Refrigeration and Air Conditioning
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Lecture No. # 02
Refrigerant Compressors and Development

Welcome to the second lesson on refrigeration and air conditioning. In the first lesson we have presented the brief historical aspects of various refrigeration systems.

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In the present lesson I will present some historical aspects of refrigerant and compressor development.

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The specific objectives of this lesson are to outline refrigerant development and various issues related to refrigerant selection and development of different types of compressors. Here the focus is mainly on vapour compression refrigeration system which is the most popular among all the refrigerant systems.

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And at the end of the lesson the student should be able to list various refrigerants used before CFCs and their limitations, list various CFCs and their impact on refrigeration and environment, list refrigerants in use after Montreal protocol and list various types of compressors and their development.

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Refrigerant, first of all let me define refrigerant. Refrigerant is defined as anybody or substance that acts as a cooling medium by extracting heat from another body or substance. This is a general definition of refrigerant and under this broad definition many substances can be called as refrigerants. For example, if you are using the block of ice for cooling then the ice can be called as a refrigerant. But since we are interested mainly in closed refrigeration cycles for as refrigerant means a working fluid that undergoes cyclic changes during the operation of the refrigeration system. So basically we are dealing with working fluids which undergoes cyclic changes.

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Now let us look at importance of refrigerant selection. In the design of any refrigerant system, selection of suitable refrigerant is a very important step and it is in fact the first step in the design of any refrigerant system even though the theoretical efficiency of a vapour compression refrigerant system depends mainly on the operating temperatures. The selection of a refrigerant decides many other practical issues. For example the type of the refrigerant used decides the system design aspects, size and weight of the system, initial and operating costs safety issues, service ability and reliability. So you can see that so many practical issues are related to the selection of refrigerant. That is the reason why suitable refrigerant selection is very important.

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Now let us look at refrigerant development. The development can be divided into three distinct phases. The first phase is the development of early refrigerants which is prior to CFCs. And the second phase consists of development of chlorofluorocarbon or CFC based refrigerants and the third phase is refrigerant after Montreal Protocol.

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Let us look at early refrigerants. As I mentioned in the last class Ethyl ether is the first refrigerant to be used by Jakob Perkins and others in their early refrigeration machines. Ethyl ether was used not because it is an ideal refrigerant. But because it exists as a liquid at ambulant conditions. So it is easier to handle and that is the reason why it was used as a refrigerant. But if you remember I have mentioned that Ethyl ether has several problems. For example if you want to have low temperatures then your system will be operating under vacuum. And operational vacuum can need to leakage air into the system which may form explosive mixtures with ether. So that is one of the main disadvantages of ether. In addition to that ether is also toxic. So as a result people have tried to develop new refrigerants which do not have these short comings. So Alexander Twining has proposed the use of ammonia and carbon dioxide as refrigerants in eighteen fifty. And ammonia is one of the most important refrigerants because of its excellent thermodynamic properties and its low cost and also it is easily available.

Next Charles Tellier has tried dimethyl ether in eighteen sixty-four. Dimethyl ether has low normal boiling point however it is also toxic as a result that was also not used for a long time.

Next Raoul Pictet has suggested the use of Sulphur dioxide in fact he has built several systems using Sulphur dioxide. Sulphur dioxide is not an inflammable substance in fact it is a flame retardant. In addition to that it also has the advantage that it acts an auto lubricant. So when you are using sulphur dioxide in a compression system you do not need any external lubricant. However the problem with Sulphur dioxide is that, if you, in the presence of water it forms Sulphuric acid and Sulphuric acid is highly corrosive so it can damage the materials of construction.

So even though Sulphur dioxide was used widely for about sixty years later it was replaced by other refrigerants. Then Linde has built ammonia systems in eighteen seventy-seven. As I said this is one of the most important land marks in the history of refrigeration. And Windhausen has used carbon dioxide in eighteen eighty-five. Carbon dioxide since it is a non toxic and non flammable and it is a safe refrigerant. So it was very widely used in marine air conditioning and refrigeration applications. But one problem with carbon dioxide is that it has low critical temperature and also its operating pressures are very high. As a result carbon dioxide was used for about sixty years and later it was phased out. But again of late there is an increase in use of carbon dioxide because of its other excellent properties. Hydrocarbons and their mixtures were also tried in domestic refrigerators and other systems. So these are the earlier refrigerants which were used before the invention of the artificial or synthetic refrigerants.

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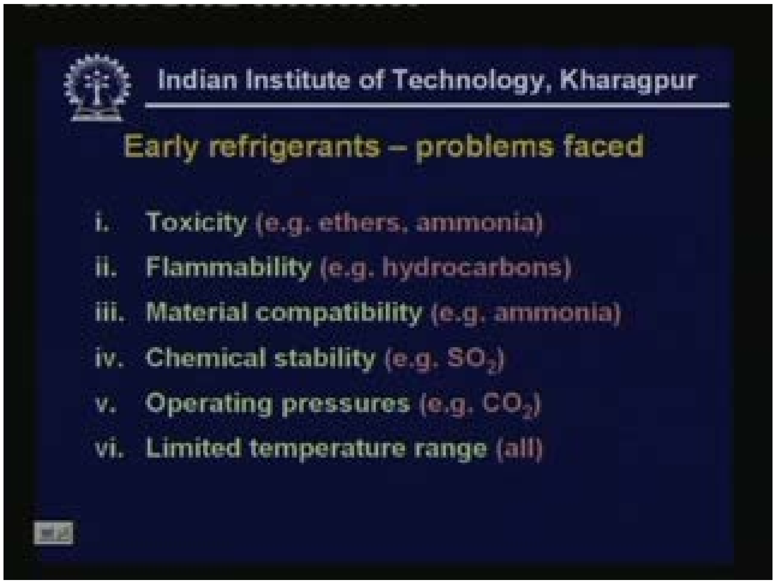

As I mentioned just now all these earlier refrigerants phased from one problem or other. Let us look at these problems, they are, some of them are toxic for example ether and ammonia are toxic. They had the problems of flammability particularly with hydrocarbons are highly flammable so this is one of the problems and material compatibility ammonia is not compatible with copper brass etcetera. So you cannot use these materials when you have ammonia in the system. Then chemical stability as I mentioned just now, for example refrigerants like Sulphur dioxide react with water and form Sulphuric acid. So it is, Sulphur dioxide is not chemically very stable. And then operating pressures this is one typical problem with carbon dioxide its operating pressures are at least one order of magnitude higher than other refrigerants. That means your system pressures will be very high. So you have to design the system to withstand for high pressures. So this is one disadvantage of carbon dioxide.

Then limited temperature range almost all the refrigerants had particular temperature range. Within which they were working and outside the temperature range they were not good. So these are the typical problems of all the earlier refrigerants. As a result refrigeration industry felt that to make progress they needed to develop refrigerants that were safe that were non toxic non flammable etcetera. And they felt that because of the safety issues the growth of refrigeration industry is not as much as it should be.

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So these led to the invention of CFCs.

Thomas Midgley is junior and his associates working at Frigidaire laboratories have been asked to develop new shape working fluid to be used as refrigerants in refrigeration system. Thomas Midgley is already famous for his invention of Tetraethyl lead which was an important antiknock agent. So he has been asked to develop safe refrigerants. So what he has done he is, he has carried out a systematic study of the periodic table and he started eliminating the elements which were found to be not volatile and which were found to be toxic, which were found to be flammable, which were found to be inert. So by these processes of elimination he has finally left with eight elements.

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So I will show you the eight elements on the periodic table.

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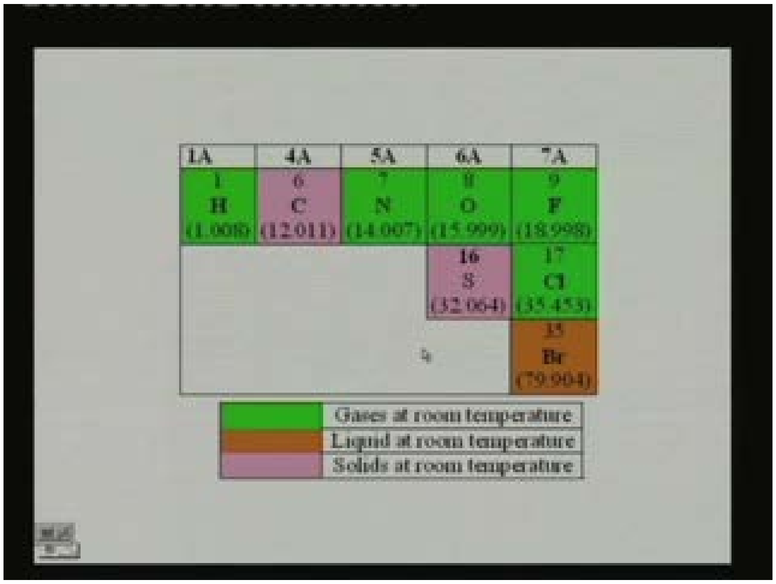

So you can see the eight elements which were left out after the elimination process and I have shown here their atomic number atomic weight and the group to which they belong. So you can see here the eight elements are hydrogen carbon, nitrogen, oxygen, fluorine, sulphur, chlorine and bromine. And the colours indicate their condition at room temperature. For example the green colour means that these elements are gases exists as gases on room temperature and the red colour shows that the element bromine for example is a liquid at room temperature and the pink colour for example carbon and sulphur they are solids at room temperatures.

