RAC Product Design
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Lecture - 05
Refrigerant properties and applications

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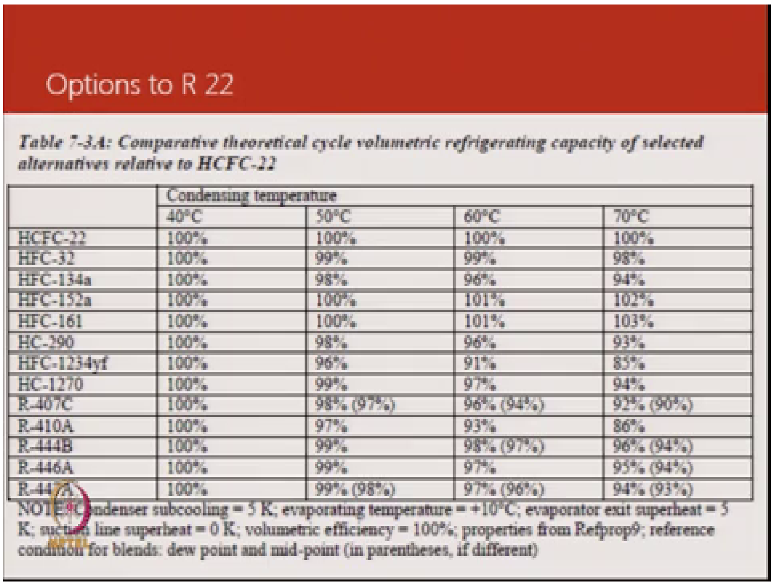
Options to R 22

Table 7-3A: Comparative theoretical cycle volumetric refrigerating capacity of selected alternatives relative to HCFC-22

	Condensing temperature			
	40°C	50°C	60°C	70°C
HCFC-22	100%	100%	100%	100%
HFC-32	100%	99%	99%	98%
HFC-134a	100%	98%	96%	94%
HFC-152a	100%	100%	101%	102%
HFC-161	100%	100%	101%	103%
HC-290	100%	98%	96%	93%
HFC-1234yf	100%	96%	91%	85%
HC-1270	100%	99%	97%	94%
R-407C	100%	98% (97%)	96% (94%)	92% (90%)
R-410A	100%	97%	93%	86%
R-444B	100%	99%	98% (97%)	96% (94%)
R-446A	100%	99%	97%	95% (94%)
R-447A	100%	99% (98%)	97% (96%)	94% (93%)

NOTE: Condenser subcooling = 5 K; evaporating temperature = +10°C; evaporator exit superheat = 5 K; suction line superheat = 0 K; volumetric efficiency = 100%; properties from Refprop9; reference condition for blends: dew point and mid-point (in parentheses, if different)

Now, when we are looking at alternatives to R 22, so when I say that today you cannot design equipment where the R 22, because manufacturing of new equipment does not allowed anymore in most countries. What are the refrigerants that you will use? So, for that, we need to look at available refrigerants, and some of this is related to what is today likely to be used. So, HFC-32 is being considered by a some companies for light commercial applications. So, and HFC-32 is a component of 410A, which is a refrigerant, which is most used for residential air conditioning systems as a replacement to R 22, and the concern about R-410A is the global warming potential.

So, HFC-32 is the component of that. And the reason there is another component in that, as if tropic mixture is to get it to a lower an acceptable safety classification of A 1. So, here in this slide what you see is comparison with HCFC-22 or R 22, if you go by the different nomenclature. So, all these refrigerants could give us a comparable theoretical cycle volumetric efficiency at 40, but then as the temperature goes up, and this is condensing temperature as it goes up, as it would happen in higher main conditions, then there will be either a penalty. So, some in some cases, we will see a drop in performance. So, when you need more air conditioning, you are seeing either slight or a significant drop in performance. In some cases, you can see a benefit, all that is tabulated here.

And then more importantly since we are talking about global warming what happens to the COP. So, if we where do we compare with a baseline of R 22 at a temperatures of 40 to 70, then we can see HFC-32 comes in fairly close. But, there is a penalty of 3 percent at 60 degree centigrade, and 5 percent at 70 degree centigrade. Now, the 70 is more relevant for Middle East conditions in a big way, and small instances of high ambient temperatures like if you look at some conditions of temperature in Bikaner or Hisar, you would see ambient temperature going up to 50 degree centigrade.

Now, in those conditions, if you going to maintain our 10 degree to 20 degree temperature difference, then you will strike somewhere between 60 and 70 for the condenser. Also there could be conditions, which would lead to block condensers partially block condensers, and therefore the condition would reach 70 degree centigrade. So, it is important to keep this in mind, that when you have the most demand for air conditioning, what is happening because of change of refrigerant. And for that, you may then choose to design a larger heat exchanger more efficient heat exchanger or use a different technology in heat exchangers like we discussed. So, we looked at micro channel heat exchangers. So, for a lower cost, we could use aluminum to aluminum heat exchanger, and get a larger heat transfer.

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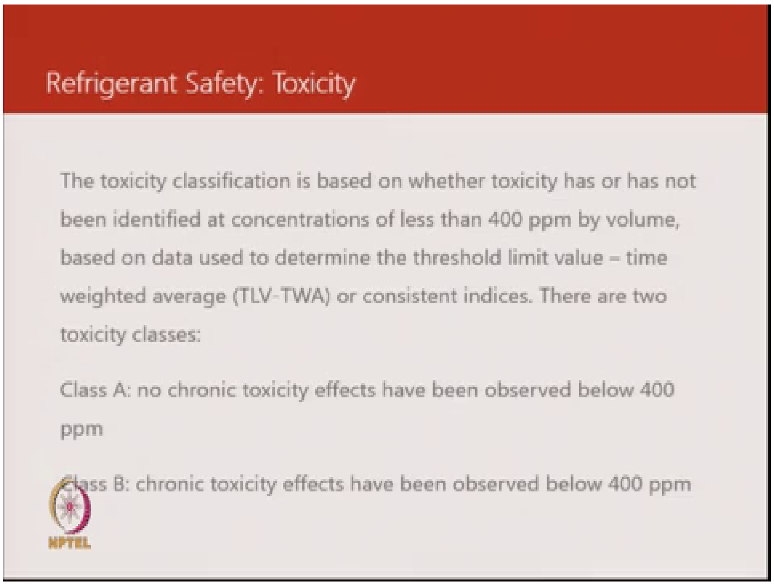

So, now we come to refrigerant safety. And in refrigerants safety let us look at two elements separately. One is toxicity. So, the toxicity this is a classification of toxicity. Based on whether toxicity has or has not been identified at concentrations of less than 400 ppm by volume, and is based on data used to determine threshold limit value.

So, there are two classifications. So, one is no chronic toxicity effects have been observed below 400 ppm and class B is there is toxicity observed below 400 ppm. So, implications of these are for people, who are involved with manufacturing, people are involved with testing, people are involved with servicing and installation, what would happen to those people. If they were exposed to such concentrations that may easily happen, when there is handling of refrigerant at these places.

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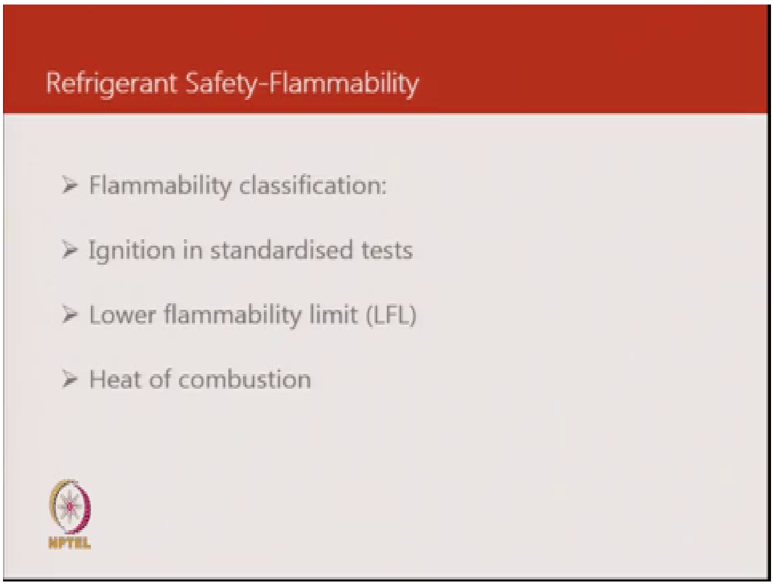

And then, there is a flammability classification there is a flammability classification based on ignition, a lower flammability limit, heat of combustion, whole lot of parameters.

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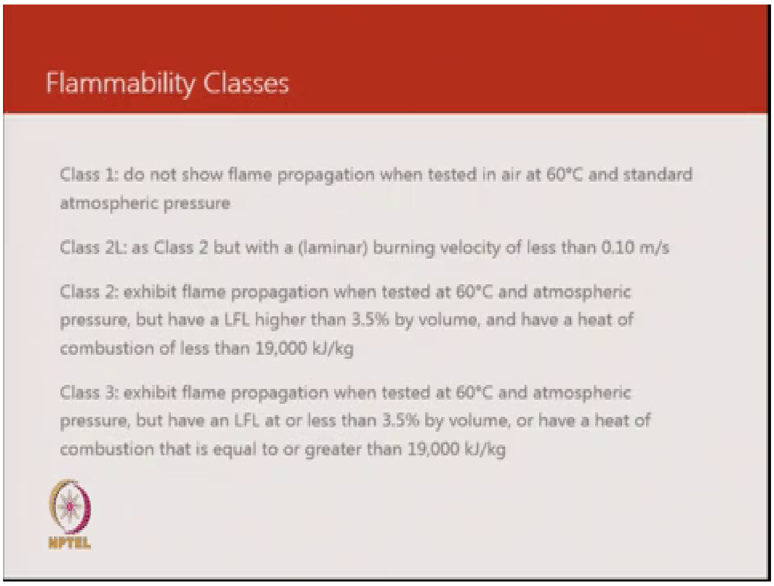

So, what are the three classes of flammability? So, class 1 is that there is the refrigerant shows no flame propagation, when tested in air at 60 degrees at standard atmospheric pressure. So, R 12, R 22, these are examples of refrigerants that have no risk of such a flame propagation. And therefore, they are categorized as class 1. This was one of the main reasons, why do you point had big business until the 90s, because these were reliable robust refrigerants with no flammability issues and toxicity issues.

