Thermal Operations in Food Process Engineering: Theory and Applications

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Lecture - 35
Heat Transfer by Radiation (Contd.)

So, we are in the process of Radiation Heat Transfer, 'right'. We have done a little on preamble. I do not say preamble some understanding of the radiation. If we look at more in a little detail and we have seen that a Stefan Boltzmann constant is one of the primary. So, this is lecture number 35 under radiation heat transfer.

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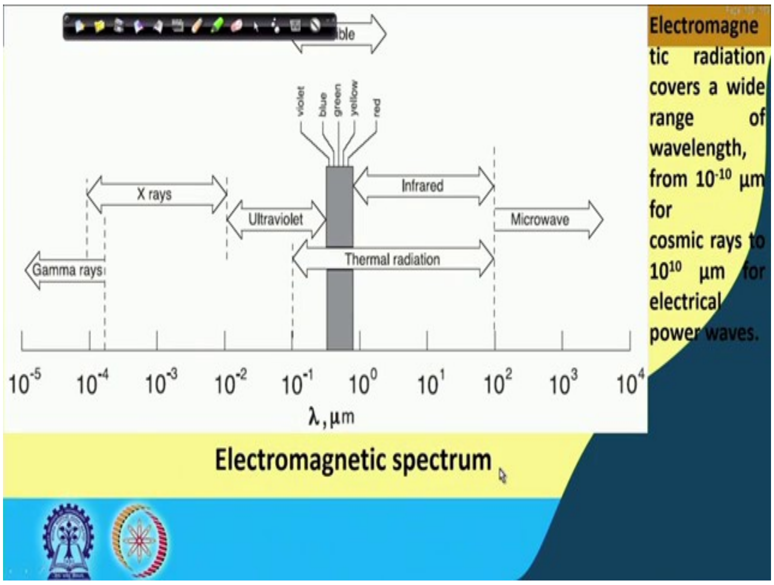

So, if you look at the electromagnetic spectrum, this is explicitly for a for understanding a real thing this is that this is under visible, 'right' visible wave length that this lambda is micrometer you see 10^{-5}, to 10^{-4}, -3, -2, -1 10, 0, there is 1, 10, 10^2, 10^3, 10^4.

So, -5 to -4 and here we are saying that electromagnetic radiation covers a wide range of wavelength from 10^{-10} μm for cosmic rays to 10^{10} μm for electrical power waves, 'right'. Out of which you see gamma rays are within this range, -4 to -5. Then X-rays are between -2 to -4 in μm ultra violet rays are somewhere between say 1 to 10^{-2} within that range and between 0.1 to 1 is our visible range, 'right' 0.1 to 1 is our visible range out of which the lowest is violet and the highest is red, 'right'.

So, violet, blue, green, yellow, red, red, vibgyor, ‘right’ so, indigo is in between; so, this is the visible range and the thermal radiation range is within that that is 0.1 to 10^2 that is under thermal radiation. Whereas, infrared is between somewhere say 1 or a little bit low less than 1 to 10^2 or 100 and micro wave is between 10^2 to 10^3 and half, ‘right’ between less than 10^4.

So, this is how the electromagnetic spectrum that is looked into ‘right’. This is more than radiation for information so that you have the idea of the spectra of the electromagnetic radiation or spectrum, ‘right’.

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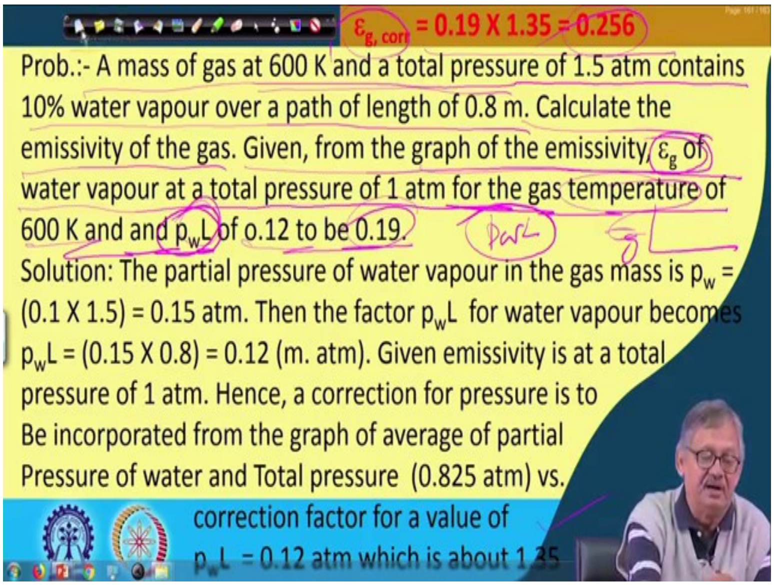

Now, let us look into a problem that a mass of gas at 600 K, ‘right’ and at 600 K, ‘right’ this is ε_{gas} corrected which will come afterwards is 0.19 10 to the power one 0.19 ×1.35 that is 0.256 which will come at the end.