So after this systematic elimination and systematic study of periodic table they have arrived at three important conclusions. The first conclusion is that the flammability reduces flame left to right that means hydrogen is highly flammable and as you move from the left to right of these eight elements the flammability reduces. This is the one important conclusion. And second conclusion is that toxicity reduces as you go from the bottom to top. That means bromine is highly toxic and other toxicity reduces as you move up. And third conclusion is that all the refrigerants that for available at that time are made out of a few elements of these eight elements. That means if you want to make some refrigerant you have to choose some elements among these eight only. These are the main conclusions arrived at by Thomas Midgley and his associates.

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Then what they have done is after this elimination process and all they have started developing a series of refrigerants by partial replacement of hydrogen atoms in hydrocarbons. This is how the CFCs were invented.

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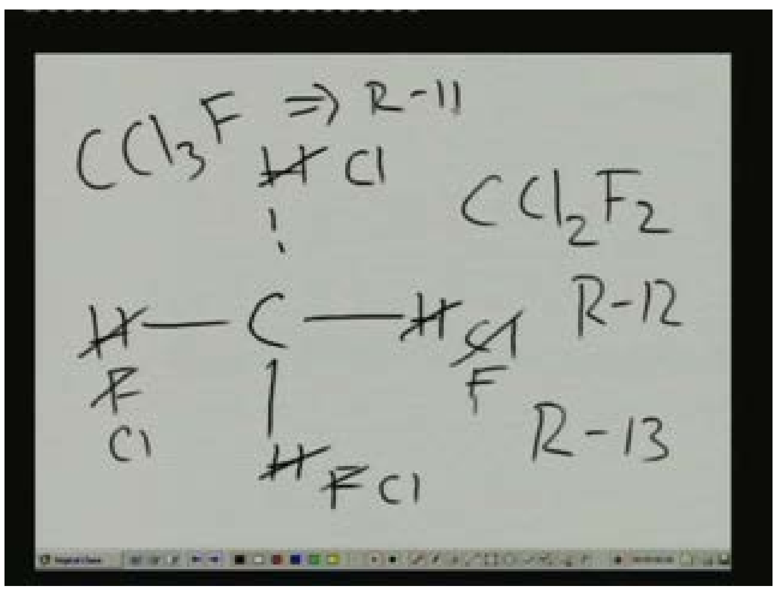

For example let me show the, this is your typical, you have methane atom okay. So if you replace this hydrogen atoms let us say by chlorine and fluorine I am replacing these hydrogen atoms by two chlorine atoms and two fluorine atoms. So what we get here is CCl two F two. So this is one important refrigerant and it is known as by its number R twelve.

So if you replace, for example instead of two chlorine atoms, for example I am replacing these chlorine atom with another fluorine atom. So I get what is known as R thirteen. So this is another important refrigerant. For example again one more, two more fluorine atoms are replaced by chlorine atoms. Let us say, that means we have CCl three F so this refrigerant is known as R eleven.

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So by early replacing hydrogen atoms with either chlorine or fluorine you get a series of different working fluids. And they have shown that, by this process you can evolve a large number of refrigerants whose properties are dramatically different from each other. And they have shown how properties like toxicity, flammability, normal boiling point etcetera can be controlled or can be varied by varying the chemical composition.

So this is the basic behind the development of several CFCs. And out of this development came the first refrigerant known as Freon twelve or CCl two F two. This is introduced in nineteen thirty-one. And the Freon is the trade name of all the refrigerants manufactured by DuPont company of USA. And as I said, Freon twelve is the first refrigerant, first CFC refrigerant to be introduced into the market and it is one of the most important refrigerants and it was widely used in domestic refrigerators and in small air conditioning systems etcetera.

Next refrigerant to come out of this is what is known as Freon eleven say its chemical composition is CCl three F. And its normally used for air conditioning in large plants. And it is also used as a foam blowing agent in insulations.

And the next important refrigerant is, what is known as Freon twenty-two. Its chemical formalized CHClF two. And it is very widely used as a refrigerant in air conditioning systems. And after this a host of refrigerants have followed by the modification of hydrocarbons.

Here all these three Freons like R eleven R twelve and R twenty-two they are derived from methane. Of course we can also have other refrigerants which are derived from say, ethane. So one can have a large number of refrigerants basically derived from the saturated hydrocarbons.

Since so many introduce refrigerant refrigerants were introduced, numbering system was introduced to identify the refrigerants from its number. So that is the reason why, for example, Freon twelve is called as R twelve. And the number one two has significance. And if you follow the numbering system you can tell what is the chemical composition by just looking at the number.So these issues I will discuss when we discuss refrigerants in a later lesson.

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Now let us look at how CFCs compared with the early refrigerants. Compared to the early refrigerants CFCs are non toxic, they are non flammable, they are chemically stable, they are compatible with common materials, they are available for a wide refrigeration temperature range.

So you can see that almost all the perceived problems of the early refrigerants were in fact eliminated by the invention of or by these new working fluidsIn fact the non toxicity and non flammability of these refrigerants used to be demonstrated by Thomas Midgley. What he is to do is, he use to take a mouth to fill up the refrigerant and he use to blow it over a burning candle and the flame is used to get extinguished. That is how he use to say that it is non toxic. Because even after inhaling there is no problem. And its non flammable because the flame use to get extinguished. So soon this refrigerant have become very popular and they have been used very widely because of all these favorable properties.

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Now let us look at the impact of CFCs. First impact is that all early refrigerants except ammonia are replaced by various CFCs. Ammonia could not be replaced because of its excellent properties. Then there is a rapid growth in refrigeration due to the safe nature of these refrigerants. And refrigeration I have entered households mainly due to the invention of CFCs. And household items like refrigerators, air conditioners have become very popular all over the world. And as a result of these the production and consumption of CFCs has increased exponentially. So you see suddenly lot of manufacturing plants coming up manufacturing CFCs. And as I was mentioning every company use to have own trade name. For example the DuPont Company used to call their refrigerants under the name Freons and general electric company use to call them as Genetrons. So as a result of all these favorable properties refrigerant based on

CFCs have been used very widely for almost fifty years and everybody felt that they have finally got a safe refrigerant.

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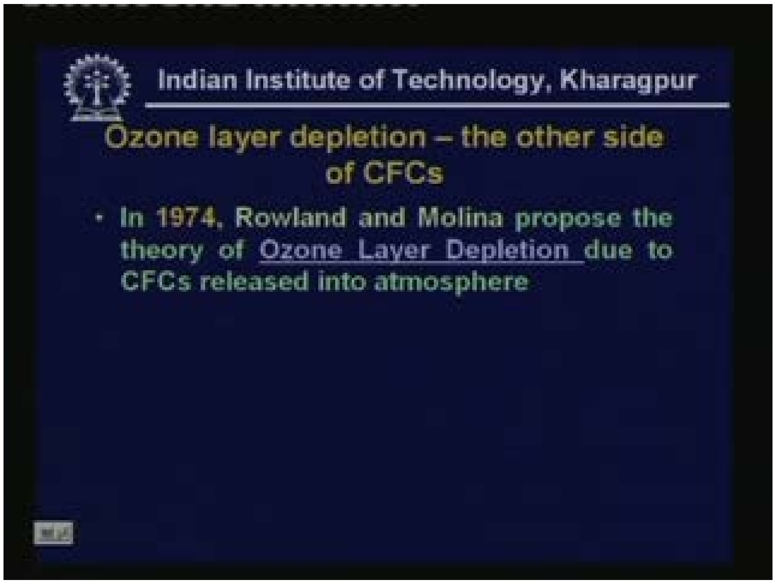

But suddenly something has happened. And in nineteen seventy-four two scientists Rowland and Molina have proposed a theory of Ozone Layer Depletion. Their theory says that the CFCs if they are released into the atmosphere will lead to the depletion of ozone layer. So let us look at what is this ozone layer and how the CFCs is lead to ozone layer depletion.