Class 2L is a new class. Earlier there was just class 1, class 2, and class 3, and then the need for looking for alternative refrigerants led different companies to reach a point, where they could not get class 1 refrigerants, which had no global warming comparable to ammonia or comparable to C O 2. So, there was there was a need to look at the level of risk that flammability of class 2 refrigerant poses. So, there was a new level created between 1 and 2, which is 12.

And this is whether laminar burning velocity of less than 0.1 meter per second. So, the flame propagation if it is not too rapid, it is considered low risk in comparison to a refrigerant, where there is a rapid flame propagation. So, therefore, there is new classification. Again, there are parameters for testing it, and then there is also a low flammability limit, and then also linked to the heat of combustion. So, I leave it more for the chemical guys to look at it more thoroughly, but there is a standard, which allows us to evaluate a refrigerant for its flammability.

And class 3 refrigerants are refrigerants like propane, and they exhibit flame propagation when tested at 60 degrees and atmospheric pressure, and have an LFL at or lower than 3.5 percent by volume. And they have a heat of combustion, which is greater than or equal to 19,000 kilo joules per kg. So, if we put aside the numbers a very different way of relating to refrigerants is the safest from a flammability perspective are class 1 refrigerants. Then comes the class 2L and R 32 is one of the refrigerants which falls into that class. It was a refrigerant, which was given up earlier, because there was no real reason for people moving to (Refer Time: 07:25) global warming potential refrigerants.

So, there was already a formulation available 410A, which was class 1. And then, when 12 became available some people, and specifically one company Daikin became aware that they have this patent for a refrigerant, that can be used, and that can used in air conditioning. So, they saw a business opportunity, and then there has been some negotiation around the patent, and they I am told, they are willing to give up the exclusive patents for that to make this R 32 refrigerant widely available for designs. They still would retain an edge, because they mastered the optimization and design of equipment without (Refer Time: 08:02) but it is also one of the promising alternatives, where refrigerant safety can be managed with proper training.

They have also sold some units in India with this refrigerant, as a way to prove that it is feasible to use this, it is another matter that we must all be aware of is, in India we do not have a very well regulated safety environment for air conditioners. So, just like we have on mandatory compliance for energy efficiency ratio, we do not have a mandatory compliance for the flammability of refrigerants or toxicity of refrigerants and that is some work that needs to be done. And there are some forums, where there is topic is being discussed, but it is yet to see maturity. It is important to voice some of these concerns, when you are in a in a place, where you can exert influence on the authorities you talk to people, because overall each one of us is impacted, either sometimes directly or indirectly by these limitations.

So, let us say today you go and buy an air conditioner, and if you do not have this thorough knowledge about standards and about risks of refrigerant toxicity, you might easily buy a propane air conditioner, and someone might use an opportunity to just do a trial. And it may work fine for many years until there is a leak. And if the leak were to happen, at a time when you are asleep, think about what can happen.

If there was a standard, it would govern what room size, what size of appliance what charge quantity can be there. And the risk becomes severe, when there is a leakage, and then you wake up, and you switch on the light, and that spark causes an explosion. So, these are some of the very very rare less risks to life and property, that we must keep in mind, and that is where there is a relevance of safety standards. And most companies would adhere to them on their own voluntarily, because they have exposure in other countries. But, the key point is that there is not a legal framework for making it mandatory yet.

If we want to take care of ozone and if you want to take care of global warming together, we will have to deal with a certain degree of flammability of refrigerants. And for that reason, we will need to be responsible. We meaning, people who are going to be designing, and people who are going to be manufacturing, and people are going to be servicing and to an extent to the users also [FL].

So, we did we touch upon lower flammability limit, perhaps indirectly right, and one of the slides. But, where does it find application, how much of refrigerant can we have in the system. We all familiar with LPG right, what happens if there is a certain quantity released, and what is the mitigating step? So, there is there is one of the things we can detect it, because there is a certain order associated with the leakage, so become alert to it, and then we take precautions. So, while going to sleep or leaving on a long vacation, you shut off wires, and then you have enough number of wires to take care of any untoward incident.

So, similarly we need to look at some ways of sensors and all that, but at the same time, we also need to look at what can potentially get released into the room. So, the example that I was sharing with you before we took a break, how much of refrigerant is there in the room, and will it be close to the lower flammability limit, if the entire refrigerant got leaked into the room, where you are sleeping. Now, if that quantity was going to be below the lower flammability limit, then when you switch on the electricity. If there is a spark, there will be no explosion; there will be no fire, so that is one way of addressing safety in an appliance by ensuring that, the quantity of refrigerant in the appliance is below the low flammability limit, if it were to be inadvertently released into the room.

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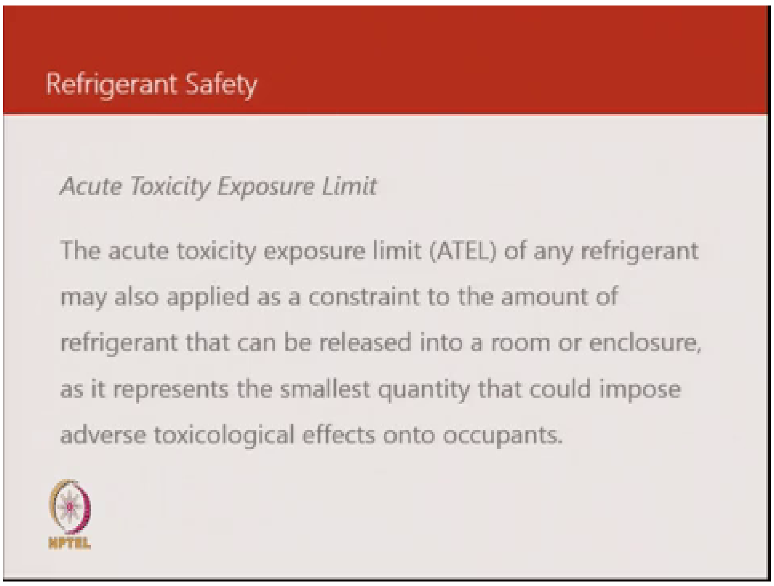

Then about toxicity exposure limit. Again this is to do more with the human body and what levels of ppm will lead to some degree of damage or concern.

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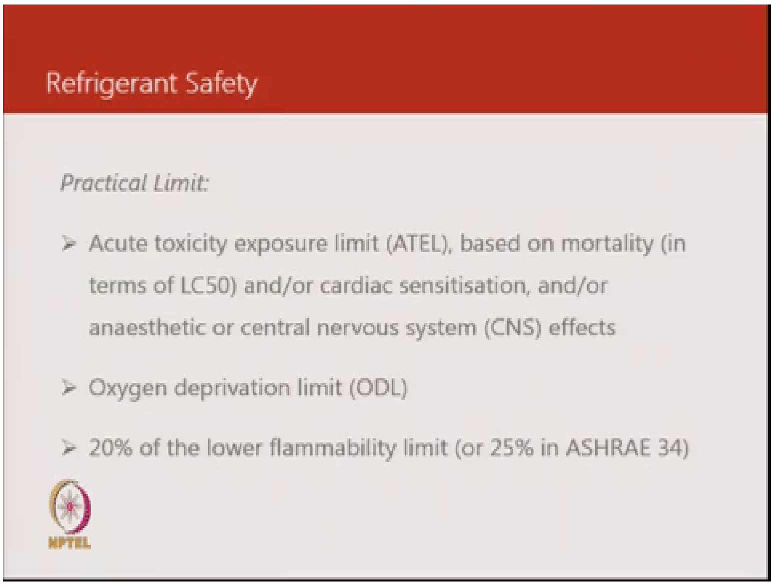

So, acute toxicity exposure limit ATEL, I find it hard to remember also, but still it is something I have to learn to understand and be responsible for. So, it is based on mortality in terms of LC50, which is another standard and or cardiac sensitization and or anaesthetic or central nervous system effects. So, now there is concern right like humans can be impacted because of toxicity in refrigerants. And then, there is a oxygen deprivation limit. 20 percent of the lower flammability limit is the practical limit, and then oxygen deprivation happens when something like CO2 displaces all the oxygen in a room, and then there is a problem.

