**Conduction and Radiation**

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**Lecture No. # 11**

**Emissivity Contd**

So, we will continue the discussion on definition of various types of emissivity. So, we started with the spectral directional emissivity, yesterday; then, it is epsilon lambda dash, right.

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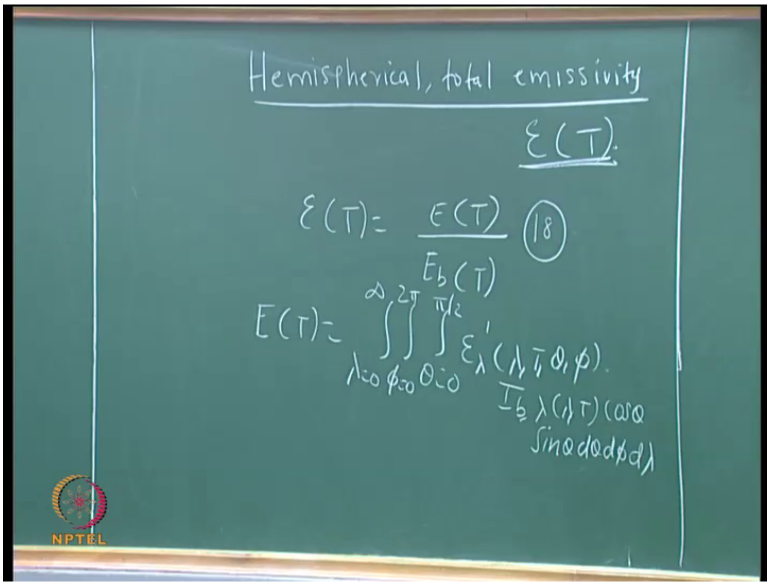


So, the lambda denotes that it is a spectral quantity, and dash denotes that it is a directional quantity. So, two directions are involved; the zenith angle and the azimuthally angle. So, namely theta and phi respectively; and lambda refers to be spectral, refers to the fact that it is spectral.

So, we started integrating one by one. So, if we integrate with respect to direction, then it is called hemispherical. So, you got hemispherical spectral quantity; but if you integrate with respect to wavelength and leave the direction; that is called the directional total emissivity.

Now, we will do both the integrations. So, we will finally get the hemispherical total emissivity, where the integration with respect to wavelength, as well as, theta and phi are done**. So,** this is denoted by… So, it should be a function of temperature; please notes that the final emissivity will be a function of temperature; however, sometimes this dependence is weak. So, you say that the emissivity is independent of the temperature.

Now, this epsilon of T is given by the emissive power; the emissive power of a real surface at a given temperature T divided by the emissive power of a blackbody at that same, at the same temperature. What is equation number?

18, good. So, we will erase this. So, what is this E T?

Epsilon lambda dash multiplied by I b lambda into sin theta cos theta d theta d theta d phi d lambda. Therefore…

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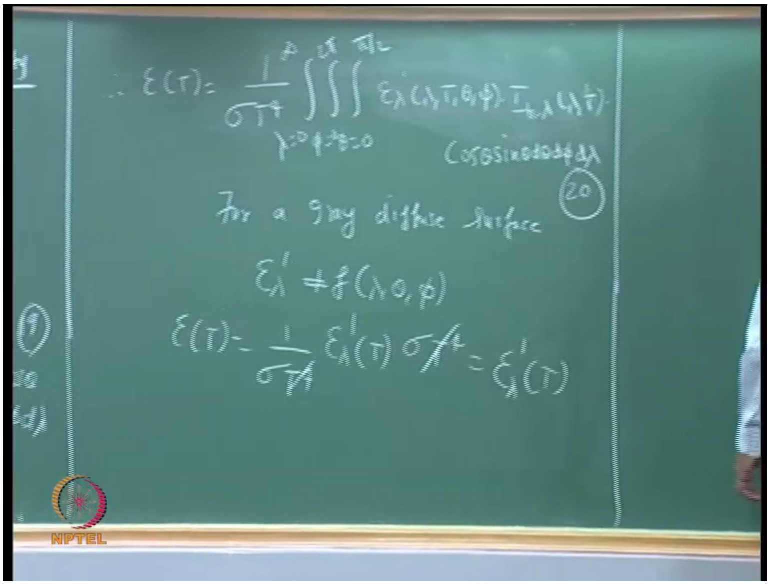


