Thermal Operations in Food Process Engineering: Theory and Applications
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Lecture - 37
Heat Transfer by Radiation (Contd.)

So, good morning; we have been doing that radiation heat transfer 'right'. So, in the previous classes we have given some idea of radiation heat transfer, how radiation is taking place, what is the role of these particles or like in convection in conduction we need to have always some medium, but radiation does not need any medium even in vacuum also it can radiate.

So, from those initial idea we let us now look into some problem. We also said that emissivity 'right' and the Stefan Boltzmann constant that we have said and we now utilize those thing into this class. So, this is the plus number lecture number 37 where we are continuing with heat transfer by radiation 'right'. This is a continued class 'right'. So, that if we know then we can directly go into a problem where this can be solved 'right'.

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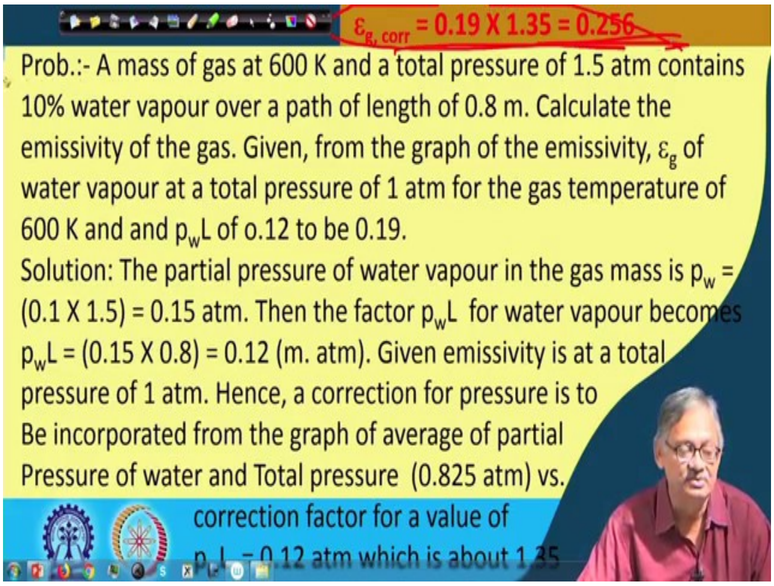

There is a mass of gas at 600 K perhaps this one we have done. Yes this solution we are done do because this is reminding me that this solution we have done where the epsilon came out to be this ok. If we have already done, so, we are not going to repeat.

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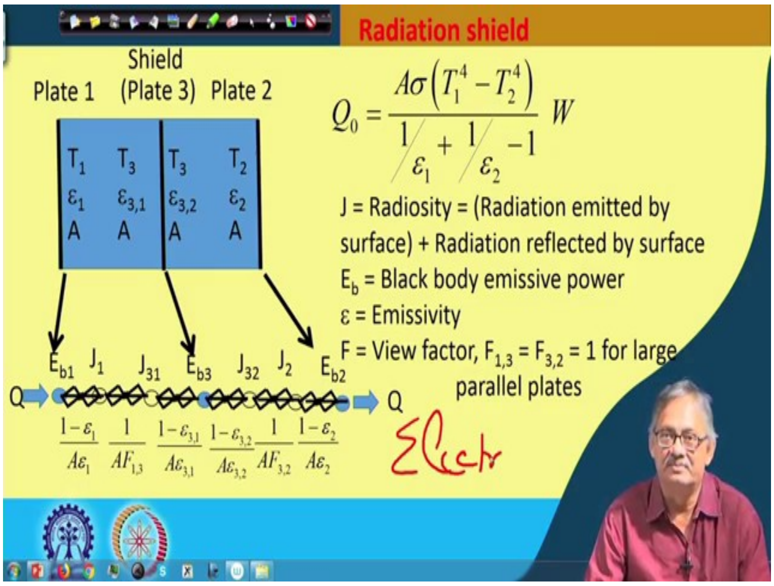

So, next we go to this. This is a very important one that is radiation shield 'right'. From this figure we see that there are 3 or 2 parallel plates 'right' in between there is a radiation shield and the properties of these parallel plates a properties values which are given that this plate is at T_1 with an ε_1 emissivity and A as the area 'right'. This plate has a temperature T_2 emissivity ε_2, but same area A and the radiation shield which you have that is giving that T_3 at one end one side facing the plate 1 and the emissivity is $\varepsilon_{3,1}$, but having the same area A.