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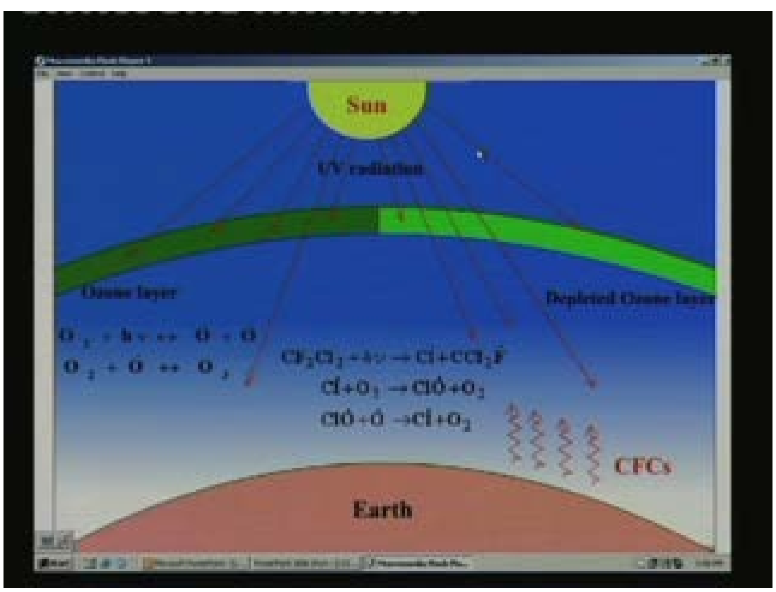

So earth is surrounded by a stratosphere which extends from fifteen kilo meters to fifty kilo meters above its surface. And this stratosphere has a layer of ozone. So how this ozone is formed. Let us look at the equations here.

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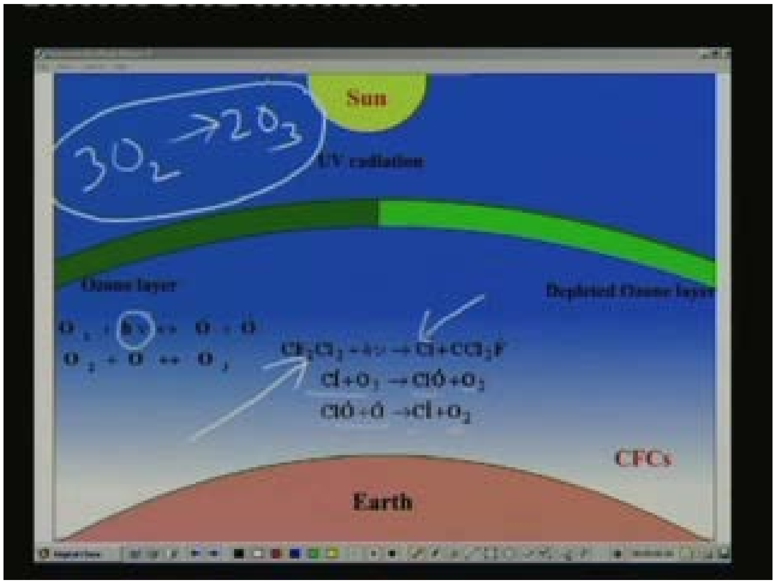

Oxygen in the ozone layer reacts with under the action of, you have the ultra violet rays, as you know sun emits a wide variety of radiation and ultra violet {radi} rays or one among them and under the action of ultra violet rays oxygen molecule splits into two radicals of oxygen. This one radical of oxygen reacts with one molecule of oxygen forming one molecule of ozone. So as a result ultimately what we have is three molecules of oxygen react reversibly to form two molecules of ozone.

So as a result of this you have a presence of ozone in the stratosphere. This ozone layer is very important for survival of life on earth. Because as I mentioned sun emits ultra violet radiation and ultra violet radiation is harmful to life. We will see what the harmful effect of this ultra violet radiation is. And thanks with the presence of ozone layer. We really do not get much of the ultra violet radiation and that is how life has evolved. That is what scientist say that life has evolved only after the ozone layer has formed on the in the stratosphere. Now let us see what is the effect of chlorofluorocarbons as I mentioned one of the favorable properties are perceived favorable properties of chlorofluorocarbon is the high chemical stability.

So when these chlorofluorocarbons are released into atmosphere. For example due to leakages or when you are servicing the systems, then they stay in the atmosphere for a long time. That means they do not break down or they do not dissociate into atoms. So chlorofluorocarbon molecules stays as the chlorofluorocarbon only and over a long period of time due to concentration difference the chlorofluorocarbon molecule slowly migrates to the stratosphere.

Once it goes to the stratosphere there it encounters ultra violet radiation. So when it comes into the presence of ultra violet radiation dissociation of chlorofluorocarbon takes place because UV radiation has high energy. So because of this you can see here that, for example one R twelve molecule under the action of ultra violet rays releases one chlorine radical. And this chlorine radical reacts with ozone and forming a chlorine monoxide C l O and one molecule of oxygen and again this chlorine monoxide react with one oxygen radical forming one molecule of oxygen and one radical of chlorine.

So what has happened in this process is one mole of chlorofluorocarbon has released has destroyed one mole of ozone. And it has formed oxygen and again it is free to react with other moles of ozone and dissociate other moles of ozone. That means a single molecule of chlorofluorocarbon is capable of dissociating several thousands of ozone molecules. As a result of which this balanced chemical reaction or this chemical reaction which is under dynamic equilibrium and which was responsible for the presence of ozone gets disturbed. That means the chlorine atom favors the reverse reaction. And there is more of oxygen and less of chlorine. As a result of which ozone holes are formed in the stratosphere. And when you have ozone holes then you can see that they allow the UV radiation to enter through the stratosphere and finally the UV radiation reaches the surface of the earth. So this is the theory proposed by Rowland and Molina initially it started as a theory. So now that is what is shown here.

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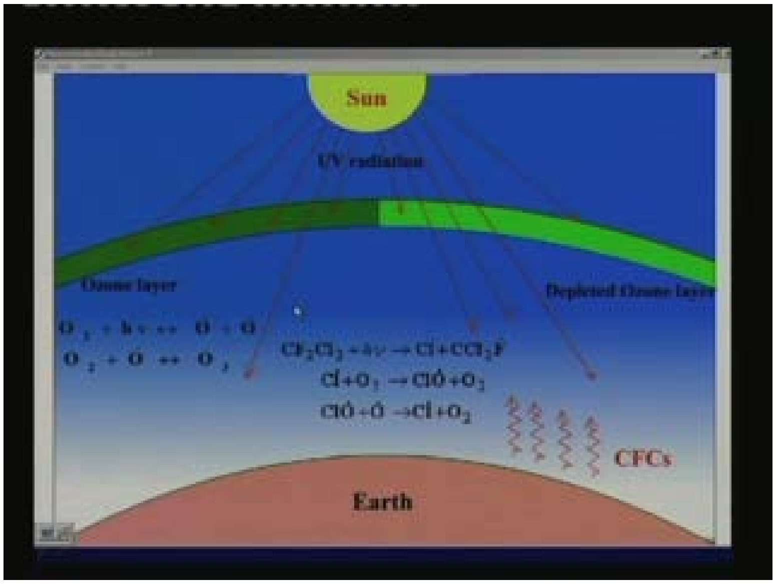

The CFCs are released from the earth and they slowly migrate to the stratosphere. Where they dissociate the ozone molecule. And as a result in the side, the greenish side where depleted ozone layer is there more amount of UV radiation passes through and reaches the earth. Whereas, where you do not have any hole less amount of UV radiation comes to the earth. So this is the principle of ozone layer depletion and subsequently experimental studies have been carried out.

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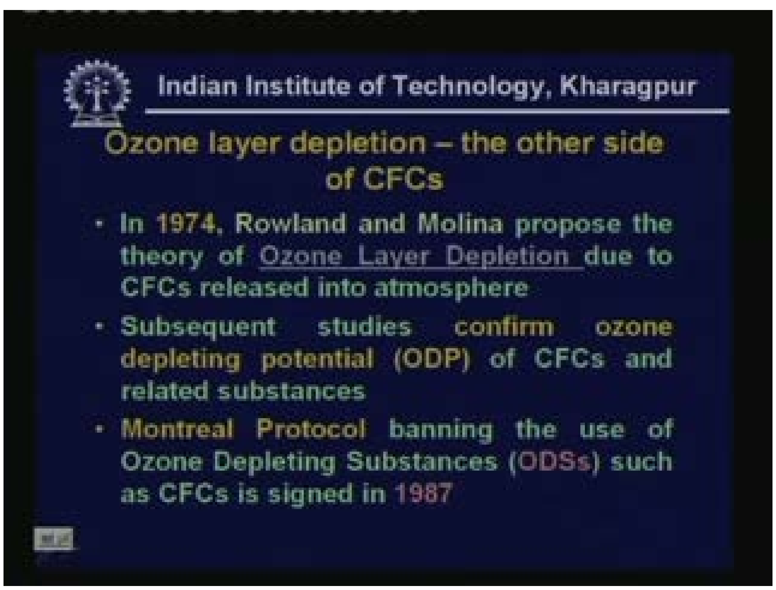

And they have found that the theory proposed by Rowland and Molina is actually true and they have discovered large ozone holes and Antarctica. For example, and it is found that not all chlorofluorocarbons are equally capable of destroying the ozone layer. So based on this observation they started rating the chlorofluorocarbons based on what is known as ozone depletion potential or ODP. ODP stands for ozone depleting potential. And for this they have taken R eleven or CFC eleven as the basis. And CFC eleven has been assigned an ODP of one and all other refrigerants have been rated against this reference of CFC eleven.