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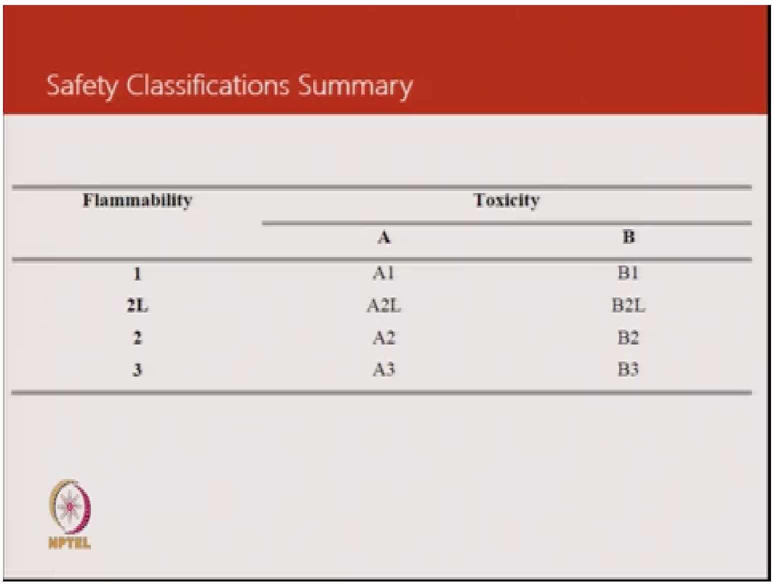

Flammability	Toxicity	
	A	B
1	A1	B1
2L	A2L	B2L
2	A2	B2
3	A3	B3

And finally, if we merge flammability and toxicity, then we will come to a single representation; so, the first letter representing toxicity, in the second letter representing flammability. So, we would end up having refrigerants over the classification A1, A2L, A2, and A3, as one category which are not toxic, but have varying degrees of flammability, with the A1 refrigerant having no flammability. And then, there would be the ones which are toxic and the B1 having no flammability, and the B2L, B2, and B3 being the ones which have flammability in varying degrees as well standard. When we are designing a product, we normally have to comply with the standard. So, so we would also need to be aware of those standards, which we will come to in a minute.

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Table A2-3: Summary of PL and charge size limits for selected refrigerant and occupancies according to ISO 5149

Refrigerant Class	Example Refrigerant	Practical Limit (g/m³)	Allowable Charge in a 15 m² Occupied Space (comfort)† (kg)	Allowable Charge in a 15 m² Occupied Space (general)* (kg)	Max. Charge in an Occupied Space (Occupancy A)	Max Charge in Open Air or Machinery Room	Max Charge for a Ventilated Enclosure
A1	HCFC-22	300	11.3	11.3	PL×RV§	no limit	no limit
	HFC-134a	250	9.4	9.4			
	R-404A	520	19.5	19.5			
	R-407C	310	11.6	11.6			
	R-410A	440	16.5	16.5			
	R-744	100	3.8	3.8			
A2L	HFC-32	61	1.3 – 4.9	2.3	12 (60‡)	no limit	60
	HFC-1234yf	58	1.2 – 4.5	2.2	11 (56‡)	no limit	56
	HFC-1234ze	61	1.3-4.8	2.3	12 (59‡)	no limit	59
A2	HFC-152a	27	0.5 – 1.7	1.0	3.4	no limit	17
A3	HC-600a	11	0.1 – 0.4	0.3	1.5	no limit	5.6
	HC-290	8	0.1 – 0.4	0.3	1.5	no limit	4.9
	HC-1270	8	0.1 – 0.3	0.3	1.5	no limit	6.0
B2L	R-717	0.35	0.01	0.01	4.5	no limit	23

Now, we talked about what is the permissible charge limit. And here are some representative numbers for a refrigerant charge for A1 category of refrigerants. So, A1 category of refrigerants are refrigerants that were used in like HCFC-22 or R 22. Then we have 134a, which is a replacement for R 12 and being used widespread in the refrigerators as a part of the phase, phase out of ozone depleting substances.

And here you can see, so 11.3 kg is the permissible charge. So, when something is safe, we can have a higher charge amount in the product. This does not mean we must have this, but this is a limit. So, a typical air conditioner today will have something like 800 grams a 1.5 ton residential air conditioner will have a 0.8 kg of refrigerant yeah, it could vary up and down depending on efficiency and heat exchanger size.

Then we have 404A, 407C, R-410A, and R-744, all of them are in the A1 category. So, this is the most preferred region of a refrigerant classification. If a people would have a choice, then we would use the refrigerant from this category. And there you can see limits other than CO2, which is 744, it is 3.8, all of them have very high permissible limits.

And then, you can see max charge in open air or machinery room. So, this becomes important for chillers and for large systems, where there is a separate room, where the equipment is installed. So, it could be packaged air conditioners, it could be chillers or a typically refer to as plant room. So, there is no limit. When you have A1, there is no limit on that quantity, and then max charge for a ventilated enclosure. So, now these differentiations are there, because there is a need to use flammable refrigerants. If we were talking about this whole thing 10 years earlier, we would not be looking at it in such detail, because the pressure for responsible use of refrigerant was not there so much.

So, now let us look at A2L. So, R 32 or HFC-32 and what does that mean practical charge limit, which is in grams per meter cube is 61. What is the allowable charge in an occupied space? So, 15 square meters of occupied space. What is the permissible charge? And you can see that drop from R 22, 11.3 kg it comes to 1.3 to 4.9 kg, so that is a constraint, but still does not prevent use of R 32 in resonantial systems up to 1.5 kilowatt. And then, what happens max charge in an occupied occupancy A, and there is a category defined there, and it is 12.

Then we look at A2 refrigerants, I am not going through all refrigerants, just giving you a sense. So, when you go A2, which is a higher permeability than A2L, then we are looking at limits of 0.5 to 1.7 kg for an occupied space same occupied space. And then we look at hydrocarbons. So, 600a, 290, so butane, propane, and HC-1270; all of them are in the region of 0.1 to 0.3. So, the highest favorability means we further have restrictions on the amount of refrigerant that can be there in a system.

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Table A2-1: Scope of different international and regional safety standards for AC&R systems

Chapter/Sector	IEC 60335-2-24	IEC 60335-2-40	IEC 60335-2-89	ISO 5149	ISO 13043	EN 378
3 / Domestic refrigeration	×					
4 / Commercial refrigeration			×	×		×
5 / Industrial systems				×		×
6 / Transport refrigeration				[×]		×
7 / Air-to-air air conditioners and heat pumps		×		×		×
8 / Water heating heat pumps		×		×		×
9 / Chillers		×		×		×
10 / Vehicle air conditioning					×	

Then we look at the standards that are applicable. So, what are the international standards that you can refer to when designing equipment, if you are concerned about refrigerant safety. So, there is an IEC standard 60335 2 dash 24. Then there is for domestic refrigerators, and this is the one to use. Commercial refrigeration, there is there are three standards. In fact, and you have two standards for industrial and transport refrigeration, there is something under development.

And particularly in India, if you had a choice between different standards, you would refer to the ISO. And normally reading the standard will also give you insight at the design stage itself, when you are conceiving the product as to what other things to be taken care of, so that you do not run into compliance issues, when the product is ready for launch.

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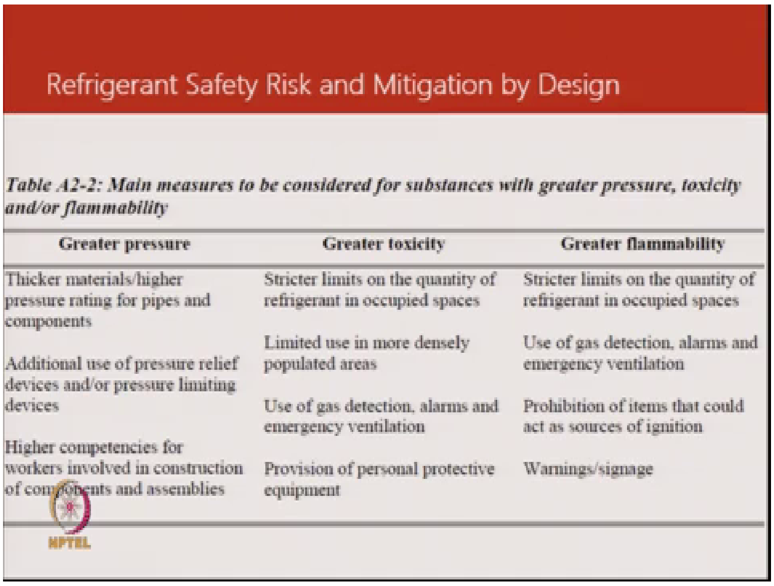

Table A2-2: Main measures to be considered for substances with greater pressure, toxicity and/or flammability

Greater pressure	Greater toxicity	Greater flammability
Thicker materials/higher pressure rating for pipes and components	Stricter limits on the quantity of refrigerant in occupied spaces	Stricter limits on the quantity of refrigerant in occupied spaces
Additional use of pressure relief devices and/or pressure limiting devices	Limited use in more densely populated areas	Use of gas detection, alarms and emergency ventilation
Higher competencies for workers involved in construction of components and assemblies	Use of gas detection, alarms and emergency ventilation	Prohibition of items that could act as sources of ignition
	Provision of personal protective equipment	Warnings/signage

Now, if we look at refrigerant safety, we have talked about two things, flammability, toxicity. The third risk is pressure. So, thicker materials and what would we do, when there is high pressure. So, tube thickness is one easy way for us to address issues related to tube bursting. So, if you are using heat exchangers, the thickness of the wall thickness the minimum wall thickness would be one of the criteria that will be influenced by refrigerants which have high pressure.

And then additional use of pressure relief devices or pressure limiting devices; so, when you think of high pressure, the refrigerant that comes to my mind always is CO2. CO2 means handling high pressures, and it is challenging. So, a lot of places, where CO2 can be thermodynamically used, it is not use because of challenges of high pressure that CO2 requires us to handle.

Then high competencies for workers involved in construction of components in assemblies. So, when there is a high pressure, there is also a tendency to look for the least cost approach. Now, when we look at least cost approach, we would look at a certain factor of safety over the burst pressure having done that, then you are going to be handling those tubes, they are going to be bending them. So, these processes if they lead to wall thickness compromise, so if you look at bending a happen right, you are twisting metal, if your outer layer has gone thinner, and you have cross the safety limit, there is a risk. And the risk is during periods of high pressure, you will just have major quantity of refrigerant leak; in some cases, it could be damaging to things nearby.

