient pressure. At its critical temperature, that pressure required is 112.5 atmospheres. If the gas is cooler than its critical temperature less pressure is sufficient to make it condense.

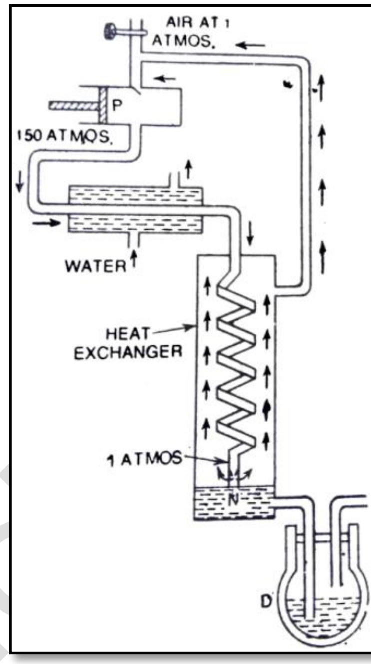
(2) By making the gas to do some kind of work against an external force, the gas loses energy and changed in to the liquid state.

The liquefaction of a gas by this method takes place in two steps. First, the gas is cooled, then it is forced to do work against some external system. For example, it may drive a small turbine, where it rotates a set of blades. The energy loss resulting from driving the turbine is sufficient then the gas to change to a liquid.

(3) By making gas to do work against its own internal forces, causing it to lose energy and liquefy.

In this method, for liquefying gas, the forces between its own molecules are used. When a gas below its inversion temperature is forced to pass through a nozzle or a porous plug the gas is cooled. This is Joule – Thomson effect. If this cooling is not sufficient for liquefaction. The same process can be repeated or the other two methods may be used.

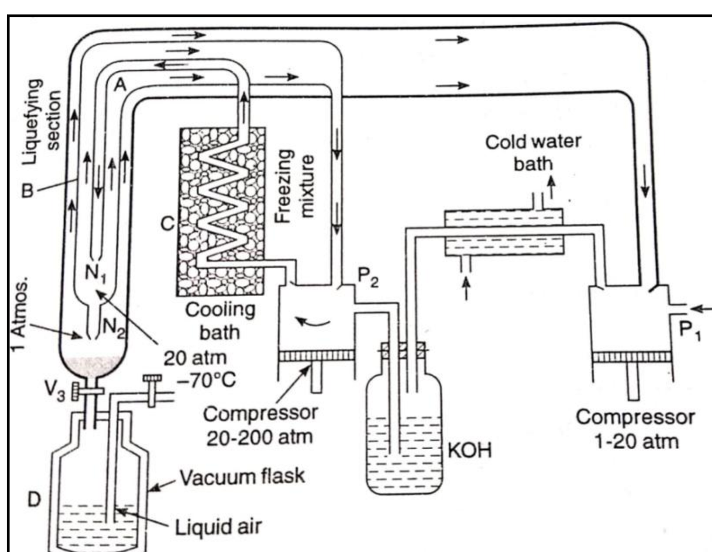
Hampson air liquefier



- Hampson air liquefier is as shown in the figure.
- Air which is free from Carbon dioxide, dust and moisture is compressed to 150 atms by a compressor P.
- The heat due compression is removed by passing the air through the tube surrounded by cold water jacket.
- Now the air is sent through the spiral tube in the heat exchanger. Here the air suffers Joule – Thomson effect at the nozzle N.
- The pressure out side the nozzle N is 1 atm. So, the air is cooled.
- The cooled air flows back over the spiral tube. This cooled air cools the incoming air in the spiral tube and goes back to the compressor P.
- The same process is continued until the temperature of air falls to $-188^{o}C$. At this temperature the air is liquefied at 1 atm pressure.
- The liquefied air is collected in the Dewar flask D.

Linde's air liquefier

- Linde's air liquefier is as shown in the below figure.
- This air liquefier consists of two compressors P_1 and P_2.
- The first compressor P_1 compresses the incoming air from 1 atm to 20 atms. When the air compressed, the right valve closed and the left valve opened and the heated air due to compression is passed through the tube which is enclosed by the cold water bath. The heat due to compression is removed by the cold water bath.

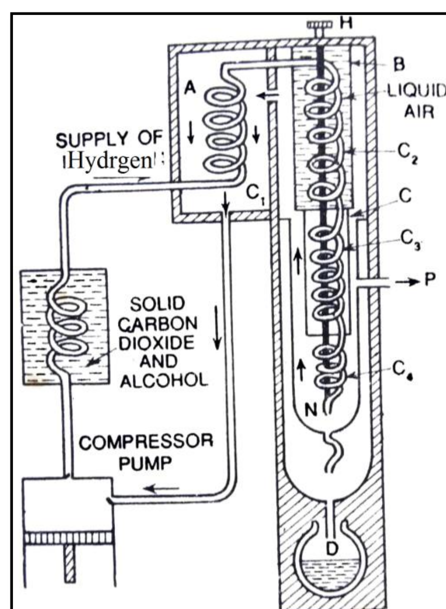


- This air is passed through the container containing 1) Caustic potash (KOH) 2) Calcium chloride and 3) Phosphorous pentaoxide to remove Carbon di oxide and water present in air.
- Carbon di oxide and water

should be removed from air before its liquefaction because Carbon di oxide and water can solidify before the air is liquefied. This solidification halts the procedure.

- This air, free from CO_2 and H_2O enters in to the second compressor P_2. This compresses the air upto 200 atms. During the air compression, the right valve closed and the left valve opened and the air enters into spiral tube which is enclosed in the freezing mixture and cooled to -20^oC.
- This high pressured air enters into the liquefying section and suffers Joule - Thomson expansion at nozzle N_1. At this stage the pressure falls to 20 atms and temperature falls to -70^o C. At this stage the nozzle N_2 is closed. So the cooled air goes through the wider tube B back to the compressor P_2. In the mean while it cools the in coming air in the tube A.
- Once again the pressure rises to 200 atms in P_2. This process is repeated and after few cycles the air is cooled to -183^oC. This is because of regenerative cooling.
- Now the nozzle N_2 is opened. Once again Joule-Thomson expansion takes place and the pressure falls to 1atms and the air liquefied and it is collected in the Dewar flask.
- The un-liquefied air goes back to the compressor P_1through the outer wider tube.

Production of liquid hydrogen

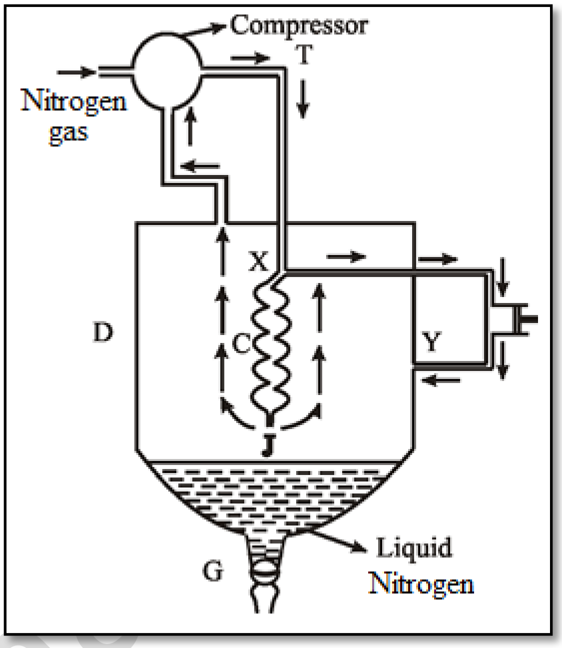


- The Hydrogen gas is made free from Carbon dioxide, dust, water vapour and other impurities.
- This pure Hydrogen is compressed to 200 atms by a compression pump.
- Then it is passed through a coil immersed in solid Carbon dioxide and alcohol.
- Now the hydrogen gas is passed through the coil C_1 in the chamber A where it is cooled by the out going cold hydrogen.
- The cooled hydrogen gas is passed through the regenerative coil C_2 immersed in the liquid air placed in the chamber B. Here the gas gets -170^oC temperature.
- Then it is passed through the other coil C_3 placed in the chamber C. Here the liquid air boils under reduced pressure. Here the pressure is reduced to 10 cm of Hg by the vacuume pump P. The Hydrogen cooled to -200^oC in C_3.
- Now Hydrogen is passed through the regenerative coil C_4 and it gets Joule – Thomson expansion at the nozzle N. Now Hydrogen is further cooled here.
- This hydrogen is circulated back to compressor and it cools different coils.
- After performing few cycles like this the hydrogen gas attains -250^oC at nozzle N. Now hydrogen is liquefied and collected in the Dewar flask D.

Production of liquid nitrogen - Claude's method

Principle

This process is based upon the principle that when a gas expands adiabatically against a piston in an engine, it does some external work, hence its internal energy falls and consequently the temperature of the gas falls. This principle combined with the Joule-Thomson effect, has been applied in the Claude's process for liquefaction of Nitrogen.

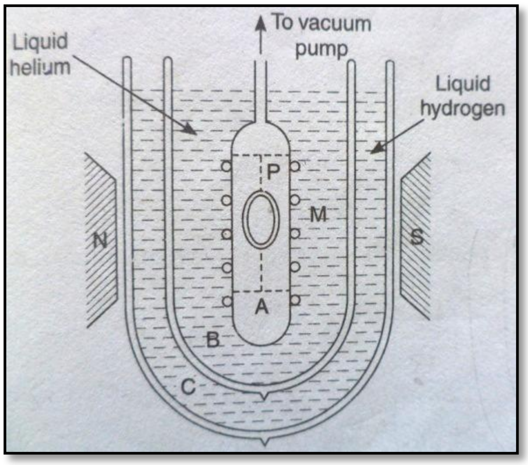


Procedure

- The purified Nitrogen i.e. N_2 free from CO_2 and water vapours is first compressed to about 200 atmospheres by compressor.
- The compressed Nitrogen is then passed through the tube T which bifurcates the incoming gas. Part of the N_2 goes into the cylinder fitted with an air tight piston and rest of the N_2 passes through the spiral coil C which ends in a jet J.
- The N_2 that goes into the cylinder pushes the piston and thus does some external work. As a result, the internal energy of N_2 falls and hence temperature falls. The cooled N_2 then enters the chamber at lower end.
- The N_2 that passes through the spiral coil is cooled by *Joule-Thomson effect* as it comes out through the jet in low pressure region (50 atm) of chamber.
- The cooled N_2 is circulated again and again with the incoming air till the N_2 gets liquefied. The liquefied N_2 is collected in the chamber and is withdrawn.

