Conduction and Radiation
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Module No. # 01
Lecture No. # 24
Enclosure Analysis Contd.

In yesterday's class, we solved few problems in enclosure analysis, we started off with one surface enclosure emissive, we just took a plate, which was having an emissivity of epsilon or epsilon 1, temperature was T or T 1 and the outside was T infinity, you can consider it to be a blackbody at T infinity.

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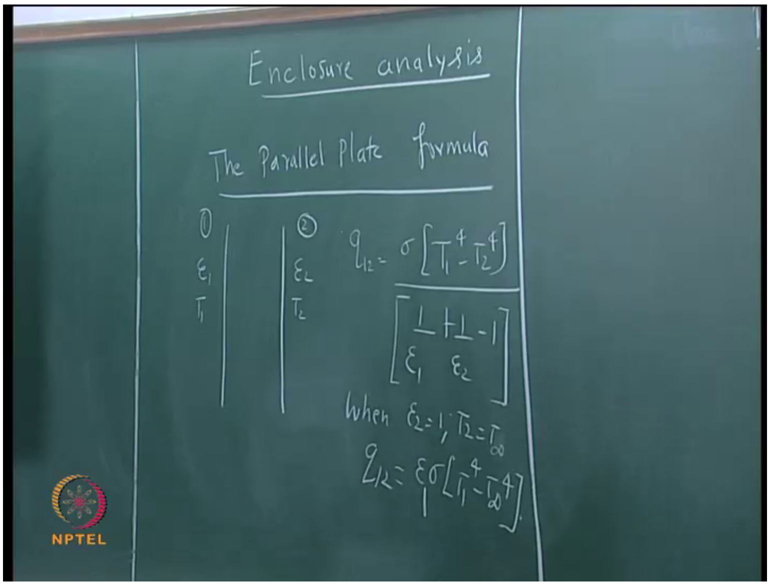

We got the very familiar result, q equal to epsilon sigma T to the power of 4 minus T infinity to the power of 4, then we went on to solve the problem of two zones or two surface enclosures, where you have two parallel plates which are infinite in extent. So, that F 1 2 equal to 1, then we wrote the radiosity relations, then we found that J 1 and J 2, we founded q equal to J 1 minus J 1 equal to J 1 minus J 2, and we got the familiar this parallel plate formula, this is very important result which can be used to module heat transfer between two plates, when the convection between them can be neglected, even if the convection is there, you can add the convection to the radiation and the addition is possible, if the temperatures are known, if the temperatures are not known you have to exploit the coupling, that become what is called a conjugate heat transfer problem.

Now, even in this case, in yesterday's class we saw that 1 epsilon 2 equal to 1 and T 2 equal to T infinity, it reduces to the simple case of one surface enclosure. So, it is all these results are consistent with common sense; they are also consistent with the way we understood. So, it is called an internal consistency check. Now, if you have two parallel plate even though you do not have convection between them, if the temperature difference between these two plates is sufficiently large, then high radiation heat transfer between them is inevitable**,** but many times we want to avoid this radiation heat transfer between them, just because you have put vacuum, it does not mean that you have solve the problem if both the services have good emissivity and they are at a good temperature, and rather we have a good temperature difference, then the radiation heat transfer will not be insignificant.

Therefore, the challenge is now to come up with some method by which. you reduce the radiation heat transfer between these surfaces, therefore you can put some thin film, which has got an emissivity equal to epsilon, epsilon 3 or epsilon shield, and we try to find out, what will be the radiation heat transfer when such a shield is inserted between two plates. Suppose, we derived the formula for the heat transfer, radiation heat transfer with one extra shield, then by induction we can find out what will be radiation heat transfer if you have two shields three shields and n shield, and then we will solve the numerical examples, so that you get an idea of, so that it reinforces the concepts you have learnt.

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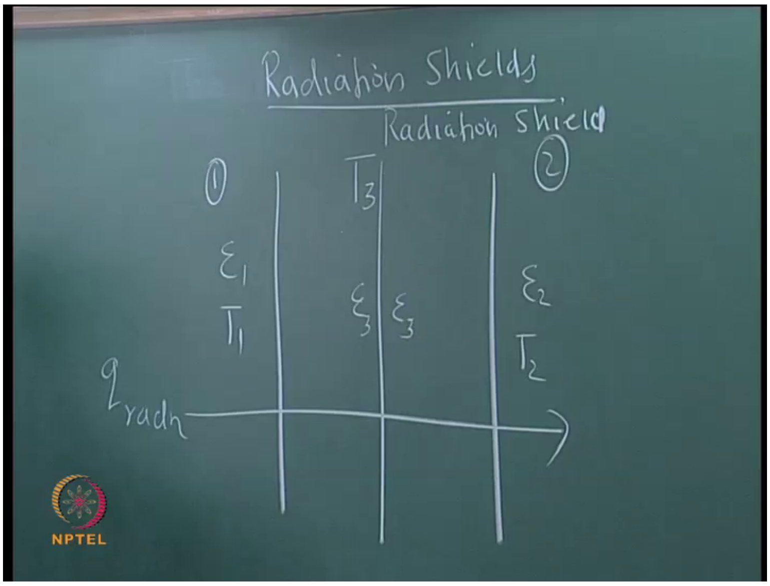

So, we will go to the problem of radiation shield. So, consider two vertical infinitely long parallel plates, which are at temperatures T 1 and T 2 respectively with hemispherical spectral emissivity epsilon 1 and epsilon 2, the intervening space is evacuated; that means, there is vacuum in between, in the absence of any shield or in the absence of any medium, in between or in the presence of a radiatively transparent medium, you already derived the radiation heat transfer between the two surfaces. Now, I insert a shield, now insert a radiation shield, let the radiation shield have a known emissivity of epsilon 3 on both the sides, I have to be very specific in saying that both sides have a same emissivity, because emissivity is just a surface property I can have different coatings on two sides, I can have different emissivity, but the whole shield may be at one temperature, but the two sides may be at different emissivity, we are still talking about an opaque, we are not talking about a transparent shield or something.