Then greater toxicity; so, we have seen how toxicity classification happens. Now, if you are using a toxic refrigerant in some particular case, what would you do to mitigate that risk. So, first is quantity of refrigerant and then occupied spaces has to be limited both manufacturing service, installation, it requires training, so it is to do with competency. And then if we have choices, we would not install such equipment in areas, which are heavily populated. We would also deploy a technology, in a way that so, if there is a leak if he had the means to detect the leak, and take corrective action.

So, let us say leakers on the condenser side, which is the high pressure side, within the system, there is high pressure, but the highest pressure would be in the condenser side. We could shut down the system; we could do a planned maintenance, so that is how a liquidator would help. In other cases, it would mean a proactive service, and then personal protective equipment. When there is a leak when there is a leak, we need people to be able to address it. So, some people need to go and close proximity to or toxic refrigerant. So, you need personal protective equipment, which could consist of a mask, gloves or any other equipment that would make sure that there is no risk to human life.

Flammability, we have touched upon already, but then this is all about the limits on quantity of refrigerant about detection again alarms and emergency ventilation. So, sometimes if you know that there is a leak, if you can throw out all the gas without any risk of flammability or explosion, then that that is one easy way of mitigating it. And then, we limit the items that could be acting as a source of ignition. So, one of the sources of ignition is the terminal block in a compressor, where a spark can happen. You need three conditions for a flame to exist, so you need flammable gas, you need oxygen, and you need a spark. So, the three can happen in a system which has flammable refrigerant, if there is a leak, and there is a spark, and there is oxygen from the air. So, how do we limit such a case.

And then of course, not everyone, who will come in contact with such appliances will be aware that there is a flammable gas. So, technicians are used to using safe refrigerants need to prepare for making use of slightly family or flammable refrigerants. So, proper labeling so, that when they come in contact with equipment for servicing and installation, they are aware of the risk and handled it accordingly.

Some of the other things to consider are let us say there is a fire in a building, and then the refrigerant used in the air conditioners is a flammable refrigerant. We would need to address that building a very different way, so fire safety has to be taken care of. And one of the main reasons, why china did not endorse use of flammable refrigerants was that they defaulted their fire department to first certify that year, they will be able to handle an emergency situation in a multi sided apartment complex, which would have a flammable refrigerant. So, this was one of the things coming out of it.

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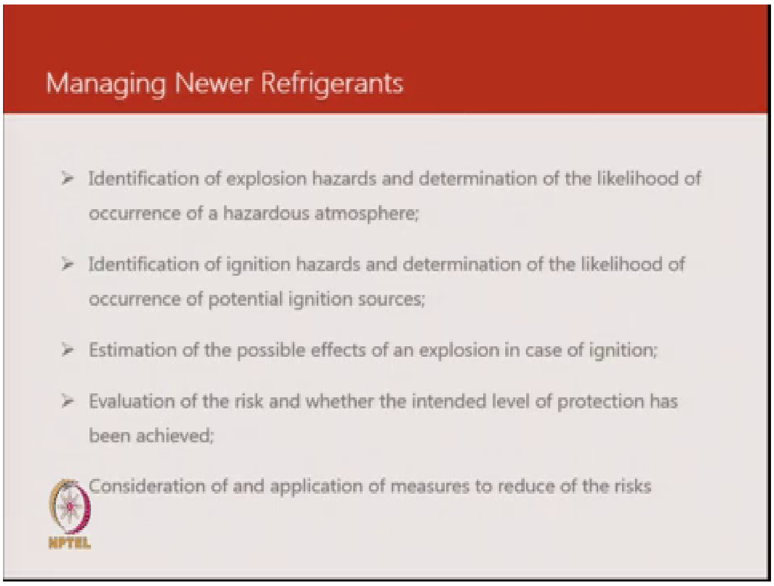

This slide, I think we have more or less covered all the points. At the design stage, we would just put it into a risk assessment plan that we have mitigated all potential risks of all right. So, the risk assessment plan is something we will touch upon, when we look at qualification of products. So, when we use our flammable refrigerant or a toxic refrigerant during the qualification phase of a product launch, we do tests to make sure that whatever is needed for safe application of the product is done right. So, we establish proof evidence, we do tests, we look at labeling, we look at all the protective measures that can be put in, including leak detection if needed.

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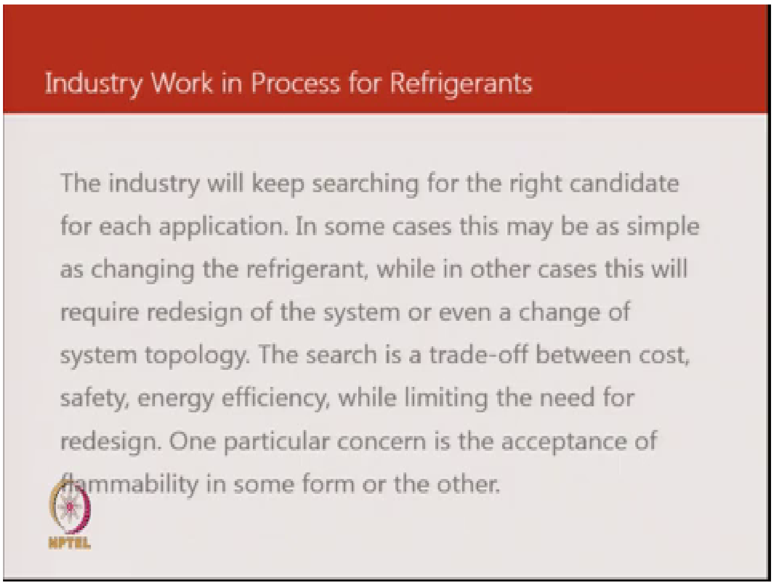

Now, let us look at some of the industry work that is in process for refrigerants. So, there is a search for newer refrigerants, because no single refrigerant has been found, which meets all the requirements. When we look at a refrigerant, which has 0 ODP and low GWP, we find that it is flammable; sometimes highly flammable, sometimes mildly flammable, but it is flammable. And then, synthetic refrigerant people who work on synthetic refrigerants companies like Dupont, Honeywell, are looking for molecules that can address low global warming, and zero ozone depleting potential with substances that will allow us acceptable values of a coefficient of performance.

The search of course, is a trade-off between cost, safety, energy efficiency, and limiting the need for redesign. If you if you were in the industry, you would find a lot of refrigerant manufacturers coming with a claim, that take this refrigerant, you can just use it as a drop in. So, you remove R 22 for this refrigerant in and you will get sometimes better performance, so that is ideal you know. From a design perspective, we need not do anything, but they do not stand scrutiny, those claims do not stand scrutiny, when they put into a lab environment, they have something which is not explicitly stated.

Now, there is a need to look at old refrigerants in a fresh way. The moment we start accepting flammability, then we start looking at ammonia a different way, we start looking at hydrocarbons in a different way, because they are putting in design measures to handle those refrigerants. And then, there is also market complexity that will come up earlier. A window air conditioner would mean R 22, if it was a product that you purchase beyond 87, before (Refer Time: 26:21) R 12 just to refrigerant.

Now, we are looking at hydrocarbons, we are looking at R 32, and we are looking at some new molecules and of course that is our 410a. So, there is complexity, where there is confusion possible in the market, where the scale level is not very high. Now, in the long run, the number of candidates is likely to fall, but today, it is too early to say, whether it will be the synthetic refrigerants or substances like ammonia, and CO2 or hydrocarbons that will be the main step.

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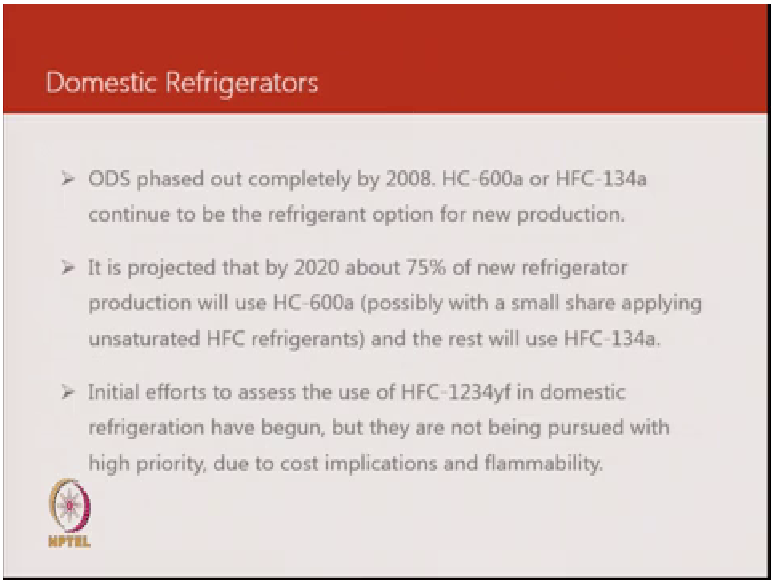

In domestic refrigerators, and the move has been to 600a and HFC-134a, which was used earlier is now being phased out for reasons of global warming. And there is no problem there, because the charge limit is not exceeded. So, we have small charge quantities. And there is often an example that the amount of gas you have in a gas lighter, which you carry in your pocket is comparable to what you have in the domestic refrigerator or some multiples thereof, so there is no concern.

US, which was finding it most difficult to approve hydrocarbons for using refrigerators, it is also accepted, now their standard allows use of hydrocarbons and refrigerators. And US, I mentioned because of the liability concerns there. If there is any problem with the damage, then the company is issued and there could be damages, which would amount to millions of dollars. So, with that, we can say that for domestic refrigerators all issues seem to have been addressed, and we can have refrigerators which have 0 ODP and acceptable GWP or in fact, very low GWP.

There is of course, a new molecule HFC-1234yf, which is under investigation, and the costs are so high that it does not become now used widely. The argument in favor of developing a new molecule is that people have not given up the aspiration to have something as safe as R 12 or R-134a, while simultaneously addressing the ozone and global warming concerns.