Because, the denominator is one by sigma t to the power 4. Now, this is equation number twenty. It is very important relationship because if you give, if you are given the spectral directional emissivity epsilon lambda dash, it is possible for you to accomplish the three integrations and get the epsilon. For a gray diffused body, gray diffuse surface or body, epsilon lambda dash is not a function of either lambda theta or phi; therefore, epsilon lambda dash can be taken out of all the three integral. And integral, triple integral I b lambda coos theta sin theta sin theta d theta d phi lambda is given by?

What is that finally?

Sigma T to the power of four; that was the Stefan-Boltzmann's law. If you pull out the epsilon lambda dash and accomplish the triple integral, you will get sigma t to the power four. Therefore, for a gray diffuse surface. So, if somebody gives you the spectral directional emissivity that is the hemispherical total emissivity for a gray diffuse surface.

So, if you look at a bird's eye view.

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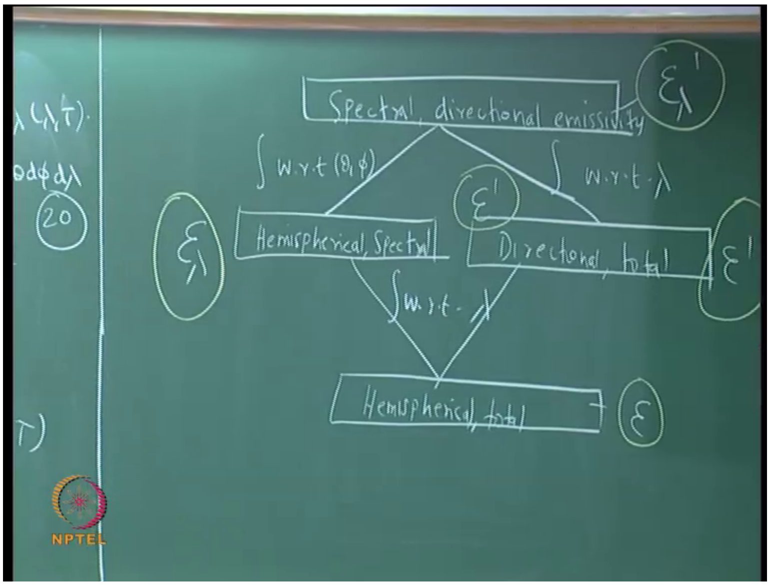


So, this is integration with respect to theta phi. So, if we have the spectral. So, we can write the symbols also. What is this? People are not able to see that. This gives you a bird's eye view or various emissivities involved.

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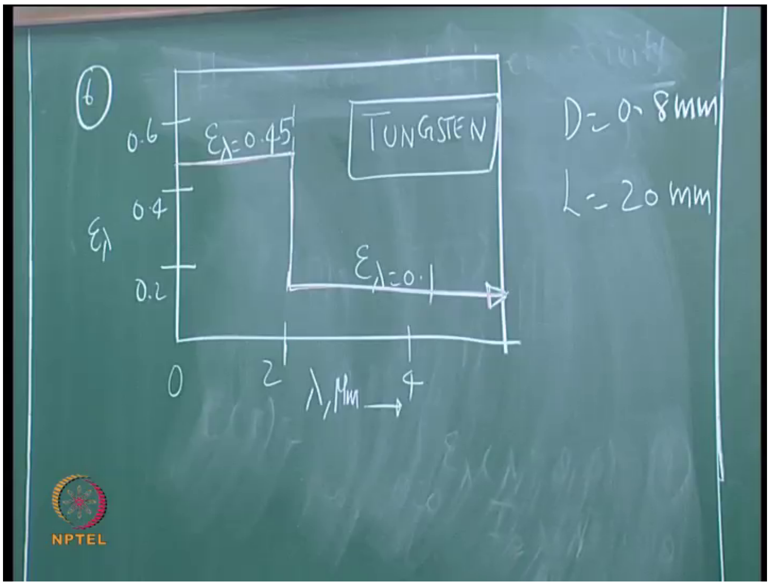


So, now let us solve some problem; problem number 6; and it is going on. So, arrow mark means it is continuously goes as 0.1 up to infinity; epsilon lambda, it does not stop with beyond two micrometer, it is having a uniform value or constant value of 0.1.