Whereas the other side facing the plate 2 that is having temperature T_3 emissivity a $\varepsilon_{3,2}$ and area A 'right'. This is a very very important one. So, that if we understand one we can do whether it is having single radiation shield or multiple radiation shields 'right'.

Now, we go into that the Q_o that is without any radiation shield the value of this would have been as we have seen earlier is $A\sigma(T_1^4 – T_2^4)/(1/\varepsilon_1 + 1/\varepsilon_2 – 1)$ that is had there been no radiation shield 'right'. This is between the 2 parallel plates how much whose who which having epsilon $1/ \varepsilon_2$ as the emissivities.

So, how much would have been the Q or the rate of heat transfer 'right' that simply like this we can find out 'right'. So, here we define another parameter called J or radiosity which means radiation emitted by surface plus radiation reflected by the surface both emitted as well as reflected this two summation is the radiosity 'right'.

We also define E_b or black body emissive power 'right' that is one black body emissive power and epsilon emissivity and another one is F that is view factor like this is parallel 'right'. So, had it been inclined like this the view factor would have been different. What we affected is having now between them that view factor is had it been inclined like this cannot be the same 'right'. So, that is why this view factor has come in that a view factor and we achieve since we are taking parallel plate. So, F_{13} that is between this two and F_{32} between these two are having view factor equal to 1 for large parallel plates 'right'.

So, once we have all these then we can apply that electrical analogy or thermal resistance concept thermal resistance already we have done many times in thermal that conduction problems 'right'. So, that same thing if we apply that a Q is flowing where first coming to this surface. So, this is having a resistance equivalent to E_{b1} 'right' or rather at this point you have a resistance of J_1 that is both radiation plus reflection together and this is 1 minus that resistance is $(1 - \varepsilon_1)/\varepsilon_1$ 'right'.

Second when it is coming to this surface is $1/A\ F_{13}$ facing this that is along with the view factor then the other side 'right'. So, this is a this is for the view factor and another for the emissivity there 1 minus that second resistance is $(1 - \varepsilon_{31})/A\varepsilon_{31}$ then the this side emissivity that is $(1 - \varepsilon_{32})/A\varepsilon_{32}$ 'right' and the view factor that is $1/AF_{32}$ and lastly the resistance due to the due to this plate that is $(1 - \varepsilon_{32})/A\varepsilon_2$ 'right'.

So, all these resistances we have 'right' and with this we can find out by change this without the plate 'right' without the radiation shield that was this. So, this we can rewrite with the shield.

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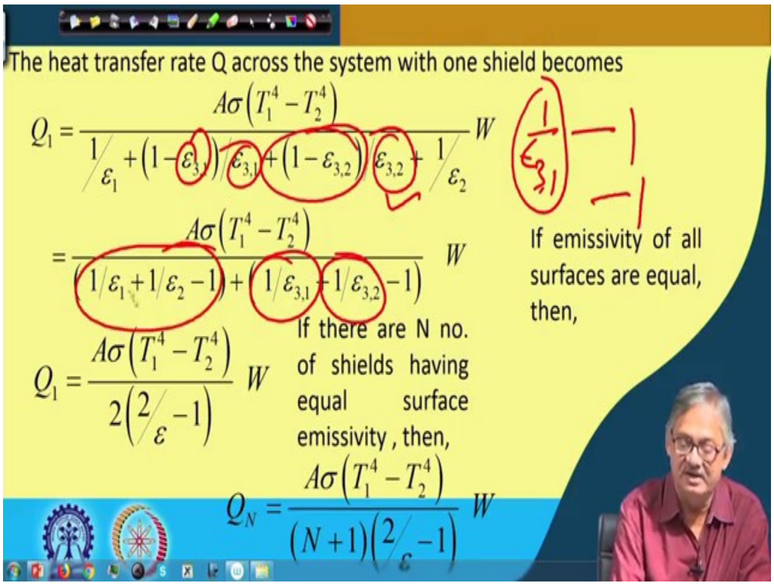

And we can see that now we can write with the help of radiation shield that the heat transfer rate Q across this system with one shield that can be written as with one shield that can be written as $Q_1 = A\sigma(T_1^4 - T_2^4)$ 'right'.