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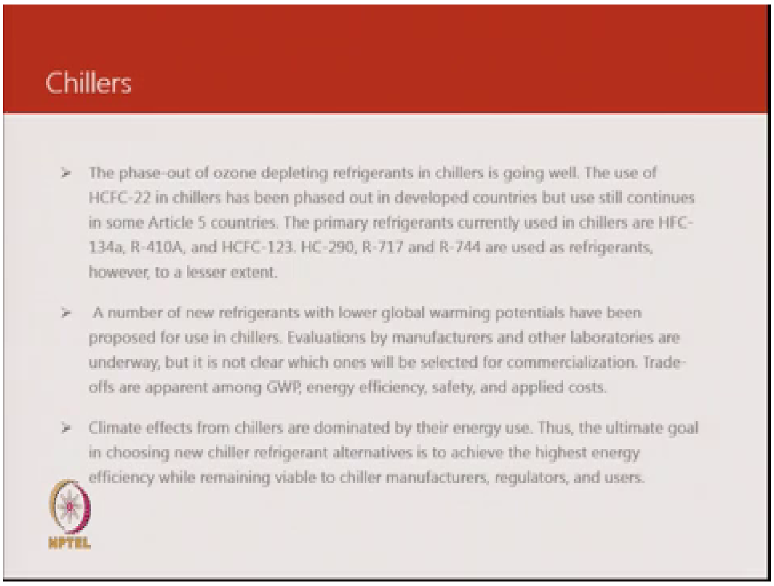

Now, what is happening, when chillers, R 22 has been phased-out in developed countries, but still continues to be used in article 5 countries. So, article five countries refers to developing countries, where there is some funding available for phasing out of refrigerants.

And here again, the scenario or the long term scenario is not so clear, there are new molecules being considered being tested, but which way the industry will finally, move is not certain, this really is an opportunity also. If you were to be getting into this field, the opportunities for engineers in R and D today is more because of these challenges. They are twin challenges of meeting ozone depleting potential, and global warming with newer systems molecules. If you have a new refrigerant, you will have to put in a lot of testing a lot of design effort to meet the EER COP numbers, as well as having reliable systems. So, a huge amount of work opens up for engineers because of these changes that are mandated almost now.

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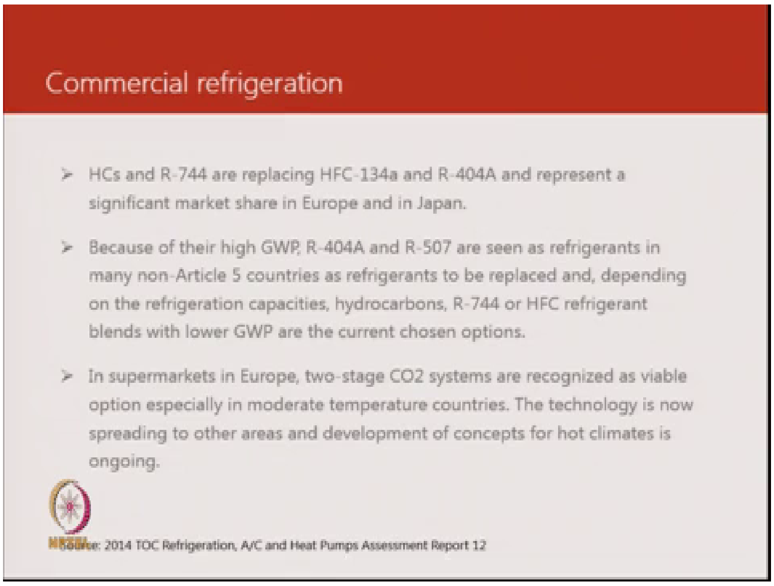

Commercial refrigeration; so, we are talking about commercial refrigeration, what comes to your mind? A large system, there we maintain low temperatures for preservation of food. So, hydrocarbons and CO2 are prime candidates, and where temperatures are high, then using cascade system becomes one of the considerations. In supermarkets in Europe, two-states CO2 systems are recognized as viable option, especially in moderate temperature, because the temperature there allows for CO2 to be accepted in a single stage. For hot climates, cascade weather ammonia would be one of the options.

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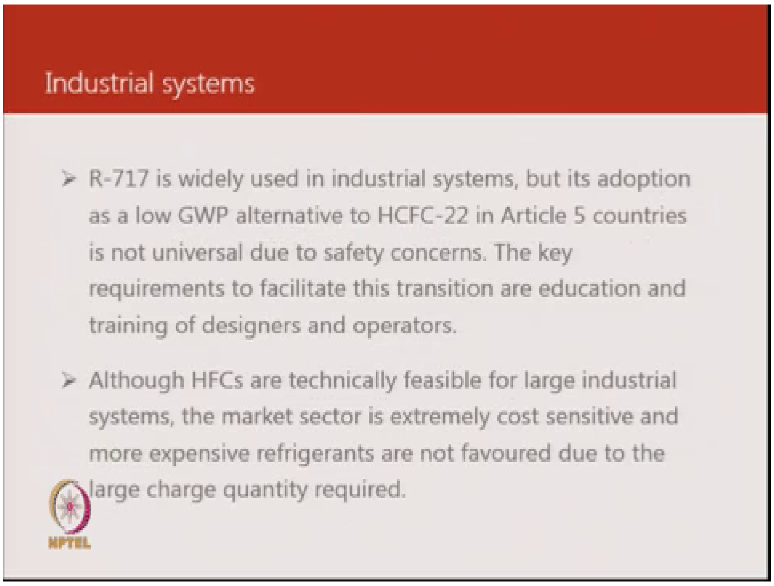

Industrial systems ammonia continues to be you remember nomenclature right 700 plus weight molecular weight, so 717 is ammonia. And HFCs are technically feasible for large industrial systems, the market sector is a very cost sensitive. See when the new molecule is developed, all the R and D dollars that have gone into developing and molecule; the company wants to recover through sale, and initial pricing is prohibitive, and air conditioning is a very price sensitive market, so determined.

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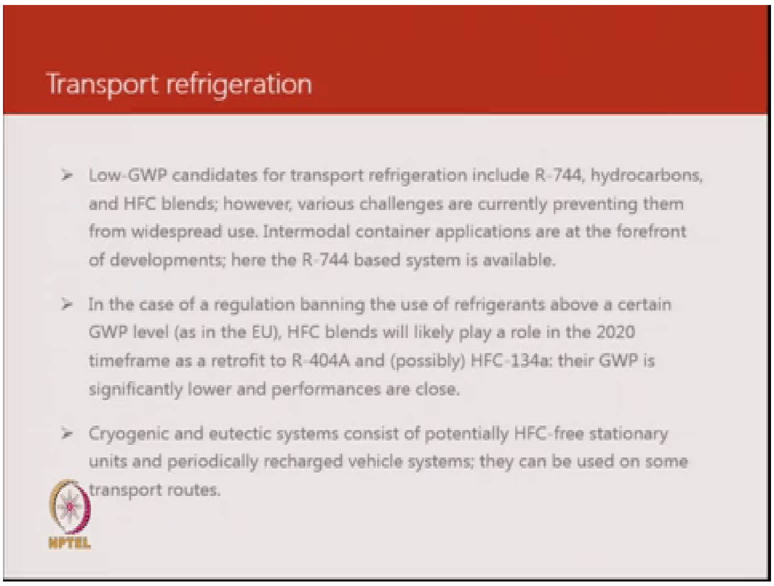

Transport refrigeration again 744. So, 744 means, what?

Student: (Refer Time: 30:58).

Hydrocarbons and HFC blends; so, various challenges are preventing them from widespread use. So, transport is primarily you know rail and ship and all that container refrigeration.

There is another unique cooling method that is being considered, and I got exposure to that in one of the conferences in Delhi last week, and that is making use of a solar power for cooling containers that are exposed, and then using a substance, which is a phase change material. So, you can store cooling. So, you can create additional cooling, when there is sun or when you have access to power, and then the panels inside the container will just keep taking care of the load. Because, if you have good insulation together with some phase change material, you do not need an active refrigeration source, so that is one other way of a looking at things.

And then a newer thing is I came across a Dearman Engine concept, which the university of Birmingham is working on, which is if you have stored cooling available somewhere, can you use that both for cooling, as well as to drive an engine. So, the opportunity for that comes in because of liquefied petroleum gas being transported. So, when you liquefied petroleum, we have cooled it down, and then when you want to reuse it, when it reaches the destination that cooling is available that stored cooling is available, so what do we do with it. So, one of the things is if that could be used gainfully and therefore, offset the energy that would be needed to create that level of refrigeration. So, those are opportunities.

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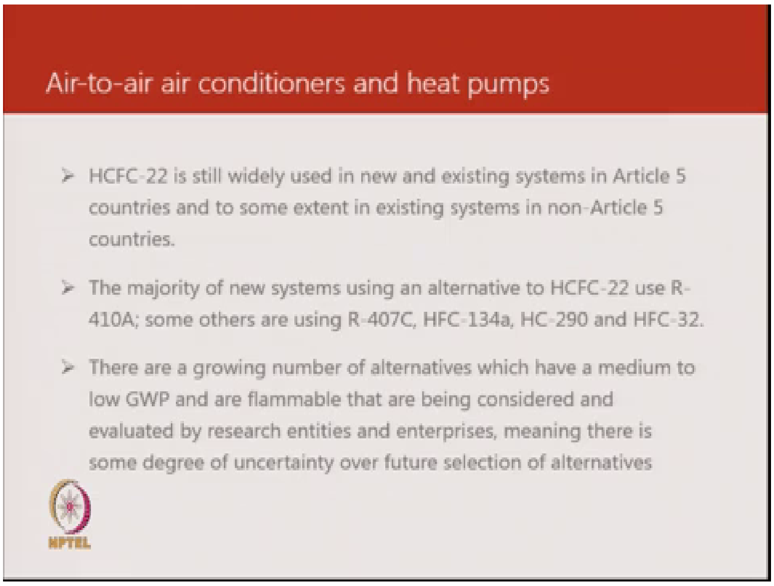

Then things that are closer to what we see and what we use air-to-air heat exchangers and heat pumps. So, HCFC-22 is widely used. In India, we continue to have production, though the production levels are capped, but no new products will be launched with R 22 products that are already there, there are limits. So, companies can produce products with R 22, it continues to be used.

