Heat Transfer
Prof. Sunando Dasgupta
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 59
Radiation Shields

In many practical applications you would see that you would like to prevent a surface from receiving radiation, or a surface losing its energy through radiation. Let us take the first point and you do not want a surface to receive energy by radiation. One of the practical examples where you encountered this situation is for cryogenic storage of liquid, of cryogenic storage of liquids which are at a very high very which have a very low boiling point.

Let us see you have liquefied air or you have liquefied nitrogen ammonia and so on. And you are storing them in containers you try to insulate them as much as possible from the outside, but in order to reduce the radiation which is coming from the ambient to the tank which is stored liquid nitrogen. Sometimes it is advisable to put an shield around the container.

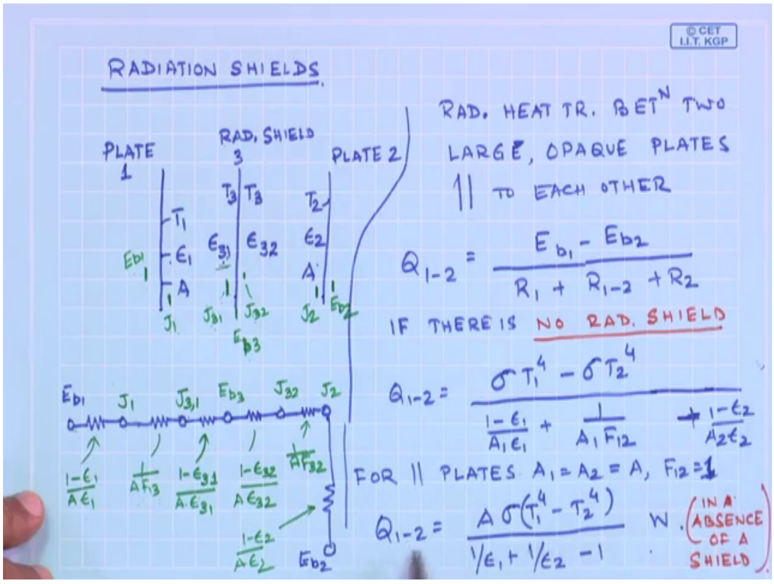
So, if you have a spherical container for storing liquid nitrogen what you do is, these spheres are never I mean the walls are not solid. You may have on the inner sphere which holds the liquid nitrogen another layer of a material which surrounds the sphere. In this outside sphere the outside covering of the main tank this significant, this significantly reduce the radiative heat that comes to the sphere from the ambient and thereby heating up the liquid nitrogen inside.

So, these kind of protective shields are known as radiation shields, so in order to choose the material of construction for a radiation shield which is going to protect the inner core which you would like to keep at a low temperature that is very important. We need to know what should be the radiative property of the radiation shield.

So, radiation shield is something which hinders the flow of heat through it, hinders the flow of radiative heat through this. Thereby protecting the cooler temperature, the cold temperature, the cold storage inside and we are going to find out what is the property that needs to be: what is the property of the material of this radiation shields. One property is obvious; that means, it should be opaque; that means, the radiation there is not going to be any transmission of incident radiation through the shield to the other side where you would like to keep the temperature cold. So, the very first property of a radiation shield is that it is it must be opaque in nature.

So, we take care of the surface property that it is to be opaque transmitivity should be 0. But what about the emissive property does it have to have a high emissive emissivity or a low emissivity, which one is going to be preferred for a radiation material. So, that is the one which we are going to study now, what would be the emissive property of the material that is to be used for radiation shield. And what kind of modification to the equation we need to have in order to incorporate the presence of radiation shield in a heat radiation problem.

(Refer Slide Time: 04:11)



So, let us look at the case in which you have a surface over here which is the plate which is a plate I call it as plate 1 which is maintained at a temperature T 1, it is property is epsilon 1, area is A. And then you place another one which is the radiation shield and we I call it as surface 3. So, the temperature is T 3 on this side and T 3 on the other side. Let us for generalization sake assume that the emissivity of the material 3 radiations shield which is facing 1 is epsilon 31, and the emissivity of 3 which is facing 2 is epsilon 32. And this is let us say the plate 2, where the temperature over here is T 2 the emissivity is epsilon 2 and the area is A.

So, this is we are considering radiation heat transfer between two so, we are considering radiative heat transfer between two very large opaque plates parallel to each other. And we put a radiation shield in between so this is more or less what we have in this. So, the heat flow from 1 to 2; therefore, Q 1 to 2 must be equal to whatever be the potential of this and whatever be the potential of plate 2, if they were black bodies so it is E b 1 minus E b 2 by the sum of all the resistances.