Please take down this problem, the hemispherical spectral emissivity of tungsten, the hemispherical spectral emissivity of tungsten, the hemispherical spectral emissivity of tungsten is given below, the hemispherical spectral emissivity of tungsten is given on the blackboard. Consider a cylindrical tungsten filament, consider a cylindrical tungsten filament that has a diameter of D equal to 0.8 millimeter and length equal to 20 millimeter, consider a cylindrical tungsten filament that has a diameter of D equal to .8 and length equal to 20 millimeter. The filament is enclosed in an evacuated bulb, the filament is enclosed in an evacuated bulb, the filament is enclosed in an evacuated bulb and is heated by an electric current, the filament is enclosed in an evacuated bulb and is heated by an electrical current, the filament is enclosed in an evacuated bulb and is heated by an electrical current to a steady state temperature of 3000 kelvin, to a steady state temperature of 3000 kelvin; a) determine the total hemispherical emissivity, determine the total hemispherical emissivity when the filament temperature is 3000 kelvin, determine the total hemispherical emissivity when the filament temperature is 3000 kelvin. b) Assuming that the surroundings are at 300 kelvin, assuming that the surroundings are at 300 kelvin, assuming that the surroundings are at 300 kelvin, what is the initial rate of cooling? Assuming that the surroundings are at are at 300 kelvin, what is the initial rate of cooling of the filament? Assuming the surroundings are at 300 kelvin, what is the initial rate of cooling of the filament when the current is switched off?

The tungsten properties are given below.

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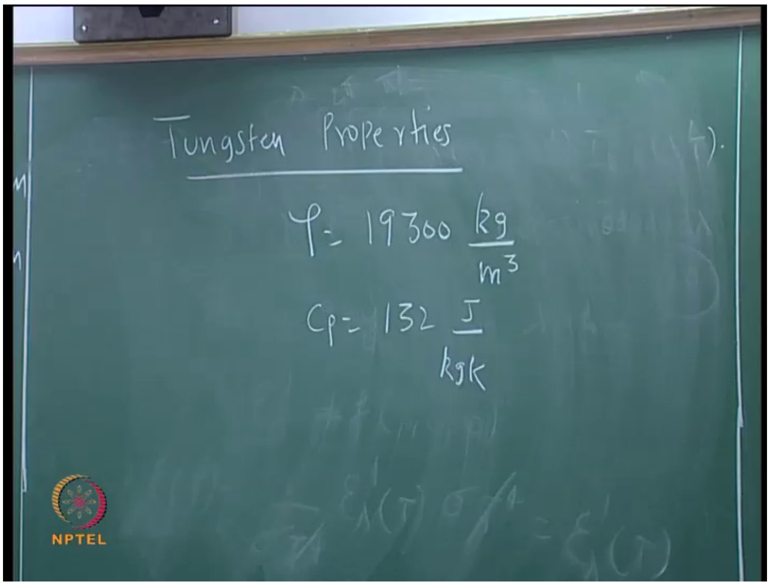


So, there are two parts of the problem, the first part, the first part is just using your fundas of various definitions of emissivity and figuring out the hemispherical total emissivity; the second is actually heat transfer problem, where using this emissivity, using a knowledge of heat transfer, you will write the governing equation and get the initial rate of cooling. I will help you the second part, but first part you should be able to do. First part, the first few steps involves the conversion of hemispherical spectral emissivity to hemispherical total emissivity; some steps are missing because, whatever I have done in the today's class, I gave you a formula to convert epsilon lambda dash to epsilon; from that you have to go to one more step, you have to you should be able to convert epsilon lambda to epsilon. The first step is getting the, the first step is very simple, given a distribution like this, how you will get the epsilon? It is not area under the curve; please note, it is not area under the curve, because there is f of zero to lambda will come. You derive it, first five minutes, do not look at me, try to do it yourself; anyway, I am going to do it on the blackboard. Start.