Adiabatic demagnetization

- If a paramagnetic material is magnetized (molecular magnets are set in the direction of applied magnetic field) then work is done on the material. So, its internal energy and its temperature increases.
- Principle :- When a para magnetic material already magnetized is suddenly demagnetized adiabatically its temperature falls slightly. This is called adiabatic demagnetization.



Construction :-

- A paramagnetic substance (specimen),

gadolinium, is suspended in a vessel A. The vessel A is connected to a vacuum pump. A coil M is wound on the vessel A & the coil is used to measure temperature by susceptibility measurement method.

- The vessel A is placed in a Dewar flask B containing liquid helium at 1 K temperature.
- The flask B is placed in another Dewar flask C containing liquid hydrogen.
- This total arrangement is placed between the two poles of a strong magnet (N-S).

Working :-

- First the vessel A is filled with helium gas at low temperature because at low temperature helium is highly conductive. So, the paramagnetic material comes in to thermal contact with the liquid helium at 1 K & cooled to 1K.
- Now the magnetic field is switched on and the paramagnetic substance magnetized & is heated. This heat flows out through helium gas in to liquid helium. The temperature of substance falls to 1 K.
- After this, the helium gas is pumped out and the paramagnetic substance is thermally isolated.
- Now the magnetic field is switched off and the temperature of paramagnetic substance falls due to adiabatic demagnetization.
- The fall in temperature of the substance is measured by susceptibility measurement method using the coil wound on vessel A.
- The lowest temperature so far attained is 0.0014 K.

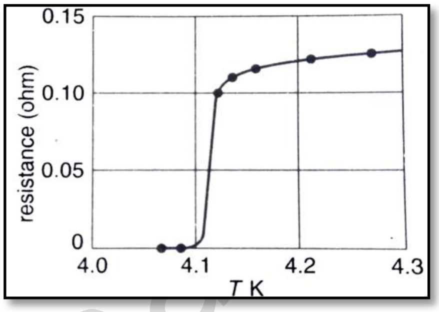
Applications &Properties of substances at low temperatures

1) At low temperatures below 90 K most of the chemical reactions ceases. At these temperatures animals and vegetable matter can be preserved without purification.
2) Materials like cotton and wool exhibit the property of fluorescence when exposed to the temperature of liquid air.
3) At a temperatures below 83K lead loses elasticity exhibits plastic nature.
4) The substances like rubber and glass become extremely brittle get these temperatures. Rubber cooled to such a low temperatures breaks into pieces when hammered.
5) For all substances the atomic heat (product of atomic weight and specific heat) becomes zero at the absolute zero.
6) Oxygen is not paramagnetic substance in the gaseous state but when they are converted into liquid at low temperature it becomes paramagnetic substance.
7) At low temperatures for paramagnetic salts like Copper Sulphate $\chi \infty \frac{1}{T}$
8) The entropy of a substance becomes zero when it is exposed to very low temperature.
9) The electrical resistance of most metals decrease as the temperature is reduced. At a particular temperature the resistance becomes zero i.e. the conductivity becomes infinity and this property is called <u>superconductivity</u>.

10) Below 2.17 K helium is called as Helium II and it exhibits super fluidity. Its viscosity becomes very low and it can pass through a capillary tube without any resistance, this property is known as <u>super fluidity</u>.

Superconductivity

Kamerling Onnes in 1911 observed that the resistance of Mercury first decreases regularly like that of the other metals but at 4.2K it suddenly decreases to zero as shown in the figure. The temperature at which the resistance drops to zero is called Critical temperature (T_C)or transition temperature.



The phenomena of disappearance of electrical resistance of material below a certain temperature is called superconductivity and the material in this state is called a superconductor.

Other substances showing superconductivity are Silver, gallium, iridium etc.

Reason for superconducting state

- ❖ The electrical resistance of an ordinary metal is due to the collisions of conduction electrons with vibrating ions of the crystal lattice.
- ❖ In superconducting state, the electrons scattered in pairs rather than individuals. This gives rise to an exchange force between electrons. This force is similar to forces between nucleons in a nucleus.
- ❖ When the electrons have opposite spins and momenta, there is very attractive force between them. In superconducting state these forces of attraction is greater than the electrostatic forces of repulsion.
- ❖ Thus all conduction electrons become a bound system. Now no transfer of energy takes place from this system to lattice ions.
- ❖ When an electric field is applied to the substance in superconducting state, the pairs of electrons gain additional kinetic energy. Thus they give rise to a current.
- ❖ As these electrons do not transfer any energy to the lattice, they do not get slowed down and as a result of this, substance does not possess any electrical resistivity. It means that the resistance of superconductor is zero.

Properties in superconducting state

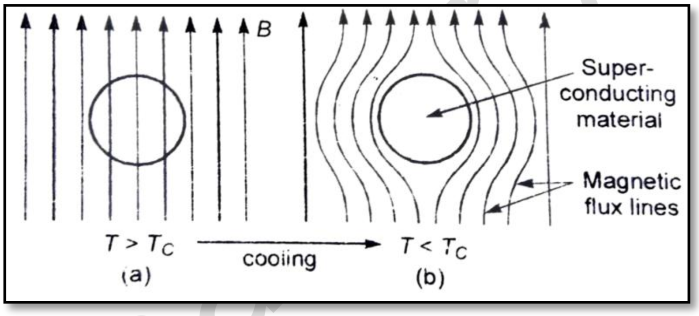
- ✓ At room temperature superconducting materials have greater resistivity than other elements.
- ✓ The transition temperature or the critical temperature T_C is different for different isotopes of an element. It decreases with the increasing atomic weight of the isotopes.
- ✓ The superconducting property of any element does not lost by adding impurities to it but the critical temperature T_C is lowered.

- ✓ The superconducting material can conduct electric current even in the absence of an applied voltage and the current can persist for years without any detectable decay.
- ✓ The elastic properties do not change in transaction.
- ✓ All thermoelectric effects disappear in superconducting state.

Meissner effect

If a superconductor is cooled in magnetic field below to its critical temperature, then the lines of force of magnetic field are expelled out from the material. This effect is called Meissner effect.

If the superconductor is in normal state the magnetic lines of force pass through it. It is shown in figure (a) but when the material is cooled below its transition temperature the magnetic lines of force are expelled out of the material and this was shown in figure (b).



- ➢ Meissner effect is reversible.
- ➢ Superconductor is perfect diamagnetic i.e. the magnetic induction B = 0 in a superconductor.
- ➢ The difference between a perfect conductor and a super conductor is that the perfect conductor is only an ideal conductor and the superconductor is an ideal conductor as well as a diamagnet.

Measurement of low temperature

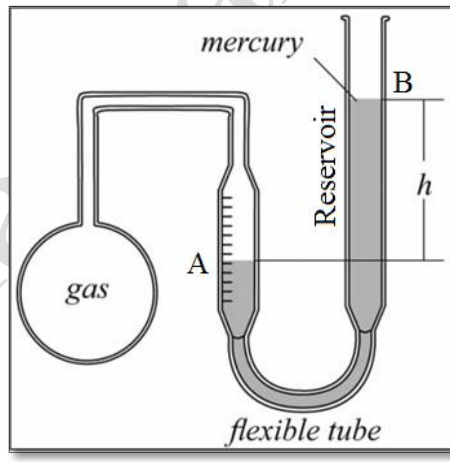
Gas thermometer

A thermometer containing a fixed quantity of gas as the enclosed thermometric substance, shows change in pressure with temperature at constant volume (or) shows change in volume with temperature at constant Pressure is called gas thermometer.

The gas thermometers are better and can be treated as the standard instruments for low temperature measurement. These thermometers could be relied upon the liquefaction point of the gas used.

The standard thermometers for the purpose are

a) The constant volume hydrogen thermometer can be used to measure temperatures down to -253^{o}C.
b) The constant volume Helium thermometer can be safely used after -268.7 ^{o}C (4.4 K). Below this temperature the gas liquefies. Helium thermometer can be used down to 1K. when the pressure at which it is operated is below the vapour pressure of the liquid helium.



Construction :-

- A spherical glass bulb filled with Hydrogen or Helium gas is connected to a mercury manometer through a narrow glass tube.
- The manometer has two arms. The left arm is a glass cylindrical bulb in which the volume of the gas can be measured. The right arm acts as a reservoir whose height can be adjusted.

Working

- First the bulb is placed in a substance of known temperature (T_1) then the pressure of the gas in the bulb changes and the mercury level in the manometer also changes. Then the reservoir height is adjusted until the mercury level in the left arm of manometer comes to the fixed point A.
- Now the height difference (AB = h_1) between the two mercury levels in the two arms of the manometer is measured.
- The pressure of the gas in the bulb is calculated as $\boxed{P_1 = (H \pm h_1)dg}$

  Here H = Atmospheric pressure in mercury column height
  d = Density of mercury.
  g = Acceleration due to gravity.

+ve sign is taken when the level B is above level A. Other wise -ve sign is taken.

- The experiment is repeated by placing the bulb in a substance of unknown temperature T_2 & the mercury reservoir height is so adjusted until the mercury level in the left arm comes to the level A.
- Now the height difference (AB = h_2) between the two mercury levels in the two arms of the manometer is measured and pressure is calculated as $\boxed{P_2 = (H \pm h_2)dg}$

The unknown temperature T_2 is calculated using the formula

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}} \quad \because \textit{The volume of the gas is constant}$$

Note :- The unknown temperature can also be measured from Pressure – absolute temperature graph at constant volume for known values. This graph is a straight line passing through origin.

Advantages of gas thermometers:

1) Gas thermometers are very sensitive because the expansion of gases is considerable.
2) The gases have regular expansion.
3) Gas thermometers have wide range of temperature scale.
4) Gases have low thermal capacity.
5) Thermometers filled with Permanent gases give the reading close to thermodynamic scale.

Disadvantages of gas thermometers:

1) It works slowly.
2) It is not a direct reading thermometer.
3) It is not portable.
4) It cannot measure the rapidly changing temperatures accurately.