Over $\frac{1}{\varepsilon_1} + \frac{(1-\varepsilon_{31})}{\varepsilon_{31}} + \frac{(1-\varepsilon_{32})}{\varepsilon_{32}} + \frac{1}{\varepsilon_2}$ 'right'. So, if this is known we can simplify it

as $\frac{A\sigma(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - \frac{1}{\varepsilon_{31}} + \frac{1}{\varepsilon_{3,2}} - 1}$. This minus came from here 'right'.

This minus came from here 'right'. This is like that $1/\varepsilon_{31}$ that minus this $\varepsilon_{31}/\varepsilon_{31}$ that is 1 'right'. So, this ε_{31} this ε_{32} we have taken it is here $1/\varepsilon_{31}$ or $1/\varepsilon_{32}$. So, one more - 1 we get it here. So, those 2 minuses are duly taken care of 'right'.

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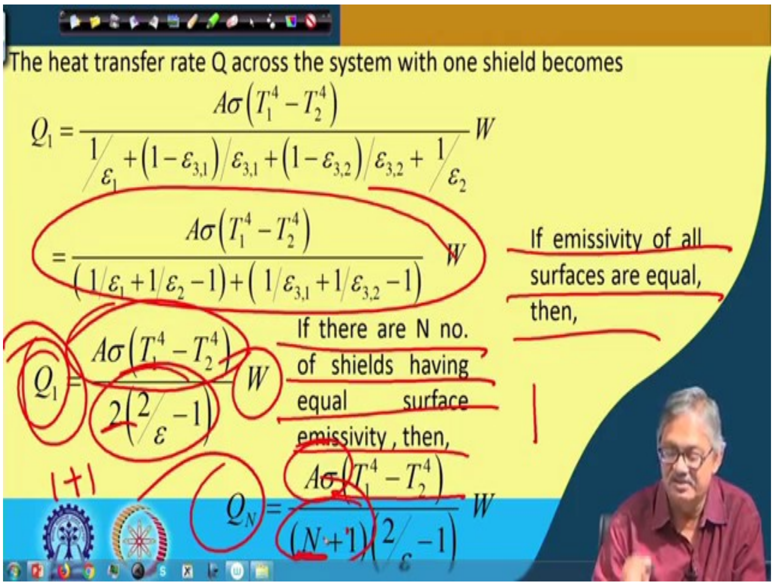

So, that is the Q 'right' and if emissivity of all surfaces are equal then we can write that Q_1 = A σ (T_1^4 - T_2^4)/[2(2/ε-1)]. So, many words 'right' and under this if there are n number of shielding having equal surface emissivity then we can write Q_n similar to this is equal to A σ (T_1 - T_2) to the power (T_1^4 - T_2^4)/(N+1) this was 2 for a single shield so; that means, 1 shield plus 1. So, n shield plus 1 is N + 1 'right'.

So, A σ (T_1^4 - T_2^4)/ [(N+1)(2/ε - 1)] is the Q_n 'right'.

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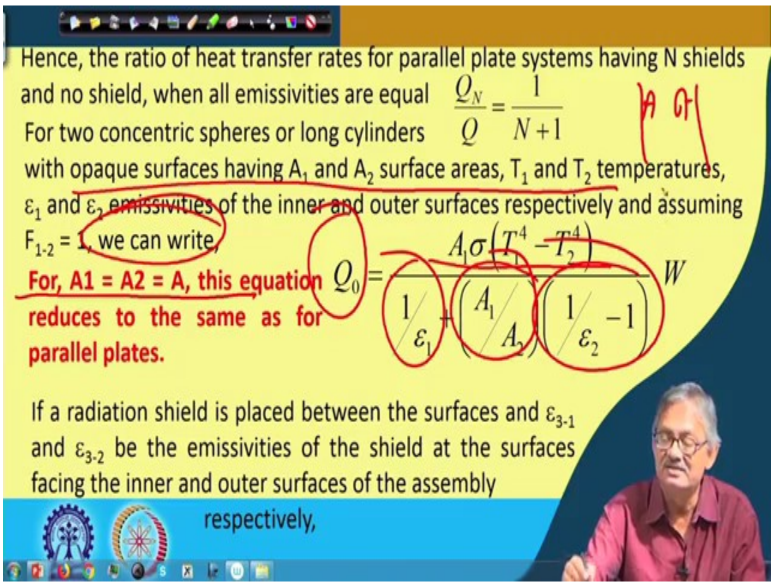

So, if this is known then we can write hence the ratio of heat transfer rates for parallel plate systems having N shields and no shield having N shields and no shield when all emissivities are equal then we can write Q_n and by Q_n/Q is equal to 1/[N+1] 'right'.