A mass of gas at 600 K and the total pressure of 1.5 atmosphere contains 10% water vapor over a path length of 0.8 m. Calculate the emissivity of the gas given from a graph of emissivity that is E gas E g of water vapor at a total pressure of one atmosphere for the gas temperature of 600 K and p_wL of 0.12 to be 0.19, ‘right’. So, p_w is water vapor pressure times L, so, p_wL that it is meter atmosphere which will see afterwards, ‘right’.

So, from a graph of the emissivity so, epsilon g versus this p_wL we find that the emissivity is 0.19, ‘right’. So, we have to find out that the emissivity of the gas because this E_g water vapor at total pressure of 1 atmosphere has been found out has been given as 0.19. So, what will be when our pressure and a total pressure of 1.5 atmosphere having 10% water vapor, 'right'.

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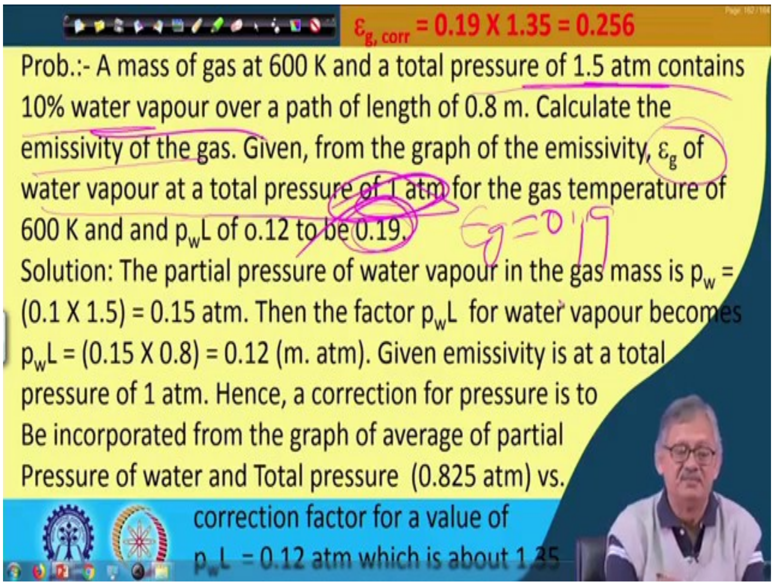

So, the value which we have gotten epsilon g from the graph, ε_g as 0.19, that is not the actual one because, we need a pressure correction, 'right'. So, the partial pressure of water vapor in the gas mass is p_w equal to 0.1×1.5 because 10 point 10% water vapor is equal to 0.15 atmosphere because total pressure is 1.5 out of which 10 % is water vapor. So, it is 0.1×1.5 is 0.15.

Then, the factor p_wL for water vapor that becomes equal to p_wL=0.15; the distance was 0.8, 'right' path length was 0.8 m. So, 0.15 × 0.8 is 0.12 m atmosphere, 'right'. Given emissivity is at a total pressure of 1 atmosphere. Hence a correction for pressure is to be done incorporated from the graph of the average of partial pressure of water and a total pressure of 0.825 atmosphere versus a correction factor for a value of p_wL equal to 0.12 atmosphere which is about 1.35.

Once we know this correction factor from the graph we can correct it as ε_g correction = 0.19 which is the value we obtain for 1 atmosphere and the corrected to the pressure is 1.35. So, 0.19 ×1.35 is 0.256. So, the ε has become 0.256.