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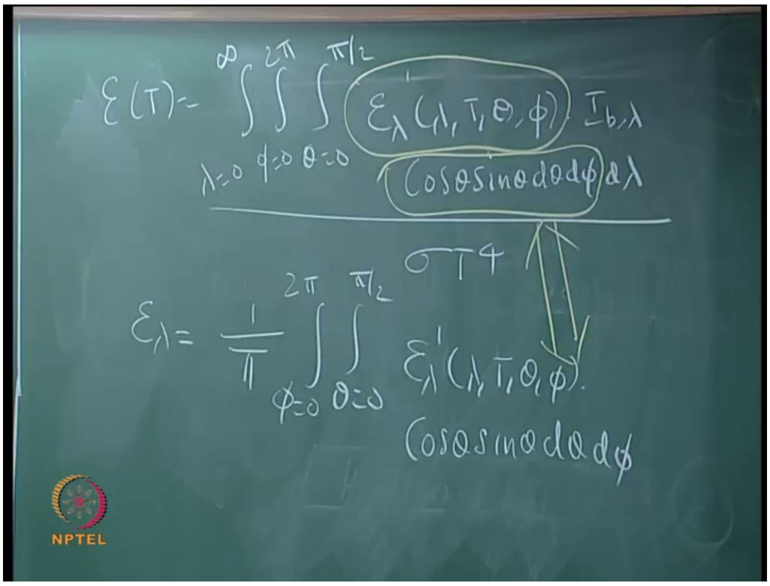

Let us look at the… Is this correct? The first thing we did this morning. Now, I also know this, what is the relationship between epsilon lambda and epsilon lambda dash? One by pi into cos theta sin theta D theta, that I b lambda does not come. I does not come.

All of you please look at the blackboard, epsilon lambda dash into cos theta sin theta D theta D 5. Now, it gives you some idea, have you taken this? I will clean this up. Are you able to get this argument?

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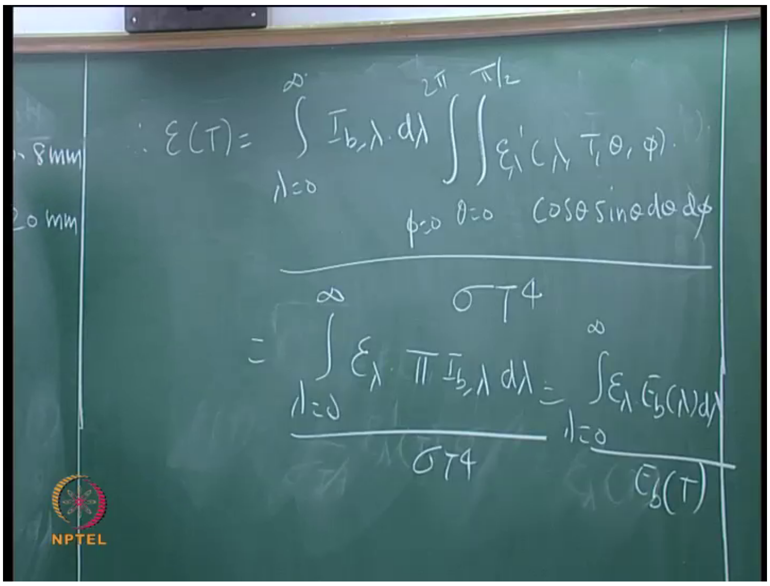

Alok, I did not do any magic, I am just shuffling, I am just keeping certain terms ahead of the integral and certain terms I am pushing it after the integral. Now, I know this is pi times epsilon lambda.

What is pi times I b lambda?

E b lambda. I did two things; I absorbed the pi and put it E b lambda, denominator I can interchangeably use E b T or sigma T to the power four. Now, we have to apply it to this case.

Vishwa, what is, what is the problem?

Ah.

No system, emissivity from the surface, no emissivity surface.

Ok.