So, what are the resistances? One is R 1 the second one is R 1 to 2 and the third one is R 2 ok. So, if there is no radiation shield let us first consider this and then we will consider the radiation shield in between 1 and 2. So, if there is no radiation shield in between 1 and 2 what you would get as Q 1 to 2 as sigma T 1 to the power 4 minus sigma T 2 to the power 4 and the first resistance, so we do not have this anymore. So, the first resistance is going to be the surface resistance to radiation for surface 1 which would be 1 minus epsilon 1 by A1 epsilon 1. And the third resistance is going to be the surface resistance of 2 which is 1 minus epsilon 2 by A 2 epsilon 2 and the right now we do not have this, we do not have the radiation shield.

So, the radiative exchange between 1 and 2 the resistance for that would be 1 by F 1 F 1 2; 1 by A1 F 1 2 ok. These three are going to be the resistances and for parallel plates A1 would be equal to A 2 let us say this is equal to A. And of course, if the parallel plates are close to each other in that case F 1 2 would be equal to 1. So, therefore, all energy emitted by 1 is going to strike 2 if these two are very close to each other. So, no energy will escape through this if there very close to each other.

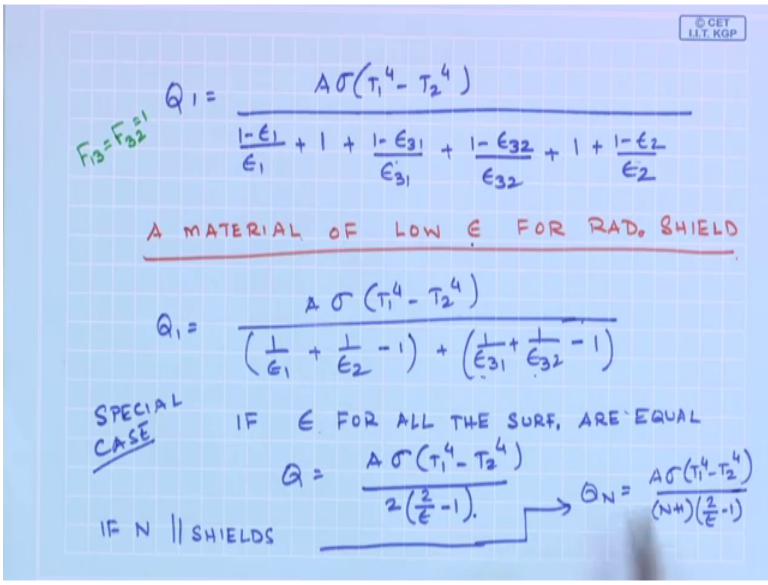
So, F 1 2 is equal to 1. So, what you would get? Q 1 to 2 would be equal to A sigma T 1 to the power 4 minus T 2 to the power 4 divided by 1 by epsilon 1 plus 1 by epsilon 2 minus 1 this is in watts. So, once you A 1, A 1, A 2 are same; so I take the A1 A 1 the numerator. So, the numerator becomes A times sigma T 1 to the power 4 minus T 2 to the power 4 and what I have here is 1 by epsilon 1 minus 1 plus 1; 1 by epsilon 2 minus 1. So, therefore, the denominator becomes 1 by epsilon 1 plus 1 by epsilon 2 minus 1. These many watts that is the heat transfer the total amount of heat transfer radiative heat exchange between 1 and 2. But in absence of a shield, now let us say we have a shield in between these two now.

So, I will draw this circuit diagram over here. So, for this one is going to be E b 1, this one is going to be J 1 and the resistance here is 1 minus epsilon 1 by A epsilon 1, so I take the A to be the same. Then between J 1 and J 3 1, so this is J 3 facing 1 this should be 1 by A F 1 3 this is the resistance. Then we have between J 3 and E b 3, so this is E b 3 and this resistance; obviously, is going to be 1 minus epsilon 3 facing 1 by A1 A epsilon 3 facing 1 epsilon 3 facing 1 this is the one. And then from E b 3 I will have another resistance for J 3 2 which is just over here. So, this is J 31, this is J 3 2. And what is J 3? The resistance that connects E b 3 and J 32 must be equal to 1 minus epsilon 32 unlike this case A epsilon 32.

Now, J 3 2 is going to be over here and this is J 2 and this is simply going to be 1 by A F 32. So, F 13 and this is 1 by A32 and this J 2 this J 2 is connected to E b 2 where the resistance in this case would be 1 minus epsilon 2 by A epsilon 2. So, what you see here is once again you start at this point which is E b 1, over here this is J 1, J 1 to J 31 that is the radiosity of surface 3 facing 1. Then you have for this one you have E 3 E b 3; E b 3 and J 3 2 is the radiosity of surface 3 facing 2; then J 32 and you have to find out what is J 2 and J 2 and inside it is E b 2, so the number of nodes that you have are 1, 2, 3, 4, 5, 6.

