Cryogenic Engineering
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Lecture No. # 33
Cryogenic insulation

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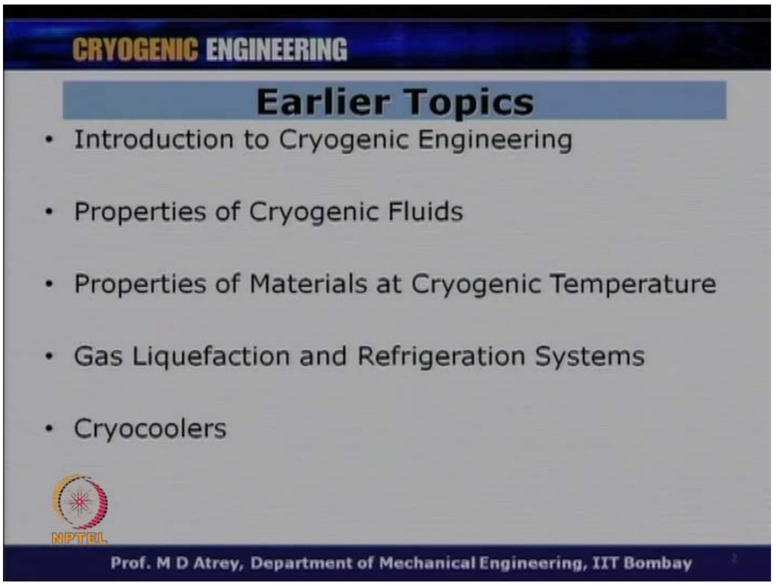

So, welcome to the 33 lecture on cryogenic engineering under the NPTEL program. We are going to start today a new topic. And the earlier topic 's that have been covered till now, are as follows; we are introduced the cryogenic engineering part. We talked about properties of cryogenic fluids. We talked about properties of materials at cryogenic temperature, we talked in detail about gas liquefaction and refrigeration systems, also we talked about gas separation there, we talked about cryocoolers.

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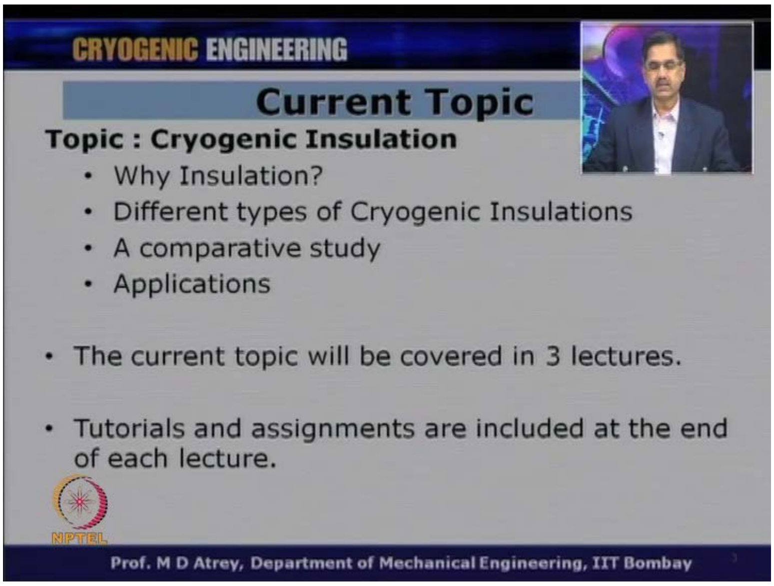

Now, taking the micro a head. In the current topic now, we are going to cover cryogenic insulation: which is a very important part in cryogenic Engineering. Under this topic, we will cover why insulation? What is the need to have a insulation in cryogenic engineering. Then we will talk about different types of cryogenic insulations, will do a comparative study amongst all this cryogenic insulation that are possible. Then will see applications of this cryogenic engineering insulations; and this topic will be covered in around 3 lectures. And then, will have tutorials and assignments during the course of these lectures.

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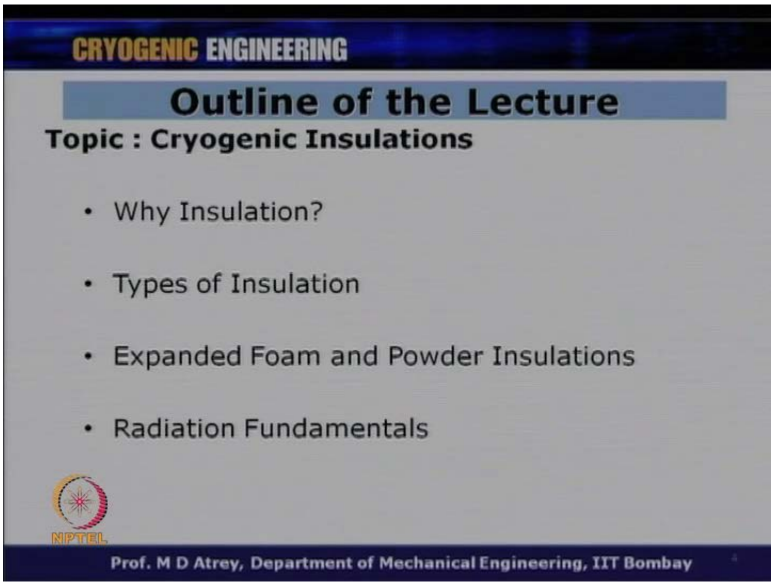

So, the outline of this lecture is cryogenic insulations. Why insulation - the types of insulations, and we will talked about expanded foam and powder insulations, and will have some radiation fundamentals - fundamental associated with radiation mode of heat transfer, which most of you know for sure.

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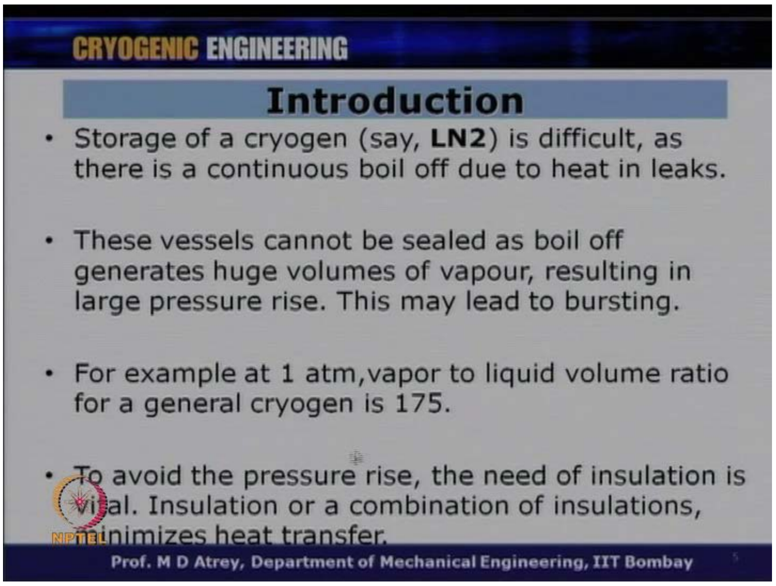

So, introduction as to why should we have cryogenic insulation. And before, we go to you know the formal lecture, you know that we are talking about very low temperature. We are talking about 77 kelvin, 4.2 kelvin. And our ambient temperature is normally around 300 kelvin which is quiet high as compare to this cryogens. So, there are naturally heat transfer from high temperature to low temperature; and therefore, we will always have heat rush from outside to inside. And therefore, our fundamental task is to reduce this amount of heat transfer from very high temperature, which is 300 kelvin which is ambient temperature to the cryogenic temperatures.

So, this is very straight forward that why should we have insulation? We should have insulation, because we want to prevent this heat in leaks from ambient temperature to the cryogenic temperature. We cannot of course, make this heat in leak to be equal to 0. So, what we should we do - we should try to minimize this heat in leaks, and therefore we should have various insulations with their capabilities, with their different capabilities. So, as to minimize the heat in leaks from room temperature to the cryogenic temperature. In fact, whatever sample we want to cool for example, in physics or we have got a cryostat, we have got a sample dipped in liquid helium or we have got a cryocooler working at 4.2 kelvin. The cooling effect of this cryocooler or cryogen is very important.

And if we do not we prevent this heat in leaks, then whatever cooling effect is produced by these machines or cryogens will be neutralized. In fact, it will be eaten up first by this heat transfer that is going to come from room temperature. And therefore, it is very essential that we minimize, this heat in leaks from room temperature to the low temperature

So, for example, storage of a cryogen let us say LN2; that is at 77 kelvin is difficult, as there is a continuous boil off. If you see, LN2 any time; and we have seen this earlier, you will always see, there is some vapors coming out of the cryostat. So, there is a continuous boil off, due to heat in leaks. That means, whatever you do you cannot prevent this boil off. If you come next day, you will find that the level of liquid nitrogen as gone down. And that is because of the heat in leaks and therefore, the liquid nitrogen level will always go down over the period of time.

This vessels, cannot be sealed as boil off generates huge volumes of vapor resulting in large pressure rise. If want to enclose everything, and if I say I I do not to see this boil off, and we are going to a lead on the top what's will happen - slowly and steadily the pressure inside will start increasing. Because the volumes of vapor will result in large pressure rise, and ultimately this may lead to bursting.

So, we want to reduce this boil off; we cannot of course, keep this cryostats or cryo continuous completely closed; you cannot have a sealed leads over there. The boil off will always occur, because the heat in leaks always occur. Although, we can just minimize this heat in leaks. For example, at one atmosphere; the vapor to liquid volume ratio is the order of 175, can you imagine this. Let us say one liter of liquid will produce around 175 liters of vapor. And that means, you can see this is a volume ratio that is going to be generated. And if you got a less volume available over there, the pressure will start increasing in the cryostat, and this can be fetal sometimes this can be dangerous also. And therefore, we have to keep this cryostat covered, I mean we have to allow this boil off to basically come out of the cryostat, and we want to minimize this boil off.

So, that the experiment can last for a longer duration; to avoid the pressure rise, the need of insulation is vital. That means, the boil off will be reduced in this case. Insulation or a combination of insulations minimizes, this heat transfer from outside to inside from ambient to the cryogenic temperature. So, what we want to do with insulation basically, we would like to minimize the amount of heat transfer that takes from outside to inside, outside temperature to the inside temperature.