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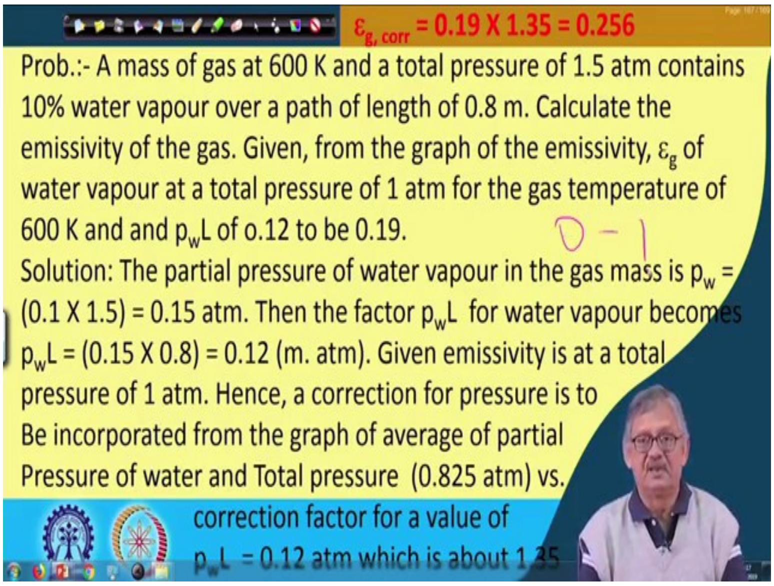

If you remember we had said that the value emissivity value that varies between 0 to 1, earlier in the last class we had said. So, it is never more than 1, 'right' and cannot also be equivalent to negative.

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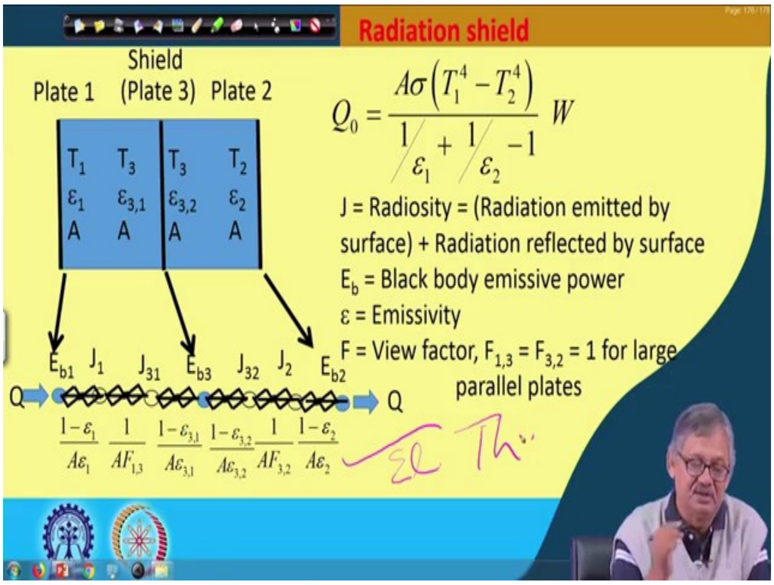

So, after this problem let us look into this. This is also another very good example which in many cases we come across, 'right'. Here we have taken a plate 1 and 2. So, this is plate 1, this is plate 2. Plate 1 is at a temperature of T_1 with emissivity of ε_1 and a area of

A; plate 2 is temperature T_2 emissivity a ε_2 and area A and we have kept a shield, this is called radiation shield, 'right'.

So, we have kept a shield radiating shield where both the phases they are at temperature T_3, but emissivity's are different at one phase it is 3, 1 and another phase it is 3, 2 this is this phasing 2, this is phasing 1. But, all are having the same area A because this same plate we are putting in all three, 'right'.

So, in this case the general governing equation is $Q_o = \dfrac{A\sigma\left(T_1^4 - T_2^4\right)}{1/\varepsilon_1 + 1/\varepsilon_2 - 1}$ so much Watt and there been no shield, 'right', without shield it would have appeared like this. Now, let us define one factor called J or normally known as radiosity or that is the radiation emitted by a surface plus radiation reflected by a surface. So, emission plus reflection together is the J or radiosity, 'right'. So, that J once we so, that is what here we are making J and J this is J_1, so, $J_{3,2}$; J_2; $J_{3,1}$, 'right'.

And E_b let us define that to be a black body emissive power E_b. So, it is plate 1 that is E_{b1} it is plate 2, E_{b2} and this is the shield E_{b3}, 'right'. So, ε is the emissivity and F which comes here also F which is nothing, but view factor means how much is visible a view factor that is also very much important. That we have a plane like this out of which some portion is this portion is may be visible, but back side some are not visible. So, in that case the view factor comes in.

