Chemical Process Utilities

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Module No # 11
Lecture No # 51
Refrigerants and Refrigeration

Refrigeration plays a very vital role in different aspect of chemical process utilities and when we are talking about the refrigeration aspect then we cannot overlook the importance of refrigerants. So welcome to the new concept of this refrigerant and refrigeration. Now in this particular lecture we are going to discuss about the brief outlay of the refrigerants, then we will discuss about the classification of refrigerants.

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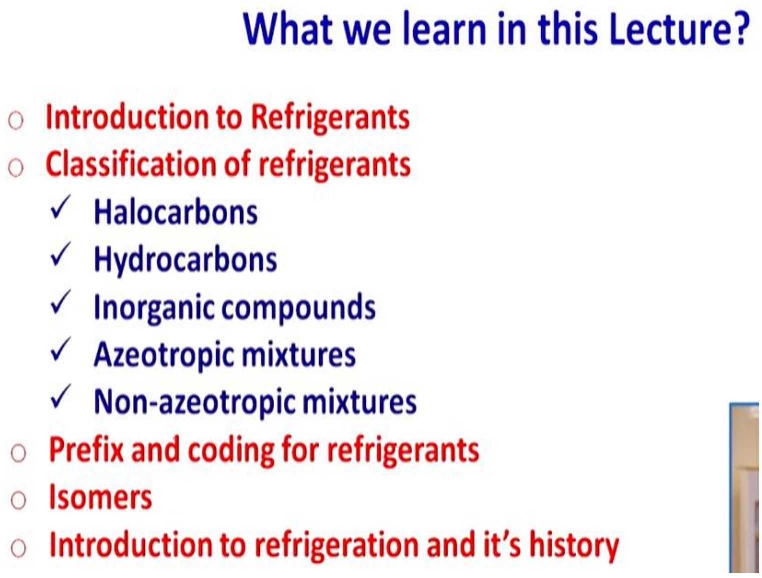

This inclusive of halocarbons, hydrocarbons, inorganic compounds, azeotropic mixtures, non-azeotropic mixtures. We will discuss about the prefix encoding of refrigerant, we will discuss about the isomers and, we will apart from this we are going to discuss about the refrigeration and it is history. See refrigeration as I told you that the refrigeration is an integral part of chemical process industries and it is clubbed under the edge of utility.

Because there are so many processes in which you need to have lower temperature operation and sometimes you need to extract the excess amount of heat from any process.

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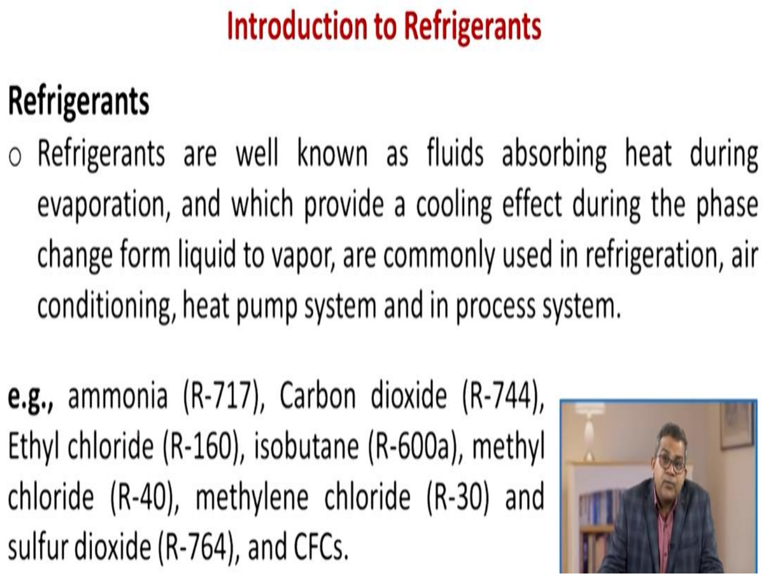

And, this usually carried out with the help of a refrigeration cycle and with the help of refrigerant. So, the refrigerant they are well known as a fluid absorbing heat during the evaporation, and which provides a cooling effect during the phase change from liquid to vapor, and are commonly used in refrigeration, air conditioning, heat pump system and in the process system.

There are a couple of examples of the refrigerants like ammonia sometimes referred as R-719, carbon dioxide referred as R-744, ethyl chloride referred as R-160, isobutane referred as R-600 a, methyl chloride R-40, methylene chloride R-30 and sulfur dioxide R-764 and other chlorofluorocarbons.

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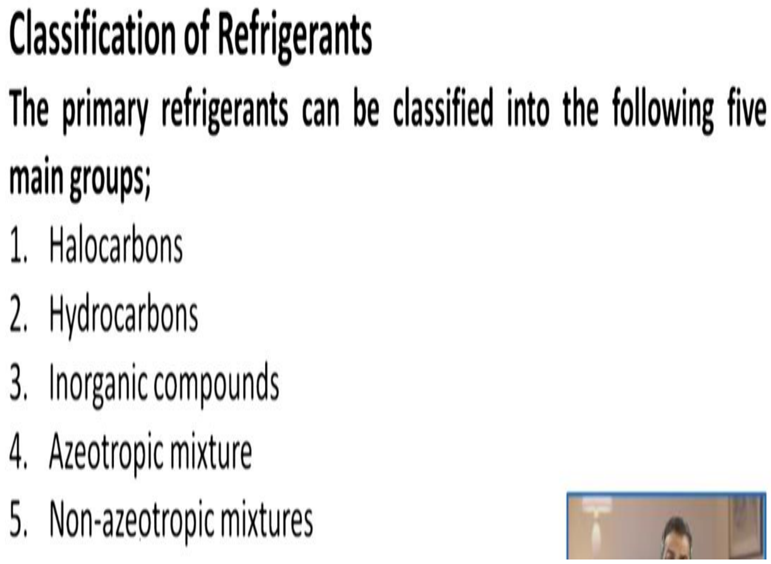

Now since they play a very vital role so based on the various parameters and aspects, we can classify those refrigerants on various basis. The primary refrigerants these can be classified into different categories and especially the 5 categories halocarbons, hydrocarbons, inorganic compounds, azeotropic mixtures, and non-azeotropic mixtures.

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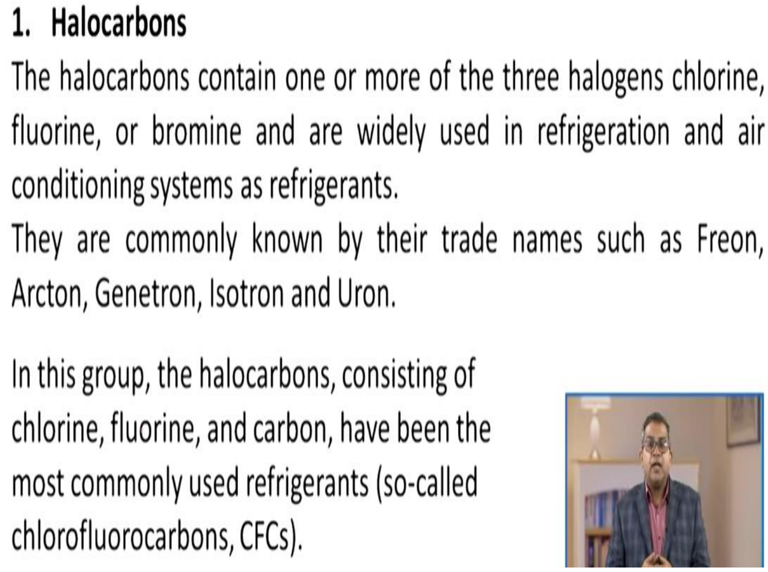

So, let us discuss about the halocarbons, the halocarbons contain one or more of the 3 halogens chlorine, fluorine, and bromine and they are widely used in refrigeration and air conditioning system as refrigerants. They are commonly known by their trade names such as Freon, Arcton, Genetron, Isotron and Uron. In this group, the hydrocarbons, consisting of chlorine, fluorine, and carbon, they have been the most commonly used refrigerant so called chlorofluorocarbon, or CFCs.

Now the CFCs have been commonly used as a refrigerant, solvents, and foam blowing agents such as most common CFCs, they are CFC-11 or R-11, CFC-12 or R-12, CFC-113 or R-113 or CFC-114 or R-14.

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- **CFCs** have been commonly used as refrigerants, solvents, and foam blowing agents such as the most common CFCs have been CFC-11 or R-l 1, CFC-12 or R-12, CFC-113 or R-l 13, CFC-114 or R-l 14 and CFC-115 or R-115.
- **CFCs** are odorless and nontoxic and heavier than air, as well as dangerous if not handled properly.

Now CFCs are odourless and non-toxic and heavier than air, as well as the dangers if they are if you are not handling them properly.

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- Inhalation of high concentrations is not detectable by human senses and can prove fatal due to oxygen exclusion caused by **CFC** leakages in an enclosed area.
- The combustion products of **CFCs** includes, phosgene, hydrogen fluoride and hydrogen chloride, which are highly poisonous if inhaled.