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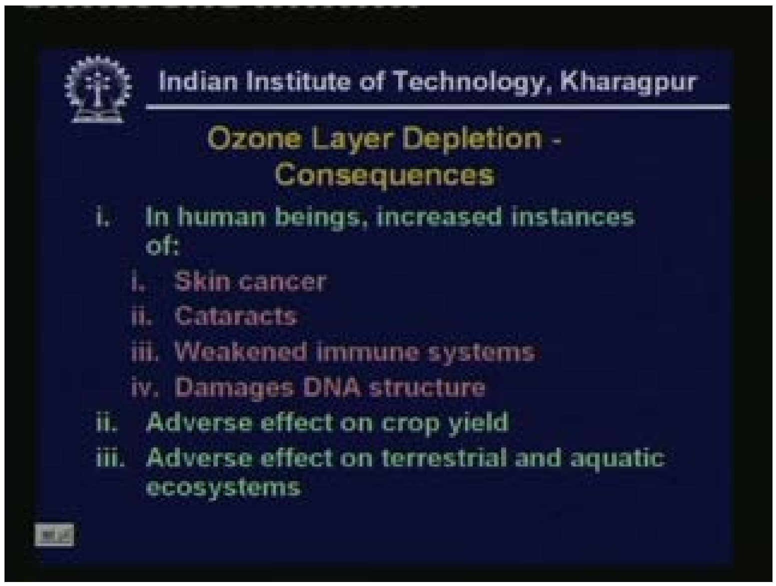

Now let us look at the consequence of Ozone layer depletion. What happens, because of ozone layer depletion it is observed that, if ozone layer depletes and ultra violet radiation reaches earth it leads to skin cancer cataracts and weakened immune system. And it also destroys DNA structure. All these problems will take place in human beings and it is also observed that, this will also have adverse effect on crop yield and it will also have adverse effect on terrestrial and aquatic ecosystems. So people have suddenly realized that this ozone layer depletion is a global problem and it is a very serious problem.

So since it is so serious in nineteen eighty-seven several industrialized nations have met in Montreal and they have proposed protocol under which they proposed the banning of all the ozone depleting CFCs in a phase wise manner. Initially only the industrialized nations have joined this protocol. But subsequently almost all the countries of the world have ratified this protocol. As a result of this Montreal protocol it has been agreed to ban completely the use of all chlorofluorocarbon based refrigerants. And since you are manning the new require a safe refrigerant. So again search for safe refrigerant has started all over. In addition to the ozone layer depletion problem there is also another environmental problem which is also related to the presence of CFCs in the atmosphere.

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This problem is known as Global Warming or green house effect. Let us look at the global warming and let me explain the principle or concept of global warming.

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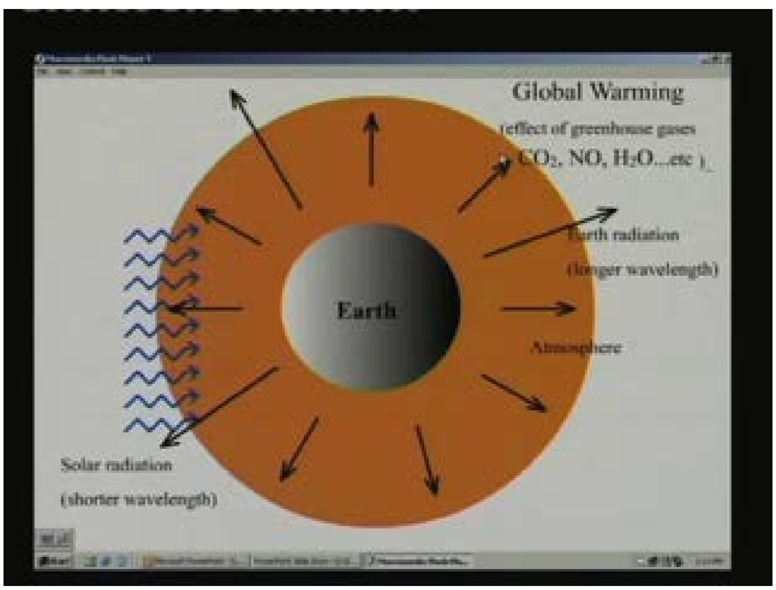

As you know earth is surrounded by an atmosphere. And this atmosphere consists of several gases such as carbon dioxide nitrogen oxygen water vapour etcetera. And some of these gases such as carbon dioxide nitrous oxide then oxides of nitrogen and water vapour act as green house gases.

What is the meaning of green house gases? As you know solar radiation mainly consists of short wave radiation. And this atmosphere consisted consisting of all these gases allows a short wave radiation to pass through and reach the earth. So short wave radiation from earth passes through the atmosphere and reaches the surface of the earth. And the earth surface absorbs this radiation and its temperature increases and the earth in return emit long wave radiation. So sun emits short wave radiation and the earth emits long wave radiation and it is this green house gas they allow short wave radiation to enter the atmosphere. But they absorb the long wave radiation and that is how they trap the long wave radiation.

As a result of which there is trapping of heat within the atmosphere. And the equilibrium is achieved at a higher temperature. That means because of the presence of these green house gases a warm blanket develops around the earth. And this warm blanket is very essential for life on earth and it is theoretical calculation show that, if in the absence of this warm blanket or in the absence of these green house gases the earth's temperature will be about minus eighteen degree centigrade and no living being can survive at this kind of temperatures.

So for us this global warming is very much essential. But unfortunately the ecosystems have developed in such a manner that they are very sensitive to the temperature of the atmosphere and this temperature in the absence of any other artificial additives is just right for our survival. But because of the presence of large scale presence of CFCs this green house effect or global warming effect is getting disturbed okay. How this happens is the chlorofluorocarbon as I mentioned during their leakage or servicing etcetera are released in the atmosphere. And it is observed that they are capable of absorbing much more amount of long wave radiation compared to the conventional green house gases such as carbon dioxide.

Now to denote the potential of these gases for absorbing long wave radiation carbon dioxide is taken as the reference. And carbon dioxide has been given a global warming potential of one, on this scale it is observed that CFCs have global warming potential of several thousand. That means one molecule of CFC is equivalent to several thousand molecules of carbon dioxide. So you see that, when you release lot of CFCs into atmosphere it is equivalent to releasing a large amount of carbon dioxide into the atmosphere. So this will obviously disturb the green house effect and as a result of which more long wave radiation gets trapped in the atmosphere leading to higher global temperatures and as i mentioned our ecosystems are very sensitive to temperatures and even a temperature variation of say one degree can lead to several catastrophic changes.

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So let us see what these problems are. These are, as I mentioned CFCs have global warming potentials which are several thousand times greater than carbon dioxide. And there is another small issue refrigerants contribute to global warming potential in two manners. One is in a direct manner that means, when you release chlorofluorocarbon into atmosphere they directly start absorbing the long wave radiation and that is how they contribute to global warming potential in a direct manner. However they also have an indirect effect that means all these refrigeration system using the refrigerants consume energy and in vapour compression refrigerants system you have to give electrical or mechanical energy as the input and now to produce this mechanical or electrical energy one has to burn. For example fossil fuels, that means electrical energy requires burning of fossil fuels and the burning of fossil fuels leads to release of carbon dioxide into the atmosphere.

So these are the direct and indirect effects of chlorofluorocarbon. And the direct effect depends upon the leakage. They were rated which you are releasing the CFCs into the atmosphere. And the indirect effect depends upon the efficiency of the system. For example if there are two systems and one system consumes less energy. And the other system consumes more energy. The system consuming less energy releases fewer amounts of carbon dioxide into atmosphere. And the system consuming more energy releases more amount of carbon dioxide into the atmosphere. So you can see that the efficiency comes into picture. And ultimately the contribution to global warming increases with the inefficiency of the system. So these are the two effects and another index called total equivalent warming index are {tewi} t e w i has been formulated to account for both the direct and indirect effects of global warming.

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Now let us look at the effects of global warming on our ecosystem. It is observed that
if due to global warming, if the temperature changes, there will be unpredictable changes in weather and wind flow patterns. And this will also give rise to increase sea levels. Because the higher temperatures will lead to more melting of polar ice caps. As a result the sea levels will increase. And as you know once sea levels increase there is every possibility that many of the low land countries may get submerged. So this is a very serious problem. And the third effect is that due to the varying temperatures or due to the increasing temperature there will be a redistribution of crops and animals.

So all these problem are of serious nature. As the result of which the global warming has become a very major concern for the global community. In fact you might have read in the news papers and all in all these Kyoto protocol. And all several industrialized nations again have met and they have discussed on base and means by which the global warming gases can be reduced. That means the releasable global warming gases can be reduced. Of course in addition to CFCs other gases also contribute to global warming potential. So the problem of the global warming potential includes other aspects also. So as a result of the negative side of CFCs with reference to their effect on ozone layer depletion and global warming effect, most of the refrigerants have to be banned.

So again you have to find some safe refrigerants. And now people have become wise and for them now the safety does not mean a personal safety only. But it is also environmental safety.