Now, let its temperature be T 3, now steady state prevails in the system so, the heat transfer radiation heat transfer is taking place like that. So, is the configuration clear, now the challenge is to come up with a mathematical expression for q with the shield.

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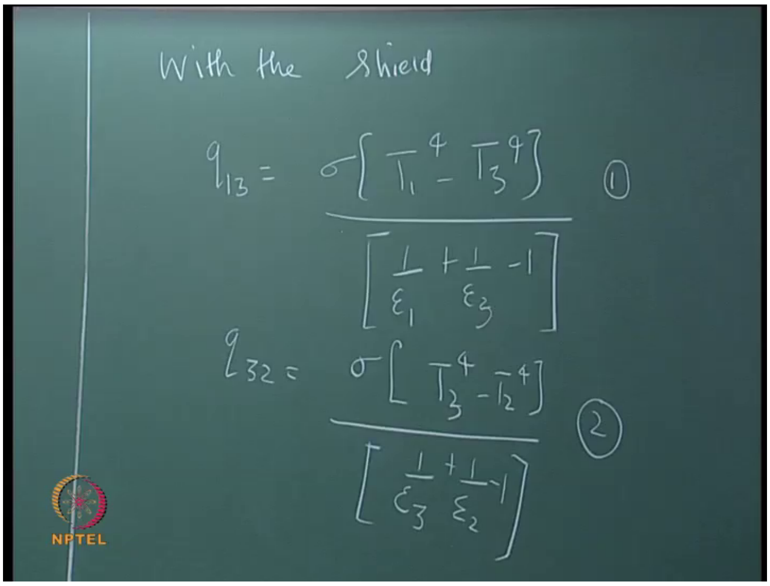

Now, q 1 3 can be written as, from the parallel plate formula q 1 3 can be written as sigma T 1 power 4 minus T 3 power 4, nothing great so, but I may not know T 3 at this point in time, T 3 is equilibrium temperature of the shield, we will talk about it little later, by the same token what can you say about q 1 3 and q 3 2. Equally steady state.

Under steady state q 1 3 must be equal to q 3 2, it is also equal to q 1 2 with shield, it is eventually the heat which is going from the left to the right. So, we can say it as, we can qualify it as, and saying that its q 1 to 2 with shield, q 1 to 2 without shield is this.

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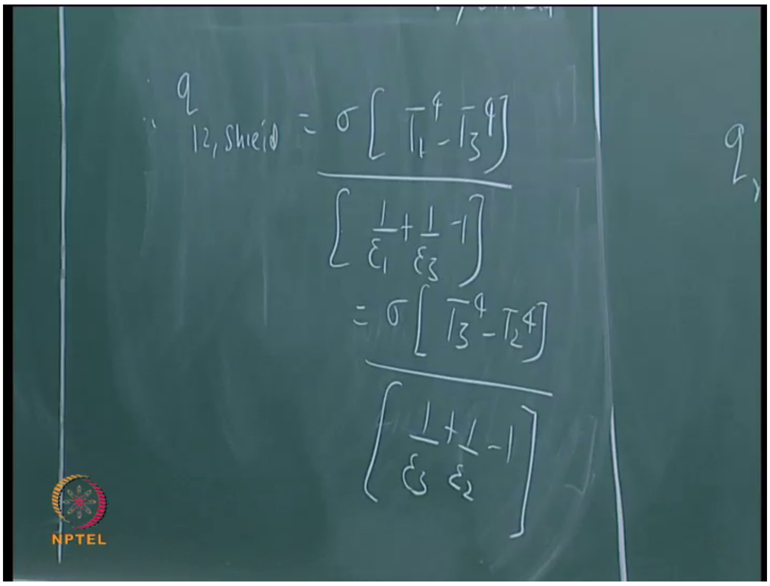

Now, q 1 2 comma shield, so that you do not get confuse. Therefore, (( )) three is not one Why From three is a radiation can go to 1 or 2 . Three as two surfaces, three itself has two surfaces is it not. (( )) one It is, come again, somebody else may have the same doubt, but they can come again, 3 2 three to two, there is nothing else, it cannot go on the back side, because there surfaces, it may be a shield, but radiation is a surface property, the front side may behave differently from the back side they have no connection, the view factor on the front side and back side are not correlated at all, is it clear, that is a good point. I am not very happy with this formula; which formula, this one, because normally in engineering applications we are keeping two plates, it is easy for us to measure the temperature of the two plate, if I put some shield, why unnecessarily take the trouble of putting a thermocouple and measuring the temperature. So, for all practical purposes, we will treat the T 3 as unknown. So, the T 3 has to be eliminated, I do not like T 3, it is useless for me, and with this expression I cannot calculate, is the point clear.

Now, we can do your mathematical manipulation, and eliminate T 3 and all that, but I have again a very cheeky way of doing it.