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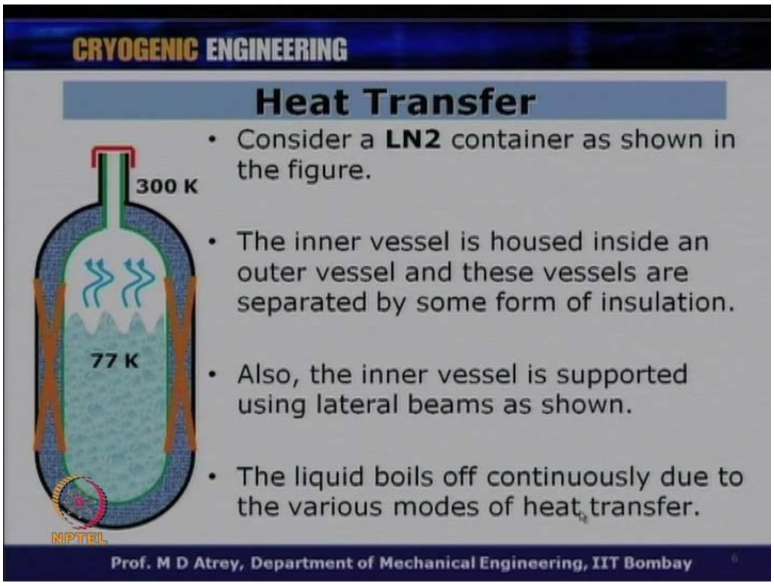

So, for example, we can see in a schematic, that we have got a a container outside temperature it is on 300 kelvin, and let us say liquid nitrogen here which is around at 77 kelvin. And this a open volume where the boil of would get stored. So, from 300 K to 77 K, we have got different ways in which the heat can transfer from outside to inside.

So, Consider a LN2 container as shown in this figure. The inner vessel is housed inside an outer vessel, and these vessels are separated by some form of insulation. So, we have got a inner vessel which houses liquid nitrogen, we have got a outer vessel which which should have actually insulation over here. So, you can see that there is inner vessel, and there we have got these members which are giving actually straight or which are holding this inner vessel, against outside vessel. Also the inner vessel is supported using lateral beams as shown here.

So, basically how will this inner vessels stand here; the inner vessel would stand here, because of this support given by this lateral beams. But do not forget, that lateral beams one part is at 77 kelvin, the other part is at 300 kelvin. That means, it is going to bring some heat inside. And what you see in a bluish thing could be some kind of insulation;

so as to prevent the amount of heat leak that happens from 300 kelvin to 77 kelvin. The liquid boils off continuously due to the various modes of heat transfer.

So, as I said whatever you do the boil off will happen continuously and therefore, the boil of would happened, and you can always see the vapors coming out of this. If this is closed, after sometime this will burse otherwise. So, we cannot keep it close at all, we have to have some way outs that is vapor will come outside. But what we will like to, do we would like to reduce the rate of this vapor generation or reduce the boil off; that means, in 1 day or in 7 days the level should not go drastically down. I would still be able to have some liquid nitrogen left over here. So, that I can do a experiments over period of time.

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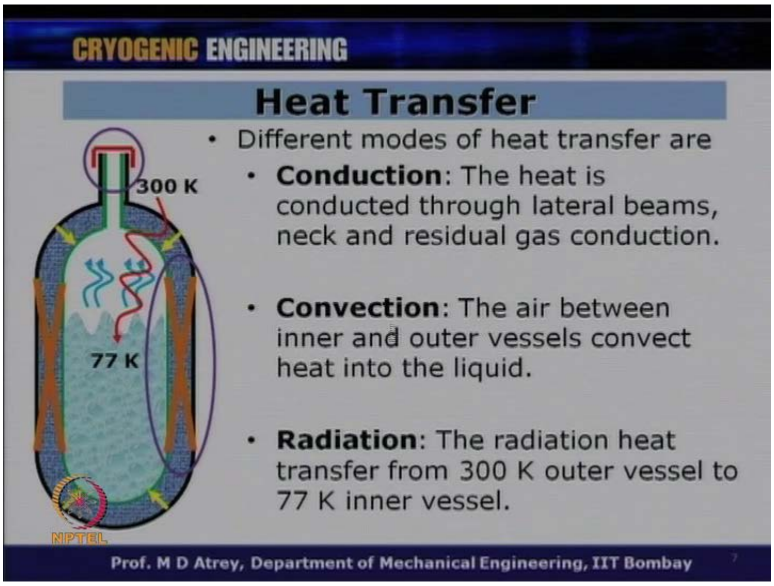

So, different modes of heat transfer, most of you know all this things will just have a one slight to you know, just brush off your knowledge. So, will have conduction. So, you can see conduction happening from across this neck; this is very important area, because this is something which we cannot avoid. So, we will have one end of this neck at 300 kelvin, the other neck will be at around 77 kelvin; and you will have always have some conductive path through which heat will get transferred from 300 K to 77 K. And therefore, this will result in boil off what we should is to minimize this conductive path. The heat is conducted through lateral beams - lateral beams are also bringing in lot of heats, so this supports structure. Whatever we have from the inner vessel would also conduct heat from outside to inside.

So, we have to minimize the conduction phenomena happening across the neck, happening across the lateral beams; also we got residual gas conduction. Many times will have vacuum between this inner vessel and outer vessel, but still depending on the kind of vacuum you have, depending on the level of vacuum we have, will always have some residual gas over here. And this residual gas, will cause residual gas conduction. Although, if you minimize, depending on the vacuum levels we are talking about.

So, conduction will occur, as a solid conduction across the neck, solid conduction across the beams, and we will have a gas conduction or residual gas conduction across the insulation, if you have vacuum over here. Whatever gas, we have we have mostly air, and we will try to minimize this air as much as we can, but still will have some residual gas conduction. Then we have got a phenomena convection also; the air in between the inner and the outer vessels will Convert heat into the liquid.

So, will have convection here, because of the motion of whatever gas we are talking about; air or any gas, and it will also have convection. If you remove this air by Vacuum; that means, will have minimal gas quantity over here, and we try to minimize this mode of convection. The third thing is also radiation. So, will always have one surface at 300 kelvin, and other surface at 77 kelvin. And therefore the radiation will always occur, you know that radiation does not require any media basically.

So, the radiation heat will transfer from 300 K outer vessel to 77 K inner vessel. So, these are the ways in which the heat transfer would always happen - conduction, convection and radiation. And find out always who is responsible conduction - who is responsible for convection, and who is causing radiation, as we know the surfaces would cause; the whole attempts of having insulation or designing this insulation is to minimize this all all this 3 modes of heat transfer basically.

So sigma conduction, sigma Q conduction, sigma Q convection, and Q radiation; we have to minimize this Q. And therefore, we will have to design insulation accordingly.

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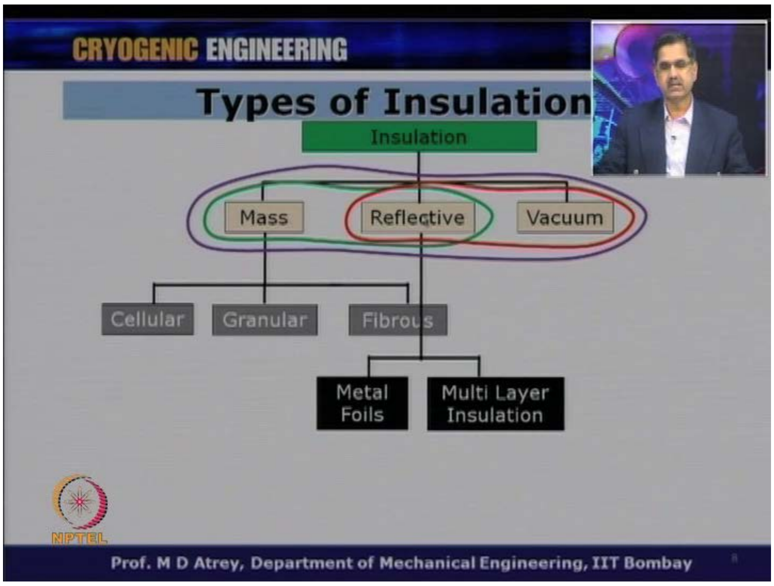

Now there are various types of insulations. And the insulation could be broadly classified as mass insulation, reflective insulation and vacuum insulation. So, you have got a mass; that means, you have got some material sitting over there; we got some reflective surfaces over there. So, so that whatever Q comes get we will get reflected back or we can have vacuum. So, we will have some mass insulation, reflective insulation or vacuum insulation. Under mass insulation, we will have cellular insulation, Granular insulation or fibrous insulation.

So, we can have material which has got cells associated with or cellular structure associated with heat, we can have granular structure associated with, and we can have Fibrous. So, kind of mass material that we are going to use, depending on the geometry of this material this is further classified. And then we got a reflux to surface between the outside surface, and the inside surface, which has you know will reflect all the Q, that is coming from outside to inside. Under this reflective insulation, we can have meat foils which most of you know, and we can have multi layer insulation about which will study more.

So, we can have either of this two things; meat foils, and multi layer insulation. And the third thing is vacuum. As you know vacuum is a very important development which devour had basically you know done, that we you know that we have got two flasks, and if you remove the air between them. The (( )) of heat transfer like conduction and convection can be taken care of, but what we cannot take care of this is radiation.

So, what we do normally, we can have a combination of mass plus reflective insulation. So, we can do any combination depending upon the kind of insulation, we have in mind. So, we can have a combination of mass plus reflective insulations or we can have vacuum plus reflective insulation or also we can have all this 3 into account. So, you can see that, we can have any combination possible, but then we have to pay for every combination. So, depending on the kind of costing we have talking about, we can have mass only, reflective only or vacuum only or we can have a combination of mass plus reflective, reflective plus vacuum or all three together.

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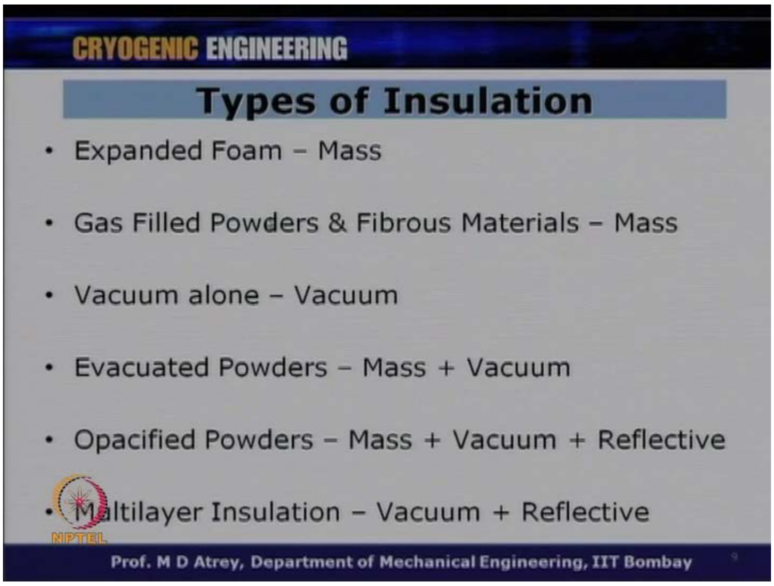

And let us see now, what what are this different types of insulations which come under this categories. So, let us a types of insulations we are going to talk about. We have got a Expanded Foam. So, in this case we are going to talk about mass insulation, where we can use foams which normally most of you know that, we have got foam in refrigeration also most of the pipes running from, you know high temperature to low temperature you can always see that, it is covered with foams.