Gas thermometer correction and calibration

Material to be prepared.

Primary thermometers

Primary thermometers are generally defined as devices that can be used to measure the temperature without any prior calibration.

Secondary thermometers

Secondary thermometers are those thermometers from which the knowledge of the measured quantity is not sufficient for direct calculation of temperature. They have to be calibrated against a primary thermometer at least one temperature or at a number of fixed temperatures.

The temperature curve of secondary thermometers is obtained by an individual calibration to other thermometers. In this case, the calibration is only valid for each individual thermometer.

Resistance thermometers

Definition: Resistance thermometer is a device that is used to determine temperature by the variation in the resistance of a conductor. It is commonly known as Resistance Temperature Detector (RTD) and is an accurate temperature sensor.

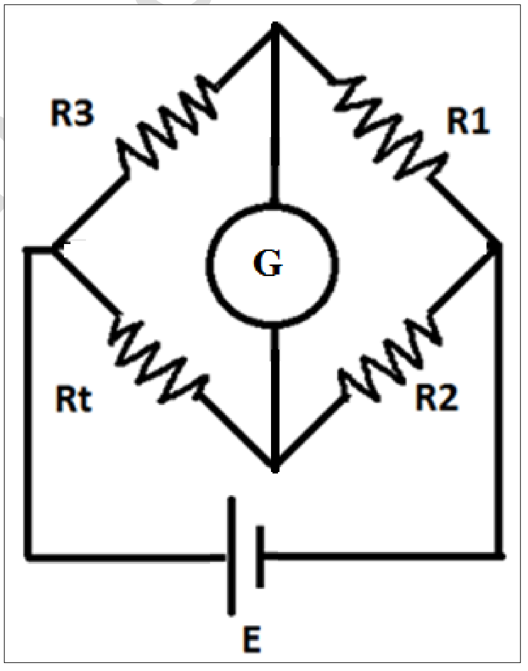
Working Principle of Resistance Thermometer

- When the temperature of the metal is increased, there is an increase in the vibrational amplitude of the atomic nuclei of the material.
- This increases the probability of collision of free electrons with that of the bounded ions. Thus, the interruption in the motion of the electron causes resistance to increase.

Resistance temperature detector is typically made up of **nickel**, **platinum**, **copper** or **tungsten**.

Circuit

The resistance thermometer circuit is basically a Wheatstone bridge circuit. However, it is not exactly a Wheatstone bridge but a modification of the circuit. It is connected to one arm of the Wheatstone bridge as shown in the figure:



The resistors R_1 and R_2 are fixed resistances and R_3 is the variable resistance. R_t is the detector resistance that is used in the circuit.

At balanced condition,

$$R_t = \frac{R_2}{R_1} X R_3$$

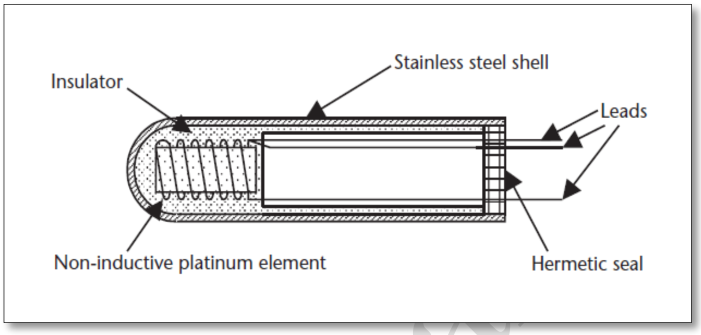
If $R_1 = R_2$

Then $R_t = R_3$

The variable resistance R_3 used is nothing but an adjustable potentiometer.
We use lead wires to connect the detector resistance to our circuit.

Construction of a Detector Resistance

- A platinum resistance thermometer consists of a platinum coil that is present inside a cross frame.
- We place the whole arrangement in an evacuated tube which is made of stainless steel. The coil arrangement generates very little strain when there is a rise in temperature. This may cause an undesirable change in resistance. For the construction, the pure platinum wire must be used. The purity of the platinum can be confirmed using the formula $\frac{R_{100}}{R_0}$. In the case of pure platinum material, the value must be greater than **1.390.**



The relation of resistance with respect to that of temperature can be given by the equation:

$$\boldsymbol{R_t = R_o\ (1 + \alpha t + \beta\, t^2)}$$

The advantages are

1) It gives an accurate result.
2) It is used in various industrial applications.
3) The temperature range is between -200 ⁰C to 1000⁰C.
4) It has endless applications.

The disadvantages are

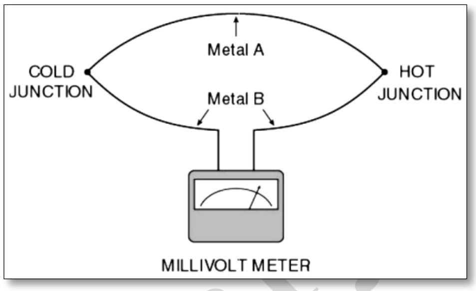
1) The sensitivity of platinum is extremely less for a small change in temperature .
2) The response time is quite slow.
3) RTD is not used for dynamic temperature measurement.

Thermocouples or Thermoelectric thermometers

Principle :- A thermocouple is a device for measuring temperature. It comprises two dissimilar metallic wires (metal A and metal B) joined together to form two junctions. When one of the junction is heated or cooled with respect to the other, a small voltage is generated in the electrical circuit of the thermocouple which can be measured, this corresponds to temperature. This is Seebeck effect.

Working :

- One junction is placed on the element or surface where we want to measure the temperature. This junction is known as a hot junction.
- And the second end is kept at a lower temperature (room temperature). This junction is known as a cold junction or reference junction.



- According to the Seebeck effect, the temperature difference between the two different metals induces the potential differences between two junctions of the thermocouple.
- If the circuit is closed, a very small amount of current will flow through the circuit. A voltmeter is connected to the circuit.
- The voltage measured by the voltmeter is a function of a temperature difference between two junctions.
- Hence, by measuring the voltage, we can calculate the temperature of the hot junction.

The equation for this is $\boxed{E_{emf} = A\,T + B\,T^2}$

Where E_{emf} = The voltage across the two junctions.

A, B = Constants, depends on the pair of the thermo couple materials.

T = Temperature difference between hot and cold junctions.

Advantages

1) Thermocouples can be used at very high temperatures.
2) Thermocouples have a fast response time.
3) Thermocouples are very accurate at a wide operating range.
4) Thermocouples have extreme durability.
5) Thermocouples are self-powered, so they do not require a current or voltage source.
6) Thermocouples can withstand high vibrations.

Disadvantages

1) Thermocouples are not as accurate as RTDs in a certain set temperature range.
2) Thermocouples are susceptible to drift over time.
3) Thermocouples, when badly insulated, are vulnerable to corrosion.
4) Thermocouple signals are not perfectly linear.

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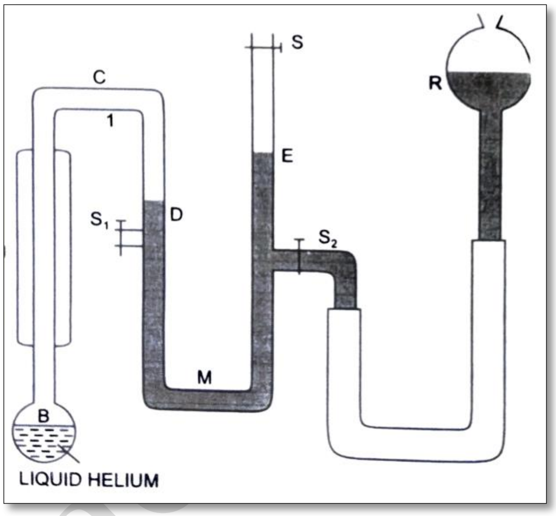
Vapour pressure thermometers

Vapour pressure thermometer are based on the principle that the vapour pressure of a liquid increases as the temperature increases.



- Helium vapour pressure thermometer is as shown in the figure. It is constructed by glass.
- This consists of a glass bulb B containing liquid Helium and Helium vapour and is connected to a Mercury manometer M by means of a capillary C. An evacuated glass jacket J is attached to the tube C in order to prevent heat loss.
- The level of the Mercury in the manometer can be adjusted by changing the height of the Mercury reservoir R.
- Initially, the reservoir R is moved until the Mercury levels in limbs D and E of the manometer stand below the level of the stopcock S_1.
- S_1 is then opened and connected to the vacuum pump to remove air from the bulb B and capillary C. After sometime S_1 is closed so that there is only liquid Helium in B and its saturated vapour in capillary C.
- Now the bulb B is put in a bath at a constant low temperature to be measured. The difference in Mercury levels of the two arms D and E gives the pressure of the saturated Helium vapour in C from which the corresponding temperature T can be found by the given formula

$$\log_{10} P = \frac{a}{T} + b\,T + c\,T^2 + d$$

P = Helium vapour pressure T = Absolute temperature to be measured

The constants a, b, c and d change depending on temperatures above and below 2.19K.

Note:- Another method to determine the temperature corresponding to any value of the vapour pressure is to draw a graph between temperature and vapour pressure of helium which can be extrapolated either way to give the required temperature. In this way the temperature upto 0.75 K have been measured

Advantages

1) Vapour pressure thermometers are very sensitive.
2) Cheaper in cost.
3) Compact and rugged construction.
4) Good time response.

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5) Maintenance is very less.
6) Good accuracy ± 1%.
7) Operation is stable.
8) No electric power requirement.

Disadvantages

1) A given vapour pressure thermometer can be used only for a small range.
2) Span of temperature is much less (compared to electrical type).
3) Not repairable. On failure the entire system has to be replaced by new unit.
4) Limited maximum temperature.
5) Errors are produced due to: (i) Radiation effect, (ii) Immersion effect, (iii) Barometric effect, (iv) Elevation effect and (v) surrounding temperature effect

Magnetic thermometers

A magnetic thermometer is a device that works on the principle of **Curie's Law**. According to this law, the magnetic susceptibility of a paramagnetic substance is inversely proportional to the absolute temperature of the substance. $\boxed{\chi \propto \frac{1}{T}}$ or $\boxed{\chi = \frac{C}{T}}$

This thermometer is used to measure a temperature of about 0.001 Kelvin.