So, view factor is $F_{1,3}$ that is this $F_{1,3}$ between this and $F_{3,2}$ between this, 'right' is assume to be one for large parallel plates, 'right'. If these be true then this situation can easily be related as that Q quantity of heat is coming 'right' Q quantity of heat is coming and first is coming to this plate number 1. So, that we are denoting it to be this E_{b1} that is causing a resistance. So, this we can easily relate like the electrical resistance analogy or thermal resistance analogy, 'right'.

So, a resistance equivalent to $\dfrac{1-\varepsilon_1}{A\varepsilon_1}$; $\dfrac{1-\varepsilon_1}{A\varepsilon_1}$,'right' coming to this point J_{b1} then J_1 rather than another resistance or $\dfrac{1}{AF_{1,3}}$ then J_{31} or $\dfrac{1-\varepsilon_{3,1}}{A\varepsilon_{3,1}}$ then $E_{b3,1}$ that is $\dfrac{1-\varepsilon_{3,2}}{A\varepsilon_{3,2}}$.

Then E_{b31} was this; then J_1 was this; J_{31} was this; E_{b3} was this; J_{32} is this one and J_2 is $\frac{1}{AF_{3,2}}$ and E_{b2} equivalent to $\frac{1-\varepsilon_2}{A\varepsilon_2}$. So, all these distances are there and if we this is the electrical resistance analogy or thermal resistance analogy as we have done earlier in conduction, 'right'.

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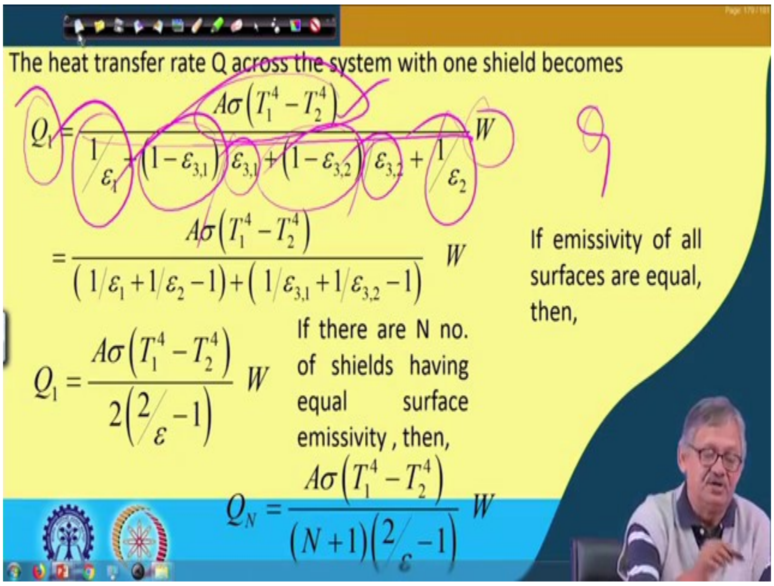

So, if we look at the solution of it the heat transfer rate Q across the system with one shield because we had given only one shield this was plate 1; this was plate 2 and this is the shied that $Q_1 = \frac{A\sigma(T_1^4 - T_2^4)}{1/\varepsilon_1 - (1-\varepsilon_{3,1})/\varepsilon_{3,1} + (1-\varepsilon_{3,2})/\varepsilon_{3,2} + 1/\varepsilon_2}$ so much of wattage.

I repeat that Q_1 that is that one surface which is getting the heat

$$Q_1 = \frac{A\sigma(T_1^4 - T_2^4)}{1/\varepsilon_1 - (1-\varepsilon_{3,1})/\varepsilon_{3,1} + (1-\varepsilon_{3,2})/\varepsilon_{3,2} + 1/\varepsilon_2}$$ so much Watt.

Which on simplification can be written as $\frac{A\sigma\left(T_1^4 - T_2^4\right)}{\left(1/\varepsilon_1 + 1/\varepsilon_2 - 1\right) + \left(1/\varepsilon_{3,1} + 1/\varepsilon_{3,2} - 1\right)}$, this happened how?