For two concentric spheres or long cylinders with opaque surfaces having A_1 and A_2 surface areas and T_1 and T_2 temperatures and ε_1 and ε_2 emissivities of the inner and outer surfaces respectively and assuming that the view factor F_{12} and 2 1 are whatever is all the factors are equal to 1 then we can write that for A_1 is equal to we can write Q_o equal to $A_1 \sigma (T_1^4 - T_2^4)/ [(1/ \varepsilon_1)+(A_1 / A_2)((1/ \varepsilon_2)- 1)]$ that is for opaque surfaces having surface areas A_1 and A_2. So, earlier we had same on the vertical plates we had same area 'right' if you remember.

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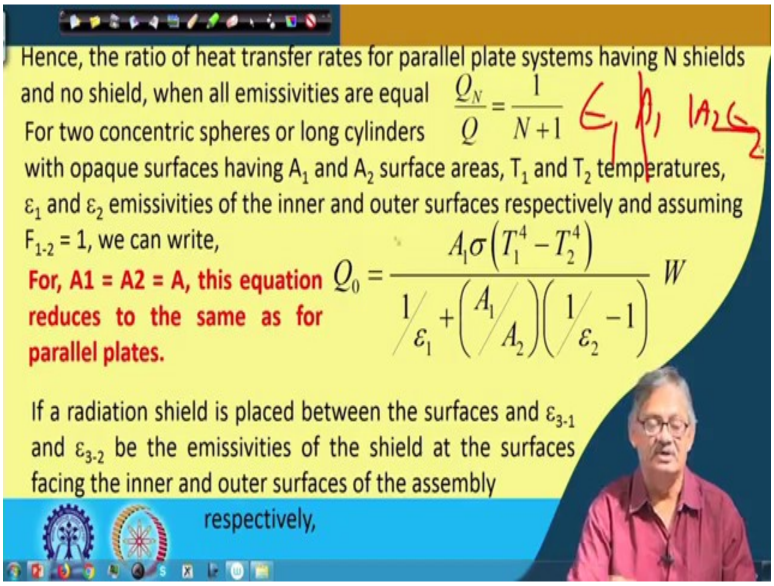

Now, here the areas are different one is A_1 and another is A_2. So, and obviously, earlier also we had ε_1 ε_2 they were different.

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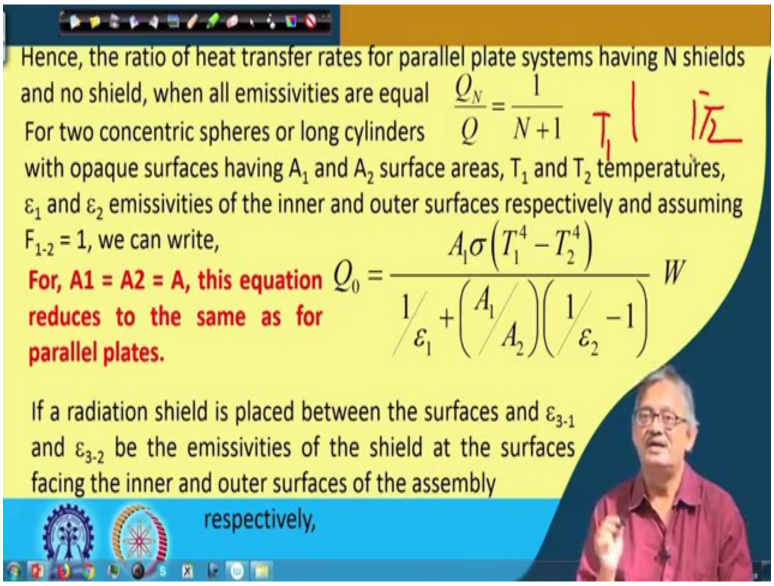

Temperatures were also different it was at T_1 it was at T_2. So, those things were 'right', but now we have changed the area and if the area is changed then the for two such system where two opaque surfaces are there and they are we said the either concentric spheres or concentric cylinders whatever it be 'right' like this. So, this is one and another is this. So, center is this Tt is not properly actually when you are drying in this you have to be a little careful. So, like this 'right'.