Newer systems make use of R-410A, and then there are attempts made to look at propane and HFC-32. Here again there is a search for the ideal molecule has not been found yet, we do not know what some company comes up with, and (Refer Time: 33:21) there is always an opportunity. But, the chemists if we were to consult them and if they were to look at a spectrum of what is possible with the different molecules that have traditionally been used for refrigeration and air conditioning, they do not see much hope, unless we accept a certain level of flammability, we will have a global warming impact, so that is a.

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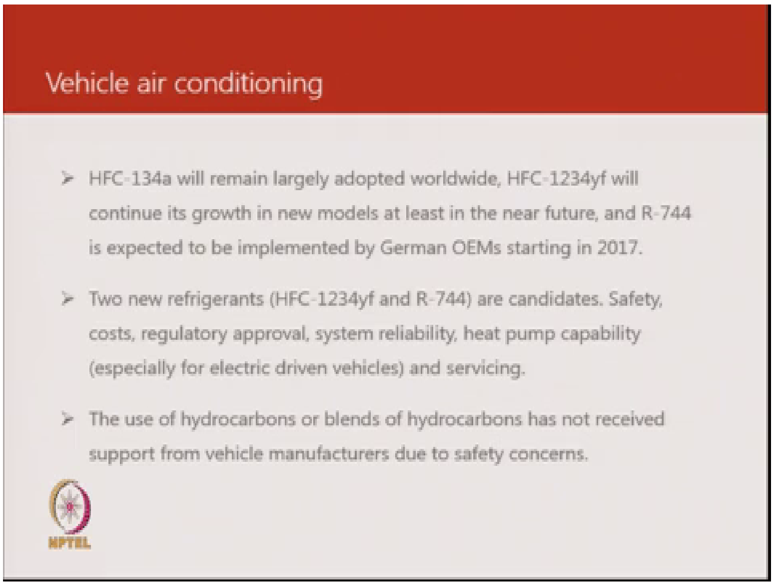

Vehicle air conditioning HFC-143a is in widespread use and seems to be there for some time because of a safety concerns. Vehicle manufacturers are not accepting hydrocarbons and vehicles, even though we use fuel. But, then there are considerations and to where the hydrocarbon would be when an accident happens or what kind of risk of explosion is there. So, they have a very I mean the automobile organizations are very organized, and have (Refer Time: 34:20) standards, they have not been able to find a way to approve use of flammable refrigerants yet.

And there are some new refrigerants. So, 1234yf and CO_2, these are the two refrigerants, which are being considered. One of the manufacturers has announced that they will be using CO_2 in their vehicle air-conditioning systems. So, what else; so, that automobile manufacture the German OEMs, and in this year, they will start manufacturing a CO_2 based air-conditioning systems for their vehicles, so that is a new trend. And 1234yf, I mentioned before already. And the long term scenario is not yet clear, so what comes out of different initiatives and different companies, who vehicle air conditioning will determined, what will finally be the mainstream.

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Single Component Refrigerants (Methane Series)

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m/ ppm)	GWP 100 Year	GWP 20 Year	ODP
Methane series												
CFC-11	CCl_3F	trichlorofluoromethane	137,4	24	0,006 2	NF	A1	52	0,26	5 160	7 090	1
CFC-12	CCl_2F_2	dichlorodifluoromethane	120,9	-30	0,088	NF	A1	102	0,32	10 300	10 800	0,73
CFC-13	$CClF_3$	chlorotrifluoromethane	104,5	−81	ND	NF	A1	640	0,25	13 900	10 900	1
BFC-13B1	$CBrF_3$	bromotrifluoromethane	148,9	−58	ND	NF	A1	72	0,30	6 670	7 930	15,2
PFC-14	CF_4	tetrafluoromethane (carbon tetrafluoride)	88,0	-128	0,40	NF	A1	50000	0,09	6 630	4 880	
HCFC-22	$CHClF_2$	chlorodifluoromethane	86,5	-41	0,21	NF	A1	12	0,21	1 780	5 310	0,034
HFC-23	CHF_3	trifluoromethane	70,0	-82	0,15	NF	A1	228	0,18	12 500	10 800	
HCC-30	CH_2Cl_2	dichloromethane (methylene chloride)	84,9	40	ND	NF	B1	0,4	0,03	9	33	
HFC-32	CH_2F_2	difluoromethane (methylene fluoride)	52,0	-52	0,30	0,307	A2L	5,4	0,11	704	2 530	
HC-50	CH_4	methane	16,0	−161	ND	0,032	A3	12,4	3,63e-4	30	85	

Now, we will go through some of the properties of refrigerants. And the whole idea is for you to become aware of for example, their chemical formulation and things like boiling point, all the parameters that we were discussing in the beginning. When we want to choose a refrigerant are presented here, we need not go through each of them line by line, but you need to have an appreciation. That this is data and this data is coming from one of the technical options committee of UNIP. It is open data; you can have access to it.

I probably will send you a link to it, so that each of you can download, and it is much more exhaustive than the information that I have used in my slides. It gives you a full overview of the refrigerant scenario globally. It is also a very good reference point to take data. So, when you are looking for a global warming potential or ozone depleting potential or the boiling points, it is a very credible source, because industry experts have come together, they have reviewed and they have been reviewed several times, before this document was published.

So, as a designer, you must have access to and have a copy with yourselves, and this is open to public, so no proprietary rights or any kind of limits on use. So, here we can look at R 11, 12, 13, they are all now history. Then R 22 or HCFC-22 is going to be history soon, but we will see it being used for products that were already in production before

2017. R 32 or HFC-32 is an emerging refrigerant, and then there are a few others. So, this was methane series, and then we have ethane series.

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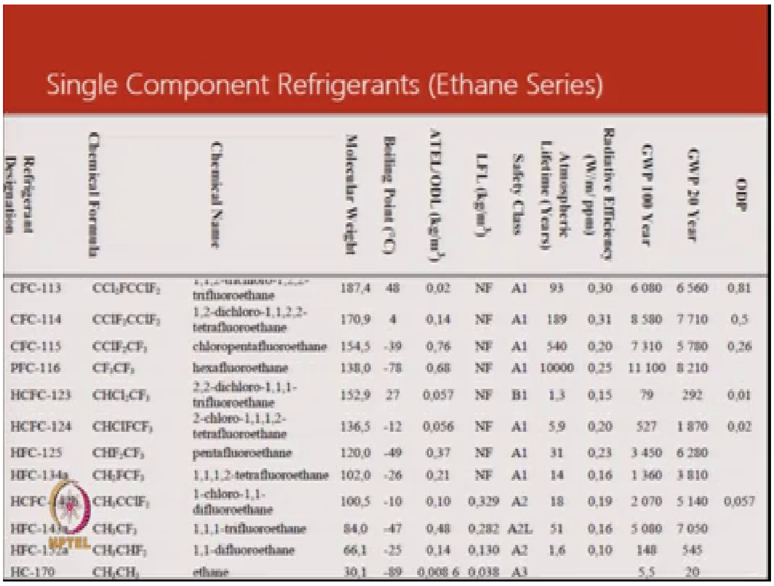

Single Component Refrigerants (Ethane Series)

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m² ppm)	GWP 100 Year	GWP 20 Year	ODP
CFC-113	CCl_2FCClF_2	trifluoroethane	187,4	48	0,02	NF	A1	93	0,30	6 080	6 560	0,81
CFC-114	$CClF_2CClF_2$	1,2-dichloro-1,1,2,2-tetrafluoroethane	170,9	4	0,14	NF	A1	189	0,31	8 580	7 710	0,5
CFC-115	$CClF_2CF_3$	chloropentafluoroethane	154,5	-39	0,76	NF	A1	540	0,20	7 310	5 780	0,26
PFC-116	CF_3CF_3	hexafluoroethane	138,0	-78	0,68	NF	A1	10000	0,25	11 100	8 210	
HCFC-123	$CHCl_2CF_3$	2,2-dichloro-1,1,1-trifluoroethane	152,9	27	0,057	NF	B1	1,3	0,15	79	292	0,01
HCFC-124	$CHClFCF_3$	2-chloro-1,1,1,2-tetrafluoroethane	136,5	-12	0,056	NF	A1	5,9	0,20	527	1 870	0,02
HFC-125	CHF_2CF_3	pentafluoroethane	120,0	-49	0,37	NF	A1	31	0,23	3 450	6 280	
HFC-134a	CH_2FCF_3	1,1,1,2-tetrafluoroethane	102,0	-26	0,21	NF	A1	14	0,16	1 360	3 810	
HCFC-142b	CH_3CClF_2	1-chloro-1,1-difluoroethane	100,5	-10	0,10	0,329	A2	18	0,19	2 070	5 140	0,057
HFC-143a	CH_3CF_3	1,1,1-trifluoroethane	84,0	-47	0,48	0,282	A2L	51	0,16	5 080	7 050	
HFC-152a	CH_3CHF_2	1,1-difluoroethane	66,1	-25	0,14	0,130	A2	1,6	0,10	148	545	
HC-170	CH_3CH_3	ethane	30,1	-89	0,008 6	0,038	A3			5,5	20	

A ethane would mean two carbon atoms, and then different molecules around how many fluorine, chlorine, and hydrogen atoms are there. And notable here is HFC-134a, which is a replacement for R 12 and has been used in domestic refrigerators.