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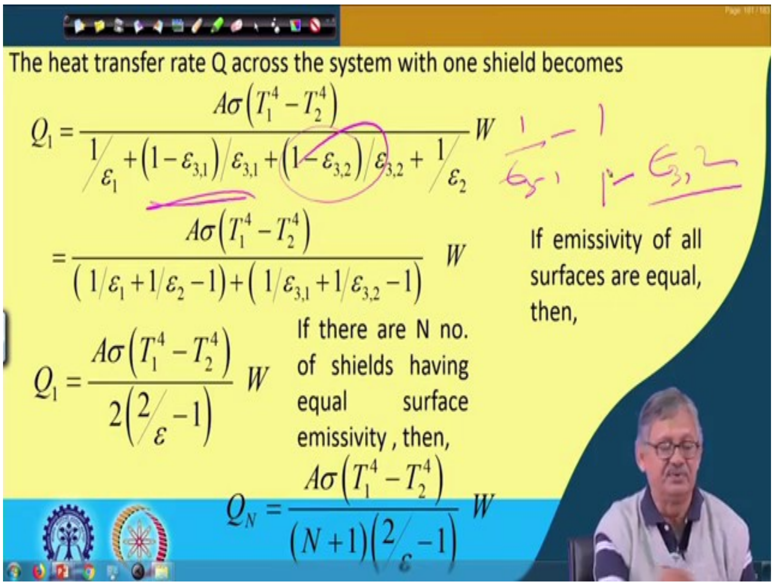

If we if we simplify this one then it becomes $\varepsilon_{3,1}$ - ε_3 $\varepsilon_{3,1}$-1/$\varepsilon_{3,1}$. So, it becomes 1/$\varepsilon_{3,1}$ – 1, ‘right’. Similarly, from here this can be that 1 - $\varepsilon_{3,2}$, ‘right’. So, this way 1/$\varepsilon_{3,2}$, no the other way it will be; it will be like this.

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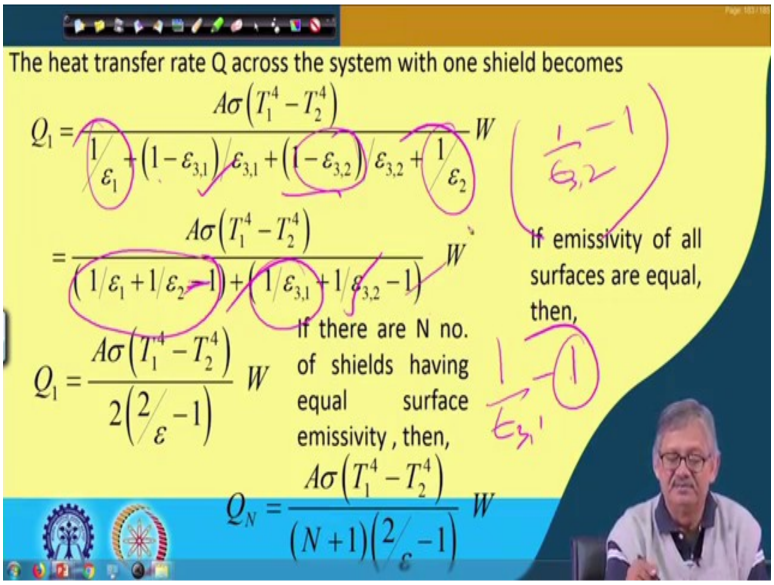

$1/\varepsilon_{3,2}$ - 1; this is from here and this one also $1/\varepsilon_{3,1} - 1$, 'right'. So, if this two minus is a taken care of that is how it is $1/\varepsilon_1 + 1/\varepsilon_2$ - 1and $1/\varepsilon_{3,1}$ from here and $1/\varepsilon_{3,2}$ from here minus that another 1, 'right' this is how it came up.

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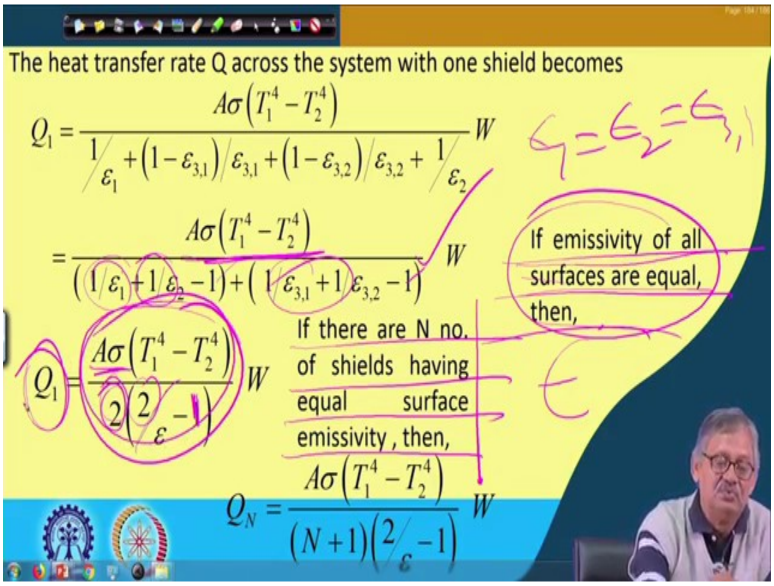