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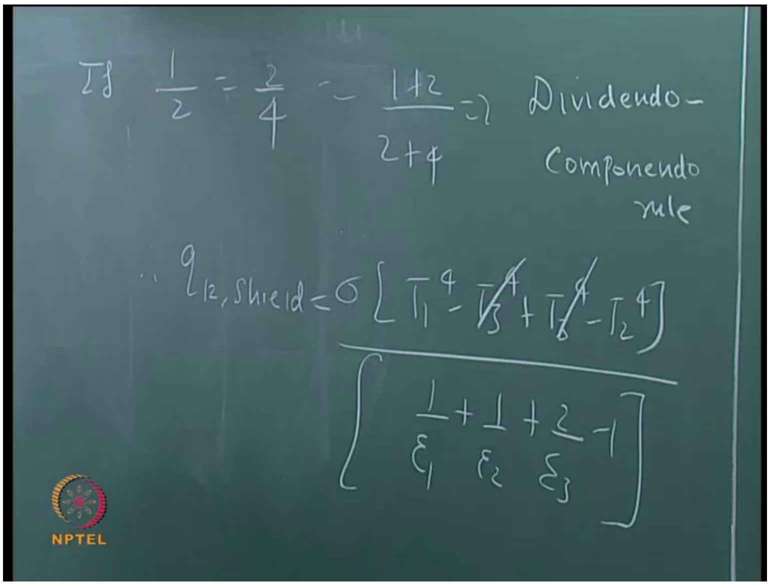

So, I will say, if 1/2 is equal to 2/4, is also equal to is a dividend component rule. Therefore, q 1 2 shield is also equal to the some of the numerator and denominator separately, you can get the same result with lot of labor, if you were not to use the dividend or component rule, still it is possible when substitute for T 3 from here, we will cross multiply, you can do all that. Now, you can assign numbers to this if you want, therefore, is this clear?

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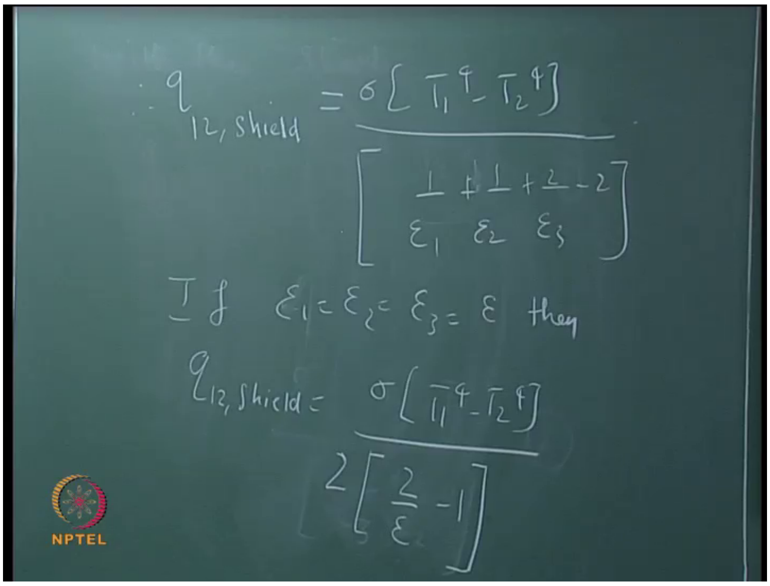

That should be minus 2 there. Yes, so what I did was, I added the numerator and denominator separately, and then say say I am declaring that it is a same q 1 2 shield, fortunately for us there is a minus T 3 to the power of 4, here it is a plus T 3 they are getting cancel, q is that fine, if all the epsilons are equal, is it shrikanth arjun checking check it check now all the epsilons are the same, what will be q 1 2 no shield.

If all the epsilons are the same then q 1 2 no shield will be sigma T 1 the 4 minus T 2 the 4 divided by 2 by epsilon minus 1, therefore, q 1 2 shield divided by q or q 1 2 shield is equal to q 1 2 no shield divided by n plus 1, where n is the number of shields, is it clear so we will write it out formally.

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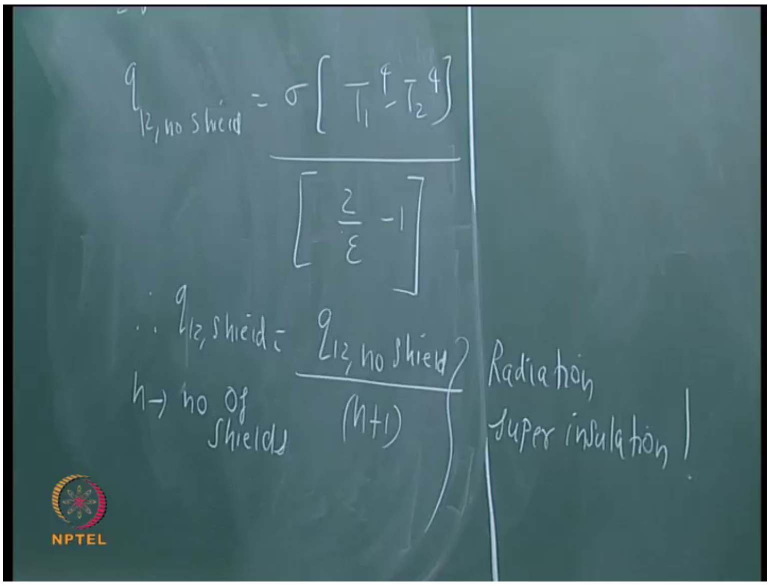

Therefore, it is possible to insulate from surface radiatively by employing n number of shields. So, just because you have vacuum, it does not mean that you already insulated, if you have vacuum you remove the convection and there is no conduction, because there is no medium, but radiation will be there. If you have evacuated and you also have n shields, you get what is called a radiation super insulation. This is the concept of a super insulation, I can make some thin sheets and insert, the position of the sheet does not matter at all, so long as a thin finite in extent, otherwise the view factors will come in to play and all that.