The inhalation of high concentration is not detectable by human senses and can prove fatal due to the oxygen exclusion caused by the CFC leakage in the enclosed arena. The combustion product of CFC includes, the phosgene, hydrogen fluoride, hydrogen chloride, which are equally poisonous if they are inhaled. Now there are some other components such as halon, carbon tetrachloride’s, perfluorocarbons. The halons are compounds consisting of bromine, fluorine, carbon, and this halon 1301 or 1211.

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- There are some other components such as **halons, carbon tetrachlorides and perfluorocarbons.**
- Halons are compounds consisting of bromine, fluorine and carbons, the halons (halon 1301, 1211) are used as fire extinguishing agents, both in built-in systems and in hand held portable fire extinguishers.

They are used as a fire extinguishing agent, both in built-in system and in hand held portable fire extinguishers. The carbon tetrachloride CCL 4 this is widely used as a raw material for many industrial uses.

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- **Carbon tetrachloride (CCl4)** was widely used as a raw materials in many industrial uses, including production of CFCs and found carcinogenic.
- **Perfluorocarbons (PFC)** have an extremely high effect on global climate change and very long lifetimes, have impact on global warming.

Including the production of CFCs and found carcinogenic and that is why it has been discarded over the period of time. Then perfluorocarbons PFCs they have an extremely high effect on global climate change and very long lifetime, they have impact on the global warming.

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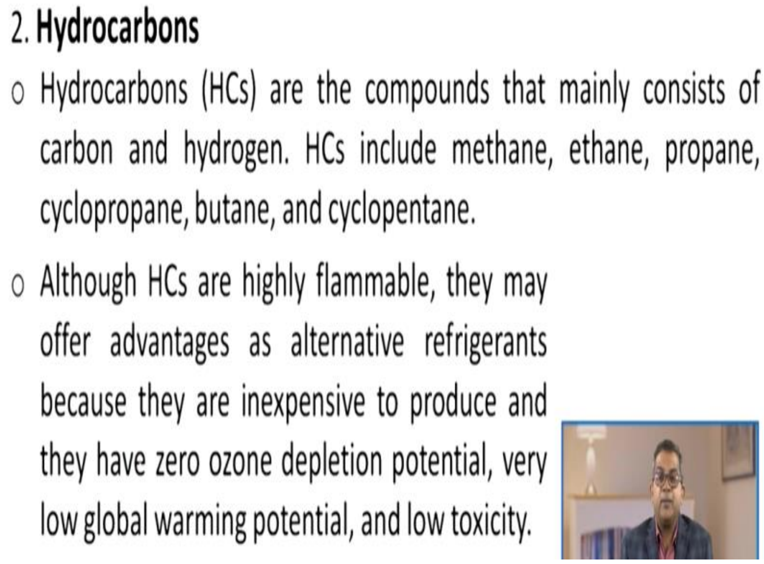

Now second category is the hydrocarbons, hydrocarbons or HCs they are the compound that mainly consists of carbon and hydrogen. And this hydrocarbon includes the methane, ethane, propane, cyclopropane, butane, cyclopentane etcetera. Although these hydrocarbons are highly flammable, they may offer various advantages as alternative refrigerants. Because they are inexpensive to produce and they have a, zero ozone depletion potential, and they have a very low global warming potential, and they possess a very low toxicity in nature.

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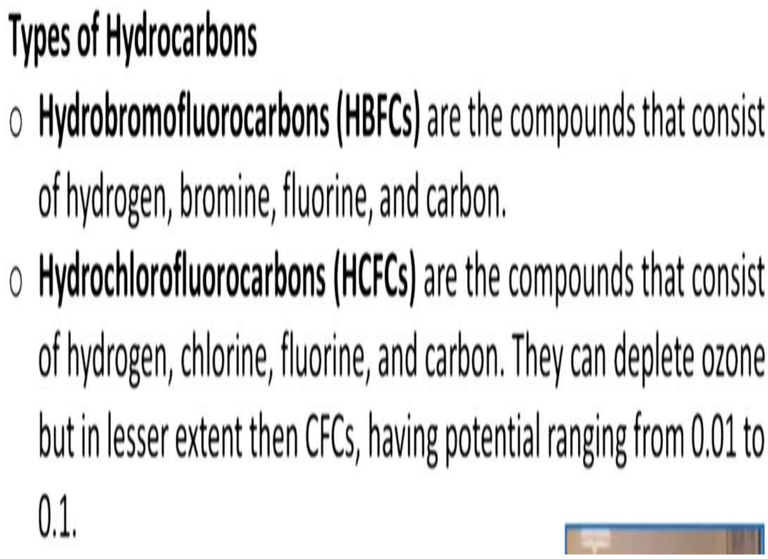

There are various you know types of hydrocarbons like, hydrobromofluoro carbon HBFCs they are the compounds that consist of hydrogen, bromine, fluorine, and carbon. Then hydrochlorofluorocarbons HCFCs they are compound that consists of hydrogen, chlorine, fluorine, and carbon. And they can deplete the ozone but in lesser extent than the CFCs, and they are having the potential of ranging from 0.01 to 0.1.

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- **Hydrofluorocarbons (HFCs)** are the compounds that consist of hydrogen, fluorine, and carbon. They Can be used as replacements for CFCs because don't contain chlorine, bromine and don't deplete the ozone layer and have depletion potential of zero.

Then hydrofluorocarbons HFCs they are the compound that consists of hydrogen, fluorine, and carbon. They can be used as the replacement of CFCs because do not contain chlorine, bromine and they do not deplete the ozone layer but and that their depletion potential is about to zero.

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- **Methyl bromide (CH_3Br)** is a compound consisting of carbon, hydrogen, and bromine. It is an effective pesticide and used to fumigate soil and many agricultural products and have depletion potential of 0.6.
- **Methyl chloroform (CH_3Cl)** is a compound consisting of carbon, hydrogen, and chlorine. Methyl chloroform is used as an industrial solvent. Its ozone depletion potential is 0.11.

Methyl bromide CH_3Br this is the compound consisting of carbon, hydrogen, bromine. It is an effective pesticide and used to fumigate soil and many agricultural products and they have the depletion potential of 0.6. Methyl chloroform CH_3Cl this is a compound consists of carbon, hydrogen, and chlorine. Methyl chloroform is used as an industrial solvent. It is ozone depletion potential is 0.11.

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Note:

- For refrigeration applications, a number of hydrocarbons such as methane (R-50), ethane (R-170), propane (R-290), n-butane (R-600), and isobutane (R-600a) that are suitable as refrigerants can be used.

For refrigeration application a number of hydrocarbons such as methane R-50, ethane R-170, propane R-290, n-butane R-600, and isobutane R-600a that are suitable as a refrigerant these can be used easily or frequently.

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3. Inorganic compounds

- In spite of early invention of inorganic compounds, today they are still used in many refrigeration, air conditioning and heat pump applications as refrigerants e.g., **ammonia (NH_3), water (H_2O), air, carbon dioxide and sulfur dioxide (SO_2).**

Note:

Here, in this study we have focused on three compounds of this family: ammonia, carbon dioxide and air.

There are certain inorganic compounds now, in spite of early invention of inorganic compound. Today they are still used in many refrigeration, air conditioning and heat pump application as a refrigerant. The examples are ammonia NH_3, water H_2O, air, carbon dioxide sulphur dioxide. Now in this particular study we have focused on 3 compounds of this family that is ammonia, carbon dioxide, and air.

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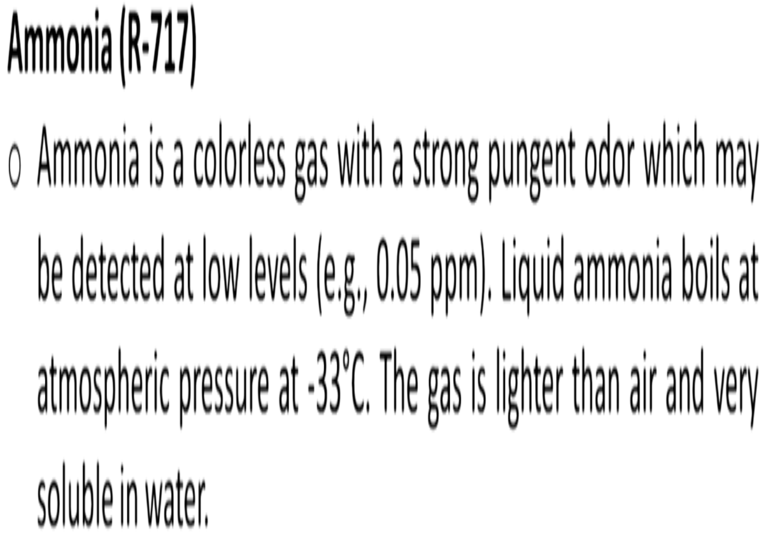

So let us talk about the ammonia that is R-717, ammonia is a colourless gas with a strong pungent order which can be detected at a very low level that is 0.05 parts per million or ppm. Liquid ammonia boils at atmospheric pressure at -33 degree Celsius. Now this particular gas is lighter than air and extremely soluble in water.