In air condition also at foam, you can see that most of the lines are covered with Foam; and same could be use at cryogenic temperature, although that may not be very very effective. Then we got a gas filled powders and fibrous material which also pass under mass category; it is normally called as powder insulation. And this powder insulation is fill with gas or it could be evacuated powder also.

Then we got a some something called vacuum alone insulation; we can call it vacuum insulation, which most of you know, that if you have got a vacuum, most of the conduction and convective heat transfer modes can be taken care of. Then, we can have evacuated powder, we had a gas filled powder then we have vacuum, and then we can have powder with vacuum, and this called as evacuated powder which comes under category of mass plus vacuum. And we can have opacified powder which is mass plus vacuum plus some reflective elements and added to the powders.

So, we can have combination of this three, mass plus vacuum plus reflective types of insulations. And lastly we can have multilayer insulation which was very well with vacuum only. So, vacuum plus reflective which will cause you multilayer insulation. So, these are all the different types of insulation that could be use in cryogenics, and depending on their temperatures we are going to talk about, depending on the costume you have going to talk about, their effectiveness can be justified. The use of this particular insulation can be justified.

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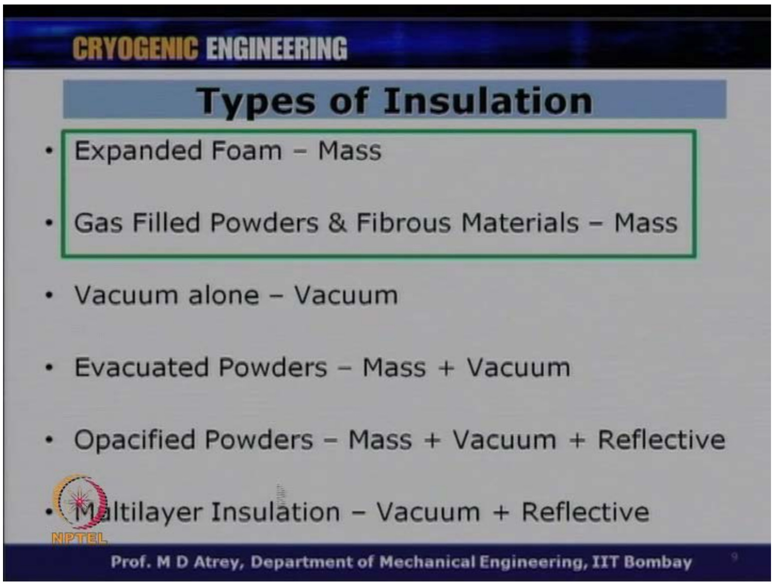

Today in this lecture, we will going to cover the first two types, and eventually in the other two lectures I will over rest of the insulation. So, will talk about now expanded foam insulation, and fallowed by gas filled powder.

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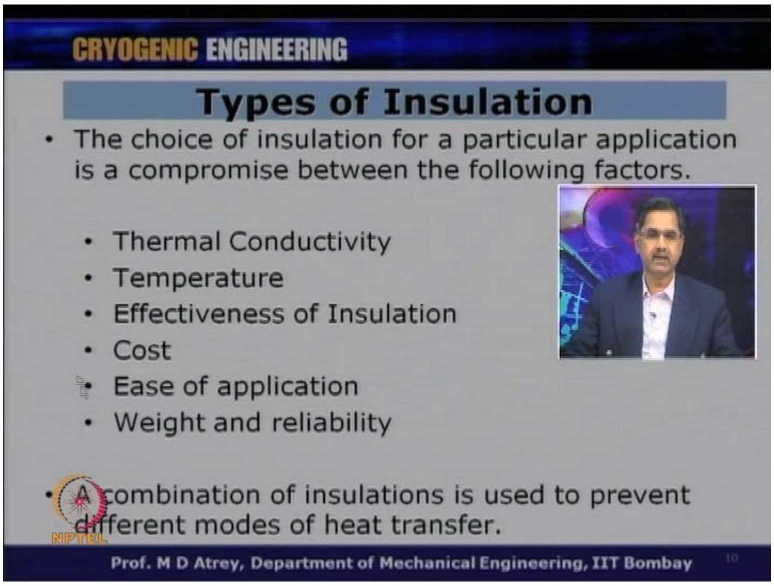

So, choice of insulation for a particular application is a compromise between the fallowing factors. So, what insulation has to be use; how do we decide that we want to use only this particular insulation in this case, will be governed by various parameter, the thermal conductivity of the material itself. You want to have minimum thermal conductivity. The temperatures we are going to talk about. What is the temperature I am talking about; 300 to 150 kelvin, 300 to 120 kelvin, 300 to 77 or 300 to 4.2 kelvin.

So, depending on the temperature levels, I will have different insulations associated with. For example, I cannot just use foam for a helium insulation. For helium cryogen I have to have something else. Now, like that depending on the temperature levels, I am going to talk about; I will decide what insulation I will choose. The effectiveness of the insulations; this is the result of various parameters and its properties.

What is the effectiveness of insulation when it is put in place, that also can be calculated depending on the net heat transfer from outside to inside. The cost of the insulation which is very important; the ease of application for example, if you have got a intricate shift container, you cannot have any insulation then you cannot have geometrically fix. We want to have, you know flexibility, we want to have lot of ease in putting up that insulation on that particular material over there.

So, ease of application also is very important, then weight and reliability. Whenever we talked about space application for example, you have got some cryogenic application in space, what is most important therefore is, weight. Weight of that insulation also is very very important, and therefore the weight and of course, the reliability. So, this is a very important term, when we going to talk about having insulation for space related applications. So, combination of insulation is used to prevent different modes of heat transfer. So, all these are basically various factors, which will enable us to decide. Depending on these parameters, we would decide ultimately that can I use a particular insulation or am I to use a combination of insulation.

So, that my effectiveness of insulation and will be very high and a cost is going to be minimum. So, all these are parameters which would decide for a particular application; how will I choose an insulation for a given application. Lets define one more parameter which is normally used in insulation studies, this is called as Apparent Thermal conductivity.

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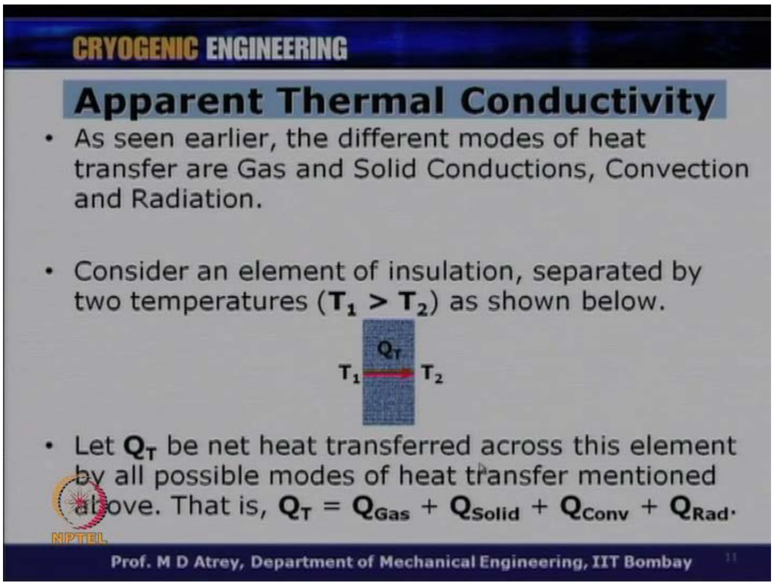

So, as seen earlier the different modes of heat transfer are gas and solid conduction, convection, and radiation; consider an element of insulation separated by 2 temperatures. Lets say T 1 and T 2, and which case T 1 is more than T 2. So, here is what we can see that one surface is at T 1, the other surface are T 2. And Q 1 is the conduction, Q 1 is basically the heat that is being transferred from this surface to other surface alright.

So, let Q T not Q 1 - this is Q T. Let Q T be the net heat transferred across the element by all possible modes of heat transfer mentioned above. So, Q T is the total heat transferred or net heat transferred, and this Q T is equal to Q gas plus Q solid plus Q convection plus Q radiation. That is Q gas plus Q solid is basically heat transferred due to conduction, that is gas conduction and solid conduction, then Q basically basically, because of convection, and Q because of radiation. So, all the modes of heat transfer have been covered, and this is what we referred to as Q T.

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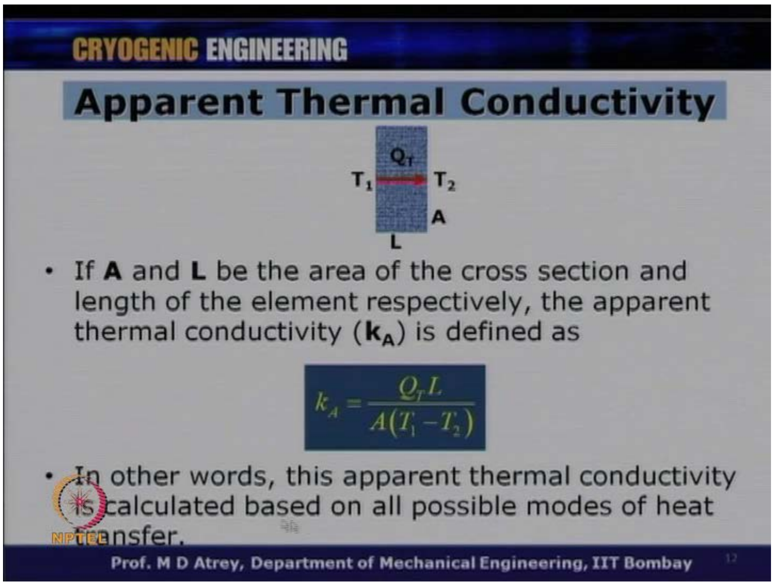

So, if we identify A and L is a cross section area, and L is a length of the of the element respectively. So, this is cross section area A, and length is L; the Apparent Thermal conductivity k A is defined as k A is equal to Q T into L divided by A into T 1 minus T 2, which is a using basically a famous fourier law. But this is using a famous fourier law, I am taking however, not fouriers law hold good only for Conducive heat transfer, but I am putting here Q T. Why I am that thing, because basically I would like to compare the effectiveness of heat exchanger, effectiveness of heat transfer, effectiveness insulation.