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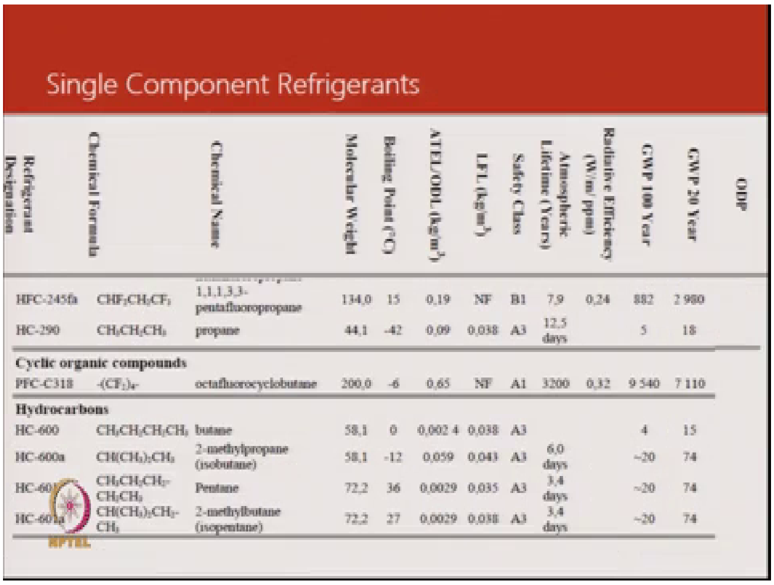

Single Component Refrigerants

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m³)	LFL (kg/m³)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m² ppm)	GWP 100 Year	GWP 20 Year	ODP
HFC-245fa	$CHF_2CH_2CF_3$	1,1,1,3,3-pentafluoropropane	134,0	15	0,19	NF	B1	7,9	0,24	882	2 980	
HC-290	$CH_3CH_2CH_3$	propane	44,1	-42	0,09	0,038	A3	12,5 days		5	18	
Cyclic organic compounds												
PFC-C318	$-(CF_2)_4-$	octafluorocyclobutane	200,0	-6	0,65	NF	A1	3200	0,32	9 540	7 110	
Hydrocarbons												
HC-600	$CH_3CH_2CH_2CH_3$	butane	58,1	0	0,002 4	0,038	A3			4	15	
HC-600a	$CH(CH_3)_2CH_3$	2-methylpropane (isobutane)	58,1	-12	0,059	0,043	A3	6,0 days		~20	74	
HC-601	$CH_3CH_2CH_2$-CH_2CH_3	Pentane	72,2	36	0,0029	0,035	A3	3,4 days		~20	74	
HC-601a	$CH(CH_3)_2CH_2$-CH_3	2-methylbutane (isopentane)	72,2	27	0,0029	0,038	A3	3,4 days		~20	74	

Now, we have another 10 minutes, and I also want to use some time for your assignment. So, one thing is I take 2 minutes, just quickly take you through. You have got an idea, these slides will be made available to you better still I would make available that link to the TOC report, so you can have access to it. It is one place, where you can look at all the refrigerants that are in use, where they are being used alright.

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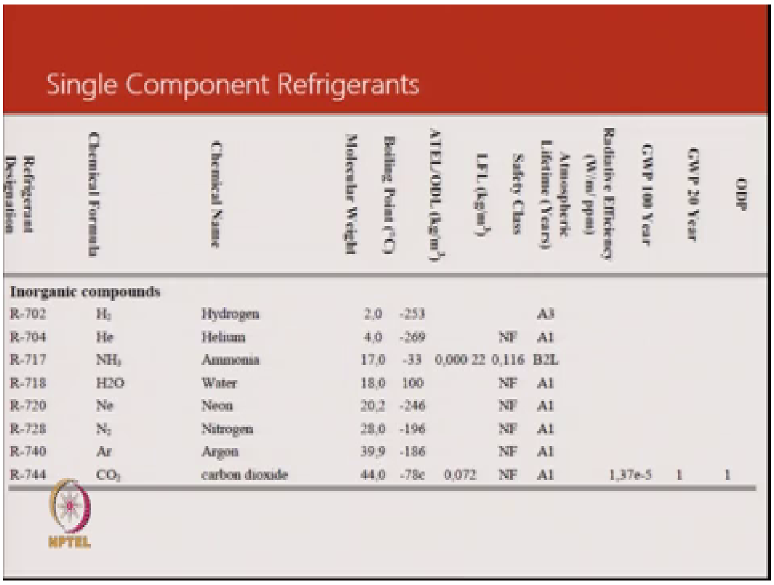

Single Component Refrigerants

Refrigerant Designation	Chemical Formula	Chemical Name	Molecular Weight	Boiling Point (°C)	ATEL/ODL (kg/m^3)	LFL (kg/m^3)	Safety Class	Atmospheric Lifetime (Years)	Radiative Efficiency (W/m^2 ppm)	GWP 100 Year	GWP 20 Year	ODP
Inorganic compounds												
R-702	H_2	Hydrogen	2,0	-253			A3					
R-704	He	Helium	4,0	-269		NF	A1					
R-717	NH_3	Ammonia	17,0	-33	0,000 22	0,116	B2L					
R-718	H2O	Water	18,0	100		NF	A1					
R-720	Ne	Neon	20,2	-246		NF	A1					
R-728	N_2	Nitrogen	28,0	-196		NF	A1					
R-740	Ar	Argon	39,9	-186		NF	A1					
R-744	CO_2	carbon dioxide	44,0	-78c	0,072	NF	A1		1,37e-5	1	1	

So, a single component Refrigerants like the inorganic compounds, so here is a list of that as well.

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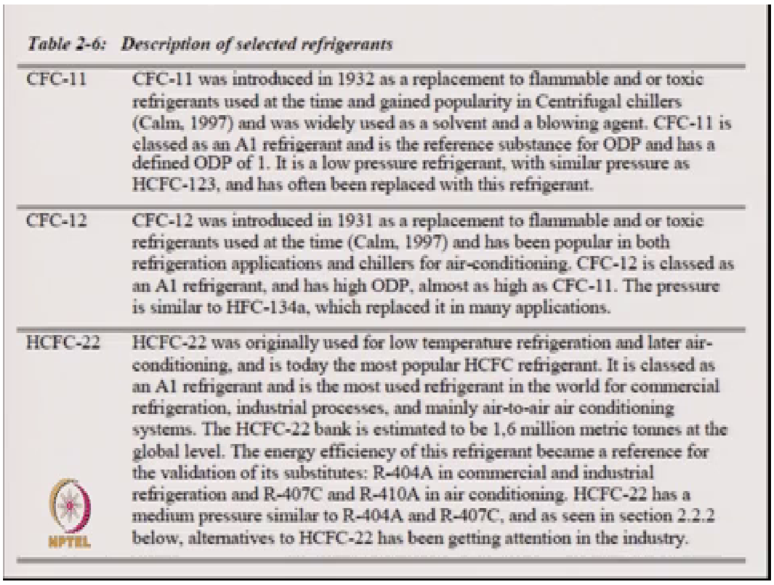

Table 2-6: Description of selected refrigerants

CFC-11	CFC-11 was introduced in 1932 as a replacement to flammable and or toxic refrigerants used at the time and gained popularity in Centrifugal chillers (Calm, 1997) and was widely used as a solvent and a blowing agent. CFC-11 is classed as an A1 refrigerant and is the reference substance for ODP and has a defined ODP of 1. It is a low pressure refrigerant, with similar pressure as HCFC-123, and has often been replaced with this refrigerant.
CFC-12	CFC-12 was introduced in 1931 as a replacement to flammable and or toxic refrigerants used at the time (Calm, 1997) and has been popular in both refrigeration applications and chillers for air-conditioning. CFC-12 is classed as an A1 refrigerant, and has high ODP, almost as high as CFC-11. The pressure is similar to HFC-134a, which replaced it in many applications.
HCFC-22	HCFC-22 was originally used for low temperature refrigeration and later air-conditioning, and is today the most popular HCFC refrigerant. It is classed as an A1 refrigerant and is the most used refrigerant in the world for commercial refrigeration, industrial processes, and mainly air-to-air air conditioning systems. The HCFC-22 bank is estimated to be 1,6 million metric tonnes at the global level. The energy efficiency of this refrigerant became a reference for the validation of its substitutes: R-404A in commercial and industrial refrigeration and R-407C and R-410A in air conditioning. HCFC-22 has a medium pressure similar to R-404A and R-407C, and as seen in section 2.2.2 below, alternatives to HCFC-22 has been getting attention in the industry.

And then you also see what refrigerant is in what is the trend, when it was introduced what happened to it, what is replacing it, all that is there in the subsequent slides.

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HFC-32	HFC-32 was originally used as a component of refrigerant blends such as R-407C and R-410A. Pressure and capacity are around 1.5 times higher than HCFC-22 and slightly higher than R-410A. It is classed as A2L. The efficiency of HFC-32 systems are higher than R-410A but less than HCFC-22. Discharge temperatures are higher than R-410A and HCFC-22 and thus some mitigation device or controls may be necessary for handling the discharge temperature of the compressor especially at high ambient temperatures.
HCFC-123	HCFC-123 is mainly used in centrifugal chillers and is classed as a B1 refrigerant. HCFC-123 is a low-GWP HCFC refrigerant, but since it is an ODS it is being phased-out under the Montreal Protocol.
HFC-125	HFC-125 is used as a component of refrigerant blends such as R-404A and R-410A to lower discharge temperature and reduce flammability from other components.
HFC-134a	HFC-134a is used in a variety of equipment including heat pumps, chillers, mobile air conditioning and domestic refrigeration and has a pressure lower than HCFC-22 and similar to CFC-12. It is classed as an A1 refrigerant. Energy efficiency is good, provided that pipes and heat exchangers are suitably sized.
HFC-152a	HFC-152a has performance characteristics similar to HFC-134a as well as 10% lower vapour pressure and volumetric refrigeration capacity. It is classed as an A2 refrigerant. HFC-152a is used as a component in several new blends.