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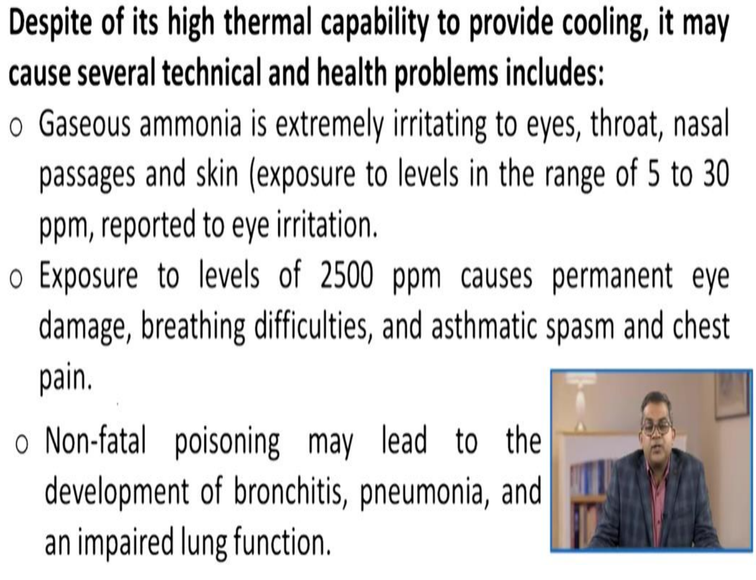

Now despite of it is high thermal capability to provide cooling, it may cause several technical and health issues or problems these may include. The gaseous ammonia is extremely irritating to eyes, throat, nasal passage, skin or exposure to level in the range of say 5 to 30 ppm, this reported to eye irritation. Exposure to the level of 2500 ppm causes the permanent eye damage, breathing problems or difficulties, asthmatic spasm and chest pain.

Non-fatal poisoning may lead to the development of bronchitis, pneumonia, and impaired lung in function.

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- Ammonia is a flammable gas and forms potentially explosive mixtures with air in the range of 16% to 25% ammonia in air.
- Ammonia vapors react with the vapors of acid (e.g., HCl) to produce an irritating white smoke.
- Ammonia and ammonia-contaminated oil must be disposed of in a proper way approved by local regulatory agencies.

Note: Ammonia is an excellent refrigerant and indicated that these possible disadvantages can be eliminated with proper design and control of the refrigeration system.

Ammonia is flammable gas and forms potential explosive mixture with air in the range of 16% to 25% ammonia in air. The ammonia vapours react with the vapours of acid like HCL to produce an irritating white smoke. Ammonia and ammonia-contaminated oil they must be disposed of in a proper way approved by the local regulatory authorities or guidelines by given by the various state boards and central boards.

Although ammonia is an excellent refrigerant and indicated that these possible disadvantages can be eliminated by the proper designing of system and control of refrigeration mechanism.

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Carbon dioxide (R-744)

It is oldest inorganic refrigerants, it is colorless, odorless, nontoxic, non-flammable and non-explosive refrigerant and can be used in cascade refrigeration systems, dry-ice production and food freezing applications.

Carbon dioxide it is the oldest in organic refrigerant, it is colourless, odourless, non-toxic, non-flammable, non-explosive refrigerant and can be used in cascade refrigeration system, dry ice production and food freezing of operation or replication. Air is generally used in aircraft air conditioning and refrigeration system it is coefficient of performance is low because of light weight of the air system. In some of the refrigeration plant it may be used in the quick freezing of food products.

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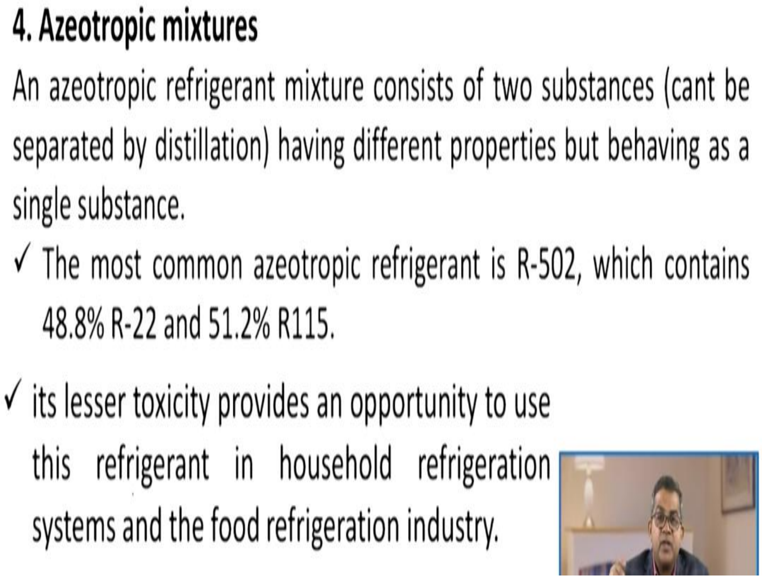

Azeotropic mixtures an azeotropic refrigerant mixture consists of 2 substances and these can be cannot be separated by usual distillation protocol. Now they are having the different properties but behaving as a single substance so that is the quality of azeotropes. The most common azeotropic refrigerant is R-502, which contains 48% of R-2020 true and 51.2% of R-115.

It is lesser toxicity provides an opportunity to use this refrigerant in household refrigeration system and the food refrigeration industry. There are certain non-azeotropic mixtures now, non-azeotropic mixture is a fluid consisting of multiple components of different volatiles, that when used in the refrigeration cycle change composition during the evaporation boiling or condensation. Non-azeotropic mixture became more attractive in research and development on advanced vapour compression heat pump system.

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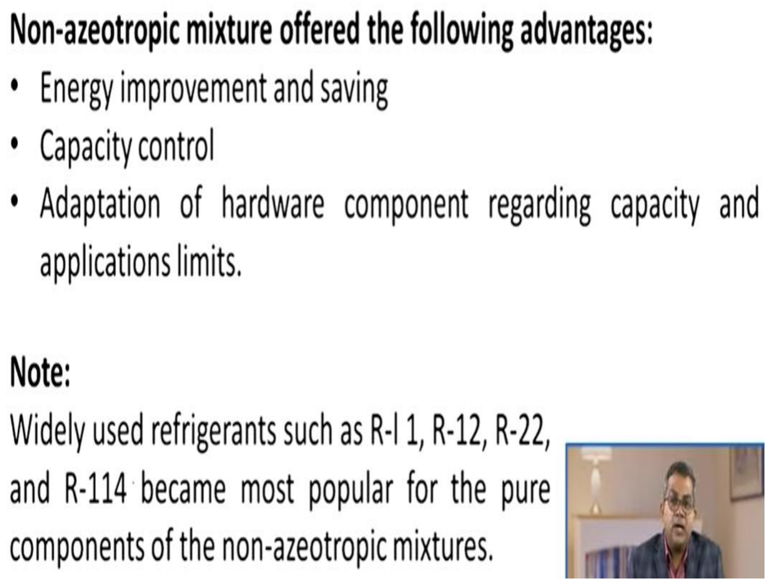

Now there are so many advantages associated with the non-azeotropic mixtures one is that energy improvisation and saving, then the capacity control, then adoption of hardware component regarding capacity and application limits. Now widely used refrigerant such as R-11, R-12, R-22 and R-114 became most popular for the pure component of non-azeotropic mixtures.

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Now there are secondary refrigerants, now secondary refrigerants they play a role in carrying heat from an object or space being cooled to a primary refrigerant or the evaporator of a refrigeration system during this it has no phase change. The most common secondary refrigerant brines, which are water salt that is the sodium chloride and calcium chloride solution, and even today they are still in use in spite of their corrosive effects.

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- The antifreezes, which are solutions of water and ethylene glycol, propylene glycol, or calcium chloride, are widely used as secondary refrigerants.
- Propylene glycol has the unique feature of being safe in contact with food products.
- Dichloromethane (CH_2Cl_2), trichloroethylene (C_2HCl_3), alcohol solutions, and acetone have also been used in some special applications.

The antifreeze, which are the solution of water and ethylene glycol, propylene glycol, or calcium chloride, they are widely used as a secondary refrigerant. Propylene glycol they have the unique feature of being safe in contact with food products. Dichloromethane CH_2Cl_2, trichloroethylene $CHCl_3$, alcohol solution, and acetone they have been used in some special applications.

There are various features attached or attributed while considering as a main criteria in the selection of proper secondary refrigerant. One is that the satisfactory thermal and physical properties, second is the stability because it goes to the various cycles under the stress of pressure and temperature conditions so it must be stable should not be decomposed or over the period of time otherwise it may become a problematic approach.