What oh? You are always looking at the surface property; that will decide the cooling rate, but we are just evaluating properties, geometry does not come at all. There is a surface, where its spectral direction character is you know how to characterize the surface first the other stories will come geometry will come; but we have not even come to that stage. First, you get epsilon then you talk about, talk about other stories. There is so much drama in converting epsilon itself. It is very important that you realize that so many things are there; simply, layman, somebody, man in the street will say epsilon sigma t to the power of four is radiation; it is not so easy, you see, we are struggling. So, many fundas are involved. It is very rigorous.

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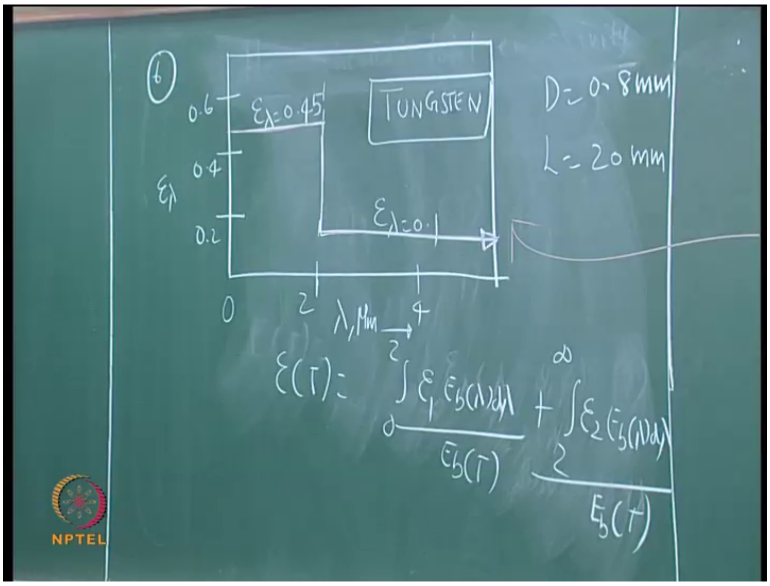


Now, what is the story? Now, epsilon for the tungsten; can I say 0 to 2? Is that right? Because, it has got only two values epsilon one and epsilon two. Suppose, I want to pain you in the exam, I can give, each time you have to stop, stop, stop and then go back to your function chart and then get the emissivity. Now, what epsilon one, for this problem?

Very good. What is epsilon two?

Now, is epsilon one constant over 0 to 2? Yeah, can you pull it out? Yeah, is epsilon two constant from two to infinity? You can pull it out, but what is this fellow 0 to 2 E b lambda divided by E b t?

Ah, that is where… I will come again, what is 0 to 2? E b lambda divided by E b of T, that is, f of 0 2 to lambda, I mean that 0 to 2, that is f of lambda one lambda. The second fellow is two to infinity means, two to infinity, that is, lambda two is infinity. Now, that you know what is the temperature change, 3000 kelvin; lambda one, you know; lambda two, you know; get the f, use the f function chart; first get the emissivity of the tungsten, five minutes, please do it. Is everybody through with this? First get the emissivity of tungsten.

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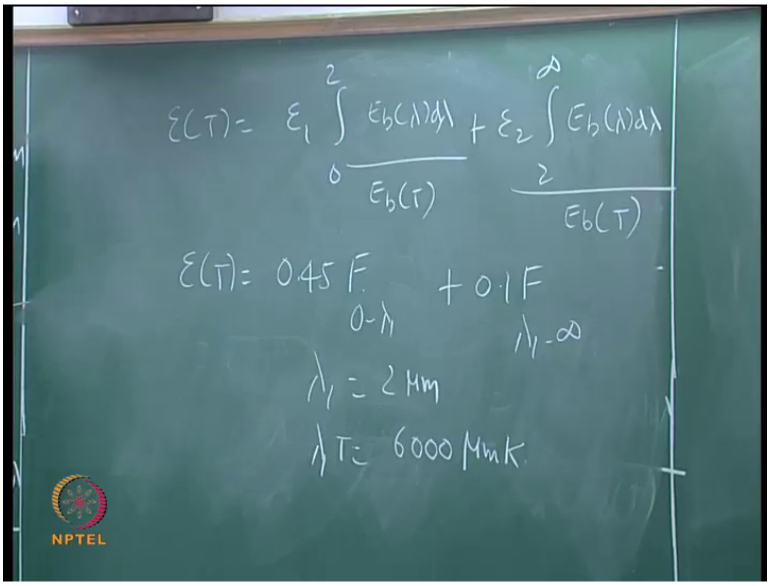


Yes 0.358, right. So, how much is this? That is all? No. So, this 0 to lambda 1, right? There is only one thing, right?