So there are, new refrigerants must be environment friendly and they also must be energy efficient.

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So what are the requirements in the context of Montreal protocol and subsequent protocols?

So for any refrigerant which should be replacement for CFCs has to be non ozone depleting. That means it should be a non ozone depleting substance. And its ozone depleting potential must be zero. And it should have as low global warning potential as possible. And people have again found several synthetic refrigerants. Which meet this criteria okay?

Synthetic refrigerants, there are several synthetic refrigerants which have zero ODP. But they have some GWP and people have also again looked at the natural refrigerants which were used the earlier and which were phased out due to some problem or other. So right now you have some non ozone depleting synthetic refrigerants. And also natural refrigerants which have zero ozone depleting potential. And some of the earlier refrigerants as I was mentioning such as carbon dioxide and hydrocarbons which were phased out or they again coming back because of their favorable effect on the environment.

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This table shows a brief look at alternatives and of which are these application. For example in domestic refrigerators, previously CFC twelve was used as a refrigerant and CFC twelve has a ozone depleting potential of one so it had to go. So in its place now refrigerant such as HFC one thirty-four and hydrocarbons are being proposed. These two have are non ozone depleting substances and they have reasonably low global warming potential. And for the air conditioning application previously CFC eleven was used, CFC twelve was used and HCFC twenty-two was used.

Now these CFC refrigerators are being replaced with HFC one thirty-four. It is, HFC stands for hydro fluorocarbon and HC stands for hydrocarbon carbon dioxide and the mixtures. So these are the new refrigerants which are being suggested in place of the older refrigerants. For air conditioning applications and in cold storages previously HCFC twenty-two that is the hydro chlorofluorocarbons twenty-two was used. And a mixture R five naught two was also used. And these substances have non zero ozone depleting potential. So they also have got to be banned and so they are now being replaced by ammonia and hydro fluorocarbon mixture. And in for heating applications in heat pumps previously CFC one four and CFC eleven were used. And both these are ozone depleting substances. So they are being replaced by hydrocarbons and water. So this is just a brief look at the possible alternatives to the CFC refrigerants. And most of the CFC refrigerants such as CFC eleven and CFC twelve have already been banned. Whereas refrigerants such as HCFC twenty-two since it has a very low ozone depleting potential people have felt that, it can, we can use it for a little longer that means you can use it up to say twenty. And that means it has to go in twenty. So this is a brief look at the development of refrigerants and how we have made a full circle starting with natural refrigerants. And again we are coming back to natural refrigerants.

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Now let us look at another very important aspect of compressor development and a brief history of compressor developments. Compressor is the most important and it is a most critical component of any vapour compression refrigeration system. In fact it is called as the heart of a vapour compression refrigeration system. This is because it is always the most; it is the major cost component of any vapour compression refrigeration system. Typically thirty to forty percent of the total plant cost is due to the compressor. So obviously it is very important that you select the right compressor and it has a great influence on energy consumption reliability and serviceability of the system. So selection of suitable compressor is another important step apart from the selection of suitable refrigerant.

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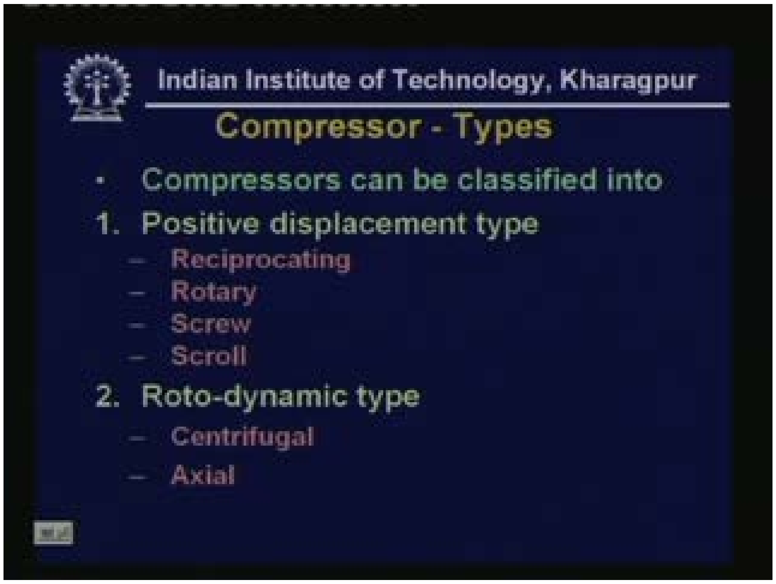

Now compressor type, there are wide variety of compressors. Let us look at these. Different types of compressors can be classified into positive displacement type compressors. In positive displacement type compressors, compression is achieved by trapping certain amount of a refrigerants or gas in an enclosed space. So first you trap some amount of refrigerant in an enclosed space and then you reduce the volume. So as you reduce the volume of a fixed mass of gas its pressure rises. So you raise the pressure till the pressure exceeds or equals that of the condenser pressure. So this is the principle of positive displacement type of compressors. And again under the positive displacement of type of compressors, we have several types. For example reciprocating compressors, rotary compressors, screw type of a compressor, scroll compressor apart from that there are also other types of compressors like trochoidal compressors and all which are relatively new. So reciprocating rotaries, screw and scroll are the most important types of positive displacement type of a compressor. The other type of compressor is known is rotodynamic type of compressor.

In all positive type, positive displacement type compressors, the, on a microscopic level the flow is not steady. In fact the flow is pulsating. This leads to actually vibrations because of the pulsations, however on a microscopic level due to the high speed you do not really feel that the flow is pulsating okay. When you, if you put a mass flow meter which gives the microscopic flow rate you cannot really detect the pulsations. But if you put a very sensitive flow meter then you find that the flow is pulsating. The other type of compressor that is rotodynamic type of a compressor is a steady flow device. And in these compressors the compression is achieved due to the exchange of angular momentum between a high speed rotating mechanical element and a steady fluid flowing through the element.

So this is the principle of rotodynamic compressors. That means you impart angular momentum to a steadily flowing fluid and then convert this angular momentum to pressure. And there are two important types of rotodynamic compressors are centrifugal type and axial flow type. Centrifugal types are also known as turbo compressors. And they are widely used in large refrigeration capacity or a large refrigeration capacity system.

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Now let us look at reciprocating compressors. A reciprocating compressor is called as the work hard of refrigeration industry that means this is the most popular among all the refrigerants, all the refrigerant compressors.

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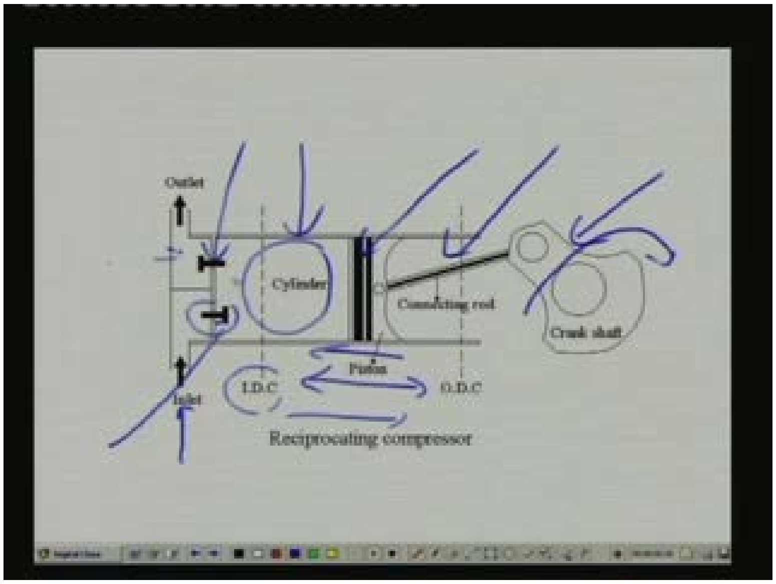

Let me explain the working principle briefly reciprocating compressor resembles in many ways. A i c engine, so here you have a cylinder, a piston, connecting rod and a crank shaft and you have a discharge valve here and a suction valve here. As this crank shaft rotate in this manner the piston slides in the cylinder. So piston reciprocates in the cylinder as the crank shaft rotates. So you are converting basically the rotating motion of a crank shaft into a reciprocating motion that's why we call it as a reciprocating compressor. Now as I was mentioning this is the positive displacement type of a compressor. So you have to have an enclosed space and you reduce the volume of the enclosed space.

So here the enclosed space is formed due to the presence of the cylinder, the piston and the two valves. When the two valves are closed, then you have an enclosed space here okay. So if you trap some amount of gas here and you reduce the volume by moving the piston in this direction then the volume reduces and pressure builds up. So the working principle is like this. Let us assume that, initially the compressor is at the inner dead center. That means it is at this position, the piston is at this position and as the crank shaft rotates the piston moves in towards the outer dead center or O D C. So as the piston moves towards the outer dead center there will be expansion of the gas inside the cylinder and so cylinder pressure drops. When the cylinder pressure drops due to the pressure difference between the evaporator here and the cylinder here, this suction valve opens. Once the suction valve opens refrigerant from the evaporator flows through this inlet and enters into the cylinder. This process continues as long as the piston is moving towards the O D C.Once it reaches O D C further rotation of crank shaft leads to the movement of piston in the reverse direction. That means now the piston will start moving from the outer dead center to the inner dead center that means in this direction. When it starts moving you see in this direction the pressure starts rising because the volume gets reduced. As this pressure exceeds that of the evaporator pressure suction valve closes and discharge valve is closed. Now at this movement discharge valve is closed.