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The following features are considered as main criteria in the selection of a proper secondary refrigerant;

- Satisfactory thermal and physical properties
- Stability
- Non-corrosiveness and non-toxicity
- Low cost and usability

It must have the non-corrosiveness and non-toxicity, and above all it should be cost effective and it must be it must possess the usability aspect. Now sometimes you see that there is certain prefix and the coding is there while we use any kind of refrigerant.

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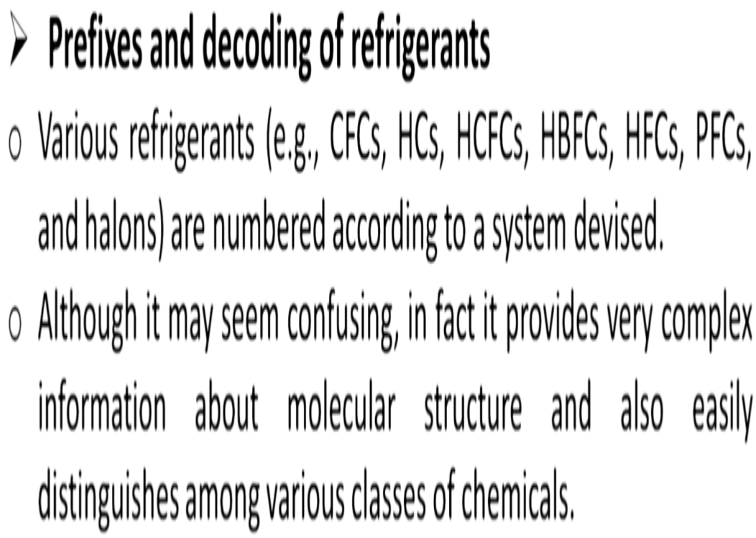

So, prefixes and decoding of refrigerant, the various refrigerants like CFSs, HFs, HCFCs, HBFCs etcetera they are number according to a system devised. Although it may seem confusing, in fact it provides very complex information about the molecular structure and also easily distinguishes among the various classes of chemicals.

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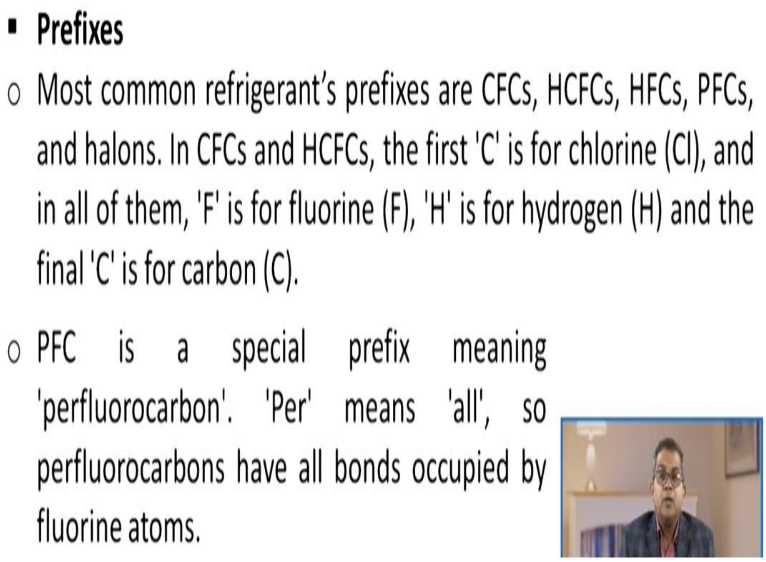

Now prefixes, most common refrigerant prefix are CFCs, HCFCs, HFCs etcetera. In CFCs and HCFCs the first C of the chlorine and in all of them F for fluorine and H for hydrogen and C for the carbon. The PFC is a special prefix meaning perfluorocarbon. Per means all, so perfluorocarbon have all bond occupied by the fluorine atom.

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Prefixes and atoms in refrigerants

Name	Prefix	Atoms contained
Chlorofluorocarbon	CFC	Cl, F, C
Hydrochlorofluorocarbons	HCFC	H, Cl, F, C
Hydrobromofluorocarbon	HBFC	H, Br, F, C
Hydrofluorocarbon	HFC	H, F, C
Hydrocarbon	HC	H, C
Perfluorocarbon	PFC	F, C
Halon	Halon	Br, Cl, H, F, C

Now here you see in this particular table, that the chlorofluorocarbon the prefix is CFC and atoms this contain chlorine, fluorine, and carbon then hydrochloro fluoro carbons HCFC hydrogen, chlorine fluorine and carbon. Similarly, hydrobromofluorocarbon HBFC hydrogen, bromine, fluorine, carbon and hydrofluorocarbon HFC hydrogen, fluorine, chlorine. Hydrocarbon usually HC hydrogen and carbon, perfluorocarbon PFC that is the flow fluorine and carbon, and halon that is represented as halon bromine, chlorine, hydrogen, fluorine, carbon.

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- **Decoding the number**

It helps us to find out the number of each types of atom, and the key to the code is to add 90 to the number; the result shows the number of C, H and F atoms. e.g., For HCFC-141b:

141+90= 2(#C) 3(#H) 1(#H).

✓ All of these chemicals are saturated, so that they contain only single bonds, the number of bonds available in carbon based molecule is 2C+2. thus for HCFC-141b, which has 2 C atoms, there are 6 bonds.

Now decoding the number, it helps us to provide or to find out the number of each type of atom, and the key to the code is to add 90 to the number; the result shows the number of carbon, hydrogen, and chlorine atoms. For example, HCFC that is 141 b, that is 141 + 90 = 2 number of carbon number of hydro 3 numbers of hydrogen and 1 number of hydrogen. Now all of these chemicals are saturated, so that they contain only single bonds.

The number of bonds available in carbon-based molecule is 2 C + 2 thus, for HCFC-141 b, which has 2 carbon atoms, and there are 6 bonds.

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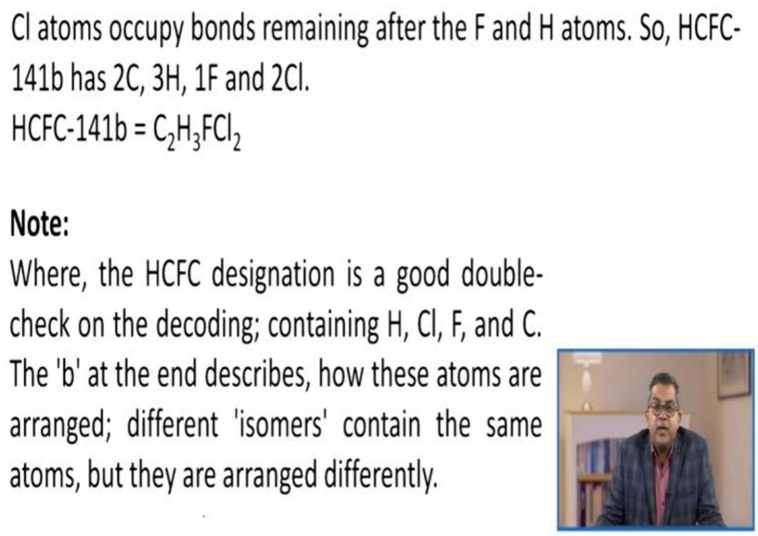

Chlorine atom occupies the bond remaining after the fluorine and hydrogen. So, HCFC-141 b has 2 carbon, 3 hydrogen, 1 fluorine and 2 chlorine, so this represents the $C_2H_3FCl_2$. Now where, the HCFC designation is a good double check on the decoding containing hydrogen chlorine, chlorine, carbon. The b at the end describes, how these atoms are arranged different isomers contains the same atom but they are arranged in a different fashion.

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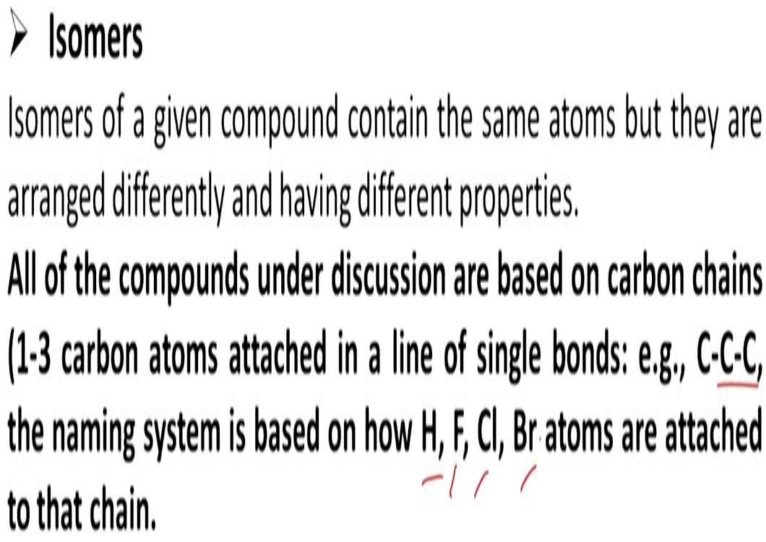

Now isomers, now let us talk about the isomers the isomers of a given compound contain this same atom but they are arranged differently and having the different properties. So, all of the compound under the discussion they are based on the carbon chain 1 to 3 carbon atom attached in a line of a single bond, like C-C-C, the naming system is based at how hydrogen, fluorine, chlorine, bromine atoms are attached to the chain.