So, this can be now equated that Q_1 is nothing, but if there are if emissivity of all surfaces are equal, 'right' that is all surfaces emissivitys are equal that is $\varepsilon_1 = \varepsilon_2 = \varepsilon_{3,1}$ everything all are coming equal. Then we can write if there are n number of shields having equal surface emissivity that will come, but if there equal then it comes to be equal to Q_1 equal to a $\frac{A\sigma(T_1^4 - T_2^4)}{2\left(2/\varepsilon\right)}$ because we said all if emissivity of all surfaces are equal, 'right'. So, that equal if that be equivalent to epsilon, 'right'.

Then this is $1/\varepsilon$ + this is $1/\varepsilon$, 'right' -1 this is also $1/\varepsilon$ this is $1/\varepsilon$ 1. So, -1 - 1, 2, so, here we have taken 2 common here also we got $1/\varepsilon$ $1/\varepsilon$ that is $2/\varepsilon$. Here also we got $1/\varepsilon$ $1/\varepsilon$ $2/\varepsilon$.

So, 2 if we take common then $2/\varepsilon$ - 1 is the Q_1, if all have the same emissivity epsilon, 'right'. That is for a single emission shield, 'right' we had two plates in between single emission sheet, then if they all have the same emissivity then we can write simplified for a of the heat transfer rate as $Q_1 = \frac{A\sigma\left(T_1^4 - T_2^4\right)}{2\left(2/\varepsilon - 1\right)}$ so much Watt, 'right'.

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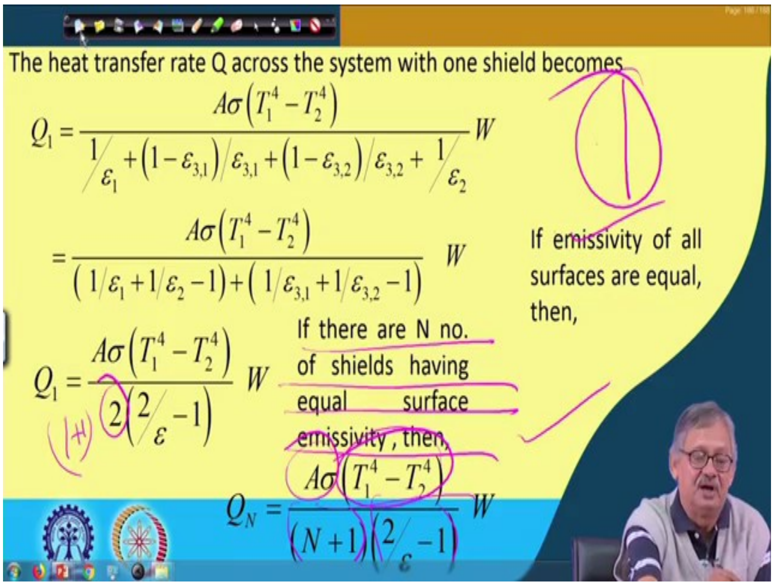

Then it comes it was for a single plate emission shield, 'right'. But, if we have N number of emission shields having equal surface emissivity then we can write this to be equal to you see for a single it was 2, 1 plus 1, 'right'. So, then we can write for N number of that this is $\frac{A\sigma\left(T_1^4 - T_2^4\right)}{(N+1)\left(2/\varepsilon - 1\right)}$, 'right'.