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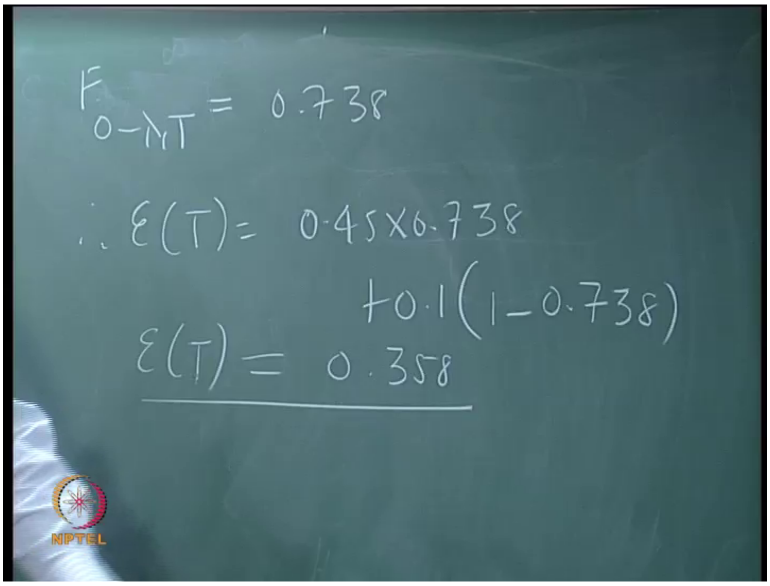


Now, 0.7377.

0.358.

So, is this surface a gray surface or a non-gray surface? Gray means epsilon lambda is independent of lambda, it is a non-gray surface. So, in today's class, you have learned how to get the hemispherical total emissivity, if the spectral emissivity is given for a non-gray surface. So, you know how to handle a non-gray surface, now; if it is completely jagged and all that, you have to do the integration; it will become very, you have to integrate with Russell Planck function. You have to write a mat lab code. Otherwise, if it is nice variation like this, then you can use the f function chart and quickly get the answer.

Now, let us go to the second part of the problem. So, I have given epsilon of t; therefore, if the temperature changes, please watch, if the temperature changes, even though this epsilon lambda remains the same with respect to lambda, if the same tungsten filament have to be a 2000 kelvin, this lambda one T will become 4000 micrometer kelvin; therefore, the epsilon T will change. Therefore, epsilon in general is a function of temperature ; but sometimes, it is because 0 to 2 is very, is such a small; 0 to 2 micrometer is such a small portion of the total electromagnetic spectrum; and for the remainder of the spectrum it is 0.1; remainder of the spectrum it is 0.1. You can actually calculate that for various temperatures, after a certain range of temperature epsilon will become more or less equal to 0.1. Because, from two micrometer to infinity, it is 0.1, are you getting the point? Fine, now.

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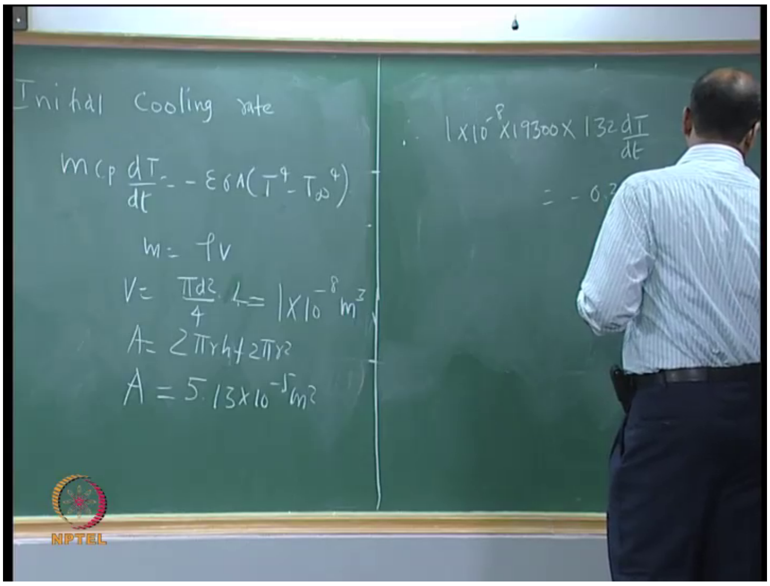