So, here you can see a full spectrum of refrigerants.

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Real Systems COP→EER

- We need to start looking at Energy Efficiency and not just system COP
- This means taking into consideration Compressor Motor efficiency, Power consumed by Fans, Blowers, defrost arrangements, solenoid valves if any and other controls for safety and regulation

And real systems; when you have designing systems, we need to start thinking a little different, so not COP, but energy efficiency ratio. So, we saw that we do not have the Ideal Carnot, Reverse Carnot cycle in systems. So, we will have some compression that will happen only in the superheated region that will lead to some inefficiency. We will have delta T between the ambient and the refrigerant that will lead to some penalty, and therefore our EER will COP will come down.

But, other than that, there are things like compressor motor efficiency power used by fans and blowers, which will bring down the COP. So, when you are looking at numbers closer to 5 and a half, they moving towards the 3.7 or 3.5 happens, because there is more power being used by different elements, and we are losing in efficiency because of compression in the superheated region.

And you can look at the Carnot cycle, and the Vapour compression cycle, and you notice, where that is being done, we have discussed that in our previous lectures. We also can look at how much work that was possible to recover in the expansion process is lost, because he give adapt for simplification and for reasons of lowering the initial cost, but you need to have an idea of it. So, before design a big system, you might want to recover, and get the energy efficiency ratio up.

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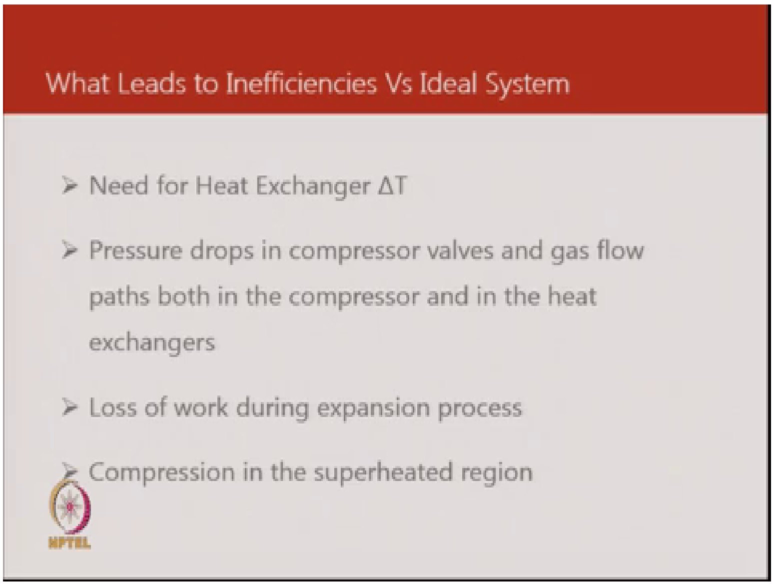

So, heat exchanger delta T, we have discussed. Pressure drops. So, pressure drops going to happen compressor or suction and discharge valves, piping, heat exchanger tubes, circuiting, that we do, all that is going to have a penalty, and that is going to lead to inefficiencies.

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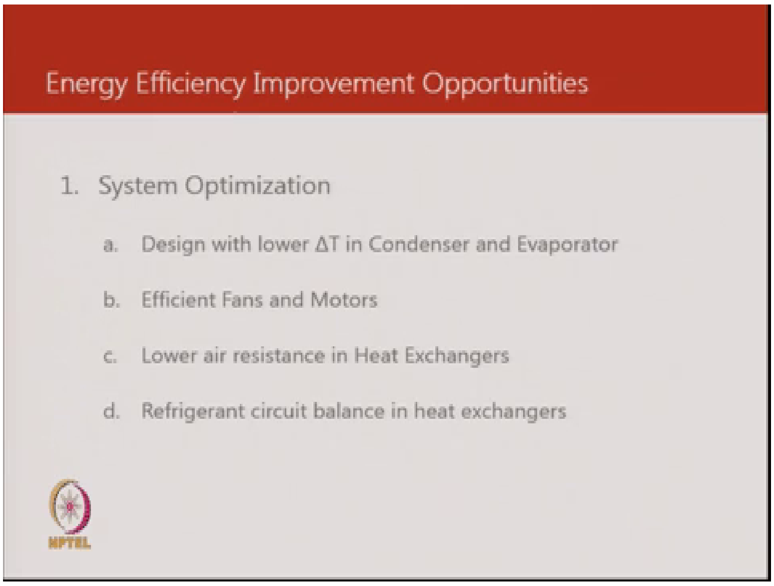

And when we are looking at designing efficient systems, then we will begin with the least delta T in the heat exchangers, and we will optimize of course, with cost and space and size available. And we look at air resistance and the heat exchangers, which is going to indirectly influence the fan power. So, what fin spacing are we going to use, how many rows you are going to use, what are the benefits you are getting in terms of approach to the ambient temperature or the temperature of air being cooled.

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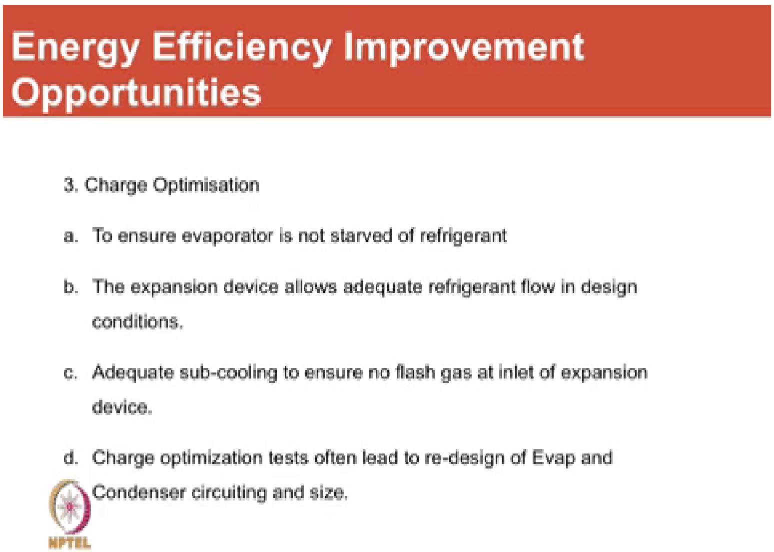

And then charge optimization. So, I think charge optimization is an important part of the system delivering, what it is designed for. So, we design a good heat exchanger, we design a good set of piping, expansion device selection, and the compressive selection, but finally, if you do not have the right charged quantity, what is going to happen. Too lower charge quality means, some part of the evaporator surface is underutilized, it is start off refrigerant, so we do not get the full heat transfer opportunity that is there. If we overcharge it, we will increase the pressures, and we will load overload the compressor right.

So, we would undertake a lot of tests to make sure that we have a balance point, we have the right degree of sub-cooling, and we have the right amount of superheat, you know optimize the system. And sometimes when you are doing the optimization process in the laboratory, we will discover one of the components is not balanced. So, we find that we have two large and evaporator or two small and evaporator, and we need to do some iterative work, because the predictive value of heat transfer software may not be as good, so that is the final part of tuning the system to deliver expected performance.

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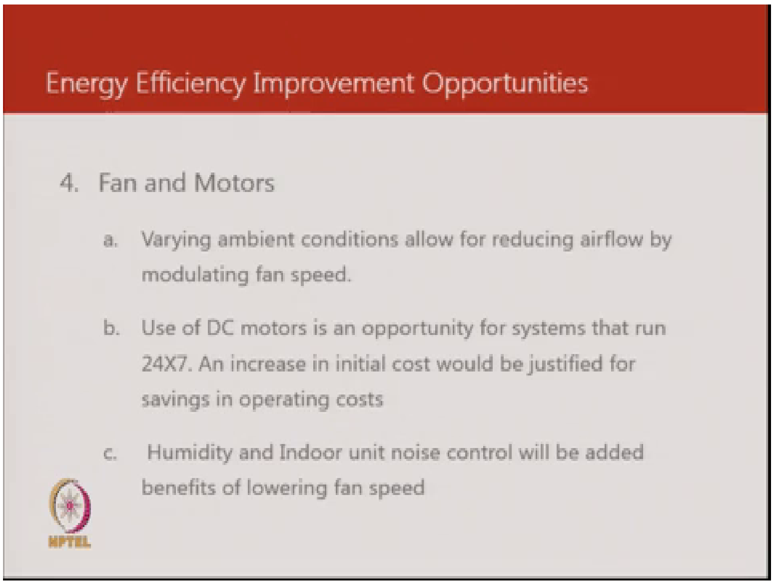

And now, talked about motors; now, one of the things is to utilize opportunity for a motor power saving. So, if we drop the fan speed, what will happen to power, now it is proportional to cube of the RPM, whereas the air flow is proportional directly to the

RPM. So, we have an opportunity for reducing fan power, when the ambient goes down, keeping the same delta T.

So, this becomes an iterative and some kind of a process of optimization. So, what is the balance point. What penalty of increase in condenser temperature is acceptable for a lower airflow volume. What is the power saving we are getting there. So, as you develop the ability to appreciate these design variables, you can optimize systems better. And then DC motors allow for more higher part load efficiency, and it is useful in systems like telecom, cooling, whether the 24 by 7 requirement.

So, with this, now I stop for this particular lecture.