So, if because the heat transfer can take place, because of conduction or convection or radiation, I would like to compare different insulation. I do not want to compare radioactive heat transfer or Conductive heat transfer. I want to see the total heat transfer, and that is why I am using instead of only Q conduction, I am using Q T over here; and using the fouriers law. And therefore, I am calling this as not thermal conductivity, I am calling this as apparent thermal conductivity which takes into consideration, the heat transfer due to conduction, convection, and radiation all three together. And this is what if I want to compare a insulation, I would compare it with total heat transfer that happens, because of all this three modes of heat transfer. So, in other words the apparent thermal conductivity is calculated based on all possible modes of heat transfer.

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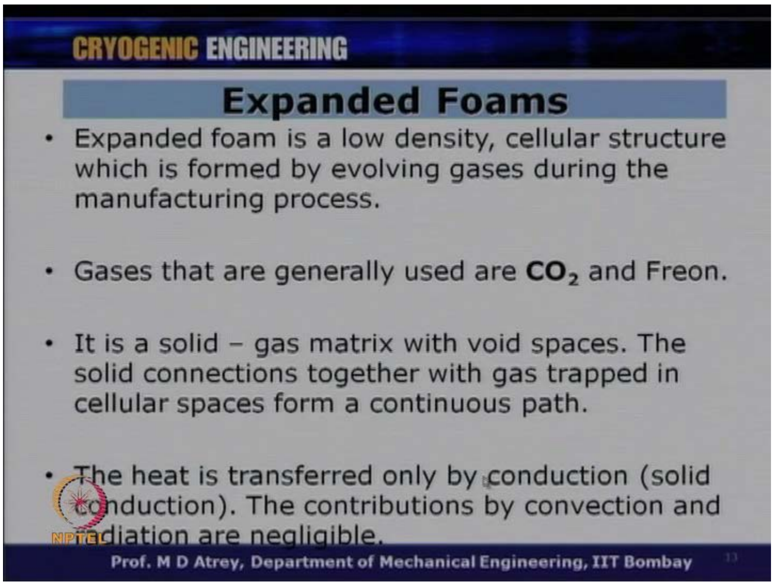

With this background, now lets come to expanded foams. Expanded foam is a low density cellular structure which is formed by evolving gases, during the manufacturing process. So, you got a cellular structure, this is what we call as a mass insulation which is formed due to cells; they have got a low density. And it is made out of evolving gases during the manufacturing process. So, you got a small small cells which are filled with gases, and all this small cells with with gas could be put on running tubes, running pipes or a cryogenic container also. The gases that generally used evolved during this manufacturing process are CO 2 or some Freon.

So, it is a solid, and gas matrix with void spaces. The solid connection together with gas trapped in cellular space form a continuous path, the heat is transferred only by conduction or solid conduction. T the gas conduction is very very minimal in this case. So, solid conduction - the contribution by convection and radiation are negligible. So, here I would just like to show you the foam here.

So, just see foam I am showing. So, here is just the structure which you must have seen, this is what we call as foam and you can see small small cells over here; we have just taken it from a running pipe line, but what you can see this will all we filled with some,

some kind of a gas, and there are lot of cellular structure which houses this gas inside. So, you got a small cells, which are separated. And for example, I have put this on a pipe - the pipe runs through this. So, long structure that can be covered up this pipe. And some times over a period of time, the powder comes of that means, the cells get distorted time and the powder comes out.

It is not a very long lasting kind of a solution, on the backside it would look like this. So, this is what is exposed to atmosphere while all this structures, you know cell which will see the cryogenic temperature alright. So, you can see some small powders falling over there when I rub my hand over this. So, this is not a very reliable kind of solution, but is a very keep solution; which is available in market; and can be used for refrigeration purposes as well as for cryogenic pipe lines.

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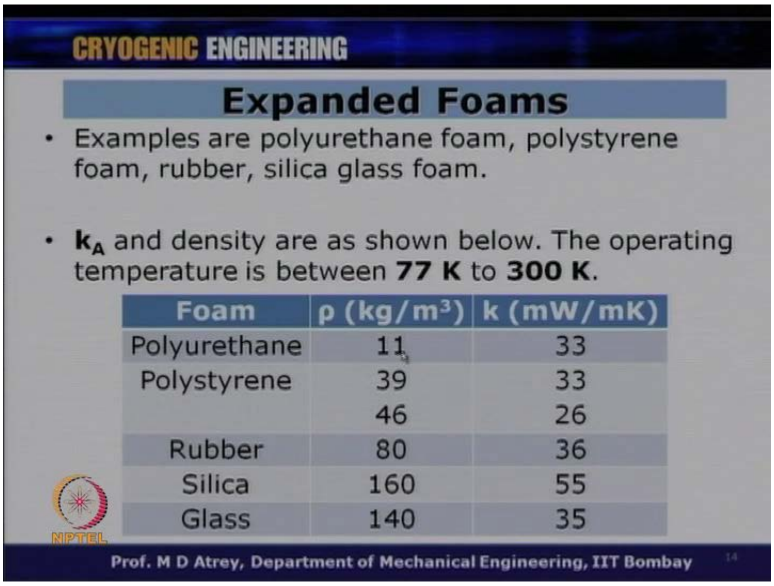

So, going ahead the examples are polyurethane foam, polystyrene foam, rubber, silica glass foam; there are various kinds of foam depending on the kind of material that is used for this, and the kind of gas used in the formation of this forms.

The Apparent Thermal conductivity k A, and density are as fallows here, the operating temperatures are 77 kelvin and 300 kelvin. So, if I got two surfaces; 300 K to 77 kelvin, the apparent thermal conductivity for this different foams would be like this. So, you can see here, I am giving names of different foams polyurethane, the density of polyurethane allowed a 11 kg per meter cube, because the conductivity varies with the kind of density we are talking about. So far, polyurethane the conductivity, the apparent thermal conductivity 33 mile watts per meter kelvin.

So, you can see that the conductivities in mille watts alright; per meter kelvin. And we are talking about a range of 300 to 77 kelvin. So, first of all note that, everything is in mille watts over here, and as you go from polyurethane, the polystyrene or rubber silica glass; the conductivity around 33, 33, 26, 36, 55. So, these are around 2 digits. And between 30 to 50 mille watts meter kelvin. Here, we can see that polystyrene as the density has increased or the density has increased from 39 to 46; the conductivity - Apparent Thermal conductivity has decreased a little bit from 33 to 26, but you can see the range is normally between 30 to 50; if I can see broadly or may be 20 to 60; if that would be correct for 30 300 kelvin to 77 kelvin temperature range.

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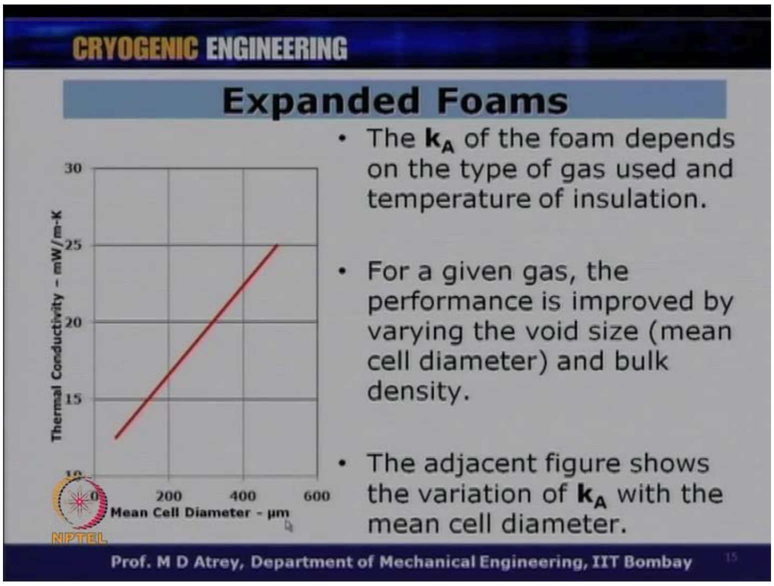

The k A value - apparent thermal conductivity of foam depends on the type of gas used and temperature of insulation; which is which is what we have talked about earlier. For a given gas now, the performance is improved by varying the void size or the mean cell diameter of the cells and the bulk density; so, for I have talked about having this mass insulation which depends on the different cells, and this cells house different gases. So, if I gone minimizing the cell diameter, the thermal conductivity will vary; the apparent thermal conductivity vary or if I change about the bulk density also, it will affect the k A value; how does it a affect. So, you can see that here, thermal conductivity on the y axis mean cell diameter, in micrometer is given on the x axis

So, if you go on lowering the mean cell size from 400 to 200 or from 600 to 200, the thermal conductivity starts decreasing. So, we should go for a small size which we can conclude from here. The adjacent figures shows that the variation of k A with the mean cell diameter.

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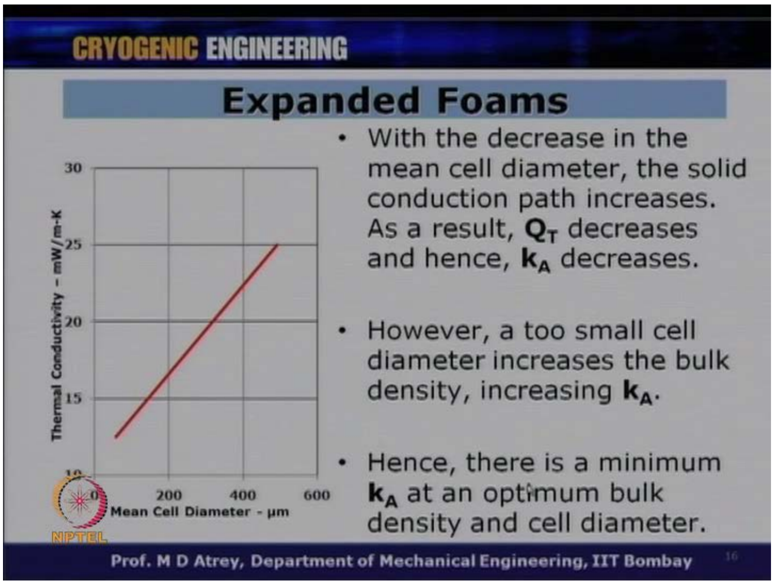

So, what you see from here, with the with the decrease in the mean cell diameter, the solid conduction path increases; if I makes small and small and small cells, the path of conduction will start increasing; the path of solid conduction, because the solid conduction would happen through the cell diameter. So, the cells and if I have makes smaller and smaller cell, this length will start increasing as a result of which Q T; the conduction path will start, conduction path increases and therefore, Q T due to conduction will definitely decrease and Q T over all will decrease. And hence, once Q T decreases we say that k A also decreases. The apparent thermal conductivity also decreases.