We want to calculate the initial cooling rate. So, we have to get an energy equation for this. We can assume that the whole tungsten filament is at the same temperature; and we can also assume that convection heat losses are negligible. Therefore, because no information is available. When its starts cooling the temperature is 32173 Kelvin, 3000 Kelvin, surroundings is are at 3000 Kelvin, I we have just calculated the emissivity, we know this Stefan-Boltzmann constant, you know the surface area; I have given you the density and you know the volume, calculate the m, you have the specific heat. So, we will get the initial cooling rate, when the current is switched off, what is the cooling rate will follow. But this cooling rate will not remain constant, because right side, it is the function of temperature; as soon as it cools, the temperature will fall, cooling rate will further fall. So, that is why it is called non-linear function; because the cooling rate, the cooling rate is a rate of change of temperature, the rate of change of temperature is itself a function of the temperature. So, that is why, it is a non-linear function.

Yeah, please calculate the volume; from the volume multiplied by density, get the mass; and then substitute, get the area; you should have the lateral surface area in the top and bottom area; also do all that and please get the initial cooling rate.

Infinity comes on the sides as the wall. The surrounding? Ah surrounding. So, how do you know that is also epsilon? No, this formula, you have to assume it as you take it as granted. After one month, you will I will derive this formula. This, I assumed that you have learned in basic heat transfer, because I am assuming how to formally, when we formally derived I b lambda, we will formally derive this also; but you just wait. Now, take it granted and then proceed. See, his question was, why did you put T infinity within the epsilon and all that. This will become clear, after I come to the concept of radiosity. Now, you can write a mat lab code for this, and find out; because emissivity will also change with temperature. So, the cooling rate will keep on changing. So, you have to write a code and…

Let us do that, what is the mass? So, what is the volume?

Amrita, what is the volume?

2.00, is it correct?

Student: 1 into 10 power minus 8.

Minus 3? 8. Volume, exactly one.

So a, what is a?

2 pi R h. What is funda here? 2 pi R h plus 2 pi R square means (( )).

2 pi R h pi R square pi R square, bottom, top, side. Yeah, what is a? 5.5,10 to the power of minus… What is m? Yeah, we can do this.

Student: Minus 387.1.

Not 387, some 1000 will come man.

Student: 3000 (( )).

Minus 3000?

286. (( ))

Do not be carried away, do not be under the impression that in 1 Kelvin, it will lose 32**79** and it becomes minus 276. This is the initial cooling rate; within a few microseconds the cooling rate is so heavy, temperature will go down, epsilon will go down, and it will reach (( )) values, got it. So, this is how you solve problem involving epsilon.

Now, there are other properties like reflection, transmission, absorption, and all that. Each of these may have a variation with respect to lambda. We need to characterize all this; and then your energy equation may not be so simple; there may be combined conduction and convection; then you have to handle this. Now, the energy equation may be such that, you have to solve the Navier-stokes equation or you may have to solve the Laplace equation, poison equation, then you have to add radiation rate, then it becomes totally, what is called a multimodal combined heat transfer problem, the analysis becomes difficult. Nowadays, in fluent, radiation modules are available. In fact, I believe the latest fluent has on optimization module also. So, some basic optimization can be done. So, the basic C F D software now also has a good radiation module. So, you can add radiation, because radiation is a passive means of enhancing the heat transfer.

Now, we have another seven minutes. We will solve a quick problem and small problem; and then we will get back to, we will take some other substance like zirconium, zirconia at 3000 Kelvin, which has a different epsilon lambda versus lambda characteristic; and compare a zirconium filament with the tungsten filament; and find out what are the energy requirements; what are the emissivity, and how much of energy is available in the visible part of the spectrum. So that we can compare from, for engineering purposes which is a better filament; but now filament itself filament is filament is gone; C F L also going. So, I think LED has come; CFL, now they say that increases cancer risk or something; your mobile phone, there was a study yesterday; too much of leads to brain tumor and...