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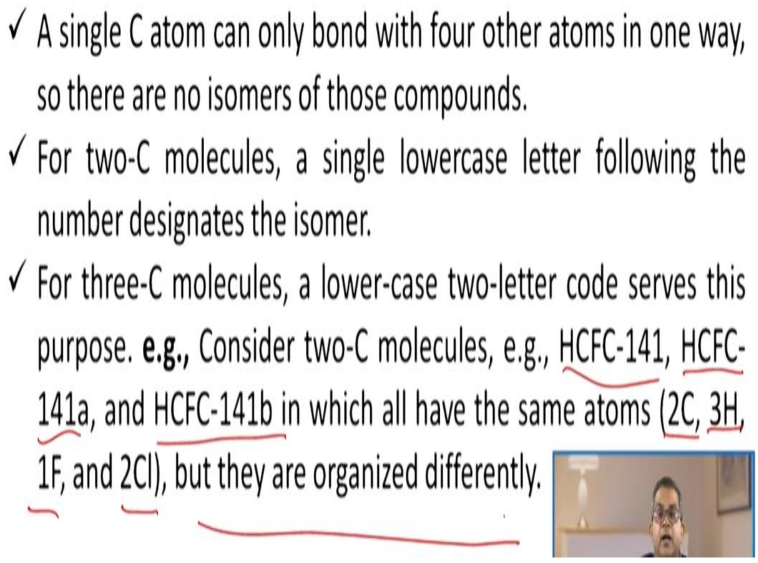

A single carbon atom can only bond with four other atoms in one way, so there are no isomers of those compounds. For 2 carbon molecule a single lower-case letter following the number designates the isomer. For three carbon molecules, a lower case 2 letter code serves this purpose. Now consider 2 C molecules, like HCFC-141 or HCFC-141 a and HCFC-141 b in which all have the same atoms 2 carbon, 3 hydrogen, 1 fluorine, and 2 chlorine, but they are organized differently and that is the beauty of isomers.

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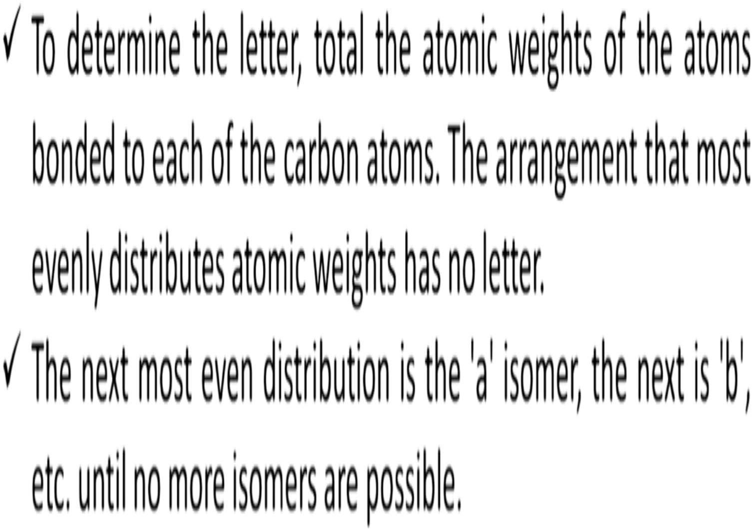

Now to determine the letter, the total the atomic weight of the atom bonded to each of the carbon atom. The arrangement that most evenly distributes at atomic weights has no letter. Now the next most even distribution is a isomer, and next is b, until no more isomers are possible. Common way of writing isomer structure is to group atom according to the carbon atom which they bond.

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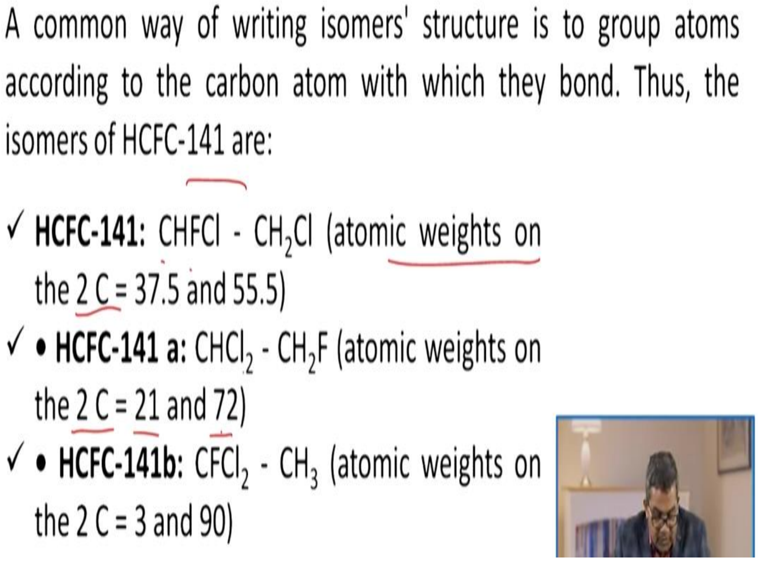

Thus, the isomer of HCFC-141 are like HCFC-141 CHFCL then CH_2Cl atomic weight on the 2 C is 37.5 and 55.5. Similarly, if we talk about the HCFC-141 a so the $CHCl_2$-CH_2F the atomic weight on the 2 C is 21 and 72. And similarly, we can describe this HCFC-141 b that is $CFCl_2CH_2$ and atomic weights on these are 3 and 90.

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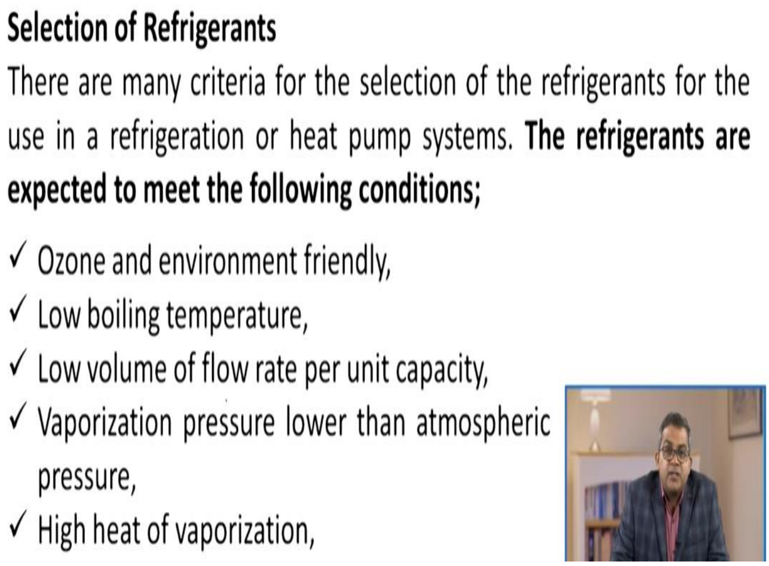

Now the question arises that we are having the enormous choices of refrigerant then what should be the criteria for the selection of proper refrigerant to the system. Now there are many criteria for the selection of the refrigerant for the use in the refrigeration or heat pump system. The refrigerants are expected to meet the different conditions.

Like, they must have ozone and environmental friendly, they must have with a lower boiling temperature, they must have a low volume of flow rate per unit capacity, the vaporization pressure low should be lower than the atmospheric pressure, and they must possess the high heat of vaporization.

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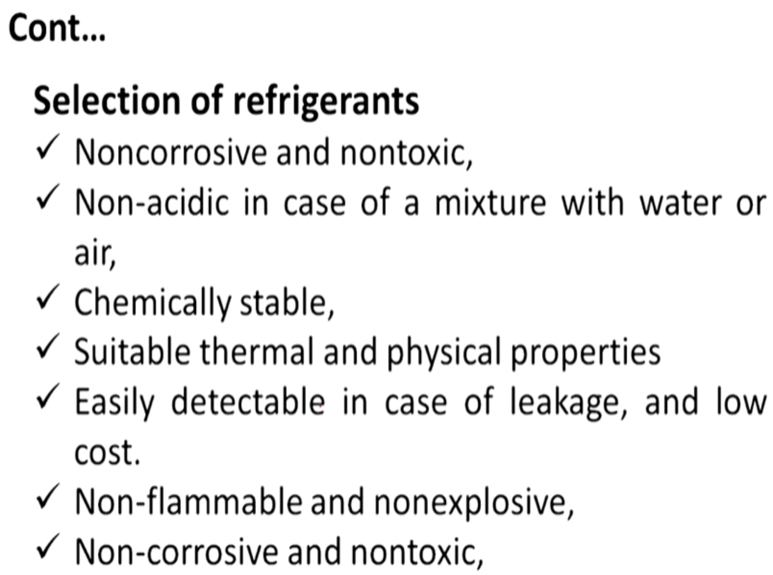

Apart from this, they must have the property of non-corrosiveness and non-toxicity. They must have non-acidic in case of a mixture with water or air because it is very common that they will be in contact with this water and air. Similarly, they must be chemically stable as I told you that they will be under the stress of pressure and temperature so they should not get decomposed.