- The experiment consists of measuring the susceptibility of a suitable paramagnetic salt by surrounding the apparatus contained it by two coils, primary and secondary.
- An alternating current is passed through the primary coil, consequently a current is induced in the secondary coil which depends upon the susceptibility of the salt.
- This current is then amplified and recorded by a sensitive Galvanometer which gives a measure of susceptibility.
- The susceptibility above 1K is directly plotted against temperature as read by Helium vapour thermometer.
- The curve is then extrapolated below 1K and thus the temperatures can be read directly from the experimental value of the susceptibility.
- Alternatively some times the galvanometer used to detect secondary current is calibrated to read temperature of the substance directly.
- The temperature will be accurate only when the susceptibility scale is related to the gas thermometer scale at low temperatures.

Advantage

- As the susceptibility of paramagnetic substance increases with decrease of temperature this thermometer gives more accurate susceptibility or temperature values at very low temperatures.

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Disadvantage

- The temperature obtained by the application of Curie's law do not give the exact values of temperature because this law itself does not hold in this region.
- From these measurements assuming the truth of Curie's law, so called magnetic temperature is obtained which is then to be converted to the thermodynamic or Kelvin temperature.

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Principles of refrigeration

Introduction to refrigeration

Refrigeration relates to the cooling of air or liquids, thus providing lower temperature to preserve food, cool beverages, make ice and for many other . 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.

Types or methods of Refrigeration System :

A. Natural refrigeration :

The natural refrigeration include the utilization of ice or snow produced naturally in cold climate. They are

1. Art of Ice making by Nocturnal Cooling :- In this method ice was made by keeping a thin layer of water in a shallow earthen tray and then exposing the tray to the night sky. The water loses heat by radiation to the stratosphere, which is at around -55°C and by early morning hours the water in the trays freezes to ice.

2. Evaporative Cooling :- The water permeates through the pores of the earthen vessel to its outer surface where it evaporates to the surrounding, absorbing its latent heat in part from the vessel, which cools the water.

3. Cooling by Salt Solutions :- Certain substances such as common salt, when added to water dissolve in water and absorb its heat of solution from water (endothermic process). Sodium Chloride salt (NaCl) can yield temperatures up to -20°C and Calcium Chloride ($CaCl_2$) up to – 50°C.

B. Artificial Refrigeration

Artificial refrigeration is the human made refrigeration.

1. Vapour Compression Refrigeration Systems :- The refrigerant used in this does not leave the system but is circulated throughout the system alternately condensing and evaporating. In evaporating, the refrigerant absorbs its latent heat from the solution which is used for circulating it around the cold chamber and in condensing, it gives out its latent heat to the circulating water of the cooler.

2. Vapour Absorption Refrigeration Systems :- In the vapour absorption system compressor is replaced by Generator, absorber & Pump. In this System, Ammonia (NH_3) is used as Refrigerant & Water + Ammonia is used as Absorbent.
3. Solar energy based refrigeration systems :- Attempts have been made to run vapor absorption systems by solar energy. Trombe installed an absorption machine with a cylinder-parabolic mirror of 20 m^2 at Montlouis, France, which produced 100 kg of ice per day.

4. Gas Cycle Refrigeration :- When the gas is throttled from very high pressure to low pressure in the throttling valve, its temperature reduces suddenly while its enthalpy remains constant. This principle is used in a gas refrigeration system.
5. Steam Jet Refrigeration System :- If the pressure on the surface of the water is reduced below atmospheric pressure, water can be made to boil at low temperatures. Water boils at 6 degrees C, when the pressure on the surface is 5 cm of Hg. The evaporating water takes heat from the remaining water as latent heat. The remaining water gets cooled.
6. Thermoelectric Refrigeration Systems :- Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. Applying a DC voltage difference across the thermoelectric module, an electric current will pass through the module, and heat will be absorbed from one side and released at the opposite side.
7. Vortex tube systems ;_ The vortex tube is a device that separates a high-pressure flow entering tangentially into two low-pressure flows, thereby producing a temperature change.

Working of air conditioner(or) refrigeration cycle and explanation with block diagram

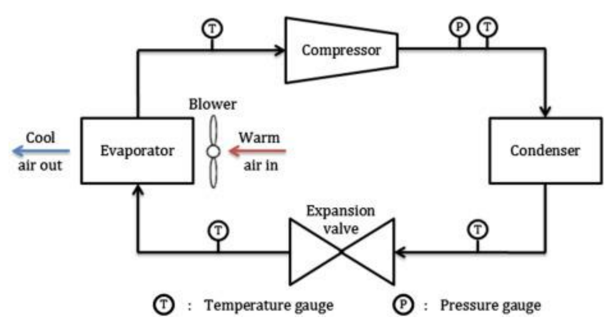
Air conditioners and refrigerators work on the same Principle. Instead of cooling just the small, insulated space inside of a refrigerator, an air conditioner cools a room or a whole house.

Air conditioners use chemicals that easily convert from a gas to a liquid and back again. This chemical is used to transfer heat from the air inside of a home to the outside air.

The machine has four main parts.

They are a) compressor b) condenser c) Expansion valve and d) evaporator.

The compressor and condenser are usually located on the outside air portion of the air conditioner. The evaporator is located on the inside the house, sometimes as part of a furnace. That's the part that heats our house.



Compressor :- The working fluid reaches to the compressor as a cool, low-pressure gas. The compressor compresses the gas. The closer the molecules are together, the higher its energy and its temperature. The working fluid leaves the compressor as a hot, high pressure gas and flows into the condenser.

Condenser :- If we looked at the air conditioner part outside a house, look for the part that has metal fins all around. The fins act just like a radiator in a car and helps the heat go away, or dissipate, more quickly. When the working fluid leaves the condenser, its temperature is much cooler and it has changed from a gas to a liquid under high pressure.

Expansion valve :- The liquid goes into the evaporator through a very tiny, narrow hole called expansion valve. On the other side, the liquid's pressure drops.

Evaporator :- When it does it begins to evaporate into a gas. As the liquid changes to gas and evaporates, it extracts heat from the air around it. The heat in the air is needed to separate the molecules of the fluid from a liquid to a gas.

The evaporator also has metal fins to help in exchange the thermal energy with the surrounding air. By the time the working fluid leaves the evaporator, it is a cool, low pressure gas. It then returns to the compressor to begin its trip all over again.

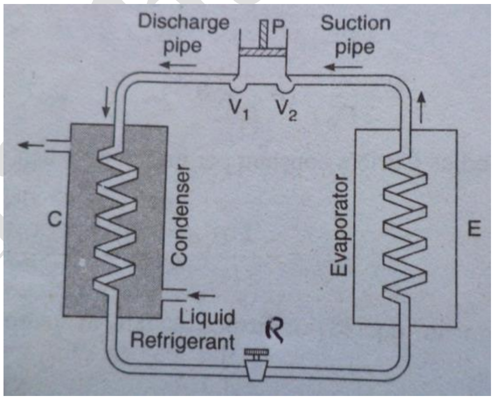
Connected to the evaporator is a fan that circulates the air inside the house to blow across the evaporator fins. Hot air is lighter than cold air, so the hot air in the room rises to the top of a room.

There is a vent there where air is sucked into the air conditioner and goes down ducts. The hot air is used to cool the gas in the evaporator. As the heat is removed from the air, the air is cooled. It is then blown into the house through other ducts usually at the floor level.

The thermostat senses that the temperature has reached the right setting and turns off the air conditioner.

Vapour compression machine (or) Frigidaire

- ✪ Refrigerator maintains an adiabatic enclosure at low temperature.
- ✪ The principle involved in producing low temperature is, evaporating the liquid under reduced pressure.
- ✪ Circulates the evaporating liquid around the enclosure. The liquid which on evaporation produces cooling is called refrigerant.



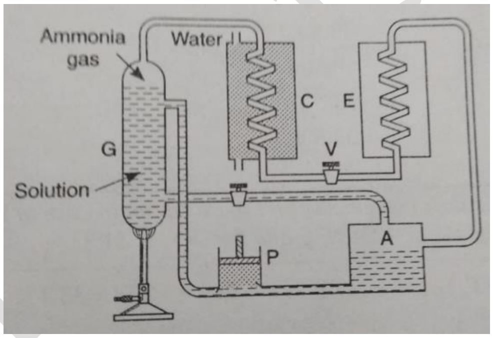
Construction and working

- ❖ The Frigidaire consists of a compression pump P in which the refrigerant is compressed. There are two valves V_1, V_2 below this pump.
- ❖ If the piston moves up valve V_1 closes and the valve V_2 opens & sucks the low pressure vapour from the evaporator E.
- ❖ If the piston is pushed down valve V_1 opens & valve V_2 is closed. Now the vapour under high pressure enters in to the condenser coil C. The condenser coil is enclosed in a cold water bath. Under high pressure and low temperature the vapour refrigerant is liquefied in the coil.
- ❖ The liquid refrigerant is now passed through the regulator R in to evaporator E. Due to low pressure, the liquid evaporates in the evaporator.
- ❖ For evaporation refrigerant takes heat from it self. So, it cools.
- ❖ Also when the liquid evaporates in the evaporator it takes latent heat of vaporization from the cold storage space.
- ❖ This process is repeated again and again. The temperature of the cold storage space falls.

Vapour absorption machine

In the vapour absorption system compressor is replaced by Generator, absorber & Pump. In this System, Ammonia (NH_3) is used as Refrigerant & Water + Ammonia is used as Absorbent.

- The vapour absorption machine is as shown in the figure. In this machine low pressure Ammonia vapour is absorbed by water.
- In the figure, G is a generator which contains solution of ammonia and water.
- This is heated by a burner. Ammonia gas escapes from water and condenses in the spiral tube of condenser C. The condenser C is cooled by running water. Then ammonia is liquefied.
- Now liquid ammonia flows into the spiral tube of evaporator E through valve V. The pressure inside spiral tube of E is low. The evaporator may be a chamber to be cooled or it may be surrounded by flowing water.
- When Ammonia evaporates under reduced pressure, the latent heat of vaporization is taken from surrounding the Chamber or from the water running in this chamber.
- In this way the Chamber E is cooled. The evaporated Ammonia now comes in to chamber A where it is absorbed by water.
- Here the solution becomes fairly concentrated. The solution is pumped to generator G by the pump P. The cycle is further repeated. In this way chamber E is cooled.