So, this area is different this area is different, but they are concentric ok. So, $A_1 \sigma (T_1^4 - T_2^4) / [(1/\varepsilon_1) + (A_1/A_2)((1/\varepsilon_2) - 1)]$.

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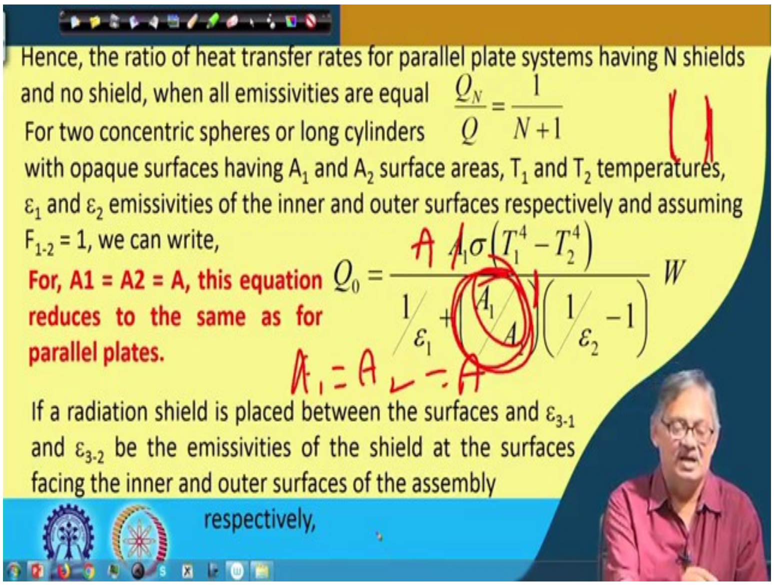

Now, had if it is like that that these two areas are same then it becomes that parallel plate having same area 'right'. So, if $A_1 = A_2 = A$ then it becomes this is unity 1 and this becomes A so; that means, it is reducing to that parallel plate. So, this is the limiting situation and since it is satisfying means this expression is correct 'right'.

Now, if radiation shield is placed between the two surfaces and ε_{31} and ε_{32} be the emissivities of the shield add the surfaces facing the inner and outer surfaces of the assembly respectively 'right'. Now we say that we had this 'right' and this was the centre. So, we are putting another radiation shield in between where this ε_{31} and ε_{32} are the emissivities of the shield 'right'.

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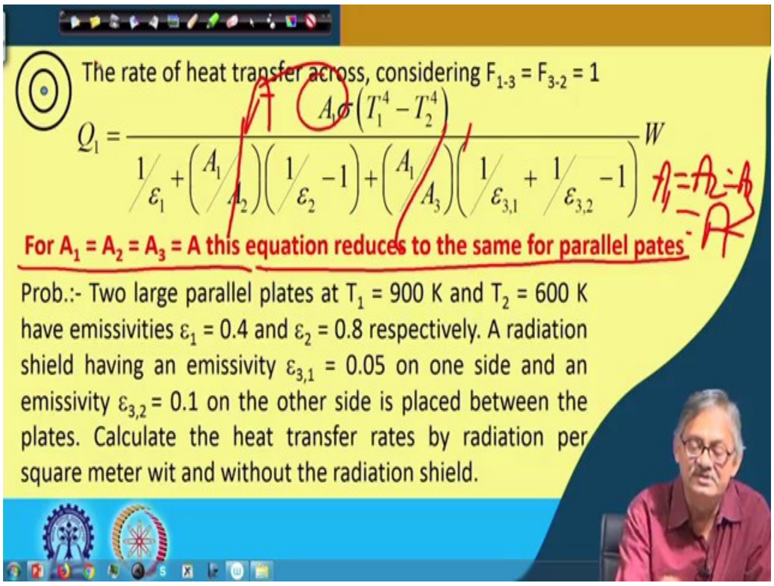

So, if that be true then we can write like this that the rate of heat transfer across the one which we I drew there it is neatly drawn 'right' of course, with the help of the facilities having. So, the rate of heat transfer across considering F_{13} and F_{32} is equal to 1 F_{13} means that first and this is the second radiation this is the third 'right' like this.