The suitable thermal and physical properties should be there, and they should be easily detectable in case of any leakage, and they must have a low cost obviously it is desirable. They must have a non-flammable and non-explosiveness, and above all they must have non-corrosiveness and non-toxicity. Now let us talk about because we have discussed the fluid in question for the refrigeration purpose.

Now let us discuss about the refrigeration, because refrigeration is the operation. So the refrigeration is the process of removing the heat from the matter which may be a solid, a liquid, or a gas. Removing heat from the matter cools it or lowers it is temperature and that is quite common phenomena in all kind of chemical engineering operations.

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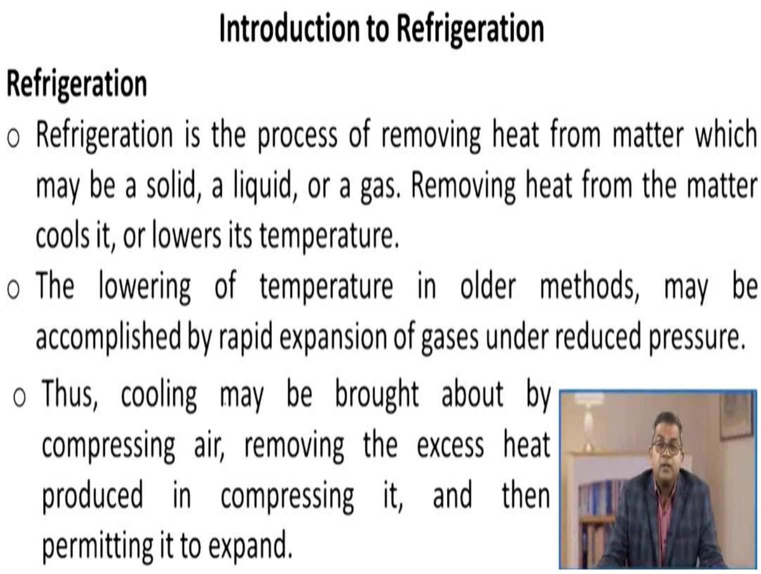

The lowering the temperature in the older methods, may be accomplished by the rapid expansion of the gases under the reduced pressure. Thus, if you see that the cooling may be brought about a compressing air, removing the excess heat producing in compressing it, and then permitted it to expand this is the common refrigeration cycle. Now the lowering the temperature is also produced by adding certain salts, such as sodium nitrate, sodium thiosulfate, sodium sulphide to water. And there are 2 common methods of refrigeration, one is the natural and second one is the mechanical.

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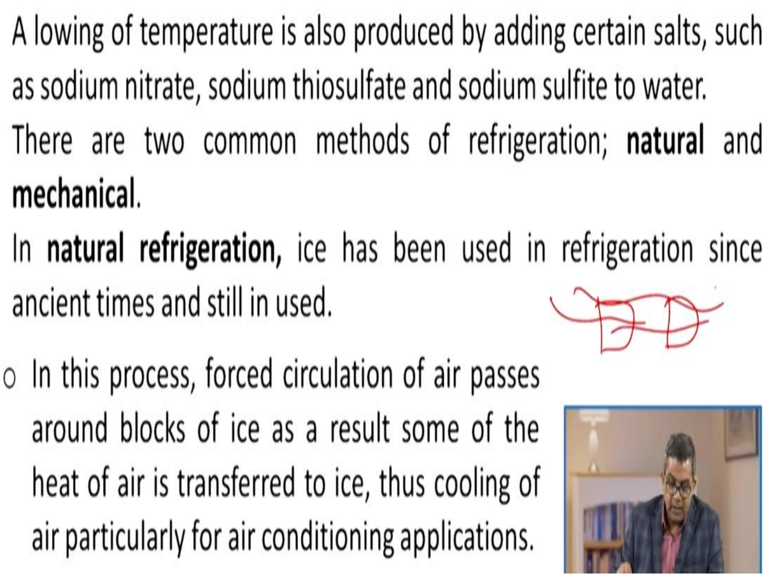

Now in natural refrigeration, ice has been used as refrigeration since initial time and is still it is being used. In this process, forced circulation of air passes around the blocks of ice like this, these are the blocks of ice and force air is passed through there as a result some of the heat of the air is transferred to the ice, thus cooling of the air and particularly for the air conditioning applications.

Now in mechanical refrigeration, a refrigerant is a substance capable of transferring heat and that is that it absorbs at low temperatures and pressure to a condensing medium. Now in this region of transfer, the refrigerant is at higher temperature and pressure.

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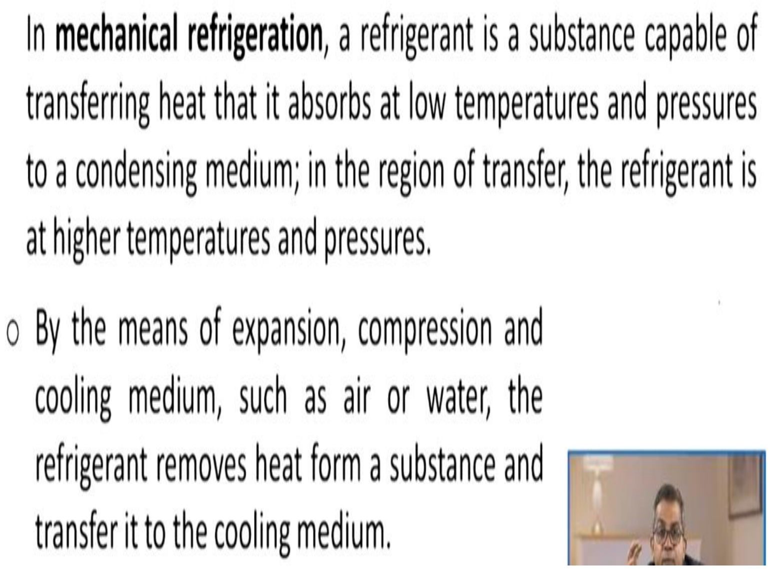

By means of expansion compression and cooling medium, such as air or water the refrigerant removes heat from a substance and transfer it to a cooling medium. Now let us talk about the refrigeration system the main refrigeration system and cycle. The main goal of refrigeration system which performs the reverse effect of heat engine is to remove the heat from a low-level temperature medium that is the heat source.

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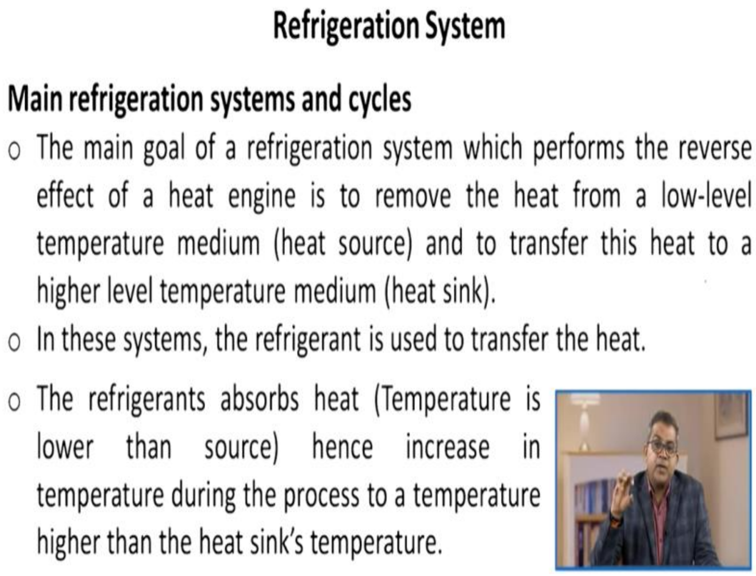

To transfer this heat to a higher-level temperature medium and that is called the heat sink. Now in this system the refrigerant is used to transfer the heat this is quite simple phenomena. This refrigerant absorbs heat and that is temperature is lower than the source hence increasing in temperature during the process to a temperature higher than the heat sinks temperature.