However can I go on reducing this cell diameter, if I make it cell very very small diameter, a too small cell diameter will increase the bulk density alright; various cells will come together and this will increase; however, because now the solid conduction path will increase in this case. And therefore, the conductivity in that case will be higher;

and therefore, we cannot have densely packed cells also. So, we cannot basically we cannot from this point of view smaller cells will be preferred, but too many smaller cells if they, if you go to very low diameter; then the solid conduction path will increase and the bulk density increases, and this will increase the k value. So, what is it imply? It implies that, we have to have a optimize diameter, where the conduction path where the effect of Q conduction is taken care of properly. So, hence there is a minimum k A at an optimum bulk density, and cell diameter. These two things have to be optimize. The cell diameter has to be optimize in such a way that, k A becomes minimum for those values. So, we have to optimize the cell diameters in this case.

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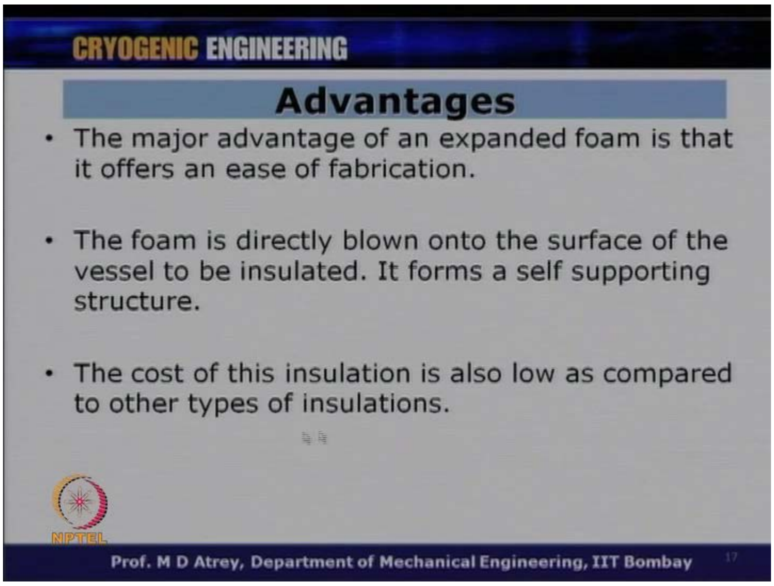

So, what are the different advantages of such expanded foam insulation. The major advantages of an expanded foam is that, it offers an ease of fabrication. That is very important, because you can have application of this insulation; the foam is directly blown on to the surface of the vessel to be insulated, it forms a self supporting structure and this is very important advantage, have got a intricate shape vessel to be you know foam, I possible cannot use other insulation, but I have to use foam in that case. Also for various space application, because its foams are lighter I have to go for foam insulation only; the cost of this insulation also is very very low as compare to other types of insulations from, costing point of view also it has various advantages.

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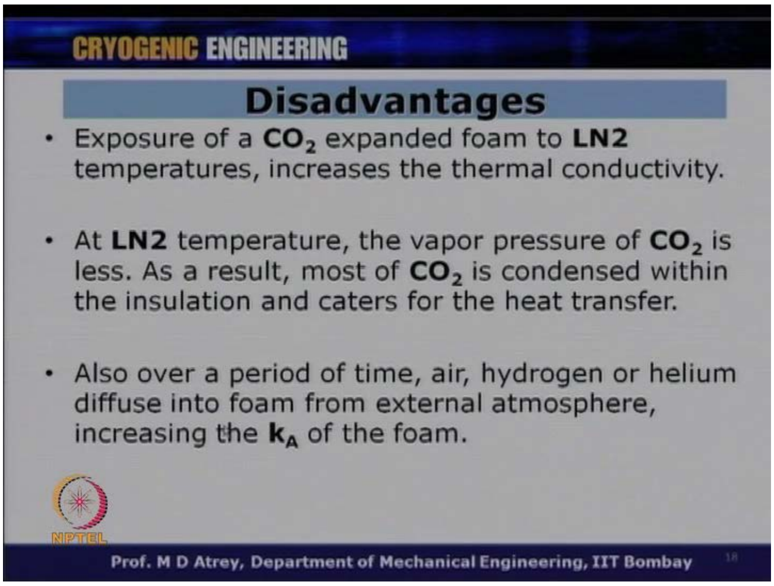

So, what are disadvantages: Exposure of a CO 2 for example, what is a gas being used, as I said CO 2. And once CO 2 get exposed to liquid nitrogen temperature, the CO 2 actually CO 2 will get condensed, it might it might get solidified; and this will increase the thermal conductivity. If I am talking about a temperatures level of LN2 in that case, thermal conductivity will increase.

So, at LN2 temperatures, the vapor pressure of CO 2 is less as a result of which most of the CO 2 is condensed within the insulation, and this will catered the heat transfer. And therefore, I may not be able to use this insulation for a very low temperature; this may be useful for 150 kelvin, 180 kelvin, 200 kelvin or so, but may not be very very useful for liquid nitrogen temperature. But of course, because it is a cost effective solution, I can use this for some time, and remove it over a period of time; and renew the insulation again that is one of the possibilities. Also over a period of time; you can find that air hydrogen, you know ambient gases would rush inside, they will defuse in the foam and from external atmosphere increase in the k A of the Foam. This is also one of the very important disadvantages of Foam.

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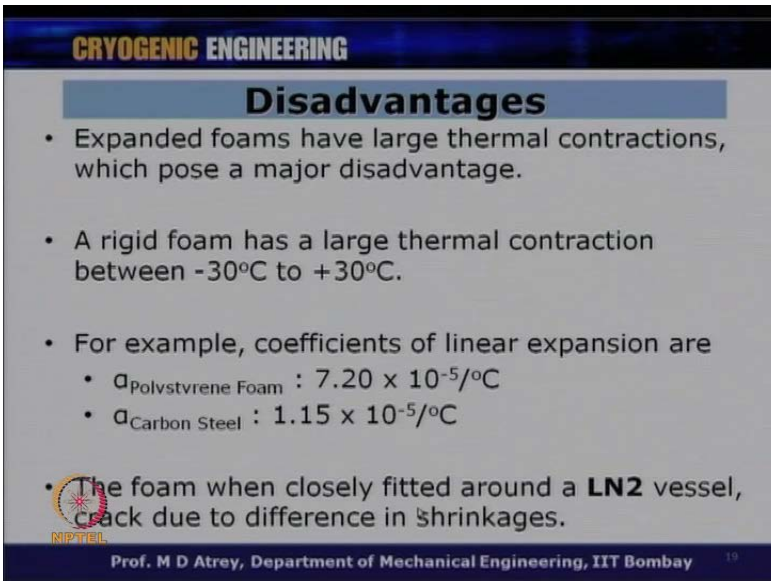

Expanded foams have large thermal contraction, and this is very important for cryogenic temperatures; the foam will get contracted, they will contract and they will pose major disadvantage over here. A rigid foam has a very large thermal contraction between minus 30 degree centigrade to plus 30 degree centigrade, and you can see for example, the coefficient of coefficient of linear expansion for foam is around 7.2 into 10 to the power minus 5 per degree centigrade; if I want to compare with carbon steels, it is just 1.15 into 10 to the power minus 5; that means, all most has higher 6 to 7 times more the linear contraction.

So, you can see that contraction will be so drastic in this case; the foam will just get, you know struck on the material on which it is struck. So, the foam when closely fitted around liquid nitrogen vessel will crack, due to difference in shrinkage. The material will crack the, foam material may crack; if the foam subjected to some thermal cycling, you know coming from LN2 room temperature and again going down to LN2 temperature, the foam may crack the reliability could be questionable in this case.

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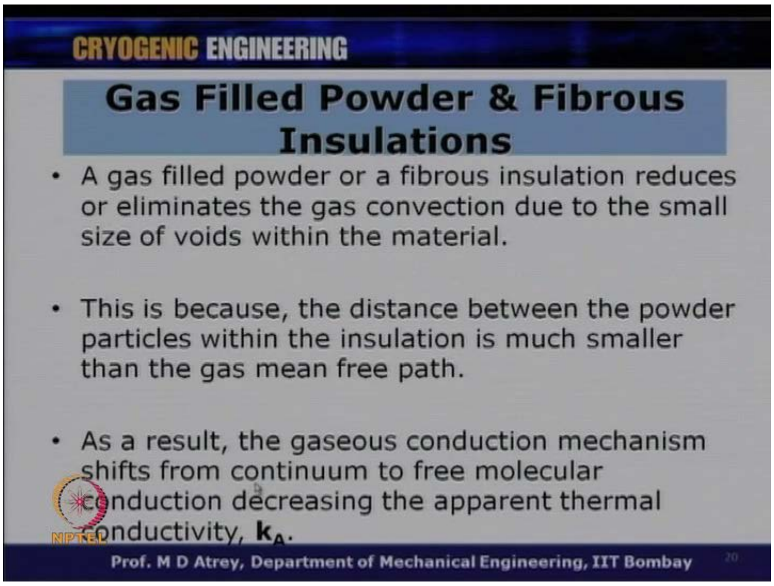

So, let us see the next insulation now, which is gas field powder and fibrous insulation. A gas filled powder or a Fibrous insulation, reduces or eliminate the gas convection due to the small size of voids within the material. As the name suggest here, it is basically a powder, and we have got a very small size of powder material basically. So, small small crystal could be there, and they will be very small size; and between this crystal what you can see, this we will have gas and later on we define that it could be evaporated also; instead of having this powder we can have sometimes fibrous material also. And therefore, this could be called as gas filled powders and fibrous insulations.

This is, because the distance between the powder particle, these are granular particle - very small granular crystals granular particles. And they were very small within the insulation, and the distance is so small, then that the gas mean free path is smaller than that alright. So, this is because the distance between the powder particle within the insulation is much smaller than the gas mean free path. That means, what you can see is a molecular region we are talking about, all the for gas element. So, as a result of which the gaseous conduction mechanism shift from continuum to free molecular conduction, that is the distance between the particle is so small, that mean free path of the gas larger than that and therefore, we are shifting from continuum region to the free molecular conduction of the gas; decreasing the apparent thermal conductivity k A over here. So, we are talking about very small granular particles in which some gas molecules are also there.