So, we are putting one layer we have put we are putting one like this 'right'. So, that is the shield 'right'. So, this shield is having F_{13} and F_{32} equal to 1 and we can write $Q_1 = A_1 \sigma (T_1^4 - T_2^4)/ [(1/ \varepsilon_1)+(A_1 / A_2)((1/ \varepsilon_2)- 1)+ (A_1 / A_2)(1/\varepsilon_{3,1}+1/\varepsilon_{3,2}-1)]$ 'right'.

Similar as we have seen without the shield 'right' here only we have added that shield. So, if this is true then our Q has become

$$\frac{A_1\sigma\left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \left(\frac{A_1}{A_2}\right)\left(\frac{1}{\varepsilon_2} - 1\right) + \left(\frac{A_1}{A_3}\right)\left(\frac{1}{\varepsilon_{3,1}} + \frac{1}{\varepsilon_{3,2}} - 1\right)}.$$

So, this is similar to earlier one earlier shield one that whatever parallel shield or parallel plates we had the shield the similar expression except the area ratios because the areas are different A_1 A_2 and A_3 because this area this area and the shield area they are all different 'right'.

Now, the limiting situation is that if all areas are same that $A_1 = A_2 = A_3$ if that be true is equal to A then we can substitute this as A 'right' this becomes 1 this becomes 1 'right' then for $A_1 = A_2 = A_3$ this equation reduces to the same for the parallel plates 'right'.

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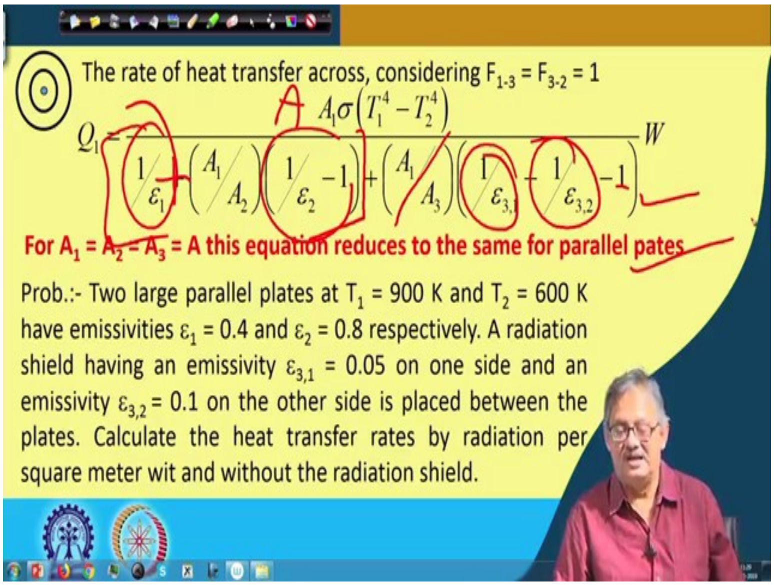

Then it becomes epsilon it becomes epsilon sorry A σ $T_1^4 - T_2^4$ $(1/\varepsilon_1) + (1/\varepsilon_1) + (1/\varepsilon_2)(1/\varepsilon_1) + (1/\varepsilon_2) - 1$ this is number 1 then plus this becomes 1; 1 by this $1/\varepsilon_{3,1} + 1/\varepsilon_{3,2} - 1$ that is nothing, but the same equation as we did it for the parallel plates 'right'.

We can solve a problem like this 2 large parallel plates at T_1 = 900 K and T_2 = 600 K have emissivities ε_1 0.4 and ε_2 0.8 respectively. A radiation shield having an emissivity $\varepsilon_{3,1}$ is 0.05 on one side and an emissivity of $\varepsilon_{3,2}$ is equal to 0.1 on the other side is placed between the plates. Calculate the heat transfer rate by radiation per square meter with and this is with and without the radiation shield 'right'.

So that means, you have to find out that heat transfer rate by radiation per square meter with and without the radiation shield 'right'. This solution is also not so tricky because we have already found out what is the expression.