So, what you have then is 1, 2, 3, 4, 5, 6 you have an extra. Let us see 1 2 E b 1 to J 1 3 J 3 1 E b 3 is this 1. So, 1, 2, 3, 4, 5, 6, 7; 1, 2, 3, 4, 5, 6 and 7 nodes and in each of these nodes between E b 1 and J 1 you have the surface resistance to radiation between J 1 and J 31. You have the resistance formula for the enclosure J 3 1 and E b 3 surface resistance and so on. So, you get the complete picture for this.

(Refer Slide Time: 14:37)



Now if I write the same Q the same formula like this one for this. For radiation shields the formula would simply be Q 1 is A sigma T 1 to the power 4 minus T 2 to the power 4 and the sum of all resistances. So, here we know where we assume that F 13. Since the plates are long and parallel they are going to be equal to 1 everything is in series.

So, the resistances, so this is the first resistance since F 1 3 is equal to 1 and I have taken A to the denominator. So, this is going to be 1 plus 1 minus epsilon 31. Once again this would be their this will have a value equal to 1 this is going to be there. This will be there this value is going to be equal to 1, and this is going to be present in the final expression. So, I have the first 1 then 1 and the third one, the fourth one, then 1 and then the last 1. So, you would aim through the use of this shield is to reduce the amount of heat that one is going to lose or one is going to gain depending on what application you have in mind.

So, when are you when you are choosing the material of construction for the radiation shield the only value that you have to consider is the emissivity ok. So, if you look at the expression once again then you would be able to find out you would be able to tell like what is the property that you want. So, let us take a look at the expression once again your epsilon 1 and epsilon 2 are known are known to you.

So, definitely you would like to use a material of low emissivity for a shield, so this is what you would prefer. It becomes even more apparent if you simply write this Q 1 as if you take this as 1 by epsilon 1 then this 1 by epsilon 2 is this and minus 1. So, just a bit of reorganization would give you that the heat flow is going to with this and this. Compare that with what we have obtained for the case of Q 12 when we did not have any when we did not have any shield. So, because of the presence of the shield we have an extra term in the denominator and additional resistance provided by the shield.

And looking at the expression you can clearly see you would like to have as small a value of emissivity as possible for the shield material such that this resistance becomes significant. So, this justifies our previous statement that we would like to have for the shield a material of very low epsilon. So, we want low values of epsilon 31 and epsilon 32 to make our shield and this part this term if you compare it with this one this term provides the additional resistance due to the presence of the shield, shield material. So, for this special case and we can make a special case when if epsilon for all the surfaces are equal. Then Q 1 would be equals A sigma T 1 to the power 4 minus T 2 to the power 4; 2 of 2 by epsilon minus 1 ok.

So, if there are if there are N parallel shields, then this one can be generalized as Q for N number of parallel shields is A sigma T 1 to the power 4 minus T 2 to the power 4 and this is going to be N plus 1; 2 by epsilon minus 1. So, if epsilon is same that is the special case you get this expression where it is this part is simply going to be 2 by epsilon minus 1. And here you are simply going to get going to get 2 and therefore, the Q N the in the case of N fields the formula is going to be this, where this is N plus 1 and this is 2 by epsilon minus 1.

So, this is more or less what I wanted to cover in radiation shields in your text you would see that if the radiation shields are also common for tubes as well. So, you have a tube which you would like to protect. So, you put another shield over here and the same concept would also be applicable that is the radiation shield is going to provide an additional resistance to radiation for the case of shield.

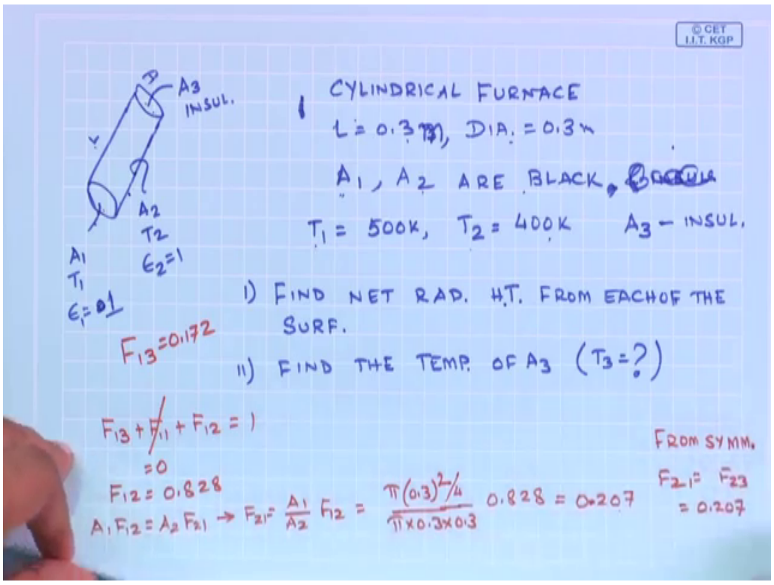
But there you just have to keep in mind that since the geometries geometry is a cylindrical one. So, your two areas the area of the tube side and area of the protection radiation shield may not be equal and while writing the resistance you have to use 1 by A tube F 1 2 in one case. And in the other case instead of A tube you have to write A shield.