So both suction and discharge valve are closed and as the piston moves the volume reduces pressure builds up. Once this pressure exceeds the pressure the of the condenser that means the pressure at this point this is the condenser pressure. Then the discharge valve opens. So once discharge valve opens the refrigerants that is trapped inside this enclosed space escapes through this discharge valve goes to the condenser gets condensed and then it flows through the expansion valve goes to the evaporator and the cycle is completed. So that means the movement of the piston inside the cylinder will give rise to suction and compression. And as you can see that flow is not steady that means at some movement during some at some point refrigerant enters and at some point it gets compressed and at some point it gets discharged. So if you put a very fine probe here then you find that the flow is pulsating okay. So this is the basic principle of any reciprocating type of a compressor.

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so now let us look at the development developmental issues regarding the reciprocating type of a compressor. P N Russel began the manufacture of the first vertical two cylinder compressor in eighteen fifty-nine. So this is the first commercialization of compressors. As the name implies it is vertical and it has two cylinders. And Charles Tellier has developed horizontal single cylinder compressor in eighteen sixty-three. And T S C Lowe has developed carbon dioxide compressor in eighteen sixty-eight and Raoul Pictet has developed horizontal oil free sulphur dioxide compressor in eighteen seventy-four and Linde has introduced horizontal double acting compressors in eighteen seventy-seven.

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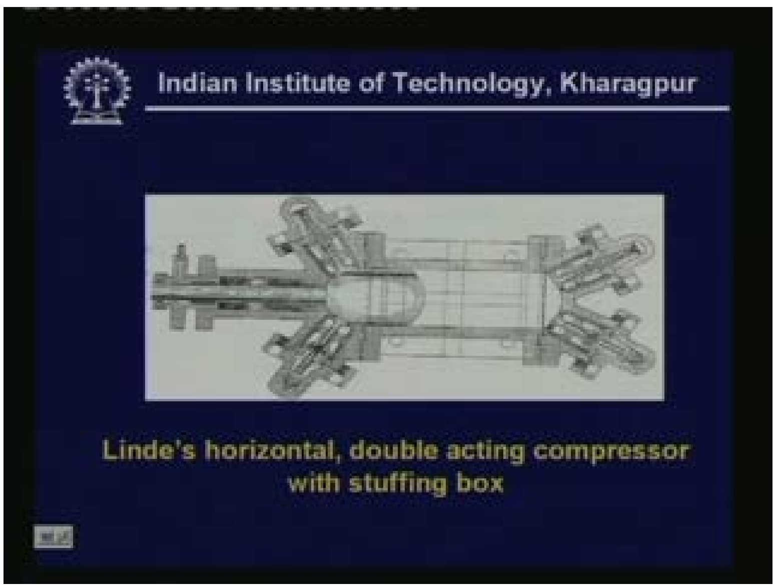

So this shows picture of Linde's compressor why I am showing this is this is one of the landmark events in the history of refrigeration. And this shows the double horizontal double acting compressor with a stuffing box.

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Now let us look at the early compressors. What are the characteristics of the early compressors? The earliest compressor is a hand operated compressor. Now you can see that if you want to run the compressor you have to supply some mechanical energy. That means some drive is required to run the compressor. And the first compressor that the drive has provided by a human being. That means it was a hand operated compressor is just like a, our normal water bore wells. And later with the hand operated compressors were replaced with steam engine driven compressors. This happened sometimes in eighteen fifties and the early compressors were essentially open type.

Open type means the body of the compressor and the driving mechanism. For example if it is steam engine then the steam engine and compressor were separated. So this is what is known as a open type of a compressor and they were typically very low speed compressors. That means speed used to be about fifty rpm and their size use to be very large. For example they use to have diameters as large as point five meters and the stroke length use to be as large as one point two meters. And they since the speed is low and the size is large typically they use to have small clearance.

What will be the effect of this clearance? And all we will discuss when we discuss the performance of reciprocating compressors. But for the time being let me say that the early compressors use to have small clearance and they also use to have large valves. As a result of this low speed and the large valves they were able to handle a mixer of liquid and vapour. So early compressors for handling refrigerant liquid plus vapour mixtures.

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Now let us look at some of the important landmarks in eighteen ninety-seven. A Belgian scientist John Lebrun has introduced a rotary stuffing box to reduce leakage. Now one of the problems with open type of compressor is that the driving shaft goes into the body of the compressor. So where it, when it enters into the body of the compressor you must provide some kind of a feeling, so that it can rotate freely at the same time refrigerant leakage is minimized. So this is the typical problem with any open type compressor. Because of this particular arrangement there will always be some leakage of refrigerant near the shaft before people have tried different types of seals to minimize the leakage. It is not possible to prevent the leakage cont completely but you can minimize the leakage.

So first break through happened when Lebrun has introduced a rotary stuffing box using the rotary stuffing box you can reduce the refrigerant leakage to a large extent. Then gradually the steam engine driven compressors were replaced with electrical motor driven compressor. This is a truly landmark event or very important event in the development of compressors. Because once you use a electrical motors for running the compressor it offers many advantages. You can have speed and you can have a compact design and many other important advantages. And this happened sometime in nineteen then high speed compressors that means speed above five hundred rpm were introduced in nineteen twenties.

Let us look at what is the effect of speed

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Now let me show the effect of speed here

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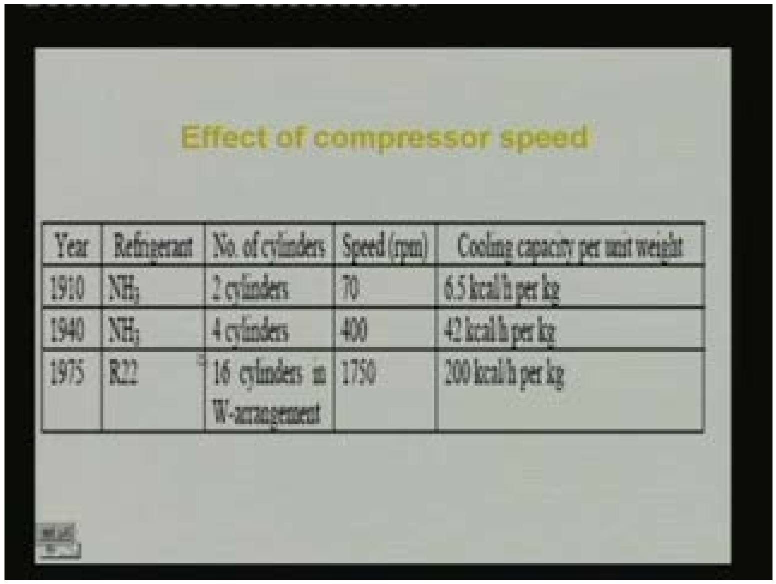

Year	Refrigerant	No. of cylinders	Speed (rpm)	Cooling capacity per unit weight
1910	NH_3	2 cylinders	70	6.5 kcal/h per kg
1940	NH_3	4 cylinders	400	42 kcal/h per kg
1975	R22	16 cylinders in W-arrangement	1750	200 kcal/h per kg

This table shows the effect of compressor speed. For example in nineteen ten we had ammonia based compressor which had two cylinders and which was running at seventy r p m speed. And it was giving a cooling capacity of six point five kilo calorie per hour per kg of the weight of the compressor. And in nineteen forty the compressors ammonia compressors used to have four cylinders and the speed use to be four hundred r p m. So now you can see that the cooling capacity per k g of the compressor weight has increased from six point five to forty-two due to the increase in the speed and also in the, due to increase in the number of cylinders. Whereas in ninety seventy-five a typical R twenty-two compressor with sixteen cylinders and with a speed of seventeen fifty r p m was giving a cooling capacity of two hundred kilo calorie per hour per k g. So you can see that there is a two order of magnitude improvement in the cooling capacity with the speed with the increase in speed.

So if you want to really increase the speed of the, if you want to make a compressor compact, one has to go for higher speeds and all these has become possible due to the use of electrical motors and multi cylinder arrangement.

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Now let us see, what the other important land marks are. A hermetic compressor which is again very important land mark in the development of compressors was introduced in nineteen eighteen.