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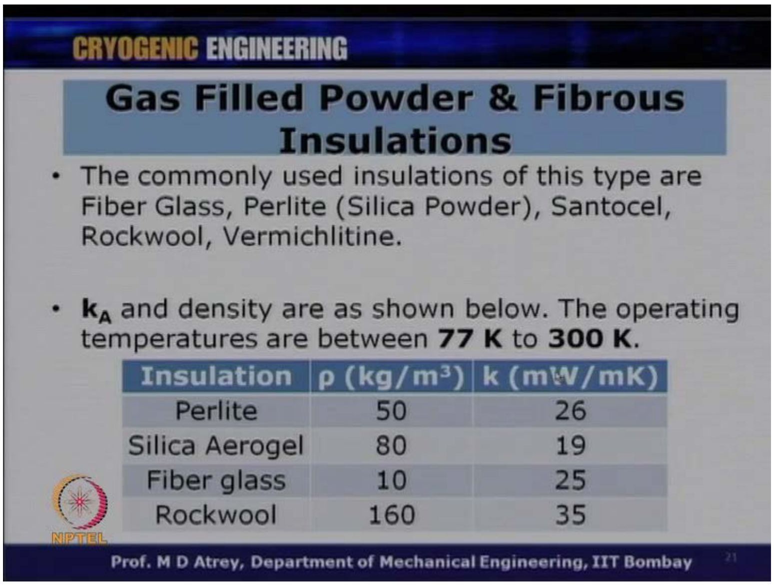

The commonly use insulation of this type are fiber glass, perlite or perlite powder or silica Powder, and normally silica perlite powder in a commercial sense; santocel, Rockwool and vermichlitine - vermichlitine is also one of the Fibrous insulation that would be used for here, in this case. So, what before I go further, I would like to show you the perlite powder. So, you can see here the whitish looking power or a Granules right now, there is no gas in this thing, but you can just see the powder, because the gas must have out it was expose to atmosphere; and you can see the powder over here. So, what can see this powder. Normally, you know this powder is of very very small Granules, and most of times you can find the liquid nitrogen plate will have this fibers insulation, because is a huge this which is filled with powder for the time. You can see this white perlite powder which is very commonly used up to liquid nitrogen temperature.

So, will have drums containing this actually you know, various places we have got a drums containing this particle which are rammed across the 77 K surface or 77 K to 300 K surfaces. Normally, this is not handled by hand, you have to use some gloves and put it in a place, but what you have to ensure that when you are putting it, it is put uniformly across the available area. So, let us see now, what is a apparent thermal conductivity of this materials. So, k A and density are as shown below for the different insulation; the operating temperatures are again kept as 77 kelvin to 300 kelvin. So, here you can see now, the insulation for perlite Powder, for silica aero gel, for fiber glass for rockwool and different density, you can see 50 kg per meter cube 80 tain kg per meter cube and 160 per meter cube. So, different densities are there.

So, that the weight also is a constant that can be taken care of properly, while what you can see the apparent thermal conductivity is 26,19, 25,35 . So, as in earlier case, we will be talked about which was expanded foam, we were in the region of 20 to 60 kind of a thing, and now we are come down below; we are come down let say from you know 20 to 35 that kind of a region. So, earlier it was mostly from 30 to 60. Now, it is from 20 to 35 mille watts per meter kelvin; the conductivity the apparent thermal conductivity is around 20 to 35 in this conductivity range.

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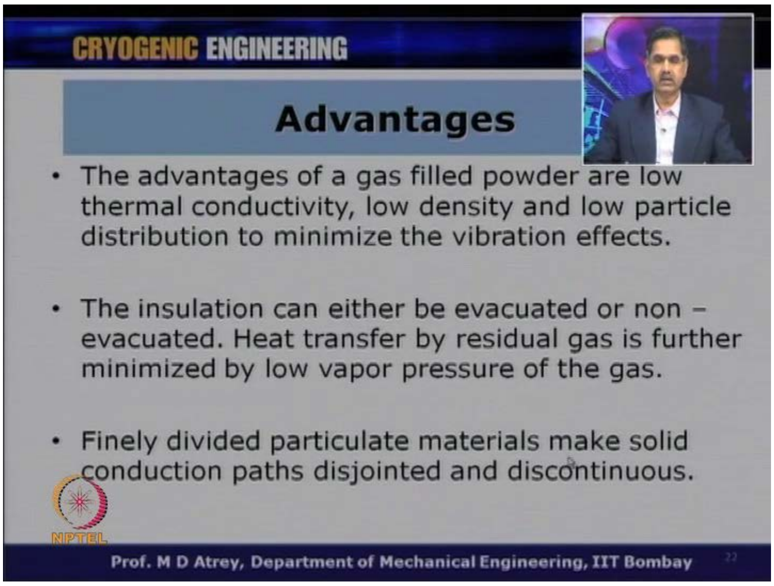

The advantages of such insulation: The advantages of a gas filled powder are low thermal conductivity, low density and low particle distribution to minimize the vibration effect. So, (( )) this can be ramped properly across the places, and it will minimize low particle distribution; that means, wherever there are vibration, the particle distribution can be taken care of properly. The insulation can either be evacuated or non evacuated; the heat transfer by residual gas conduction is further minimized by low vapor pressure of the gas, if I evacuated then whatever conduction occurs, because of even gas conduction that also can be further minimized. Finely divided particulate materials make solid conduction path disjointed, and discontinuous. And this is the reason why the this particles are used.

So, all this granular particulate – all this granular particle are finely divided and therefore, this creates a solid conduction path disjointed; there is no continuous path for solid conduction plus they got a gas also. So, they got a some solid conduction which is disjointed plus we have got a gas conduction depending on the kind of gas which we are being using. And the conductivity conductivity of gases is very low. Therefore, here while in foam case we had a continuous path alright; we had a continuous; so, solid conduction path. But in this case, we have got a discontinuous per conduction path and therefore, the k A value in this case is less than as compare to what it was or Expanded Foam.

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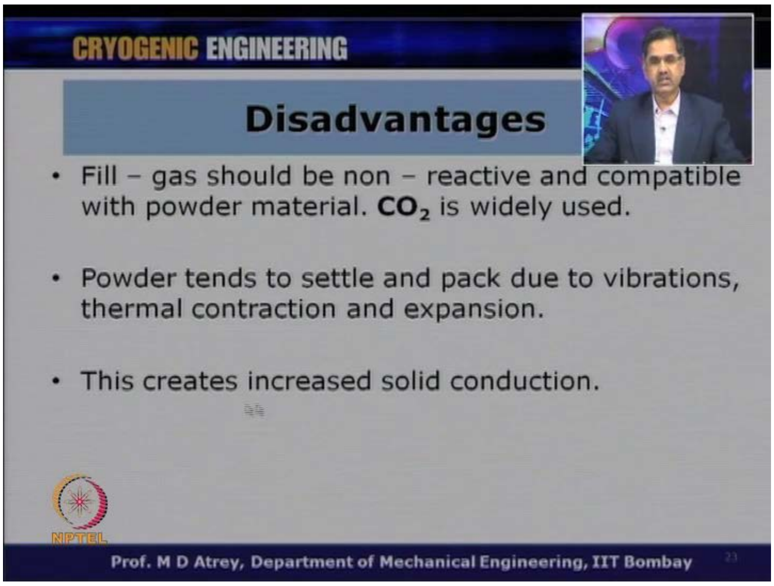

The disadvantages in this case the fill gas should be non reactive, and compatible with powder material CO 2 is again widely used. And this is true for earlier insulation also, that it should be a non reactive and compatible with powder material. The powder tends these are one of the disadvantages; the powder tends to settle and pack due to vibrations, thermal contraction and expansion.

So, this powder over a period of time; although we say we got minimum vibration, but you got a some vibration. And over a period of time, this powder may tend down to settle; and therefore, exposing particular path for heat in leaks or we can have cake formation at the bottom where the powder settles. And therefore, this is one of the very important disadvantages, that has to be considered for a particular application or a tends to settle and pack due to vibrations; then you have got his thermal contraction and sometime expansion also, because of the heating effect also. This creates increased solid conduction. And therefore, this has to be considered in the usage of such insulation.

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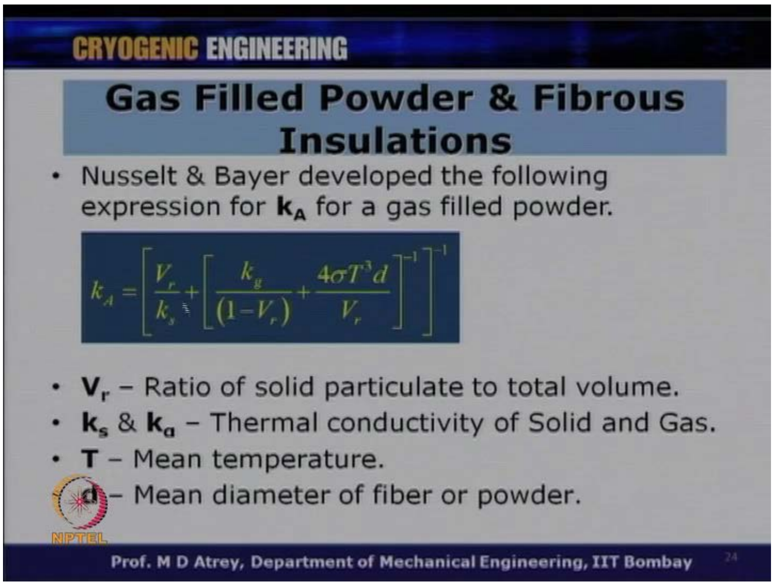

The gas filled powder and fibrous insulation conductivity can be calculated by Nussle and bayer developed the fallowing expression for k A for gas filled powder, and this expression. So, you got a k A is equal to V r upon k s plus k g upon 1 minus V r plus 4 sigma T cube d divided by V r to the power minus 1, and entire thing to the power minus 1. So, apparent thermal conductivity can depend on various parameter, V r is ratio of solid particular to total volume k s and k A are thermal conductivity of solid and gas, T is the mean temperature over here sigma is the Boltzmann consent, d is a diameter of this particulate, d is a mean diameter of fiber or powder powder.

So, you can see that k A depends on various parameter related to the gas, related to packing fraction V r related to the conductivity of the solid material, that is use as fiber or power, temperature, diameter and of course, the Boltzmann constant.

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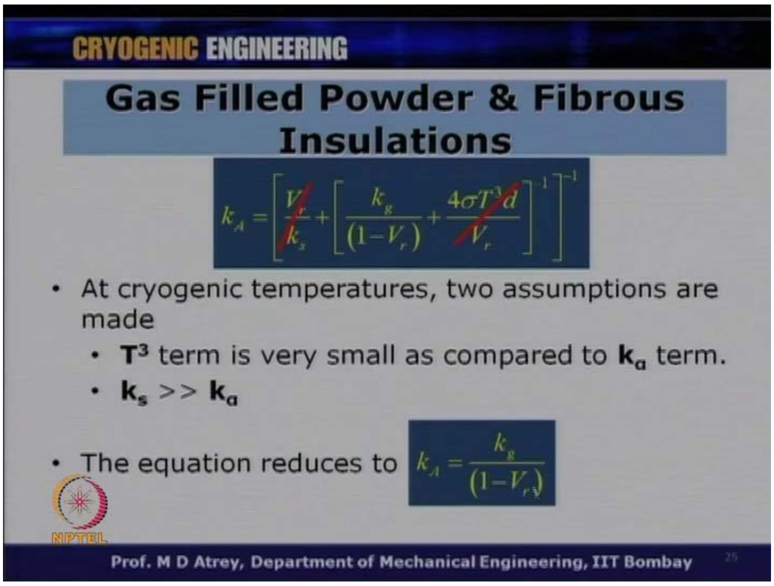

So, this is our expression; we can say at cryogenic temperatures the two assumptions can be made; T cube term, this is a T cube term is going to a very very small as compare to the k g term. So, T cube term is very small as compared to k g term and therefore, we can neglect this term in front of this term. So, then I can say that this k s term which is a solid conduction is also very large as compare to k g. So, gas conductivity term is always very very less, the gas conduction k g part is very less; and therefore, if this is very large V r up on k s becomes a neglected term as compare to this. And therefore, I can in that case k s is being very large, I can neglect V r by k s. So, my equation can reduce down to under this assumption as k A is equal to k g upon 1 minus V r. So, basically it is a function of now packing fraction, how much what is the ratio of solid you know content, solid part to the total volume which is what I call as packing fraction and the value of k g.