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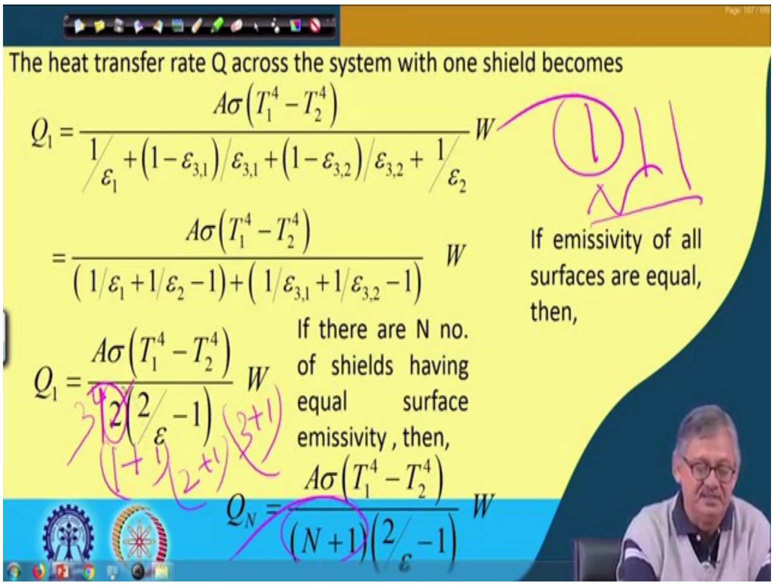

So, I hope it is understandable that this 2 came to be equal to this was for 1 shield. So, that 1 shield can be written as 1 shield plus 1 if and there been 2 shields then it would have been 2 shield plus 1. So, it would have been 3, if it would have been 3 shields then it would have been 3 shield plus 1; that means, it would have been 4. Like that if we have N number of shields then it is N + 1 and this of 2.

So, it was (N+1) × (2/ε - 1) that is what is the Q_N, 'right'. So, we found out Q_1 or we found out Q_N had there been same emissivity for all the surfaces equal to ε, 'right'.

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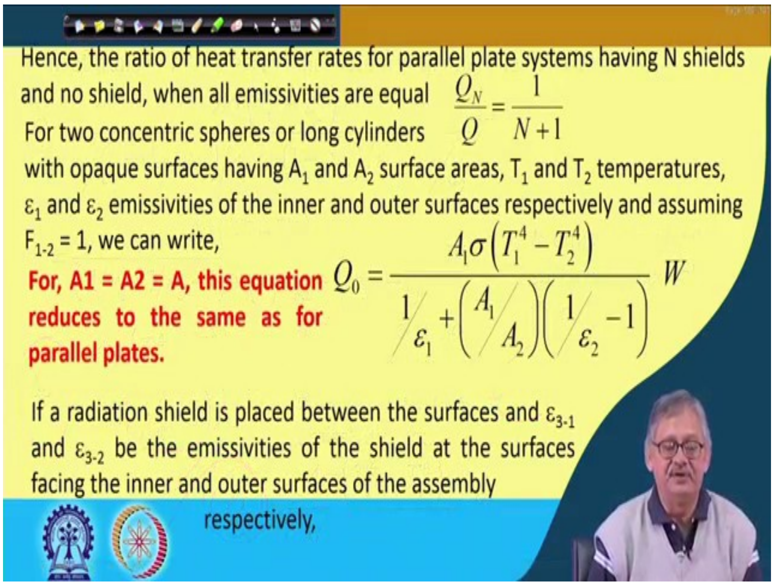

Now, let us look into hence the ratio of heat transfer rates for parallel plate system having N shields and no shield when all emissivitys are equal are like this Q_N/Q is nothing, but 1/(N +1), 'right'. Why it is so?

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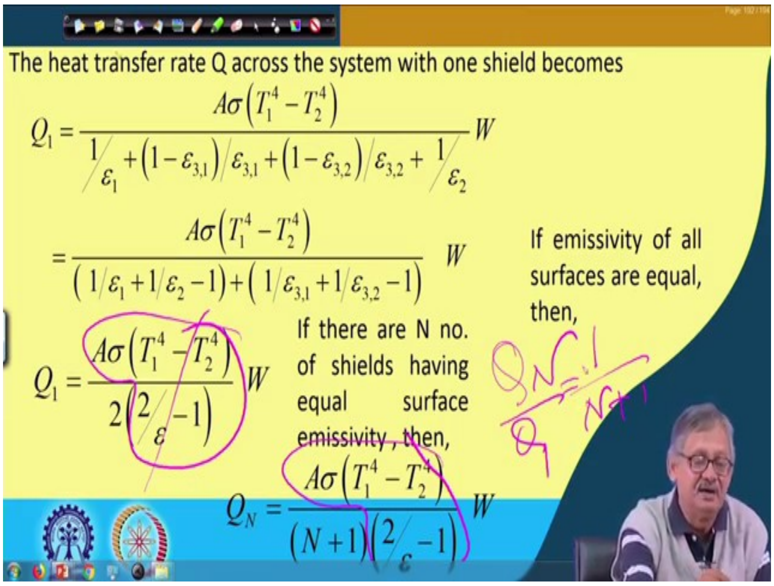

Because, we saw that; we saw that here it was this factor; it was this factor which is common in both the cases, 'right'. It was this factor which was common for both the cases, 'right'. So, this goes out, cancels out when there is a ratio. So, Q_N/Q_1, 'right' this was like this 1/(N +1), 'right'. So, that is what exactly we have shown in the next page that is Q_N/Q is 1/(N + 1), 'right'.