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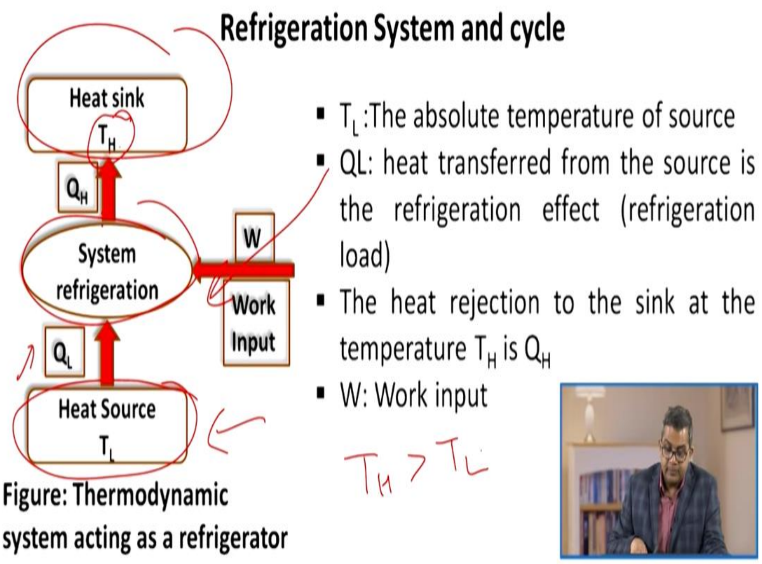

Now here this represents the pictorial diagram now this is the heat sink, this is the system refrigeration, and this is the heat source. Now T_L this is the absolute temperature of the source and which is maintained at the lower temperature, and you need to extract the Q_L amount of heat from this heat source through the system by incorporating the W amount of the work. And you need to discharge this Q_H amount of heat to the heat sinks which is maintained that at T_H now here the T_H is greater than T_L.

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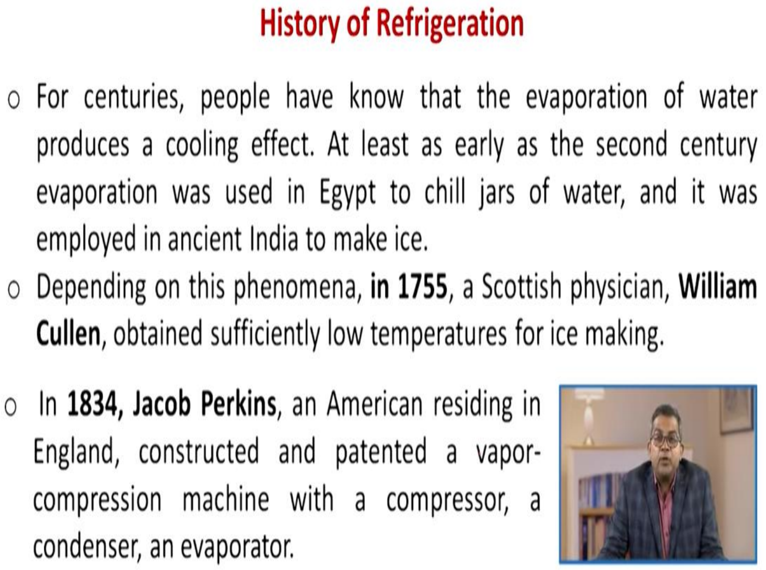

Now for centuries, if because this is very common phenomena and we are following this phenomenon for ages. So, it is good enough to have a brief history discussion about the refrigeration. Now for centuries, people have known that the evaporation of water produces a cooling effect. At least as early as the second century evaporation was used in Egypt to chill the jars of water, and it was employed in ancient India to make a ice.

Now depending on these particular phenomena, in 1755 a Scottish physician, William Cullen, obtained sufficiently low temperature for ice making. In 1834, Jacob Perkins, an American residing in England, constructed and patented a vapor compression machine with the compressor, a condenser, and an evaporator. Now new substance like ammonia and carbon dioxide, which were more suitable than water and ether, were made available by faraday and others and they demonstrated that these substances could be liquefied.

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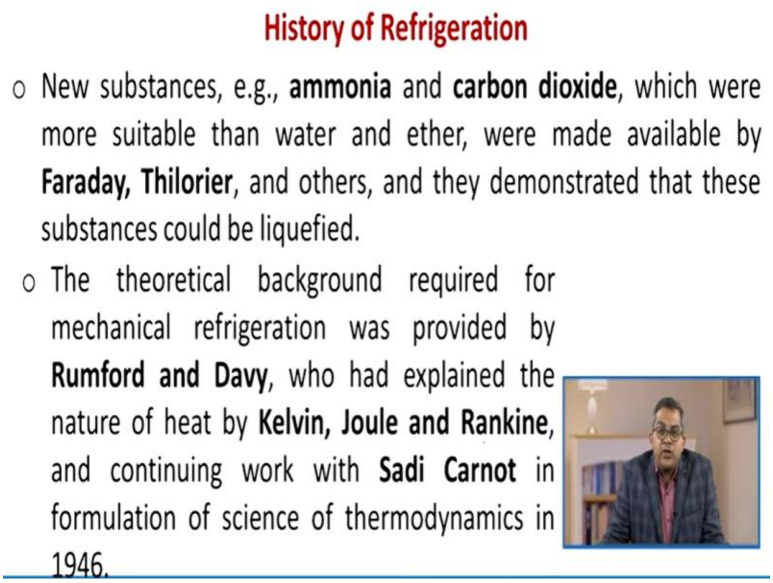

The theoretical background required for the mechanical refrigeration was provided by Rumford and Davy, who had up explained the nature of heat by Kelvin, Joule and Rankine, and continuing work by Sadi Carnot in formulation of science of thermodynamics in 1946.

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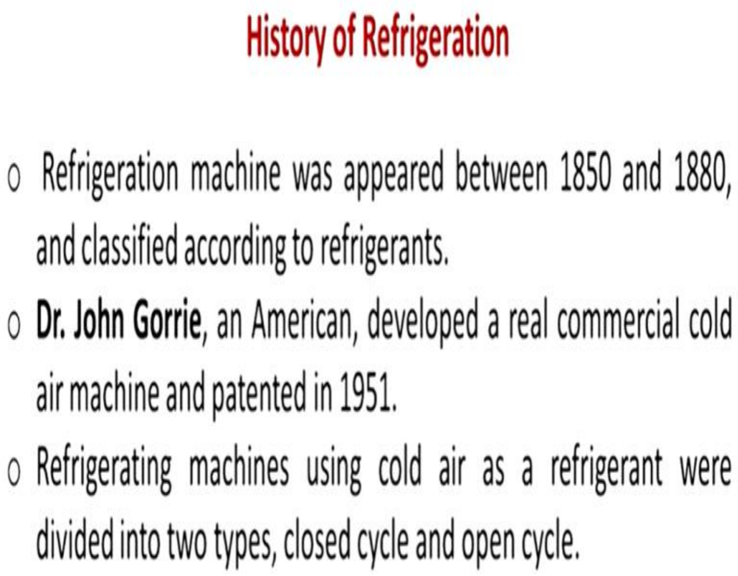

The refrigeration machine was appeared between 1850 and 1880, and classified according to the refrigerants. Dr. John Gorrie, an American, developed a real commercial cold air machine and patented in 1951. And the refrigerating machine using cold air as a refrigerant was divided into 2 types close cycle and open cycle.

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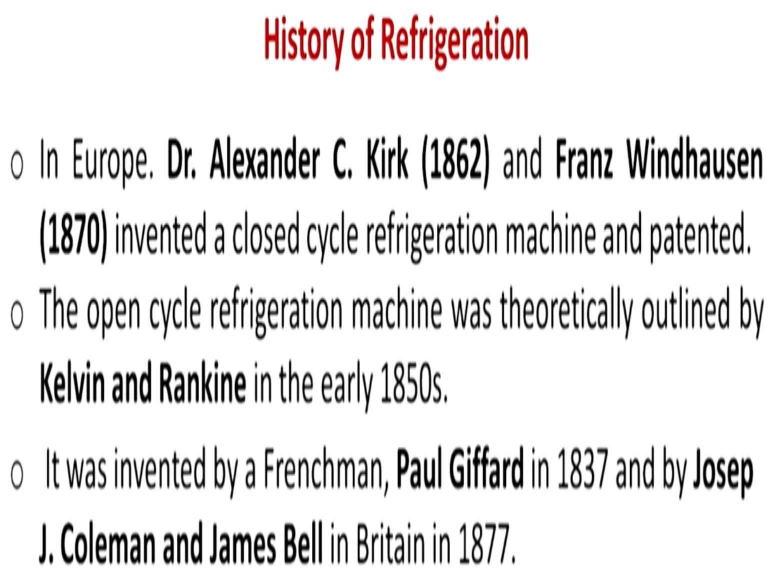

In Europe. Dr. Alexander C. Kirk in 1862 and Franz Windhausen in 1870 they invented a closed cycle refrigeration machine and patented. The open cycle refrigeration machine was theoretically outlined by Kelvin and Rankine in early 1850. And it was invented by Frenchman, Paul Giffard in 1837 and by Josep J. Coleman and James Bell in Britain in 1877.