Let us solve a numerical example, while the heat transfer rate is straightforward, suppose for some reason, I want to know whether this radiation shield I have introduced can withstand some particular temperature, it is imperative on my part to evaluate the T 3. The T 3 has to be evaluated as a post process quantity and see whether, that T 3 is for this material, without the T 3 we got this result. So, now as a post processing step, we will have to evaluate the T 3. Let, us solve a problem in which you determine both the q and the T 3; problem number 32. Determine the steady state temperatures of two radiation shields, placed in the evacuated space between two infinite plates at temperatures of 600 and 300 Kelvin respectively, all the surfaces are gray and diffuse with emissivity of point 85, please start solving, the figure is not required, nevertheless I will draw the figure for the sake of completeness.

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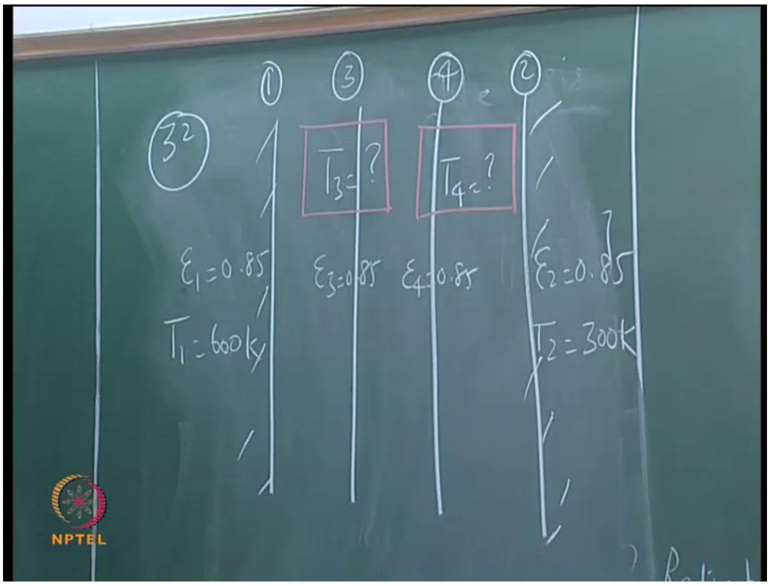

So, there are two plates, 1 and 2, there is no need to call the emissivity are as epsilon 1 epsilon 2 epsilon 3 epsilon 4, all are equal to point 8 5 epsilon is enough, T 2 equal to 300 Kelvin. Now, I have put two shields, how many surfaces are there in this problem totally. Six surfaces are there, there are two surfaces for the two shields, which make them four surfaces, and one surface each, we do not care about the left side of one and the right side of two, we do not care about these two, but we do care about the left side and right side of the intermediate fellows. So, point T 3 equal to not known, T 4 equal to not known, simply write the no shield formula, divided by n plus 1, n equal to 2, therefore n plus 1 is 3, we will get the q with two shields, then this q with two shields, we locally apply between one and three to get the temperature of three, we locally apply between three and four to get the temperature four, we have to do it systematically this will take somewhere between 10 to 15 minutes, it is pretty straightforward.

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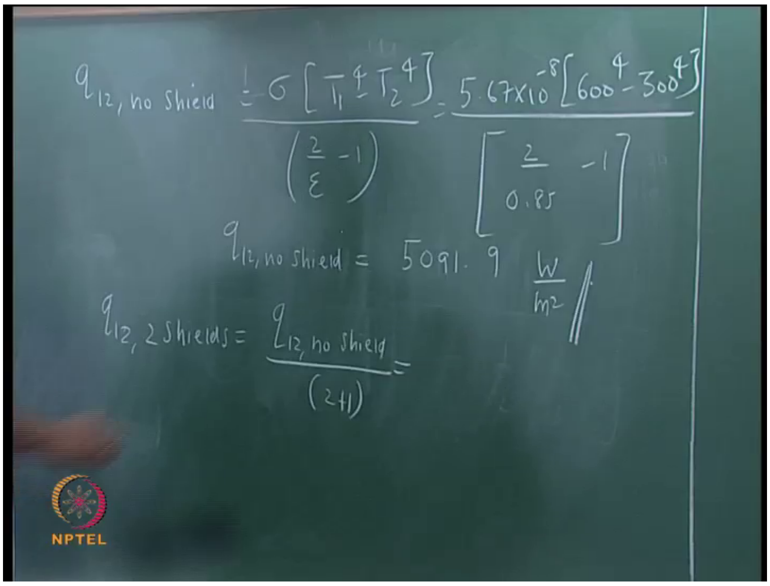

First we will write the q 1 2 no shield 5091 point 9, what are the units, watts per meter square area, this is the first step. Now, we have to do q 1 2 2 shields 5091 point 9 divided by 3.