For two concentric sphere or long cylinders with for two concentric sphere or long cylinders with opaque surfaces having A_1 and A_2 surface areas, T_1 and T_2 temperatures, ε_1 and ε_2 emissivity of the inner and outer surfaces respectively and assuming $F_{12} = 1$, we can write, for $A_1 = A_2 = A$ we can write that $Q_o = \frac{A_1\sigma(T_1^4 - T_2^4)}{1/\varepsilon_1 + (A_1/A_2)(1/\varepsilon_2 - 1)}$, 'right'.

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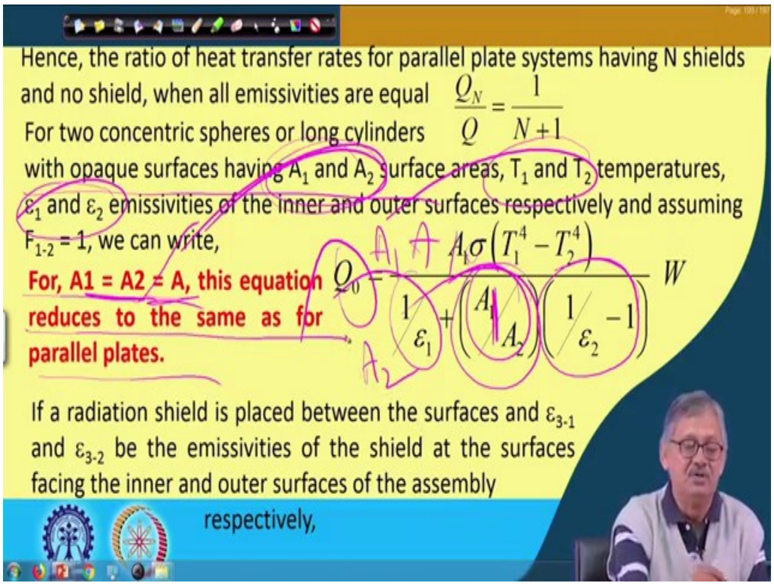

So, for $A_1 = A_2 = A$, this equation reduces to the same for parallel plates, 'right'. $A_1 = A_2 = A$ so, this becomes 1 and this becomes A. So, it was same as for parallel plate A × ΔA × σ × (T_1^4 - T_2^4) /((1/σ_1+ 1/σ_2)-1), 'right'.

But, if it is we said two opaque surfaces having areas A_1 and A_2 surface areas. So, areas changed from A_1 to A_1 and A_2 temperatures where T_1 and T_2, fine, but emissivity also, we have ε_1 and ε_2 only the areas we got changed. So, our Q that became equal to $A_1\sigma$ (T_1^4 – T_2^4) / (1/ε_1 + 1/A_2) times (1 - ε_2) -1, 'right'.

And in earlier also we had shown that if the limiting condition is valid then that means, the expression is correct, 'right'. Here what is the limiting condition? That we have written on the red ink red line or red ink that for $A_1 = A_2 = A$ this relation should now be equal to two parallel plates which we have done earlier, 'right'.

So, if that be true then it becomes A_1 is A and this A_1/A_2 since they are same so, that becomes equal to 1. So, this expression e becomes the expression for the parallel plates, 'right'. If a radiation shield is placed between the two surfaces and $\varepsilon_{3,1}$ and $\varepsilon_{3,2}$ be the emissivity of the shield at the surfaces facing the inner and outer surfaces of the assembly respectively; then the situation will which will come up is quite different and that we will find out, 'right'.

Hopefully, today whatever we have said we could have got it and since our time is now limited so, we will stop it here. But, in the next class we will do that if there is a radiation shield between them then what will be the Q and how it will be varying and maybe we will do some problem, so that our understanding becomes more confident, ok.

So, thank you.