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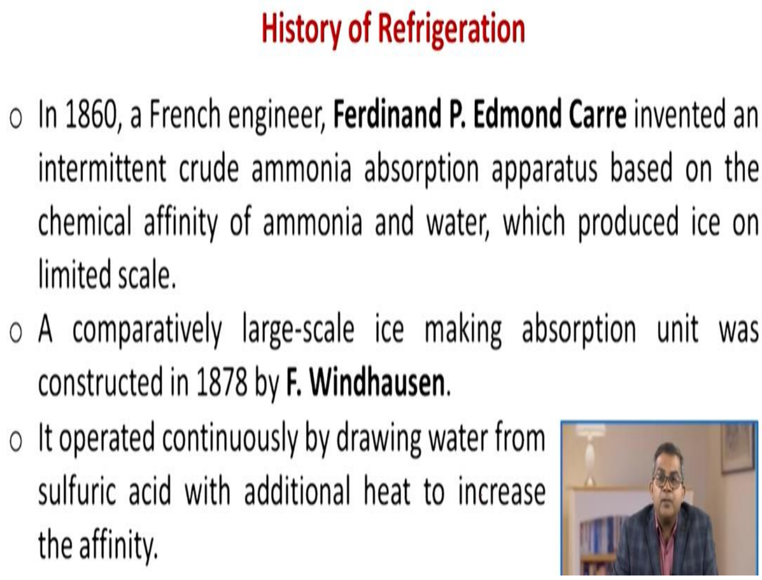

In 1860, a French engineer, Ferdinand P. Edmond Carre invented an intermittent crude ammonia absorption apparatus based on the chemical affinity of ammonia and water, which produced ice on limited scale. A comparatively large-scale ice making absorption unit was constructed in 1878 by F. Windhausen. And it operated continuously by drawing water from sulphuric acid with additional heat to increase the affinity.

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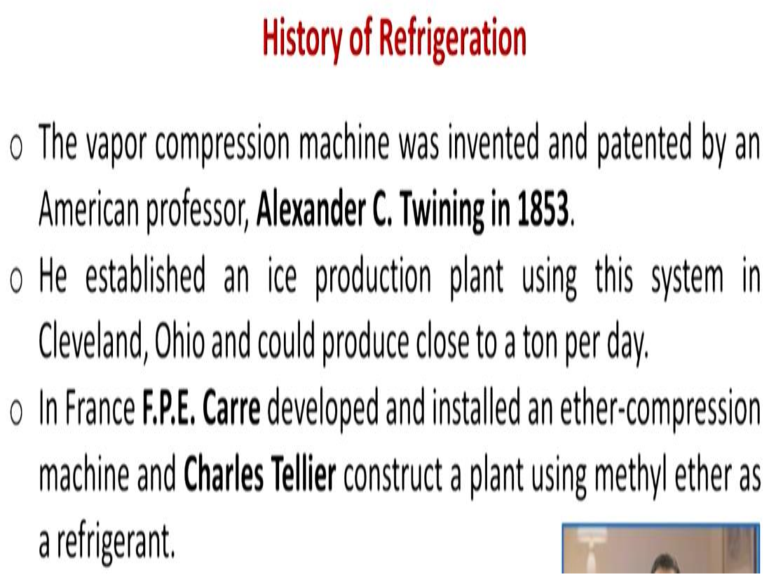

The vapour compression machine was invented and patented by an American professor, Alexander Twinning in 1853. He established an ice protection plant using the system in Cleveland, Ohio and could produce close to a ton per day. In France Carre developed and installed an ether-compression machine and a Charles Tellier construct plant using methyl ether as a refrigerant.

Linde common protocol being used in various kind of vapour compression cycle, he had paved the way of great improvement in refrigeration by demonstrating how its thermodynamic efficiency could be calculated and increase.

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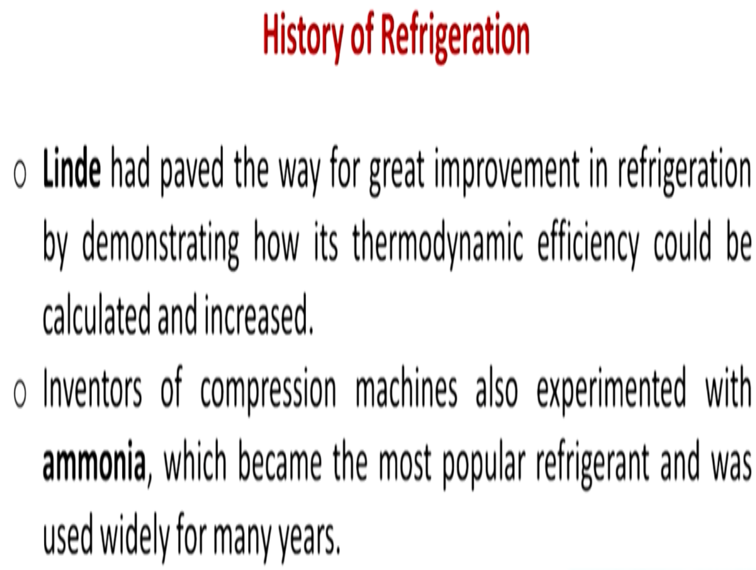

The inventor of compression machine also experimented with ammonia, which became the most popular refrigerant and was used widely for many years. In 1860, the Tellier developed an ammonia-compression machine. The ammonia had thermodynamic advantage, the pressure it required was easy to produce, and machine which used it could be smaller in size.

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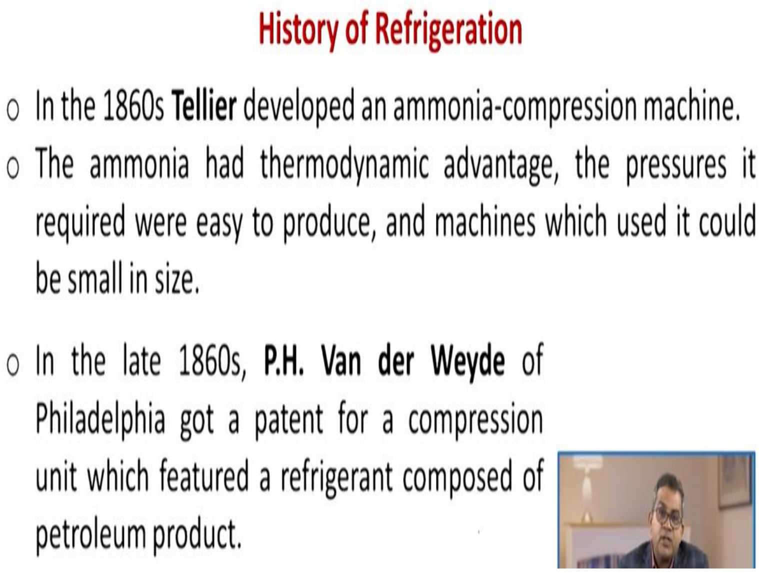

In late 1860, the P.H Van der Weyde of Philadelphia got a patent for a compression unit which featured a refrigerant composed of petroleum product.

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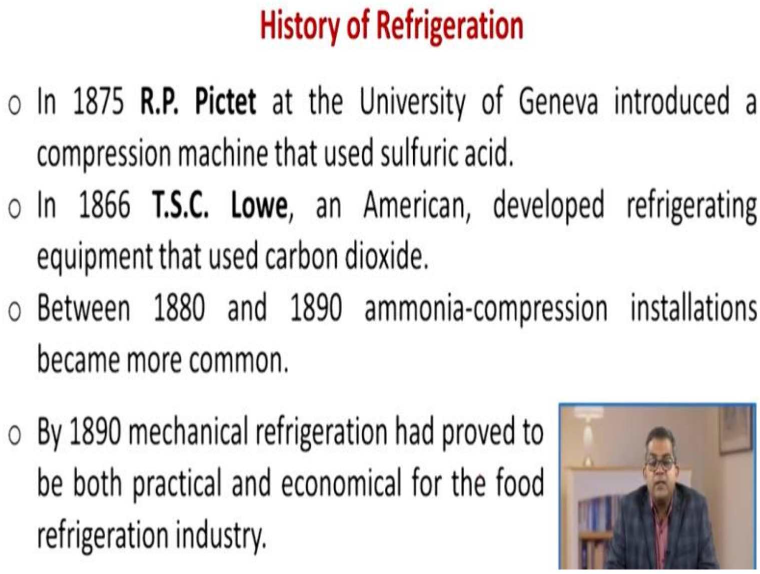

In 1875 R.P Pictet at university of Geneva introduced a compression machine that used a sulphuric acid. In 1866 T.S.C. Lowe, an American, developed refrigerating equipment that use the carbon dioxide. Between 1880 and 1890 ammonia-based compression cycles the installation became more and more common. By 1890 the mechanical refrigeration had proved to be both practical and economical for the food refrigeration industry.

Now study technical progress in the field of mechanical refrigeration they marked effect in 1890. The revolutionary changes were not the rule but many improvements were made in several countries in the design and construction of refrigerating unit as well as in their basic component compressor and condenser evaporators. So, in this particular lecture we discussed about the different kind of refrigerant, classification of those refrigerant. We discussed about the basic theory of refrigeration; we had a discussion about the history of refrigeration.

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References

- Ibrahim Dincer, Refrigeration systems and applications, John Wiley & Sons, Ltd.,(2003), ISBN 0-471-62351-2.

And if you wish to have a further reading then you can have a look of this particular reference, thank you very much.