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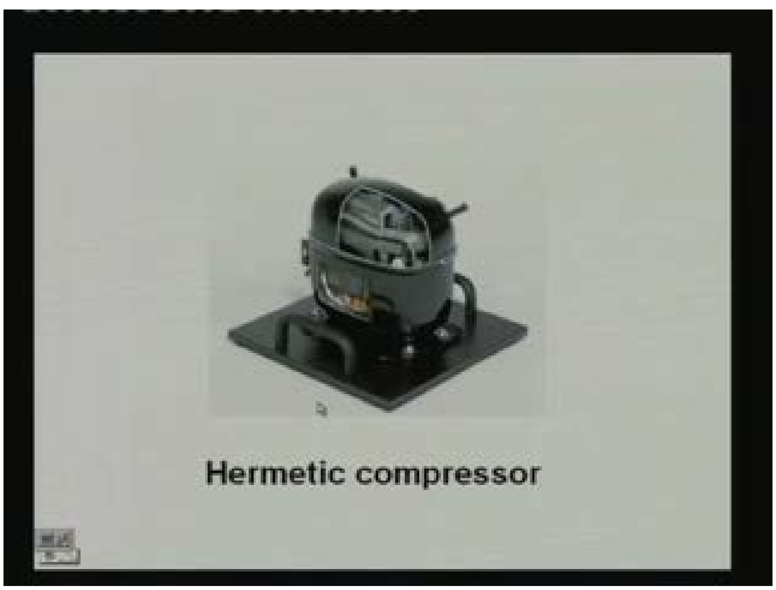

Now let us see what the hermetic compressor is as I was mentioning in a open type of a compressor you always have a problem of refrigerant leakage. Because that compressor and the motor for example R placed widely apart and the rotating shaft has to pass through the body of the compressor where the leakage takes place. Now if you have a leakage in system a continuous refrigerant leakage from the system. Then after some time its performance gets affected. So what is done in system using open type compressor is that you have to provide a large refrigerant storage. Which will take care of the leakage to some extent? But after certain time you have to recharge the refrigerant into the system. That means all open type of compressors require periodic maintenance.

Obviously periodic maintenance is not possible if you are planning to use this compressors in say domestic refrigerators. You cannot have regular maintenance at in your house. So people felt that this problem of open type of a compressor has to be eliminated. So this led to the development of a hermetic compressor. So you can see the photograph of a hermetic compressor here. In a hermetic compressor both the motor and the compressor are house in the same external housing. That means both are mounted in an external shell. As a result any refrigerant leakage from the compressor is confined within the shell. And to this shell are attached the suction and discharge lines through a permanent welding or resin process as a result the leakage of refrigerant is completely eliminated.

So because of this important advantage hermetic compressors have become very important for the development of domestic refrigerators and small compressors small air conditioners etcetera.

Of course one of the problems with hermetic compressor is that since you are keeping the motor also inside the refrigeration system. The heat losses because of the inefficiency of the motor become load on the refrigeration system. As a result hermetic compressors are less efficient compare to open type of a compressor. So normally we use hermetic compressors in small systems. Where efficiency is not so important and use open type compressors in large systems where efficiency is important.

Now let us look at other types of positive displacement type of compressors

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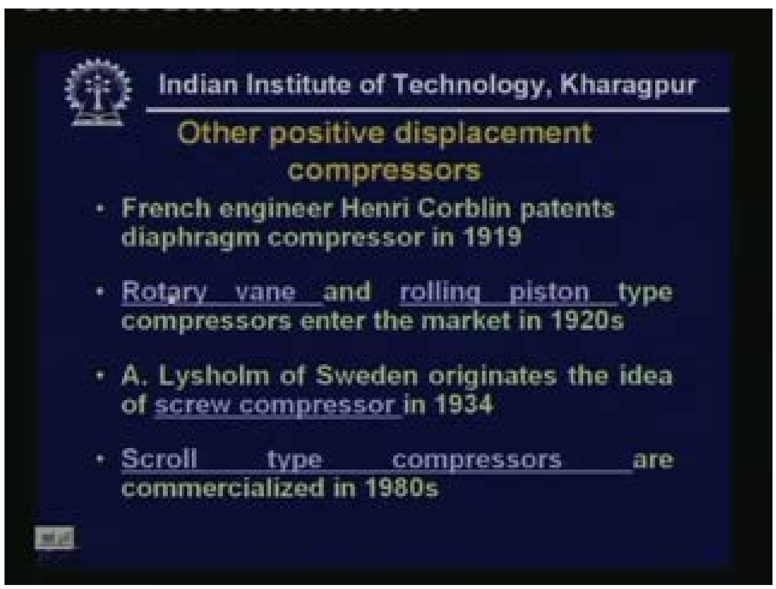

One of the major problems is the reciprocating compressor is that you are converting a rotary motion into a reciprocating motion. This will give rise to a vibrations and higher noise. As a result people have tried to use positive displacement made machines where you do not have to convert rotary motion into reciprocating motion. And several of these machines have been invented and there have been used in refrigeration industry. The first diaphragm type of a compressor was patented in nineteen in France and a rotary vane and rolling piston type of compressors entered in the market in nineteen twenty. I will not explain the working principle of these compressors. Because we will be discussing these when we discuss compressors. But I will just show the schematic of a rotary compressor a rotary vane.

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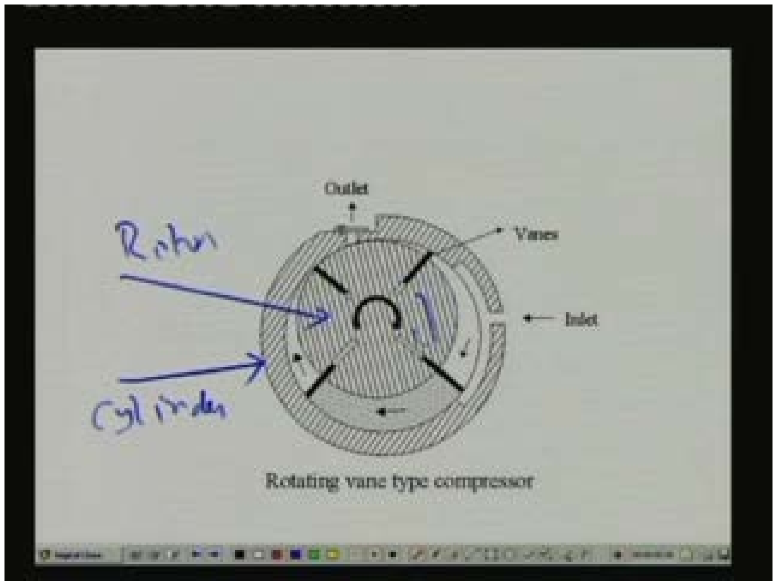

This picture shows schematic of a rotary vane type of a compressor and here we have the cylinder here and a rotor. And it consists of different number of vanes. For example this particular type here consists of four number of vanes which are freely supported or spring loaded. And which are kept in the slots cut in this rotor so this is the rotor. And the shaft which rotates is mounted on the rotor and the axis of rotation of the shaft is in line with the center of the rotor.

But it is eccentric with reference to the this outer cylinder. So as a result of this eccentricity when this rotor rotates in this direction it creates suction and discharge effect within the compressor. So this is the principle of rotating vane type of a compressor and it is mainly used in small refrigeration systems. And I will discuss the performance aspects and detailed working principle in a subsequent lesson.

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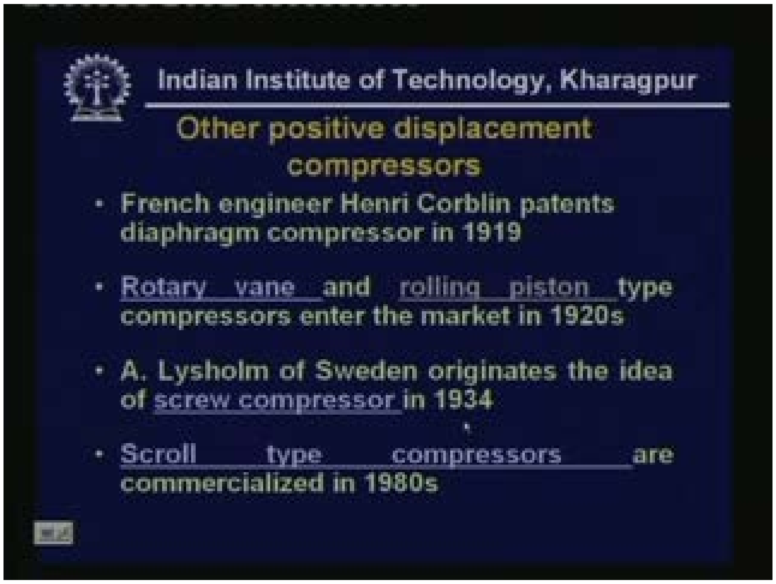

And this picture shows the schematic of a rolling piston or compressor. And another very important type of a compressor called as screw compressor was invented in nineteen thirty-four by Lysholm in Sweden.