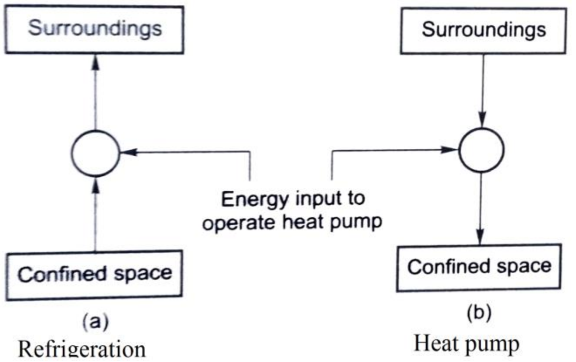
Air conditioning :- In general, air conditioning is defined as the simultaneous control of temperature, humidity, cleanliness and air motion. Depending upon the requirement air conditioning is divided into the summer air conditioning and the winter air conditioning.

The former uses a refrigeration system and a dehumidifier. But a heat pump and humidifier used in the latter.

Air conditioning is also subdivided into the comfort air conditioning and industrial air conditioning.

The former deals with the human comfort which as well requires noise control.

While the latter is meant for the production of an environment suitable for commercial products or commodities, production shop Laboratories, manufacture of materials and Precision devices, printing works, photographic products, textiles, cold storages, pharmacy, computers, dams etc.



(a) Refrigeration (b) Heat pump

Refrigerant:- Refrigerant is working substance in a Refrigeration systems (or) Refrigerant is a substance which will absorb the heat from the source which is at lower temperature and dissipate the same to the sink which is at higher temperature than the source either in the form of sensible heat (or) in the form of latent heat.

In selecting refrigerant for a particular purpose their thermodynamic chemical characteristics safety characteristics and physical characteristics must be considered.

Properties of an ideal refrigerant

1. The refrigerant should have low boiling point and low freezing point.
2. It should be vapour at normal temperature and pressure
3. It should be non flammable & non explosive.
4. It should not have bad effects on the stored food material.
5. It should have high thermal conductivity.
6. The latent heat of vaporization of the refrigerant liquid must be large.
7. The specific volume should be small in order to reduce the size of compressor.
8. The pressure necessary to liquefy the vapour in condenser coil must be small.

Classification of refrigerants :-

Refrigerants are classified into primary and secondary refrigerants.

Primary refrigerants are those fluids, which are used directly as working fluids, for example in vapour compression and vapour absorption refrigeration systems. These fluids provide refrigeration by undergoing a phase change process in the evaporator.

The primary refrigerants are classified as follows.

1. Halocarbon compounds:- These groups contain one or more of three halogens, chlorine fluorine and bromine. These refrigerants used for domestic, commercial and industrial purposes.
2. Azetropes :- This group consists of mixtures of different refrigerants which do not separate into their components with changes in pressure or temperature or both.
3. Hydro-carbons :- Most of the organic compounds are considered as refrigerants in this group used in commercial and industrial purposes. Ex :- Methane, Ethane, Propane
4. Inorganic compounds :- The refrigerants under this group were universally used for all purposes before the introduction of halocarbon groups. Ex :- Ammonia, Water, Air etc.
5. Unsaturated organic compounds :- The refrigerants under this group are mainly hydrocarbon group with ethylene propylene base. Ex.:- Trichloroethylene, Dichloroethylene etc.

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.

The secondary refrigerants are classified as follows.

If it is not desirable to carry the heat from heat generating source directly by refrigerant, then it is carried by using the secondary refrigerant as air, water or brine.

1. Water:- when the required temperature to be maintained is above the freezing point of water, then water is universally used as secondary refrigerant mostly in Air Conditioning the plants and industrial cooling installations.
2. Brines :- When the temperatures required to be maintained are below the freezing point of water, then the water cannot be used as secondary refrigerant. In such cases brine solutions are commonly used.

Brine is a solution containing the salt, in dissolved condition, in water. The freezing temperature of the brine is lower than the freezing temperature of water and it decreases with the increase in salt concentration.

The commonly used secondary refrigerants are water sodium chloride brine, calcium chloride brine and propylene glycol.

Commonly used refrigerants

- Air was used as a refrigerant in many refrigerant systems in olden days considering most safest refrigerant.
- Ammonia, Carbon dioxide and Sulphur Dioxide were are also used as successful refrigerants for different purposes.
- Methyl chloride was used for domestic and commercial purposes until Freons were available.
- Invention and development of chlorinated hydrocarbons and most of the refrigerants from this group are successfully used for all purposes in different fields.

The most common refrigerants used for air conditioning over the years include

- ✓ Chlorofluorocarbons (CFCs), including R12. This is known to contribute to the greenhouse gas effect.
- ✓ Hydrochlorofluorocarbons (HCFCs), including R22.
- ✓ Hydrofluorocarbons (HFCs), including R410A and R134.

- The most common type of refrigerants used today across the world are **hydrofluorocarbons (HFCs)**. Previously, chlorofluorocarbons (CFCs) were more widely used, but were phased out following the introduction of the Montreal Protocol in 1987.

Environmentally Friendly (or) eco-friendly Refrigerants

- The eco-friendliness of a refrigerant can be measured by its ODP (Ozone Depletion Potential) and GWP (Global Warming Potential).
- The most environmentally friendly refrigerants are hydrofluorocarbons (HFC) and hydrofluoro-olefins (HFO).
- HFCs are comprised of fluorinated hydrocarbons. While HFCs can contribute to global warming, they do not affect the ozone layer directly.
- HFOs are made up of hydrogen, fluorine and carbon and have zero ODP, along with a very low GWP and therefore are considered to be the currently most environmentally friendly type of refrigerant.

List of Environmentally Friendly Refrigerants

The following refrigerants have been designated as environmentally friendly by the Environmental Protection Agency (EPA).

HFOs

These HFO refrigerants are found in commercial and industrial air conditioning and refrigeration systems, water chillers, automobiles, portable air conditioners and heat pumps.

These include: R449A, R454C, R513A, R1234yf , R1234ze, R1233zd , R1336mzz

HFCs

These HFC refrigerants are used in industrial refrigerators, residential and commercial air conditioners, automobiles, and centrifugal chillers.

These include: R32 , R134a, R426A , R428A, R434A , R442A & R453A

HFO/HFC Blends

There are also refrigerants made up of a blend of HFOs and HFCs that are often found in supermarket refrigeration systems, vending machines, heat pumps and air and water chillers. These include: R448A, R450A, R455A & R464A

3.4 Refrigerator

A refrigerator is a home appliance consisting of a thermally insulated compartment and a heat pump that transfers heat from its inside to its external environment so that its inside is cooled to a temperature below the room temperature

Working Principle of refrigerator

1. Cool refrigerant is passed around food items kept inside the fridge.
2. Refrigerant absorbs heat from the food items.
3. Refrigerant transfers the absorbed heat to the relatively cooler surroundings outside.

Fig.3.37 Refrigerator

Working of Refrigerator

The refrigeration cycle starts and ends with the compressor. The refrigerant flows into the Compressor where it is compressed and pressurised. At this point, the refrigerant is a hot gas. The refrigerant is then pushed to the Condenser which turns the vapour into liquid and absorbs some of the heat. The refrigerant then proceeds to the Expansion Valve where it expands, losing pressure and heat. The refrigerant coming out of the expansion valve is cold and slow due to the loss of pressure. It enters the Evaporator in a liquid state where the exchange of heat takes place thus cooling the load inside the refrigerator. As the gas cools down the load, it absorbs the heat which turns it into a gas. The gas is then pushed back into the Compressor where it can start the cycle again.
During the refrigeration cycle, a build-up of ice around the evaporator may occur. Both commercial fridges and freezers will combat this build-up with some form of defrost system.

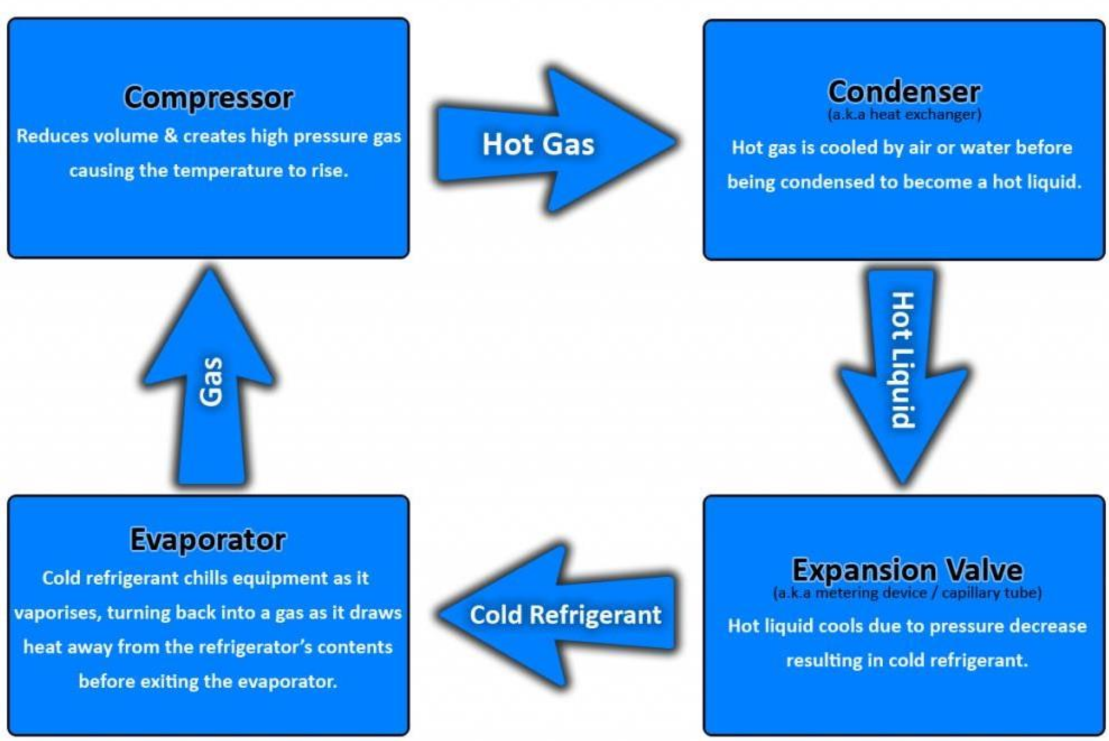


Fig.3.38 Process cycle in Refrigerator

Main parts of Refrigerator

1. Compressor
2. Refrigerant
3. Condenser
4. Expansion valve
   (or capillary tube)
5. Evaporator
6. Thermostat
   (or temperature control device)