So, if these are very close to each other you can make an approximation that A shield is equal to A tube and you will get back to the same result that we have obtained just now.

Otherwise just draw the circuit diagram in all these cases draw the circuit diagram identify what is epsilon 1? What is A 1? If are they equal and not epsilon 1 epsilon 2 etcetera write the resistance to heat transfer in an enclosure and also write the resistance for heat transfer the resistance. The surface resistance to irradiation what is 1 minus epsilon 1 by A1 epsilon 1?

So, and see whether they are collected in parallel or they are connected in series, are those shields in the case of shields they are going to be connected in series one after the other. And you simply have to add the resistances in order to find out what is the total flow of heat in presence or absence of one or a number of shields. So, what have you do is, I will give you one more problem to practice on for the case of radiative heat exchange in an enclosure. Discuss some of the salient features and in the rest you have to you are going to solve that problem.

(Refer Slide Time: 23:32)



So, for this problem what we do is, we have chosen a cylindrical furnace. So, this is a cylindrical furnace in which let us call this as my surface 1. So, it is area is A 1, temperature is T 1, and it is a black body. So, F epsilon 1 is equal to 1.

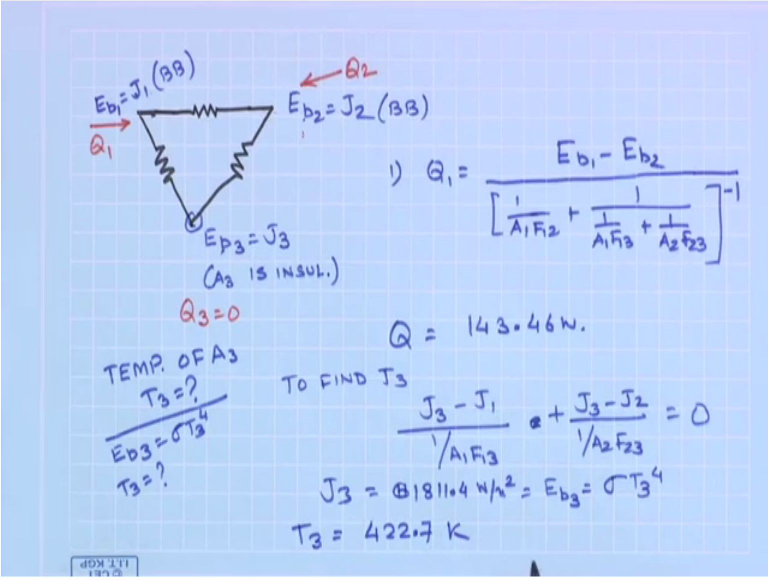
So, it is a black body for the case the surface 2 is A 2 and it is temperature is T 2 and this is also a black body. So, epsilon 2 is equal to 1, the surface A 3 is insulated ok. The length, so this is a cylindrical furnace, the length is 0.3 meter, and diameter is also 0.3 meter. So, this is 0.3, and this diameter is also 0.3 meter ok. The surface A1 and A 2 the end surface and the lateral surface are black. As you can see the way I have drawn it epsilon 1 and epsilon 2 are both equal to 1. Since they are there they are since they are black bodies and they are insulated as well ok.

The temperature of 1 is maintained is at 500 Kelvin, temperature at 2 is 400 Kelvin. I will I will change this A 3 is insulated as I have drawn over here. So, let me state the problem once again it is a cylindrical furnace whose length and diameter are equal. So, this is 0.3 meter, this is also 0.3 meter the surface 1 and the lateral surface 2 are both black; A1 is to be maintained at 500 Kelvin, A 2 has to be maintained at 400 Kelvin, the last surface A 3 is insulated ok. You have to find the net radiation heat transfer net radiation heat transfer from each of the surfaces. And find the temperature of A 3 that is you have to find: what is the value of T 3? It has been given that for such a system F 13 is equal to 0.072.