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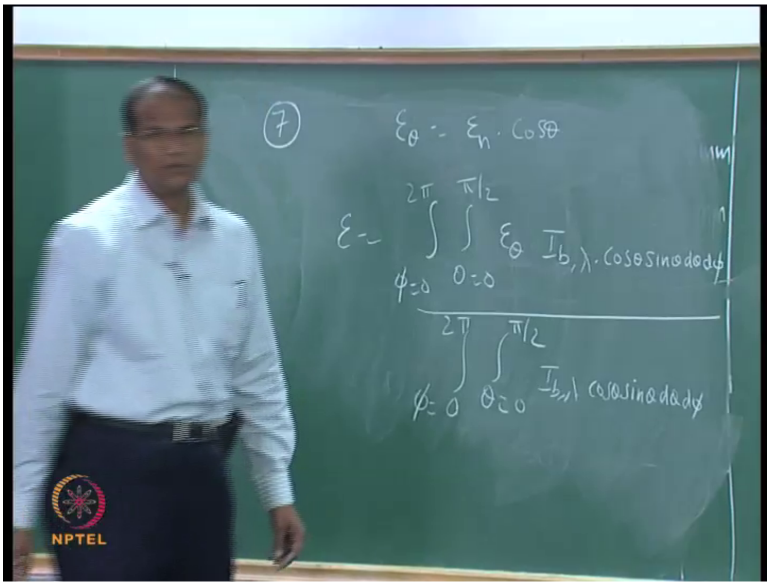


Problem seven, the directional total emissivity, the directional total emissivity of nonmetallic materials, the directional total emissivity of nonmetallic materials, the directional total emissivity of nonmetallic materials may be approximated as, may be approximated as epsilon theta equal to epsilon n cos theta, where epsilon n is the normal emissivity; given by epsilon n cos theta, where epsilon n is the normal limit. What does it mean? When theta equal to 0, cos 0 equal to, cos 0 equal to one. So, corresponding to zero angle, zenith angle, it is, it is like this, is a maximum value, that is epsilon n. Show that the total hemispherical emissivity, show that the total hemispherical emissivity, show that the total hemispherical emissivity for such materials, show that the total hemispherical emissivity for such materials is two-thirds of the normal emissivity, show that the total hemispherical emissivity for such materials is two-thirds of the normal emissivity; is it quick one? I wanted to give you a flavor of one problem in lambda variation, one problem in theta; we will get back to this filament problem of zirconium filament, it will it will take about 20 minutes, we will do that in the next class.

So, from now on, some definitions of absorptive, then lots of problem, reflectivity problems, it will get get back to my regular format of other courses, where lecture problem, lecture problem, we did lot of theory in the first two three weeks; now, theory and problems we will intertwined. What is epsilon I b lambda? I b lambda divided by…

Student: (( )).

Why?

Student: (( )).

Yeah, but anyway, it is not coming. I can.

Student: (( )).

Have you done integration with respect to lambda?

Student: This expression, we have not done sir.

Ah

This expression, I have not written

No no no no no no that is not. I gave you directional total. So, I can put it as I b, right? Anyway, that I am going to pull out. I b can be taken out. What is epsilon theta? Denominator is pi? I did so many things, I did one integration with respect to azimuthal angle, I pulled out two pi in the numerator, denominator the total solid angle is pi, I kept the denominator as pi; then for epsilon cos theta, epsilon I pulled out of the integral, cos theta into cos theta I got cos square theta. So, yeah I quickly read some steps, all these you know. I changed the variable from theta to cos theta; therefore, 0 to pi by two, I changed; there was a minus sign; then again, I changed from one to zero. Now, cos q, this is... So, if you tell me the normal emissivity, I can give you the total, give what is that emissivity? I can give you the directional total emissivity, if you, if you give me the directional total emissivity, I can give you the total hemispherical emissivity. It is two-thirds of the… But epsilon n is king, he is highest, it is like this. So, we will stop here.