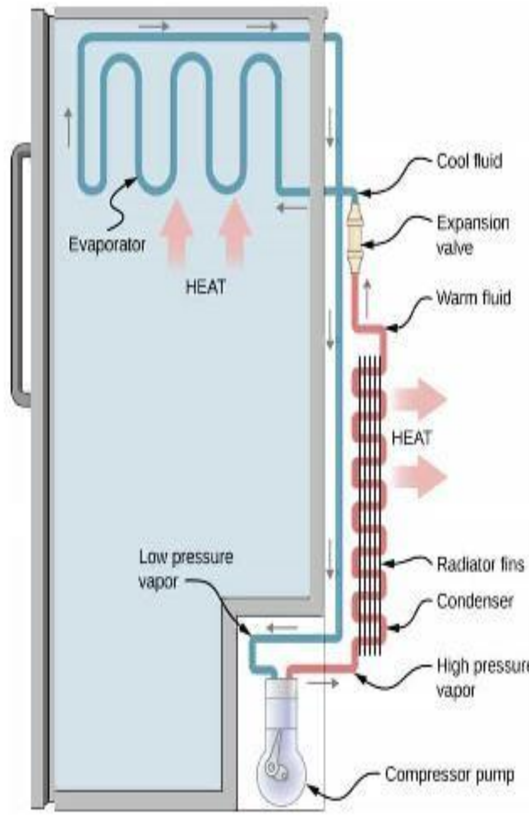


Fig.3.39 Parts of refrigerator and Process in refrigerator

1. Compressor

The compressor consists of a motor that _sucks in‘ the refrigerant from the evaporator and compresses it in a cylinder to make a hot, high-pressure gas. It is located back of the refrigerator.

Fig.3.40 Compressor

2. Refrigerant

Refrigerant is actually a specially designed chemical that is capable of alternating between being a hot gas and a cool liquid. It is truly the lifeblood of a refrigerator. It starts in the form of a gas, then a liquid, and back to a gas as it cycles through the refrigerator‘s parts.

3. Condenser

The condenser consists of a coiled set of tubes with external fins and is located at the rear of the refrigerator. It helps in the liquefaction of the gaseous refrigerant by absorbing its heat and subsequently expelling it to the surroundings. As the heat of the refrigerant is removed, the temperature of refrigerant drops to condensation temperature. So, the state of refrigerant changes from vapour to liquid.

Fig.3.41 Condenser coils with external fins

4. **Expansion valve (or Capillary tube)**

This cooling process then shifts to the expansion valve, which is a thin set of copper tubes. The expansion valve lowers the liquid refrigerant's temperature and pressure dramatically, causing about half of it to evaporate. This refrigerant repeatedly evaporating at extremely low temperatures is that creates the cool temperatures inside the refrigerator.

5. **Evaporator**

The evaporator absorbs heat from the stuff kept inside and as result of this heat, the liquid refrigerant turns to vapour. The cooling process ends at the evaporator. The compressor takes vapour to start process of the next cycle.

6. **Thermostat or temperature control device**

To control the temperature inside the refrigerator there is the thermostat, whose sensor is connected to the evaporator. The thermostat setting can be done by the round knob inside the refrigerator compartment. When the set temperature is reached inside the refrigerator the thermostat stops the electric supply to the compressor and compressor stops and when the temperature falls below certain level it restarts the supply to the compressor.

Applications of low temperature and refrigeration

Applications of low temperatures

Preservation of biological material

Biological materials are materials those are produced by living organisms, such as, blood, bone, proteins, muscle and other organic material. Biomaterials, on the other hand, are materials which are created specifically to be used for biological applications.

Examples of Biological materials are

1. Blood.
2. Urine.
3. Human tissue.
4. Semen.
5. Vaginal secretions.

Cryogenic freezer storage often deemed to be the gold standard for long-term storage of biological samples. At these extremely low temperatures all biological activities are suspended and no degradation occurs.

Cryogenic freezing is ideal for sensitive samples and specimens which cannot be suspended in a preservative.

Since most identified metabolic processes stop at temperatures below the glass transition phase, cryopreservation reduces the risk of microbial contamination or cross contamination with other tissue or cell samples.

A cell component (DNA, RNA, etc.) [Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA)] can typically be stored at -20°C, -40°C, -80°C. Bacteria can typically be stored at -80°C.

As per the FDA (Food and Drug Administration), frozen samples should be kept at –28°C to –18 °C and refrigerated samples between –2°C and –8 °C. ambient samples should be protected from heat and moisture.

Vaccines and biologics should be stored in a refrigerator that can maintain constant temperatures between +2ºC and +8ºC.

The commonly used preservative materials are 10% formalin solutions, 40% isopropyl alcohol solutions and 70% ethyl alcohol solutions.

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Food freezing

When the food products to be preserved are to be in its original fresh state for longer periods, then they should be frozen and stored at – 15^{o}C or below, such storages are known as frozen storages.

They differ from cold storages both in size and temperature. The high quality food products in good condition should only be frozen.

Both the vegetables and fruits require considerable processing (cleaning and washing) and also blanching (peeling) in to hot water or steam at 100^{o}C for about 1 or 1½ minute before freezing.

Many bacteria may survive after this blanching. To prevent spoilage by these bacteria, the vegetables should be chilled to – 15^{o}C immediately after blanching. But fruits can not be blanched because it affects their state. This freezing is at about -20 ^{o}C.

Methods of freezing

1. Slow or sharp freezing : - In this method food products are placed in a low temperature room and allowed to freeze slowly in still air by natural convection. The temperature range is – 17^{o}C to – 40^{o}C. The time duration is from 3 hrs to 3 days.
2. Quick freezing :- In this method the freezing is due to the forced circulation of cold air and in this, the different methods are
   a) Immersion freezing :- In this method, the food products are immersed in to low temperature liquids. This results in rapid cooling and freezing due to the high thermal conductivity of the liquid medium at low temperature. The liquid should not produce any bad effect on the immersed food.
   b) Indirect contact freezing :- During this process, the food product and a heat transfer fluid are separated by means of an interface or barrier (metal plate boxes) between the cooling medium and the product.
   c) Air blast freezing :- In this method, a very low temperature air is circulated with very high velocity around various parts of the product. The temperature range is – 20^{o}C to – 40^{o}C and the velocity range is 30 m/min to 120 m/min

Liquid nitrogen and liquid hydrogen in medical field

- Liquid nitrogen is a chemical that is extremely cold, about -200°C. Liquid nitrogen will instantly freeze anything that it touches. It is used to kill cells that make up diseased or cancerous tissue. Tissue that has been frozen dries out and falls off.

- ❖ Liquid Nitrogen is used as a cryogen to freeze and preserve blood, tissue and other biological specimens and to freeze and destroy diseased tissue in cryosurgery and dermatology. It is also used to supply power to medical devices.
- ❖ Liquid nitrogen, which has a boiling point of -196^{o}C, is used for a variety of applications, such as a coolant for computers, in medicine to remove unwanted skin, warts and pre-cancerous cells and in cryogenics.
- ❖ Although liquid nitrogen is nontoxic, it can cause severe damage to skin and internal organs if mishandled or accidently ingested (taken in to stomach), due to the extremely low temperatures.

- ✓ Hydrogen gas has been recognized as one medical gas that has potential in the treatment of cardiovascular diseases, inflammatory diseases, neurodegenerative disorders and cancer.
- ✓ Hydrogen Gas suppresses inflammatory Cytokines.
- ✓ By regulating inflammation, hydrogen gas can prevent tumor formation, progression, as well as reduce the side effects caused by chemotherapy/radiotherapy

Superconducting magnets in MRI

- ➢ Superconducting magnets are most commonly used in MRIs. Superconducting magnets are similar to resistive magnets i.e. coils of wire with electrical curren, create the magnetic field (Electro-magnets).
- ➢ An MRI system consists of four major components. 1) Main magnet formed by superconducting coils 2) Gradient coils 3) Radiofrequency (RF) coils and 4) Computer systems.
- ➢ The main magnetic field is generated by a large superconducting electromagnet in which an electric current flows. The coils or wires will become superconductors (having zero resistance) at very low temperatures i.e. around 10 K. Due to very low resistance of superconductor, it allows very strong currents to flow with no heating in the material and hence enables to get very high magnetic field values of several teslas.
- ➢ Most MRIs generate a strong magnetic field using superconductors which gives the highest-quality imaging.
- ➢ Superconducting magnets at 1.5 T and above can allow functional brain imaging, MR spectroscopy and superior SNR and improved time and spatial resolution. Magnets above 1.5 T have additional challenges from RF heating of the subject. This RF heating is also removed by the cooling effect.
- ➢ There are two main types of MRI machines 1) Closed bore MRI and 2) Open MRI. While closed bore MRI machines take the highest quality images, open MRI machines may provide more comfort during the imaging due to the lack of an enclosed space.

Tissue ablation (cryosurgery)

- Cryosurgery is a procedure in which an extremely cold liquid or an instrument called a cryoprobe is used to freeze and destroy abnormal tissue. A cryoprobe is cooled with substances such as liquid nitrogen, liquid nitrous oxide or compressed argon gas.
- In medicine, the removal or destruction of a body part or tissue or its function is tissue ablation. Ablation may be performed by surgery, hormones, drugs, radiofrequency, heat or other methods.
- Cryosurgery is used to treat tumors on the skin, as well as certain tumors inside the body. Cryosurgery may also be called cryotherapy or cryoablation.
- In cryotherapy, doctors spray liquid nitrogen on a precancerous growth to freeze and destroy it. You may feel a burning sensation for several seconds. The treated area turns pink and forms a blister, which can be peeled off.
- Cryotherapy can cause redness and irritation of the skin. You may lose some hair on the treated area. But, these effects are generally temporary.
- Cryotherapy can help with muscle pain, as well as some joint and muscle disorders, such as arthritis. It may also promote faster healing of athletic injuries, reduction of joint pain and a bolstered metabolism. Doctors have long recommended using ice packs on injured and painful muscles.