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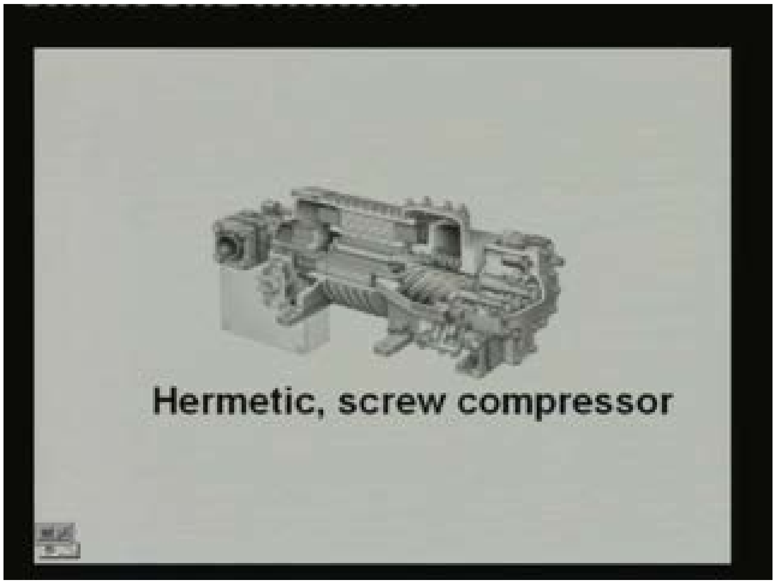

This picture here shows the photograph of a hermetic screw type of a compressor. As you can see here a screw compressor uses helical screw and a mating component. And rotation of this helical screw and the mating components gives rise to suction and compression effects.

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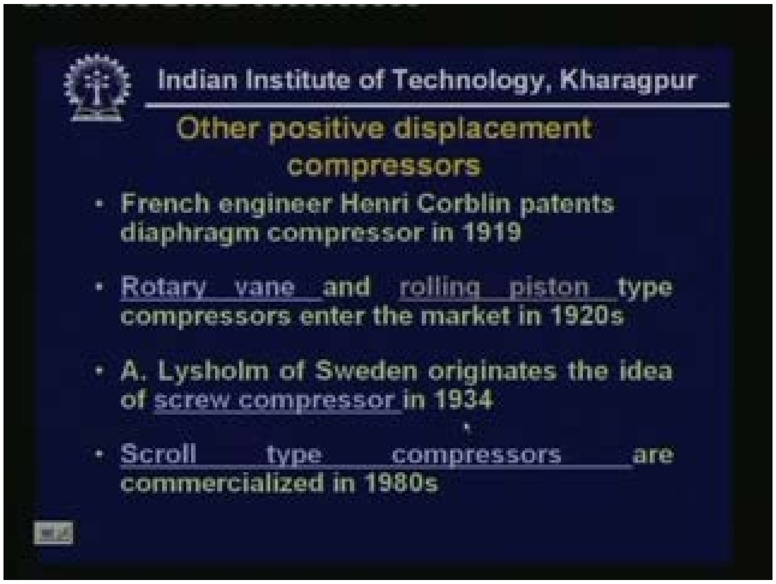

Then the scroll type of compressor are commercialized in nineteen eighties scroll type of compressors are used in a small refrigeration system.

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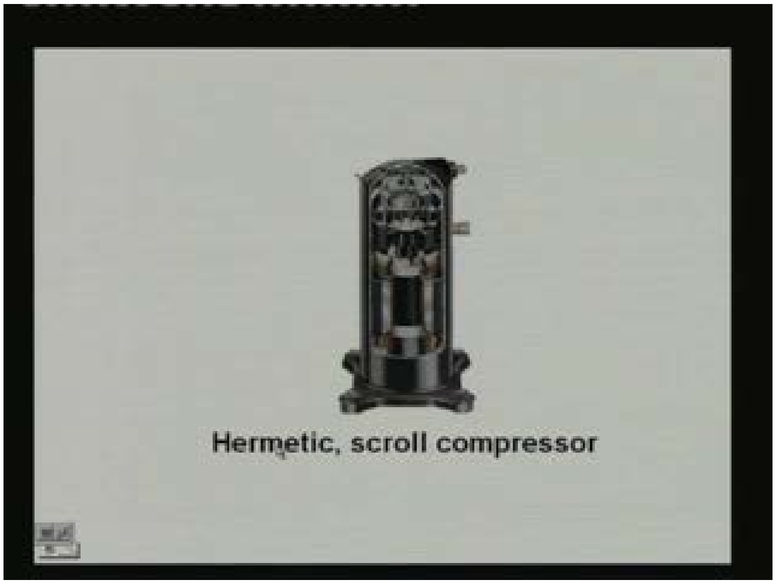

And this picture here shows the small hermetic scroll type of compressor.

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Now let us briefly look at the centrifugal compressor. As I mentioned and a centrifugal compressor comes under the rotodynamic type and it was first conceptualized by Auguste Rateau of France in eighteen ninety.

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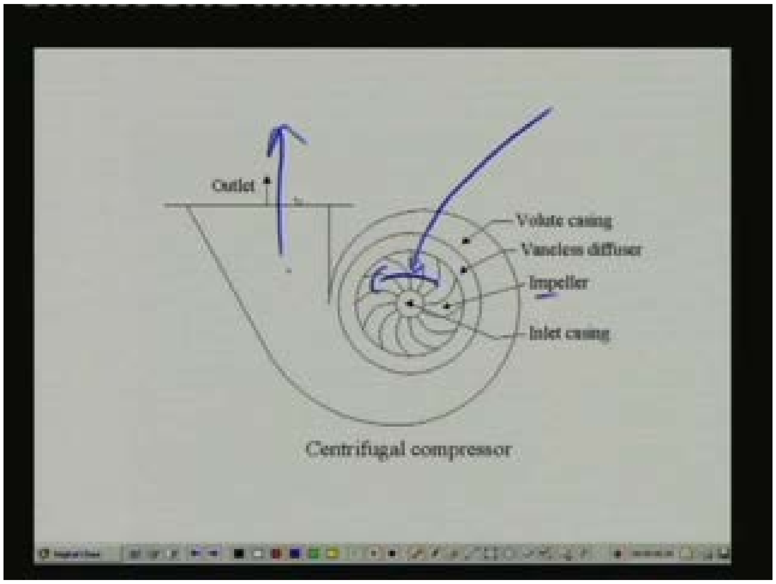

And let me show the schematic of a centrifugal compressor. This shows the schematic of a centrifugal compressor. You have a fast rotating this will rotating in this direction or in the opposite direction this is called as the impeller here. And the gas enters through this inlet casing and it fills the space between the impeller blades. So as the impeller rotates at high speed it imparts angular momentum to the gas. That means the gas gains angular momentum and the gas is thrown out because of centrifugal action. And it enters into this vane less diffuser and in the vane less diffuser some part of the kinetic energy is converted into pressure. And from this vane less diffuser it enters into the outer volute casing. And as you can see the cross section area of the outer volute casing gradually increases as a result the kinetic energy of the fluid is converted into pressure so ultimately a high pressure gas comes out of the outlet. So this is the basic working principle of a centrifugal compressor. And it is a steady flow device as I have already mentioned that means you get a steady stream of fluid outside out of the compressor. And the one advantage of this type of compressor is that since it is a steady flow machine.

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You do not have many vibrations like what you seen in the reciprocating type of a compressor. As i mentioned this was conceptualized in eighteen ninety. And in ninety twenties this is actually perfected by Willis Carrier in U S A. And he used these compressors for air conditioning applications to start with. Now a days, of course these are also used in large refrigeration plants also. And there was a rapid growth of these compressors in nineteen thirties with the invention of CFCs. Currently they are used for a wide variety of applications with a wide verity of refrigeration in mainly in large capacity plants.

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Now let us just look at a brief comparison between centrifugal versus reciprocating type of compressors. Compared to reciprocating type a centrifugal compressors are compact for large capacity systems refrigerant flow is steady there is less vibration and wear and compared to reciprocating compressor. Compared to for a centrifugal compressors reciprocating compressors are simpler in construction and they are rugged and they offer good part load performance. So as a result you find that in refrigeration industry a wide verity of compressors are used for different applications.

When you want small capacity you normally use the reciprocating compressor or other positive type of displacement compressors. When you want very large refrigeration capacity one generally uses a centrifugal compressor because it is more efficient and more compact for large capacities. And screw compressor comes in between reciprocating and centrifugal. So almost all types of compressors are used in refrigeration industry for different types of application.

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So this is the brief history of refrigerant and compressor development. Now let us conclude, let us see what are the conclusions based on this lesson. We have seen that vapour compression refrigeration technology has achieved a high level of maturity mainly due to development of large number of refrigerants and development of large variety of efficient compressors for various applications.

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Currently the efforts are on to develop eco friendly refrigerants in the view of ozone layer depletion and global warming effects the focusing on eco friendly refrigerants for different applications. And development of more energy efficient compact reliable and quiet compressors, there are also other types of compressors such as linear piston type trochoidal type acoustic type compressors. These are being the developed and they are still at a various levels of development and they have certain advantages compared to the conventional refrigerants. But these are as I said they are not yet been commercialized

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So now I will give some questions based on this lesson and the answers for these will be provided in the next lesson.

Thank you.