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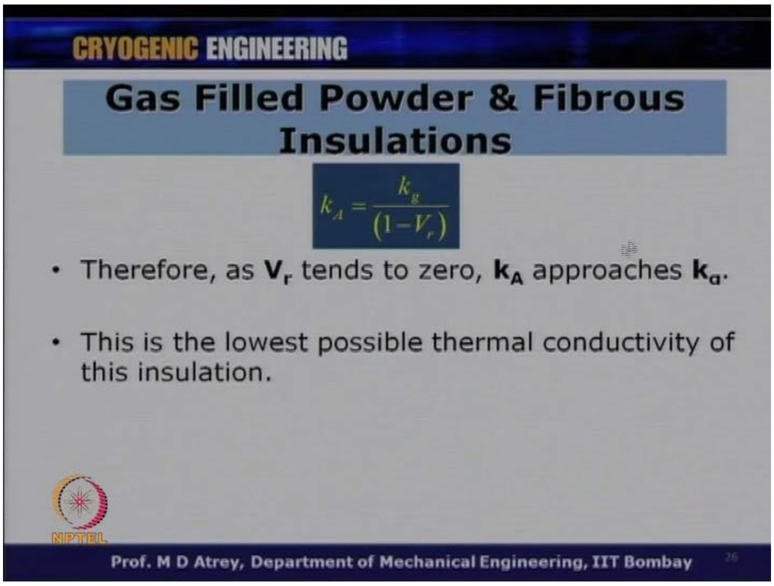

And therefore, if we say that V r tends to 0; that means, there is no solid particular at all, the k A will approach to k g; and k g is going to be very very low. So, is actually approaches to the gas conductivity in that case basically. So, this is the lowest value that we can have, but we cannot of course, have a gas; only gas over there. Because having only gas will have its own problem, because the gas will get you know Liquefied or condensed or get frozen, also at those low temperatures. And therefore, k A approaches k g in gas case, this is the lowest possible thermal conductivity of this insulation. So, if you have got a V r, the k A is going to be higher than the value of k g, but it also tells you that, the kind of gas that is going to be used its conductivity also plays a very important role, because the lowest conductivity that it can reach is basically equal to the conductivity of that particular gas which is used in Gas Filled Powder.

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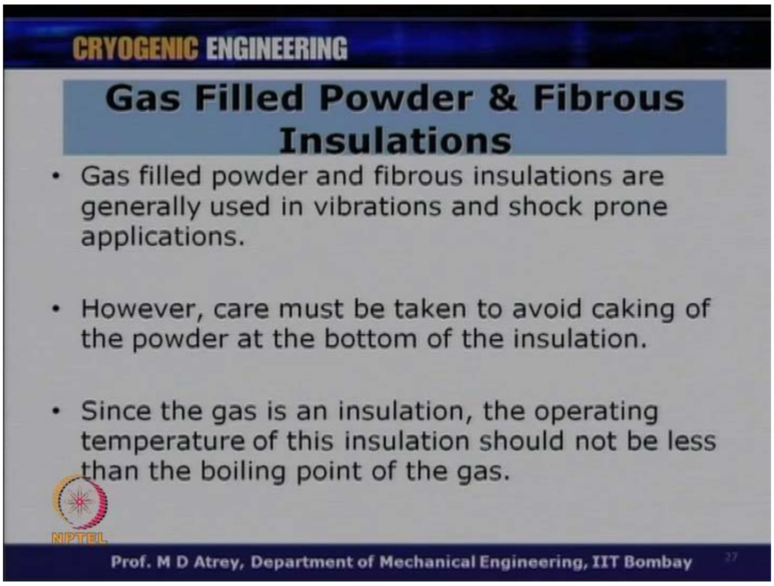

So, gas filled powder and fibrous insulations are generally used in vibrations and shock prone application s. So, wherever we find that wherever there is no vibration, and we do not want to shocks, and we do not want to have vibration; it will always preferred to have a gas filled power, and fibrous insulation; however, care must be taken to avoid caking of the powder at the bottom of the insulation. So, we we should insure that, the powder does not get you know sitting at the bottom, it do no settle at the bottom over a period of time, formation of caking should be avoided in this case.

Since, the gas is an insulation; the operating temperature of this insulation should not be less than the boiling point of the gas. So, whatever gas, we are going to use; we should ensure that the operating temperature is not less than that, otherwise that will the gas will get condense in that gas. Coming from the gas filled powder and fibrous insulation now, will have our next possible way is of having transfer which is radiation; and before we go further, what is important is to understand the radiation fundamentals. And let us just brush our radiation fundamentals; so, that we can use, we can understand why the shields are used to minimize this radiation.

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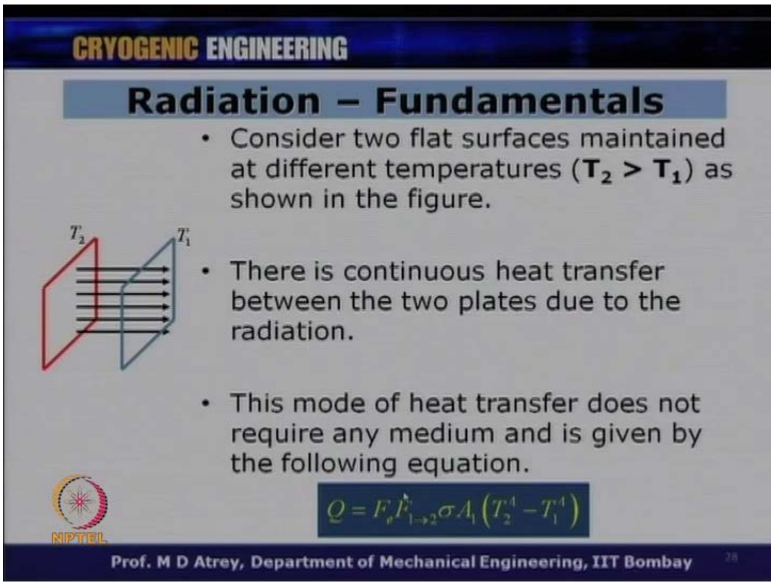

So, let us see the radiation fundamentals. So, Consider two flat surfaces maintain at different temperatures, and now we are going away from mass insulation, and we are basically going to radiation heat transfer Fundamental, and then we can use vacuum in that case alright. So, going away from mass insulation in which, we had examples of expanded foam and powder. Now, suppose if you have got two surfaces at temperature T 1 and T 2, and lets say T 2 is larger than T 1; T 2 is more than T 1 then will have a heat transfer from surface at T 2 to T 1. And there is continuous heat transfer between the 2 plates due to the radiation. Because this two temperatures and if the temperature differences is a very very large, they will have a very effective heat transfer because of radiation.

This mode of heat transfer does not require any medium, and is given by the following equation for radiation happen; we do not require any medium. So, if you got a vacuum also, the conduction and convection in that case could be minimize, but radiation you cannot prevent. So, if I remove whatever medium is present between T 2 surface and T 1 surface; I can minimize the heat in lick due to conduction and convection, but I cannot minimize the heat transfer due to radiation.

So, this mode of heat transfer does not require any medium, and is given by the fallowing equation, which is Q is equal to F e into F 1 2 into sigma A 1 T to the power 4 minus T 1 to the power 4; this is the very standard equation. So, Q is basically Conduct the heat transfer due to radiation, F is a emissivity factor depending on the emissivity's of the surface at T 2 and surface at T 1. F 1 2 is what we call as configuration factor or shift factor depending on the geometry of this two surfaces; sigma is Stefan Boltzmann constant, A 1 is the area of heat transfer which receives the heat from T 2, and while T 2 the power 4 and T 1 to the 4; the temperature difference to the forth order that is what we talked about, for a standard radiation heat transfer equation. And this most of you know and therefore, I will not go in the details of this derivation and understood basics of this is very straight forward.

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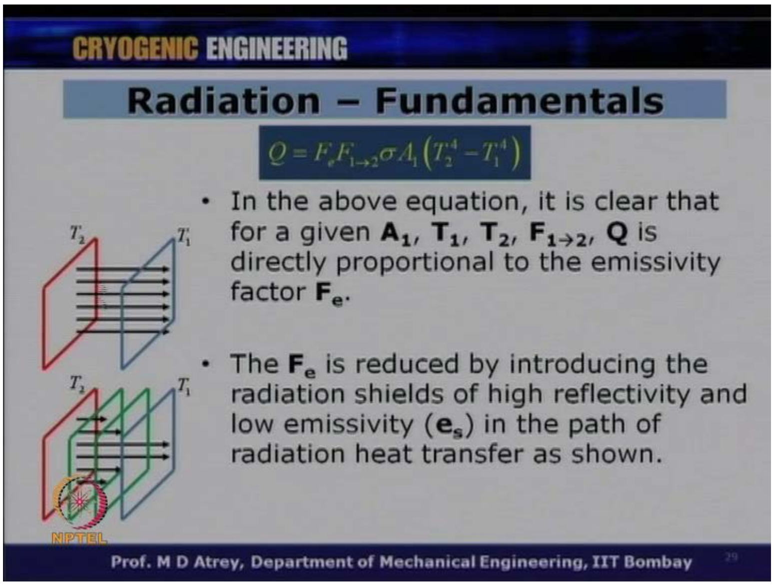

So, in the above equation; it is clear that for a given A 1, T 1 and T 2 and F 1 2, Q is directly proportional to the emissivity of the factor F e. So, Q is directly if all this parameters are same, Q is directly dependent on the parameter F e which related to the emissivity's of this two surfaces alright. The F e is reduced, now if I want to reduce the value of F e for a given T 2, T 1, A 1 and F 1 2; that means, everything is defined; the geometry is define, the 2 temperatures are defined and therefore, A 1 also is define, because the geometry is already been defined.