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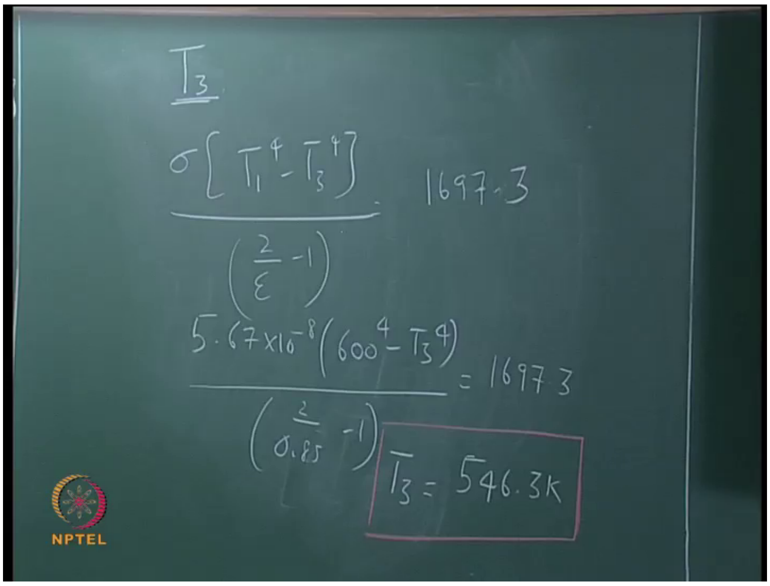

546 point 3, if all the emissivity is not the same more labor is involved, it will become more pain for that is all, but most of the relations will hold good, everybody got this 546 point 3. So, the interesting thing is, if both the surfaces are black, and you have a shield, the equilibrium temperature T 3 will be T 1 to the power of 4 plus T 2 to the power of 4 divided by 2, whole to the power of point 25, I do not know, it is not harmonic, what mean is it i do not know. You take the fourth part, you take the fourth part. Take the average and then take the fourth root, tell me. Fourth part to the arithmetic place

So, it is, that is a way it works. So, you will get an approximate idea of, T 1one to the power of 4 plus T 2 to the power of 4 divided by 2, whole to the power of point 25, do not take it as a formula, only if the two are black and other things, this is asymptotic case, always when you do some engineering analysis, you must look at the asymptotic case what happens; what happens if both are black, what happens if emissivity zero, what happens if T 2 is equal to T infinity, somewhere you must get an answer which is consistent with their common sense, then you know this must be right.

Now, we will do the last part q, the other way of checking is T 3 and T 4 must be between T 1 and T 2, otherwise you are in trouble, there is no heat generation in the problem, heat is flowing from left to right. So, from left to right the temperatures have to continuously decrease. So, these are what are called common sense checks.

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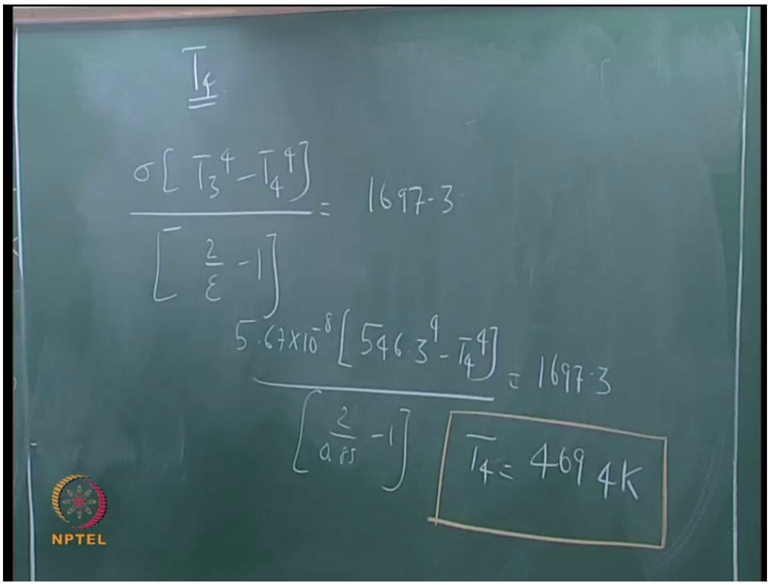

Now, T 4, 169 point 4. So, now, we have got all the answers, what will be the heat flux without the shield, what is a heat flux with two shields, what are the intermediate temperatures, you answered all the questions. Now, let us solve a problem involving a two zone enclosure is slightly more involved.

Shrikanth the value of T actually, we just use the fact that they are equal, for finding out the temperatures we did not use point 85, it is get cancelled where, we got the surface we do not need the (( )). As long as they are equally (( ))

As long as they are equal, otherwise you have to do take that, because what he is saying was 1697 point 3, itself you are taking to be epsilon minus 1, the epsilon will. So, it some sort of an equilibrium temperature, we just mostly determine by the other two temperature that is all. Even if the emissivity is something else, finally it will remain the temperature.

But, I am not sure what you are saying I agreed with what you are saying, but if epsilon 3 1 is different from epsilon 3 2 1 epsilon 4 3 is different from epsilon 4 2, then we are in trouble, and then if each of this is different from epsilon 1 epsilon 2. So, what he is saying is, he is qualifying whatever I told a little earlier further, I told you they have to be black, but he says so long as all are having equal emissivity, whatever I told T 1 to the power of 4 plus T 2 to the power of 4, divided by 2 whole to the power of point 25 holds, but you can call it as T e q, what is e q equilibrium temperature. In fact, a reradiating surface will also behave like this; these are the two shields reradiating surfaces.