Cryogenic rocket propulsion system

- A cryogenic rocket engine is a rocket engine that uses a cryogenic fuel and oxidizer i.e. both its fuel and oxidizer are gases which have been liquefied and are stored at very low temperatures.
- The cryogenic engine gets its name from the extremely cold temperature at which liquid nitrogen is stored. Air moving around the vehicle is used to heat liquid nitrogen to boil. Once it boils, it turns to gas in the same way that heated water forms steam in a steam engine.
- When nitrogen boils, excess pressure will be created which can explode the nitrogen tank. These limitations will avoid liquid nitrogen from being a rocket fuel.
- So, cryogenic engine makes use of Liquid Oxygen (LOX as oxidizer) and Liquid Hydrogen (LH_2 as fuel) as propellants which liquefy at -183^o C and -253^{o}C respectively.
- Compared to other propellants, such as solid and liquid propellant rocket engines, a cryogenic engine provides more force with each kilogram of cryogenic propellant it uses . Also these rockets should carry heavy payloads & cryogenic engine is more efficient. So, it is used in rockets.
- Researchers have developed an advanced new rocket-propulsion system once thought to be impossible. The system, known as a rotating detonation rocket engine, will allow upper stage rockets for space missions to become lighter, travel farther and burn more cleanly.

Applications of refrigeration

Domestic refrigerators

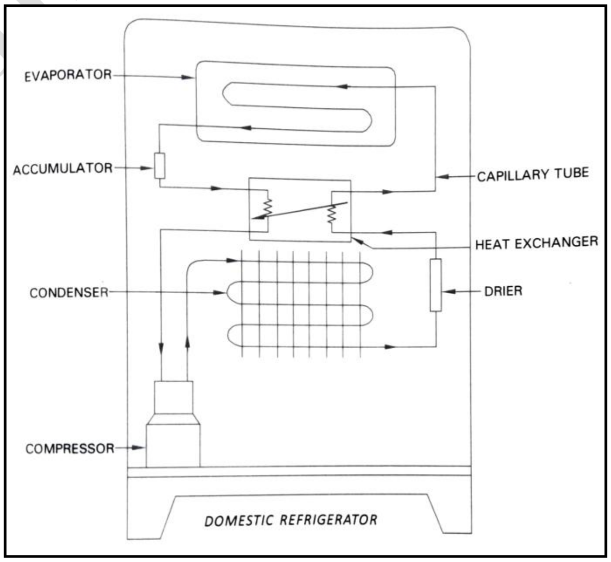
- The main purpose of a domestic refrigerator is to provide a low temperature for storage and distribution of foods and drinks.
- It has been found that food destroying microorganisms growth is much faster (about 1000 times) at temperature of 10^{o}C than at 4 ^{o}C.
- This is enough to high light the use of refrigerators for preserving food items.
- These are small in size and vary in capacity from 0.1 m^3 to 0.25 m^3 i.e. 100 lit to 250 lits.
- The domestic refrigerator have generally hermitically sealed units in which the motor and compressor are enclosed in one chamber and is located at the base of the cabinet.
- The refrigerant used should be non - irritant and non – toxic. Generally methyl chloride R - 12 and R – 11 or Freon - 12 are used as refrigerants.

Parts :

The main components of domestic refrigerator are 1. Compressor 2. Condenser 3. Receiver 4. Drier 5. Capillary tube 6. Operator 7. Accumulator

Working :

- In this, mechanical vapour compression system is used because of its compactness and more efficiency.
- The refrigerant vapour drawn from the evaporator is compressed in compressor and deliver to the condenser.
- It is then expanded in capillary tube and passed on to the evaporator. Capability tube is used as throttling device to reduce the pressure of the refrigerant.
- The low pressure liquid refrigerant evaporates by absorbing its latent heat and thus producing refrigerating effect in the evaporator (or) freezer.



Condenser is essentially a air cooled coil.

The evaporator coil is placed at the top of inside Cabinet. The evaporator produce low temperature upto – 15^{o}C and the temperature around 7 ^{o}C to 10 ^{o}C can be maintained in the refrigerating section due to convection current of air inside the cabinet.

Division of storage space

- ✓ The freezer is a mini cold storage in which ice cubes, ice creams, frozen foods, meat, poultry and fish can be preserved.
- ✓ A thermostat is provided to control the temperature in the freezer.
- ✓ Chiller drain tray is provided just below the freezer to prevent the accumulation of water drops.
- ✓ Refrigerator section below the freezer, comprises adjustable shelves to preserve fruits, vegetables cooked food etc.
- ✓ Egg trays, dairy bins, bottle shelves are provided inside the door panel.

Refrigerator should be placed in a clean and dry ventilated area which is properly leveled. It is important to check the functioning of thermostat, door switch light.

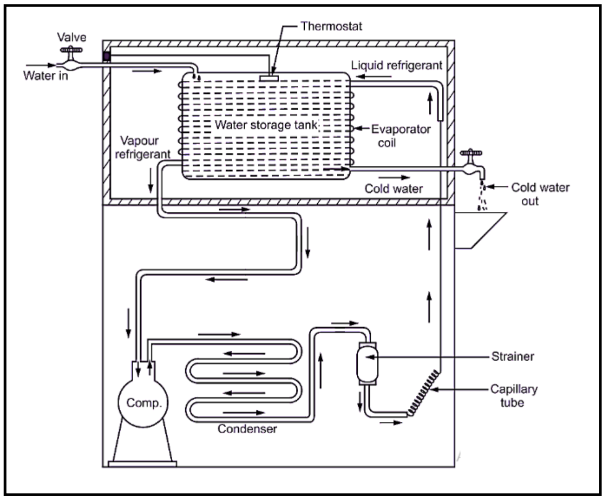
Water coolers

There are two types of water coolers

1.Storage type 2. Instantaneous type

Storage type water cooler

In storage type, water to be cooled is stored in a large storage tank. It is surrounded by cooling coil. Here vapour compression machine is used. The refrigerant used is R – 134a.

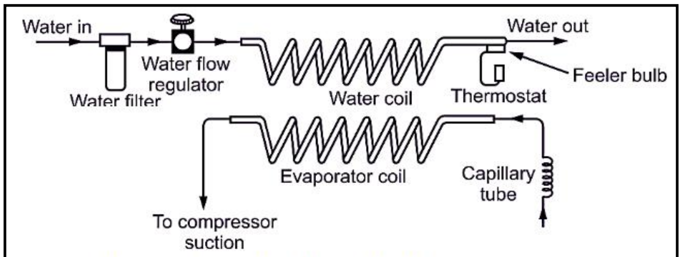


Working :- The water cooler has a metal sheet cabinet. The cooler consists of hermetically sealed compressor, condenser, capillary tube accumulator, refrigerant coil, water cooling coil, thermostat etc.

- ➢ When the vapour compression system starts to work, the heat of water is taken by the refrigerant flowing through the evaporator coil and gets evaporated.
- ➢ This vapour refrigerant is sucked by the compressor and compressed to high pressure and high temperature. This is sent to the condenser.
- ➢ From condenser out let, the liquid refrigerant is passed through a capillary tube to the evaporator coil. This cycle is repeated number of times until the desired cooling of water occurs. As soon as the desired temperature is attained the compressor is cut-off by the thermostat.

Instantaneous type water cooler

Instantaneous type water cooler gives cold water as and when required. The cooling coil is directly wounded on the tap water line.



Instantaneous Type Water Cooler.

- In case of instantaneous type of water cooler evaporator consists of two separate cylindrically wounded coils made up of copper or stainless steel.
- One coil is cooled as cooling coil and second coil is water coil. The liquid refrigerant received from capillary tube flows through the evaporator coil where as water to be cooled is made to pass in the water coil through a filter and a flow regulator.
- Both coils are located close to each other to permit heat transfer by conduction. Thus the liquid refrigerant absorbs heat from the water by conduction reducing its temperature. Thermostat controls the on / off operation of compressor to maintain the water temperature within the required limits.

It is very important to control the flow rate of water as per the needed capacity of the evaporating coil.

Cold storages

Cold storage is a building designed to store certain goods like food stuffs, fruits, vegetables and dairy products within well defined temperature range and relative humidity.

The cold storage is also an application of air conditioning, in a way that the air is cooled by passing it over a cooling coil of refrigeration plant and supplied back to the room.

The temperature and humidity conditions inside cold storage depend upon the type of the product stored inside it. The most appropriate temperature to retard the deterioration of vegetables and fruits is about 0.5 ^{o}C to 1 ^{o}C.

Here the conditions are of two types.

1. Cold storages maintained at 0^{o}C and above.
2. Cold storages maintained below 0^{o}C.

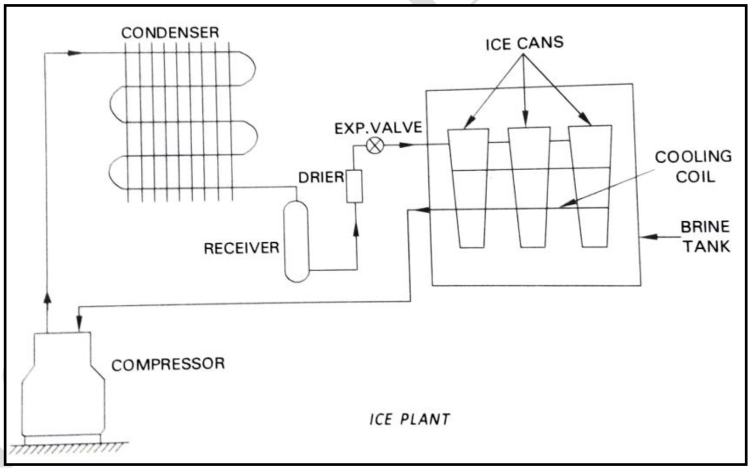
The refrigeration does not improve the quality of the food product but it slows down its deterioration.

Working

- It works on vapour compression system. Here Ammonia is used as refrigerant. Relatively small amount of ammonia is sufficient to get a large reduction in temperature. Refrigerant at low temperature enters the cooling coil and produce the refrigeration effect in the coil.
- The refrigerant vapour drawn from the coil is compressed to high pressure and delivered to condenser where it is condensed to liquid state.
- The liquid refrigerant is throttled down to low temperature and pressure before entering the cooling coil.
- The air is cooled as it comes in contact with cooling coil. Chilled air is blown into the room through dampers.