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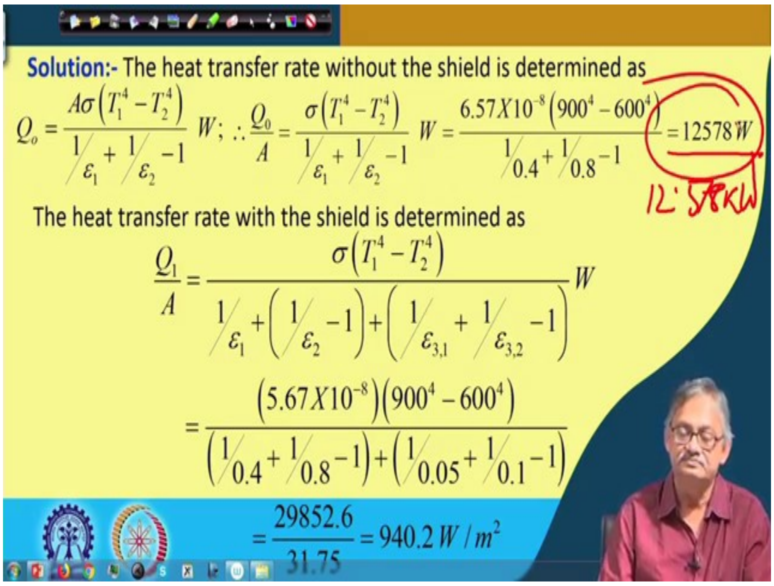

So, if we solve it comes to like this that the heat transfer rate without the shield is determined as $Q_o = \dfrac{A\sigma\left(T_1^4 - T_2^4\right)}{1/\varepsilon_1 + 1/\varepsilon_2 - 1}$ 'right' and $\dfrac{Q_o}{A} = \dfrac{\sigma\left(T_1^4 - T_2^4\right)}{1/\varepsilon_1 + 1/\varepsilon_2 - 1}$ so much watt.

So, by substituting the values we get σ is 6.57× 10^{-8}. This is what you have to remember throughout life that the sigma Stefan Boltzmann constant is 6.57× 10^{-8} in many interviews or many such kind of; such kind of exams things are or that oral exams these things may be asked 'right'.

So, (900^4 - 600^4) 'right' over (1/0.4 + 1/0.8 – 1) 'right' this is Q_o/A this has come 12,578 W 'right' 12,578 means 12.578 kW 'right'. Then we also need to find out this was without. So, we also need to find out width. So, the heat transfer rate with shield that can be written as $\dfrac{Q_1}{A} = \dfrac{\sigma\left(T_1^4 - T_2^4\right)}{1/\varepsilon_1 + \left(1/\varepsilon_2 - 1\right) + \left(1/\varepsilon_{3,1} + 1/\varepsilon_{3,2} - 1\right)}$ 'right'.

So, for the surfaces that is this surface and this surface and this is for the shield for both the faces facing this and facing that 'right'. So, if that is known then by substituting the values sigma value 5.67× 10^{-8} 'right' and 900^4 T_2^4 - 600^4 these are the 2 temperatures given T_1 and T_2 over ε_1 is given 1/0.4 ε_2 is given 1/0.8 1 'right' - 1 and $\varepsilon_{3,1}$ is given 0.05 is 1/0.05 $\varepsilon_{3,2}$ given 1/0.1 or point given 0.1. So, it is 1/0.1 - 1 'right'.

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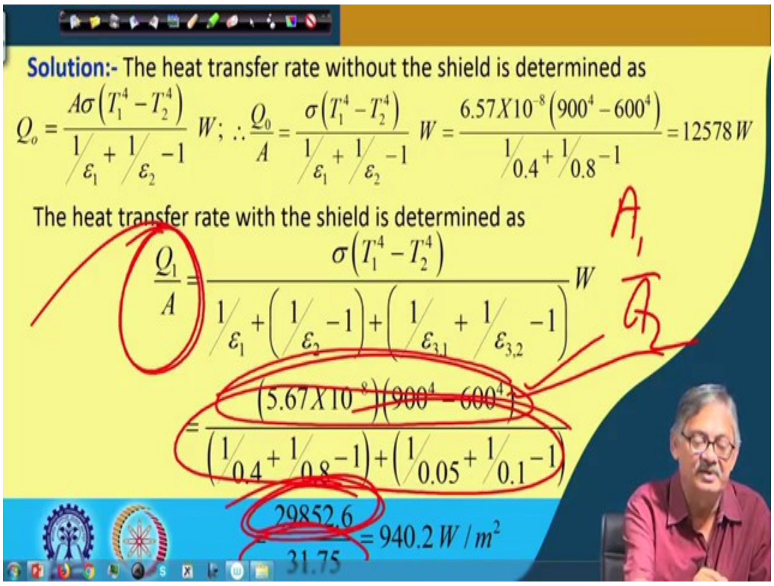

So, this on simplification gives the numerator to be 29,852.6 because that is how it such big numbers can be handled. So, we write first the numerator do not do all at the time it there may be a mistake 'right'. So, or if the mistake is not there at the numerator if it is at the denominator then the entire thing goes out.