Yes whatever heat they receive from the left side they give it to the right side. So, the q net from that surface is zero. q net is whatever is going from right, when whatever is going from left, whatever is coming from the left is positive, whatever is going from the right is negative, so they cancel out. So, in fact, to the radiation shields are reradiating surfaces. Two different surfaces.

But if you considered them as one body, because they have only one temperature, because they are reradiating surface, that temperature or radiosity must be independent of the emissivity that is what we derived in yesterday's class. See, if you work out problems, you can understand the subject; you can appreciate a subject better. So, the common complaint that people are using software, software is not true very correctly. Suppose, you continuously keep on using fluent, it is possible that your fluid mechanics knowledge will increase, because you will learn how to interpret, but you repeatedly use fluent for a longtime, then hopefully your knowledge of fluid dynamics also improves.

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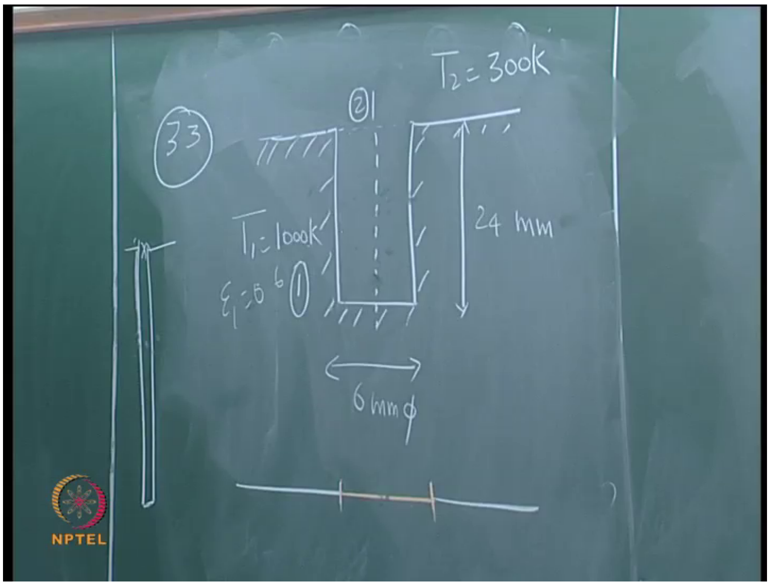

Now, we look at a very interesting problem, where I will explain the configuration to you, I have a flat bottomed hole, a hole has been bored in to a plate, the depth of the hole is 24 millimeter, and the diameter of the hole is 6 millimeters, it is evacuated or it is filled with air, which is radiatively nonparticipating. The temperature of the surface one, which includes the bottom as well as the lateral surface area of the bored hole is basically 1000 Kelvin, and this has an emissivity of point 6.

Let us say, this has an emissivity of point 6, it is opening this hole, this bored hole is opening to the surroundings at 300 Kelvin. Now, we can treat it as a two zone enclosure problem, that is this whole thing is surface one, that is one two three, that is this lateral area and the bottom is surface one, which is having a emissivity of point 6, it is at 1000 Kelvin, surroundings are at 3000 Kelvin, you treat the surroundings to be a blackbody at 300 Kelvin, two zone enclosure we can solve and get the resultant heat transfer from one to two, but the beauty of this problem is, suppose this hole were not there, and you have this surface alone, you just have the surface two, that is you have something like this. This is basically a circle with a radius of 6 millimeters, but now I say, this circle of 6 millimeters radius is a surface which is a blackbody.

Now, this is at 1000 Kelvin, it is also loosing heat to the surroundings at 300 Kelvin, this will dissipate a certain quantity of heat to the surrounding, I want to see compared to this, how much this will dissipate; the ratio of these two, the ratio of these two is called the effective emissivity, why is it so, because we saw the hole run, if I make it like this, there is so much of internal reflection, but the radiation coming out of this, will be equivalent to the radiation coming out from a blackbody at this temperature. Therefore, as the depth of the whole keeps increasing further and further, its effective emissivity will approach one. So, why so much pain and difficulty we want to take, suppose we do not get a surface which is having a good emissivity, it is possible for us to bore holes in a few places and increase or augment the heat transfer, passively without using any pumping power, is the concept clear.

Now, please take down the problem, a flat bottomed hole 6 millimeters in diameter is bored to a depth of 24 millimeter in a gray diffuse material, now all the problem this will come gray diffuse. In a gray diffuse material having an emissivity of point 6 under uniform temperature of 1000 Kelvin, the surroundings are at 300 Kelvin, gray diffuse material emissivity point 6 temperatures 1000 Kelvin. Surroundings are at a temperature of 300 Kelvin. A; determine the net radiant heat transfer leaving the opening of the cavity.