Ice plants

It is made by filling metal cans with water and lowering them into a bath of brine (usually sodium chloride or calcium chloride) refrigerated to well below the freezing point of water. The water freezes in the cans and the ice blocks are removed from the cans after several hours of freezing.



Construction :

- ✓ Ice making plant consists of a vapour compression system with ammonia as a refrigerant.
- ✓ It has a brine tank made of M.S. plates and of thickness 6 mm. The tank is insulated to prevent heat transfer from surroundings to it.
- ✓ Clean water is taken in ice cans which are made of galvanized sheets of 2 mm thickness and tapered down wards. These ice cans are placed in brine tank.
- ✓ The water level in the cans should be 20 mm below the brine level and the cans should be projected above the brine level.
- ✓ The cooling coil is wrapped around the cans with good contact. Brine acts as secondary refrigerant. This brine is cooled to -10^{o}C by ammonia evaporating at -15^{o}C.

Working :

- ❖ High pressure vapour delivered from the compressor enters the condenser and here it condensed to liquid state.
- ❖ This liquid refrigerant flows through a drier and expansion valve. In this valve expansion takes place, so the pressure decreases.

- This refrigerant flows through the cooling coils where it evaporates by taking heat from brine. This cooled brine in turn takes heat from water in the cans and ice is formed in the cans.
- The ice blocks can be removed from the cans just by shaking the cans.

Food preservation methods

a. Heat processing :- :- The temperature of the product is raised to a level to all spoilage agents and is maintained at this level until they are all destroyed. The product is then sealed in sterilized airtight containers. The product so processed will remain in a preserved state for long time.

b. Dehydration :- The process of removing the moisture from the product is called dehydration. Both the enzymes and micro-organisms (spoilage agents) require moisture for their growth. So, it has to be stopped. Some of the dehydrated food are dried milk, instant coffee, dehydrated soups etc.

c. Chemical preservation :- Salt as a preservative is used for preserving vegetables and fruits, tamarind, raw mango, Amla, fish and meat. It may be used in dry or brine form. The presence of high concentration of salt prevents the water from being available for bacterial growth. The principle of sugar as preservative is same as that of salt.

d. Oil and spices :- The oils and Spices along with salt and sugar provide a medium that resists the activity of the micro organisms in food. Moreover, they improve the flavour of the food being preserved. Spices such as chillis, fenugreek, mustard and Pepper are used in pickling. when oil is used in pickling the top layer of oil prevents the micro organisms in the air from coming into contact with the food

e. Canning :- The canning is preservation of food in sealed containers, after applying high temperature (135^{o}C to 172^{o}C) under pressure. During this process some of the microorganisms are destroyed and the rest are rendered inactive. The enzymes are also inactivated. The containers are then sealed to prevent recontamination. This method is used for fluid products such as fruit juices, syrups etc.

f. Pasteurization :- This method is generally used on large scale to protect milk against bacterial infection. This milk is used for preparation of milk products. The pasteurization may be brought about by the holding process or high temperature short time method. In holding process, the milk is heated to at least 62^{o}C and kept at that temperature for at least 30 minutes. In the high temperature short time method the milk is heated to 70^{o}C and kept at the temperature for at least 15 seconds.

Chemical and process industries

- ❖ Although chemical and petrochemical reactions are not as strictly controlled as the reactions in the Pharmaceutical field, control of temperature is an important factor in reaching high efficiency in their transformations.
- ❖ Distillations, crystallizations or condensations are the operations requiring the removal of heat. Hence refrigeration systems are necessary to obtain their products. In chemical and petrochemical industries, large scale cooling plants are used in their processes.
- ❖ Compression and absorption cycles are used to cool down the hot stream dissipated in different operations.
- ❖ Since hot streams are also required in other parts of the process, heat exchangers are usually applied to heat these streams and maximize the efficiency of the operation.
- ➢ It is well-known that some bacteria are responsible for degradation of food. Enzymatic processing cause ripening of the fruits and vegetables. The growth of bacteria and the rate of enzymatic processes are reduced at low temperature. This helps in reducing the spoilage and improving the shelf life of the food.
- ➢ In case of fruits and vegetables, the use of refrigeration starts right after harvesting to remove the post-harvest heat, transport in refrigerated transport to the cold storage or the processing plant.
- ➢ Long-term preservation of fish requires cleaning, processing and freezing.
- ➢ Meat and poultry items also require refrigeration right after slaughter during processing, packaging. Short-term storage is done at 0°C. Long-term storage requires freezing and storage at -25°C.
- ➢ The important dairy products are milk, butter, buttermilk and ice cream. To maintain good quality, the milk is cooled in bulk milk coolers immediately after being taken from cow. Bulk milk cooler is a large refrigerated tank that cools it between 10 to 15°C. Then it is transported to dairy farms, where it is pasteurized.

Cold treatment of metals

The heat causes the length or volume of metal to expand due to the increase in temperature. On the other hand, when the metal is cooled, the atoms will take less space and will be contracted. As the temperature of the metal is decreased, it will shrink and may differ in some properties.

Quenching is rapid cooling of metal in air, oil, water, brine or another medium. Usually quenching results in hardening but it is not always true that quenching or otherwise rapid cooling results in hardening.

Heating makes metal work pieces weaker. As a result, cold-working processes are used in applications requiring a strong finished product. Not only it offers increased strength, but also cold working is easier to perform.

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A cryogenic treatment is the process of treating work pieces to cryogenic temperatures (i.e. below −190 °C) in order to remove residual stresses and improve wear resistance in steels and other metal alloys, such as aluminum. Cryogenic treatment of steel is a distinct process that uses extreme cold to modify the performance of materials.

The cryogenic treatment improves mechanical such as hardness, toughness and tribological properties such as wear resistance, coefficient of friction, surface finish, dimensional stability and stress relief. The deep cryogenic treatment is the most beneficial treatment applied on cutting tools.

This produces an accurate dimension of the parts. It increases the strength and hardness of the metal but reduces the ductility. As this procedure is performed without heat no oxide is formed on the surface resulting in a smooth surface. This process is mostly used for bulk production.

Steel that has been produced by cold quenching can have a hardness that is four times greater than normal melted and formed steel.

Construction field

Setting of concrete is an exothermic process. If the heat of setting is not removed, the concrete will expand and produce cracks in the structure. Concrete may be cooled by cooling sand, gravel and water before mixing them or by passing chilled water through the pipes embedded in the concrete. Another application is to freeze the wet soil by refrigeration to facilitate its excavation.

- The heavy concrete construction requires cooling to remove the heat released during mixing of aggregate and setting.
- In absence of refrigeration the large temperature gradients render cracks of the surfaces and structure.
- The latter endangers the water tightness and stability of the structure. The surface cracks on the other and requires increased maintenance cost.
- Moreover to ensure proper setting construction has to be made in small blocks which would require enormously large time to complete the dam.
- The aggregate is pre cooled to 15^oC to 18^oC such that the block temperature after setting may remain with in the desired temperature of 32^oC.
- The water chilling is done by the Ammonia refrigeration system. The vacuum cooling is the latest development.

Desalination of water

Desalination can be defined as any process in which excess salts and minerals are removed from water (or) the chemical process of changing seawater into potable water are called desalination.

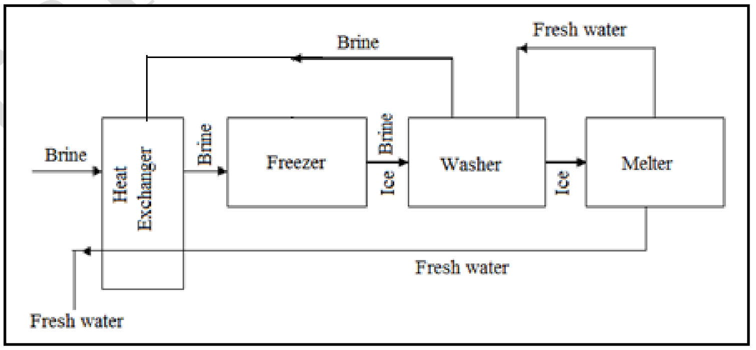
Compared to other desalination processes, the freezing process offers a number of advantages. It requires the transfer of less energy, needs almost no pretreatment and has minimal corrosion and metallurgical problems.

There are four basic components in all freezing desalination processes

1) Freezer
2) Washer
3) Melter and
4) Heat removal systems.

The various freezing processes generally differ in the apparatus which removes heat from the brine in order to produce ice crystals which can be easily transferred, removed, separated, washed and then melted.

The freezer consists of a vessel in which ice crystals and vapor are formed simultaneously.



- The feed seawater is first pumped through a heat exchanger to reduce its temperature, then entered into the freezing chamber, where it is cooled further to the temperature at which the ice crystals are formed.
- The ice and brine slurry is pumped to a wash column where the ice and brine are separated. The ice is transported to the melter. Here ice is melted by the heat, released from condensation of the compressed refrigerant and fresh water is formed.
- A small part of the product, fresh water, is bypassed to the wash column and is used to wash the ice crystals and the major part is passed through the heat exchanger to cool the feed seawater and is then discharged for storage.
- The brine from the wash column is returned to the heat exchanger to cool the feed seawater and discarded.

- Regarding the refrigeration process, the evaporator is fixed in the freezer to take heat from brine and to form ice crystals and condenser is fixed in the melter region to melt ice & to form fresh water.

Data centres

- Data centers store groups of servers used to process and distribute data.
- The servers naturally produce heat during operation and if the heat is not removed, the temperature rises.
- This can adversely affect the functioning of the servers. To prevent this problem, powerful air-cooling systems are usually placed in these data centers, dissipating the heat produced and minimizing maintenance operations.
- Proper cooling of data center allow servers to stay online for longer time. Overheating can be disastrous in a professional environment . So any failure at the server level will have bad effects on business.
- These cooling systems are commonly air-based or liquid-based, depending on exterior conditions.
- Furthermore, new cooling systems are starting to be more environmentally friendly, using seawater as a refrigerant.
- The cooling system serves three important functions. First, it removes excess heat from the engine; second, it maintains the engine operating temperature where it works most efficiently and finally, it brings the engine up to the right operating temperature as quickly as possible.
- New emerging technologies like Microsoft's “boiling water cooling” are used for cooling data center servers and driving evaporative cooling technology.