So, F 1 to 3 is 0.172 the first thing that you have to do is you have to find out the unknown view factors. So, F 13 is 0.172 so F 13 plus F 11 plus F 12 is equal to 1. Since it is a plane surface F 11 is equal to 0. So, you get F 12 is equal to 0.828. You can also write from reciprocity relation that A1, F 1 2 is A 2 F 2 1. And therefore, the unknown F 2 F 21 is A1 by A 2 times F 1 2, A1 is the circular area 0.3 whole square. A1 is this circular area, times A 2 is the A 2 is pi D L. The lateral area pi D L pi into 0.3 into 0.3 times by square is 4 times F 1 2 is given as we have calculated this. So, this is equal to 0.207, so this F 12 F 1 to 2 is 0.207.

So, from symmetry from symmetry we can write F 21 2 to 1 equals F 2 to 3 is equal to 0.207. So, F 2 to 1; if it is 0.207 F 2 to 3 should also be equal to 0.207 because of the symmetry of this case.

(Refer Slide Time: 28:51)



So, this is A if I if I draw the circuit diagram for this case ok. Now E b 1 is equal to J 1 since they are 1 is a blackbody ok, E b 2 is equal to J 2 both 1 and 2 are black bodies. So, therefore, E b 1 is equal to J 1 and E b 2 equals J 2 since they these are all these two are black bodies. Additionally E b 3 is equal to J 3, but for a different reason not for a blackbody since A 3 is insulated. Here A 3 is mentioned A 3 is insulated. So, for a different reason E b 3 is equal to J 3. However, we have some heat which is coming in as Q 1, some heat where is coming as Q 2. And of course, in this case Q 3 is 0, since it is insulated.

So, the problem is pretty straightforward now. So, in order to find the net radiative heat transfer from each of these surfaces let us found Q 1. Q 1 would be E b 1 minus E b 2; Q 1 is E b 1 minus E b 2; this one is in series with these two. So, taking an analogy from electrical circuits it is going to be 1 by A 1 F 1 2 plus 1 over 1 by A1 F 13 plus 1 by A 2 F 2 3 to the whole to the power minus 1. So, when you put the values to be this is equal to sigma T to the power 4 and this is sigma T 1 to the power 4; sigma T to the power 4. And, when you put all the values in there you are going should get Q 1 to be equal to 143.46 watt, so that is what Q 3 is.

The next one is temperature of A 3 or in other words what is the temperature T 3 in this case. In all such cases you need to find out what is J 3 and since J 3 is equal to E b 3, I need to know: what is the numerical value of E b 3. Because the moment I know the value of numerical value of E b 3; E b 3 is simply equal to sigma T 3 to the power 4 ok. So, I should be able to find out what is T 3, so, the step the trick the requirement for this specific type of problem is to find out what is J 3. And in order to obtain J 3 what I am going to say is that to find J 3 the flow of heat J 3 from J 3 to J 1 by 1 by A1 F 1 3 must be equal plus J 3 minus J 2 by 1 by A 2 F 2 3 should be equal to 0. That means, the algebraic sum of the current or the in this case the heat at any node is equal to 0.

So, J 3 minus J 1 by the resistance and J 3 minus J 2 divided by the resistance must be 0 at steady state. So, if you do this when you put all these values in here you should be able to see J 3 to be equal to 1811.4 watt per meter square. This is equal to E b 3 and E b 3 is equal to sigma T 3 to the power 4. When you put the values in there you should get the value of T 3 to be 422.7 Kelvin. So, this is another example of how do you, how you convert the complex radiation exchange geometry to something which now you have the analogy from electrical science and find out what is surface resistance to radiation.

What is a radiation exchange between these between the enclosures and then see which is in which resistance is in parallel, which resistances in series. And the flow of heat is simply going to be the potential difference based on the black body emissive potential divided by the effective resistance between those two surfaces. And everything else follows from there. And in some cases you have to use the view factor algebra the relations of the view factor and you also have to remember that for reradiating surfaces the black body emissive power is equal to the radiosity for that surface. So, if you keep all these in mind then the problem on these can be tackled without much of a problem.

So, we have one more class left and in that class we are going to I am going to mostly talk about what happens, if the system the enclosure that we are talking about is filled with a participating medium which is a very common occurrence where the gases present in the enclosure would start to participate in the radiation process. It would start to absorb some of the radiation and therefore, it is going to violate one of the major assumptions of the network method that the gases are not participating in the radiative exchange process.

So, that would conclude our study on radiation as well as our this course on heat transfer.