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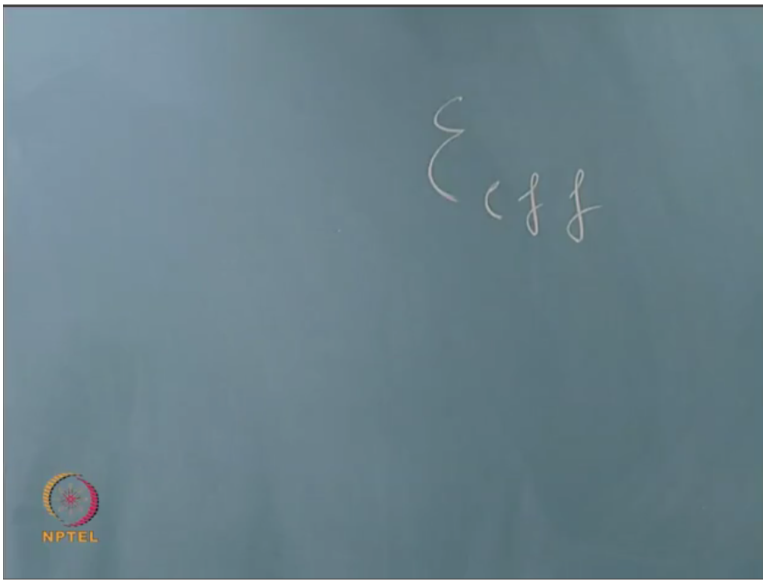

B; the effective emissivity epsilon e f f of a cavity is defined as, I am giving you the definition, the effective emissivity of a cavity is defined as the ratio of the radiant heat transfer from the cavity, that is what we calculated in part A, the effective emissivity is defined as the ratio of the radiant heat transfer from the cavity to that from a blackbody, having the area of the cavity opening under temperature of the inner surfaces of the cavity. So, the concept I have already explain, what I given is the mathematical definition. Calculate epsilon effect, effective for this cavity.

Part C; if the depth of the cavity increases, will epsilon effective increase, if so, what is the asymptotic limit. So, lot of fundas are inbuilt into this problem, the first part of the problem is simple two zone enclosure. Now, please retain up to three or four decimal places, it is very tricky. Now, let us start solving, so what is a first step in an enclosure problem, it is view factors.

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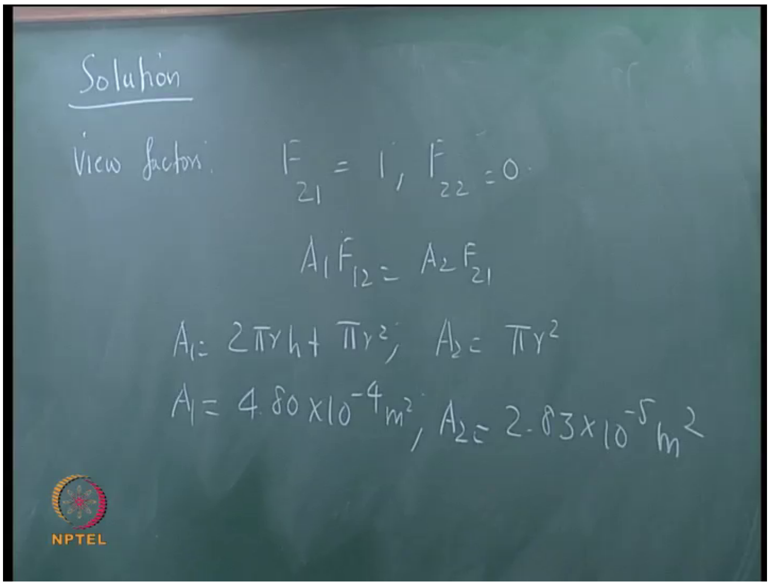

Solution, F 1 1 I do not know, F 2 1 is 1, F 2 2 is 0. So, A 1. So, r equal to 3 millimeters, h equal to 24, full or half, is it fine. Please tell me A 1 and A 2, 4 point 8 into 10 to the power minus 4, is it calculated, just check A 2 first, tell me if I made a mistake just 2 pi r square.

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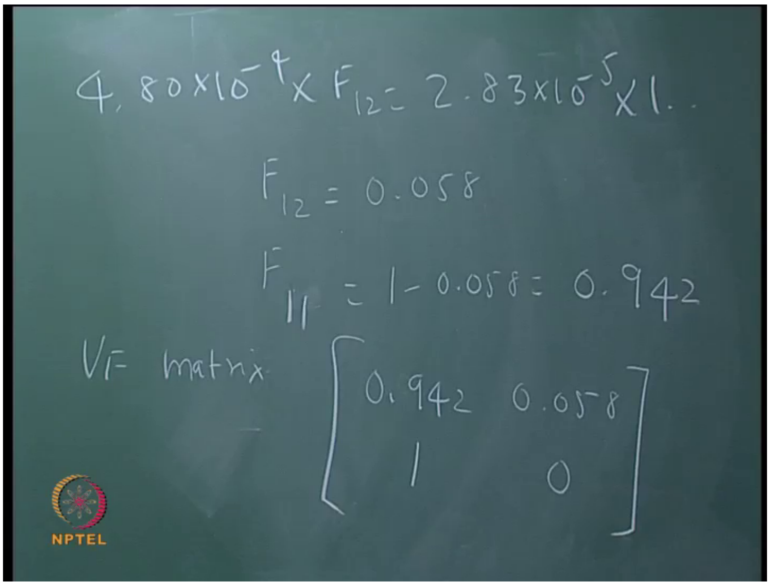

So, F 1 2, point 0 5 8, point 0 5 8, we have 1 1, that is F 1.