So, that is why first do that numerator. So, it is 29,852.6 and then the denominator that is 31.75 'right'. So, here having the same area otherwise if it would have been different areas like A_1 and A_2 they are A_3 then it would have been a little different than this 'right' this is for the same area of all.

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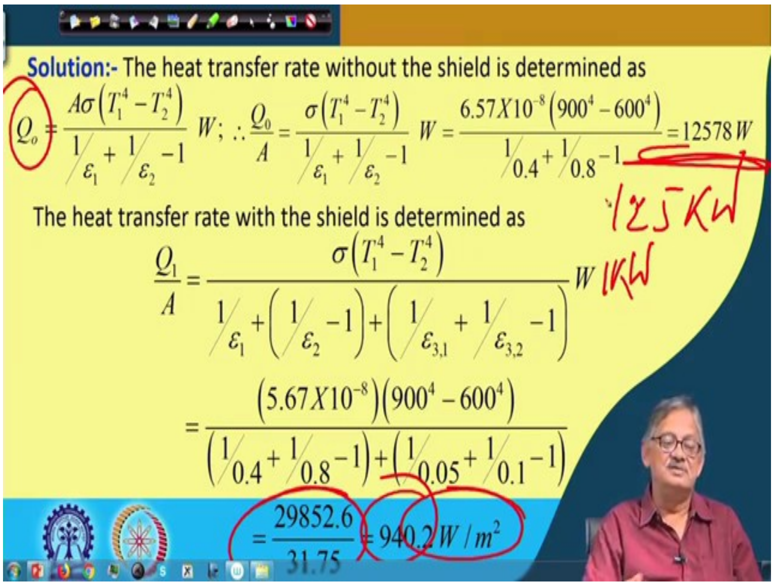

So, this has become 29,852.6 by 31.75 is 940.2 watt per meter square. So, without shield the heat transfer rate was 12.5 kW whereas, this is 940; that means, almost 1 kW ‘right’. So, 10 to 10 times the heat transfer has been reduced by putting the shield. So, this is how and why the shield is being put and people do prefer for big things or for valuable things to protect by from the radiation by putting radiation shields ‘right’.

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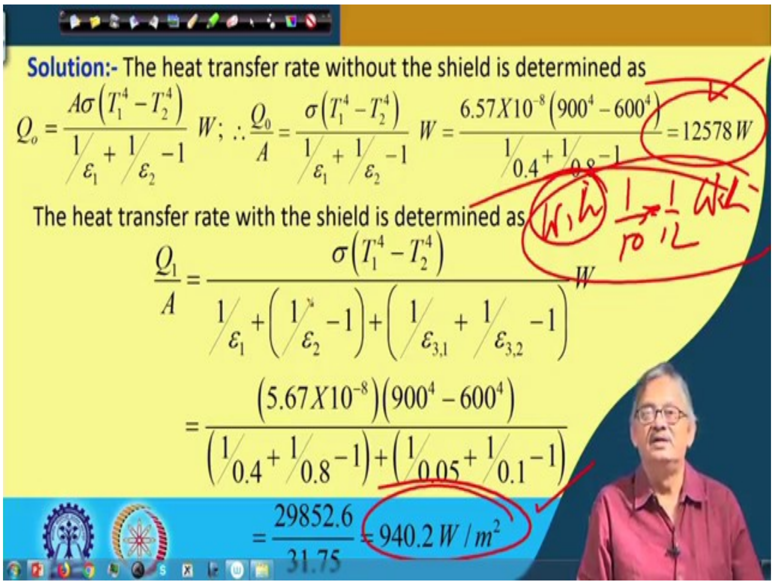

So, do us do similar problems here we have shown that it is almost one tenth or one twelfth ‘right’ the without shield and with shield it is one tenth or one twelfth of the without with shield is one tenth or one twelfth of the with shield ‘right’ sorry without shield I mean with shield the value is one tenth or one twelfth ‘right’ one tenth to one twelfth of the with this is with shield without shield ‘right’.

So, you can reduce the heat transfer rate by 10 times from the with shield by giving a shield ‘right’ to the from the without shield by giving a shield ok.

Thank you.