So, what I can do, I can minimize the value of Q, if I could minimize the value of F e which is a emissivity factor. The F e can be reduce by introducing the radiation shields of high reflectivity; and low emissivity which is e s value in the path of radiation heat transfer as shown. So, if I introduce different shields in between T 2 and T 1 shields; T 1, T 2 and T 1 surfaces as shown in this figure; this green thing show the shields which have got very higher reflectivity. So, that whatever radiation come from here can get reflected, and low emissivity values. So, the e s associated with this, its minimum in this case.

So, if I have a such surfaces; if I have such tradition shields, and if I put them between these surfaces of having temperature T 2 and T 1; my factor F e will get reduced, and how it get reduced most of know that it is a rule of parallel surfaces, one upon is equal to one upon e 1 plus one upon e 2 minus 1 by this formula; if I have put this surfaces having minimum e s in that case, my F e factor will get reduced further.

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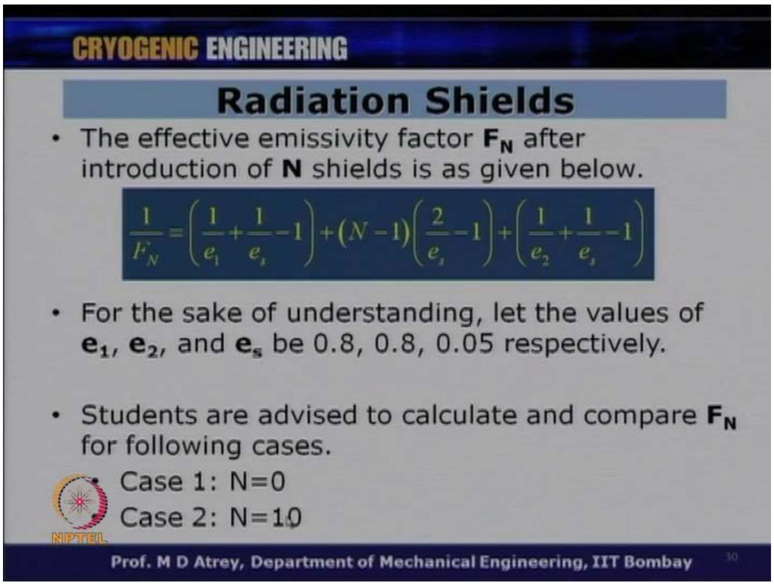

So, the effective emissivity factor F N, after introducing N shield; suppose I have put N shields, and this N could be equal to 2 or 5 or 10 not 20 and my emissivity factor now, for N number of shields will be given as below. So, one upon F N is equal to one upon e 1; this is my first surface which pressure the temperature having T 1 as temperature. So now, I have got a effective emissivity of that particular shield one upon e 1 plus one upon e s minus 1. This gives me effective emissivity of two surfaces, which are facing each other having shield emissivity as e 1 and e s; and if I last term this is my effective emissivity of the last 2 surfaces having T 2 temperature and facing the e s, one upon e 2 plus one upon e N minus 1.

So, this is my effective emissivity of the last surface having e 2 and e s as emissivity. The first surface has e 1 and e s shield; and then in between now, I have got N minus 1 shields, and if I go on adding all this shields will have e s as emissivity, and effective emissivity of all this will be N minus 1 into bracket 2 upon e s minus 1. I will go into derivation of thing, because very straight forward; one can always do all of you can do this things.

So, one upon F N is equal to now; instead of one upon F e, we got 1 upon F N is equal to this entire expressions; and for the sake of understanding, let us put some values to this lets get e 1 and e 2 has 0.8, and e s having low emissivity, the shield emissivity should be as small as possibility as 0. 5. Now, I would advise you to calculate the value of F N in this cases, and I will just give you directly value; and lets call the students are advised to calculate, and compare the value of F N for the following cases; lets have a one case where there are no shield; that means, N is equal to 0; and the second case when we got a N is equal to 10, where the value of emissivity for the shield given as 0. 5.

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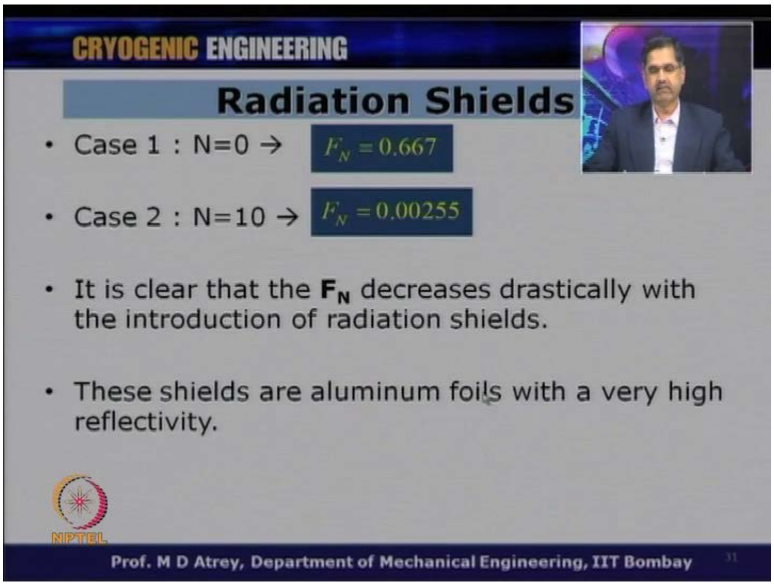

So, if I calculate all this things; what will get for the case one; when N is equal to 0 my F N will be equal to 0.667 and if I put N is equal to 10, my F N will be as small as 0.00255. So, its away from here, that if I put 10 shields of low emissivity and high reflectivity; my F N get drastically reduce my F e value now, will get drastically reduce from 0.667 to 0.

00255; this effectively means that my Q, because of radiation will get reduced by such a factor.

So, it is clear that F N, decreases drastically with the introduction of radiation shields; and this is one of the ways in which I can reduce the radiation heat transfer. So, if I want to have some fast reduction in fast ways of reducing the radiation heat transfer, what I should do I just add the radiation shields which has got low emissivity value, and high reflectivity values, and I can put those shields between the surface number 1 and surface number 2; and in this way the radiation heat transfer will we will get drastically reduced.

So, these shields are aluminum foils; many times you must have seen that for your you know food items also with pack them up with in aluminum Foils. So, this aluminum Foils have got very large reflectivity, and low emissivity. And therefore, these are normally used as metal shields to reduce the heat transfer.

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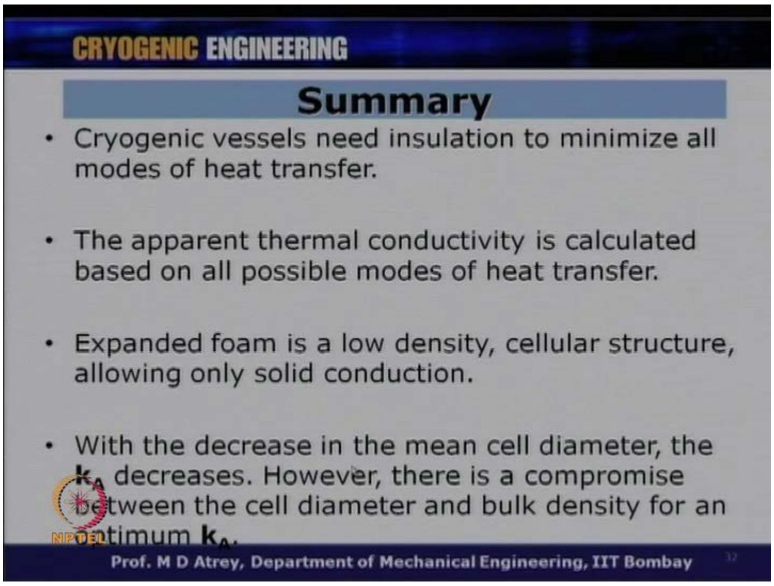

So, summarizing the whole lecture on insulation cryogenic vessel need insulation to minimize all modes of heat transfer, this is what we saw. The apparent thermal conductivity k A is calculated based on all possible modes of heat transfer, it does not take into consideration only conduction, but it does take into consideration; various modes of heat transfer which is conduction, convection, and radiation.

Expanded foam is a low density cellular structure allowing only solid conduction; with the decrease in the mean cell diameter the k A decreases; however, there is a compromise between the cell diameter, and the bulk density for an optimum value of k A for expanded foam insulation. And this is what we see how does that coming to picture.

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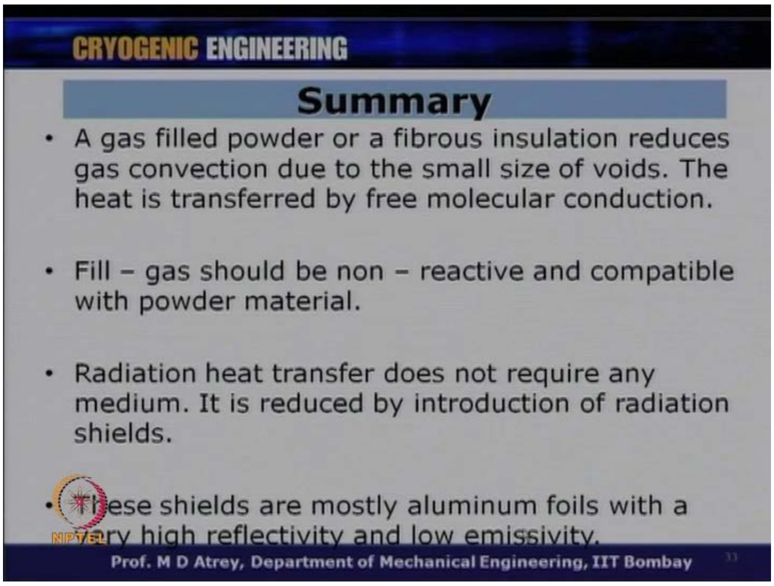

A gas filled powder or a fibrous insulation reduces gas convection due to the small sizes of voids. So, you have got a very small particulate matter particles sitting over there, in which there to be gas; and this will effectively reduce the apparent thermal conductivity from 30 to 55 mille watt for expanded foam to around 20 to 35 for gas fill powder case. The heat transfer is reduce by free molecular is transfer happing, because of free molecular conduction in this case.

The fill gas should be non reactive and compatible with powder material. radiation heat transfer does not require any medium, it is reduced by introduction by introduction of radiation shields; and this is what we saw how addition of this radiation shields would reduce the radiation heat transfer, what we require is to have reflective material and low emissivity material. These shields are mostly aluminum foils with very high reflectivity, and low emissivity. And in this case now, the F N value or the emissivity factor will be reduced from a very high value to a very low value, depending on the kind of material you are using, its reflectivity and emissivity and the number of shields that are used. Thank you very much.