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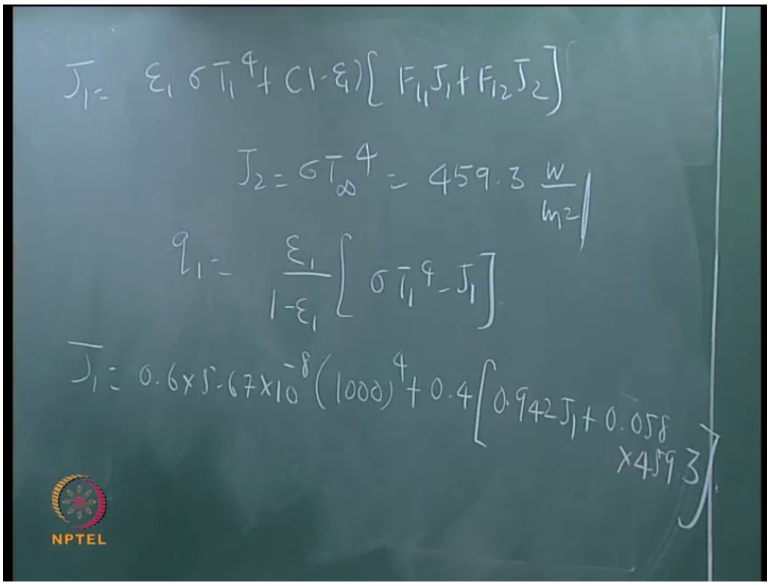

Now, we write the radiosity relations J 1, what is J 2; J 2 is a blackbody at T infinity sigma T 2 to the sigma 459 point 3, what is the value, 5 point 67, 10 the minus 8 into 300 of power 4 power, 459 point 3. So, certain values you should remember, for 1000 Kelvin you will get 56700 watts per meter square, that is clear 5 point 67 into 10 to the power of minus 8, into 10 to the power of 12. Now, we can use this. Let us, get J 1 now, please do the algebra. So, you will have point 4 into point 942. So, 56000, 55000, no we have to be careful, 54606 Point 3, all of you should get this radiosity.

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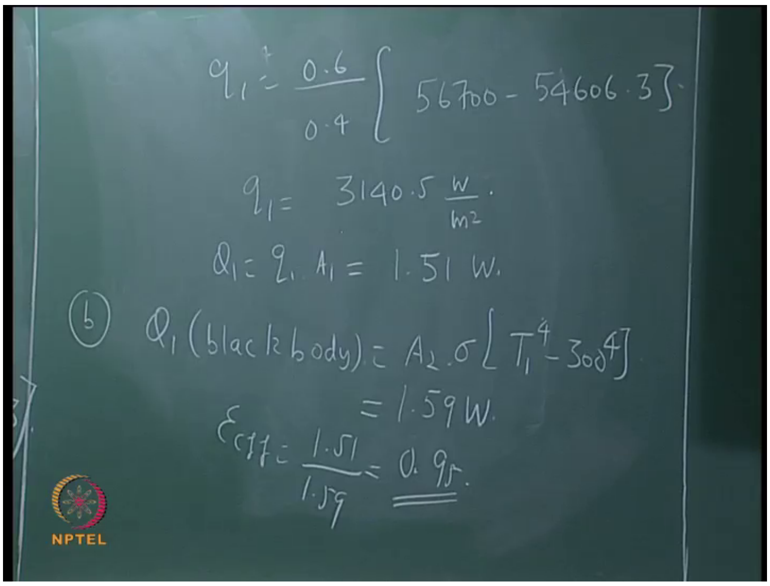

So, q 1 is 3140 point 5, this is only the flux, this is the heat transfer rate, how much is that, into 4 point 8 into ten the minus 4, its 1 point 5 watts, how much is it?

Student: 1 point 51 watts.

1 point 51 watts. So, this is the solution of the part A of the problem, net radiation heat transfer, I hope it is clear, but we will have to revise this. Now, as far as part B is concerned, what will be q 1 for the blackbody, there is a six mm dia surface which is having a temperature of 1000 Kelvin, which is radiating to outside 300 Kelvin. So, this is, how much is this.

Student: 1 point 59 watts

1 point 59 watts, A 2 is area of the opening pi d square by 4, where d is 6 millimeter Stefan-Boltzmann constant 1000 Kelvin minus 300, please be careful to multiply only the area A 2, because that is from the definition given in the part B of the question. Now, epsilon effective equal to how much is it, point 95.

Very significant result, I have this surface, please look at me for a minute i have this surface, if I take a 6 millimeter hole, the area is pi d square by 4, it can emit only pi d square by 4 into sigma into point 6 into 5 point 67 into 10 to the power of minus 8, the maximum will be 1 into sigma into 8 into 5 point 67 into 10 to the power minus 8. Now, if if i have a great diffuse material with an emissivity of point 6, which has for example, for a hole of 6 millimeters diameter, there is only this much, there is a finite amount of heat transfer it can emit it can lose to the surrounding, suppose I bore a hole then I can get a heat transfer rate of 1 point 51 watts. Suppose, I just leave an area at the top like this, if it is a blackbody the heat transfer rate is 1 point 59, if it is a body with emissivity of point 6 the heat transfer is only 1 watt, are you getting the point. Therefore, by drilling a boring a hole from 1 watt we are able to take it up to 1 point 51.

So, if I keep on increasing the depth further, it is possible for me to reach the asymptotic limit of 1 point 59, but never will I be able to exceed sigma T to the power of 4 minus T infinity to the power of 4 into pi d square by 4, all this increase of the effective area, because of the increase in the depth, is only helping me overcome my deficiency of having a poor emitter of point 6, because it is very difficult to get a blackbody, and suppose from point 6 to point 9 I have to put some costly coatings or something, if the material is thick enough, I will put a hole in several places and passively increase a heat transfer rate, this is a technique adopted. For fluid mechanics also in golf balls they put dimples and all that, to increase heat transfer rate also to, and somebody is doing a b tech project on golf balls I remember.