Conduction and Radiation

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Lecture No. # 31
Emissivities and Absorptivities of Gas Mixtures

Hopefully today, we will come to the last lecture of radiation. Already we have passed thirty lectures. So, it is time to wind up our study of radiation. But, I will teach you something, which is very important from an engineering point of view, namely how to calculate gas emissivities and absorptivities in a mixture of gases, which is of fundamental engineering interest.

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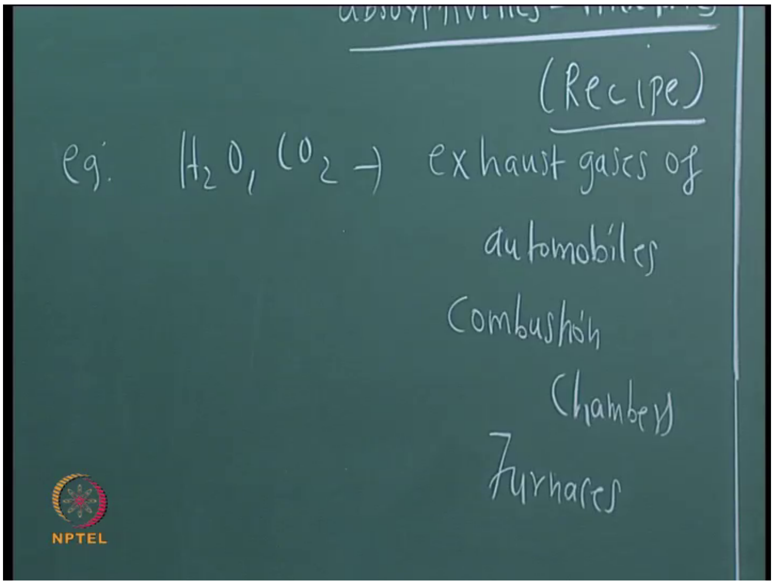

As you know, mixtures of gases are very important; combustion chambers, furnaces and so on. Wherever you burn hydrocarbon, you get this water vapor and carbon dioxide. And, water vapor and carbon dioxide are both radiatively participate and they interact. So, there will be an overlapping band; you cannot separate out the absorption band. If you see, we got a sneak peek into what carbon dioxide and water vapor can do when I projected a slide, which showed the attenuation of the radiation entering the earth. From the outer atmosphere, it is like a Planck's distribution of a black body at 5800; then, it enters the atmosphere; then, it becomes zigzag; it becomes jagged. So, there are various wavelengths or frequency ranges in which carbon dioxide absorbs or water vapors absorbs and all that. So, if you want to do a detailed calculation, you have to solve the equation of transfer for every spectral band knowing the properties: absorptivity and emissivity, which must come from a molecular spectroscopy and then solve it band by band or interval by interval. So, it is called a line by line model. I already told you that it is very advanced; it is very time consuming.

But, for practical purposes, we do not practicing engineers; or, if you want to have first cut analysis of a… or design of a combustion chamber or a furnace and so on, then we do not have to do those detailed calculation. So, we want a simplified approach what we essentially call recipe – a cook book recipe, so that we do minimum calculations; we do not do too much of math; we use some tables or charts and arrive quickly at the absorptivity; then, get on to our enclosure theory and proceed with the calculations. That is a goal. So, these charts were developed by Hottel. Hottel was a chemical engineer for the H 2 O and C O 2 mixture developed by Hottel.

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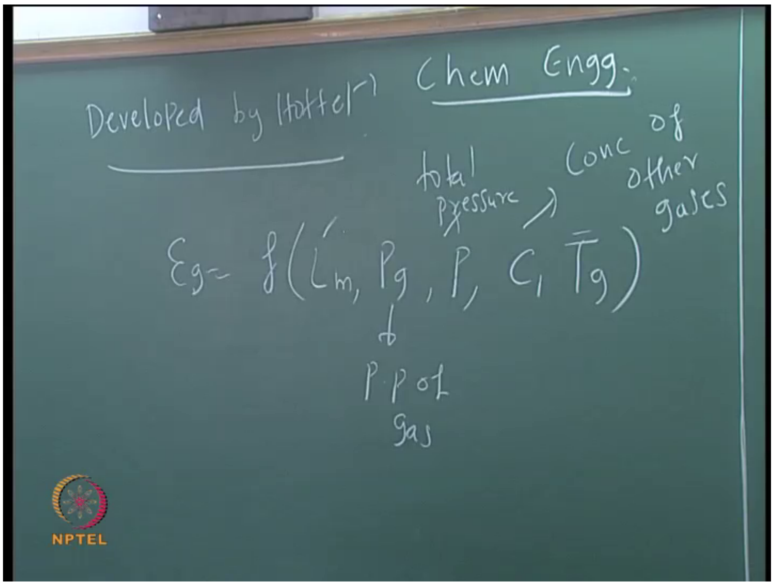

And, the Hottel charts – I have given to you for water vapors and carbon dioxide. These are… So, now, if you see epsilon g, that is, a gas emissivity should be a function of what all variables from your study of… of optical depth; instead of optical depth, can we start with mean beam length? Epsilon g – why should it vary on optical depth? Epsilon g need not depend no? Optical depth will decide the absorption. No, that is not possible always. We will see that. Then, this is partial pressure of gas; total pressure. Why am I writing it as a function of temperature? Because I know that emissivity is a function of temperature; we have done it so many times when I gave epsilon lambda versus lambda. If I change the temperature, epsilon changes, because f of 0 to lambda 2, minus f of 0 to lambda 1 changes. So, it should be a function of… There is no doubt about this. It should be a function of mean beam length; correct? There is no doubt about it. Now, it should be a function of partial pressure of the gas. What is the concentration of that gas carbon dioxide with respect to the total mixture? Then, this is the total pressure and concentration of other gases. Why does the concentration of other gases affect this? Because it is possible that there can be interaction; there can be an overlap band; there could be some band in which more than one gas absorbs and so on. So, this is the general functional form of this. Now, the total pressure affects the emissivity because…

Among other things what happens, the total pressure also gives you an idea of how much of gas is contained in some particular volume; and then, because of that, the intermolecular spacing will change; and, because of which, its capacity to absorb and emit will also change. So, first of all, the baseline charts have been developed for total gas pressure of one atmosphere; and then, some correction charts are also available, which will correct for pressures other than one atmosphere. So, once we do a problem, it will be clear.

Now, Hottel has prepared the chart for this. It is very interesting to note that Hottel was a chemical engineer. Why do the chemical engineers were interested in this? Of course, they are also interested in burning, converting chemical energy into heat and this thing; they are also interested in all...

So, chemical engineer Hottel prepared this. Hottel has written a very good book – Hottel and Sarofim Radiative Heat Transfer, 1967. He is basically a chemical engineer. When was this? Maybe he prepared this in 1945. Even today we are doing, but now… See the whole point is the fluent has stabilized for CFD (( )) stabilized for finite element analysis. But, no software has stabilized for radiation so far. That is why we people are in the business. Once it starts stabilizing, then we have to work on other types of problem since lot of…

Even today not many people want to get into radiation. And then, because even if some people are to develop a general purpose tool, there is a big learning curve involved in trying to run the curve, run the tool and all that. Fluent is very easy; third day you can start running Fluent, CFD software. But, this is not like that. Therefore, it has not caught on. And, as I told you, very few people work on this.

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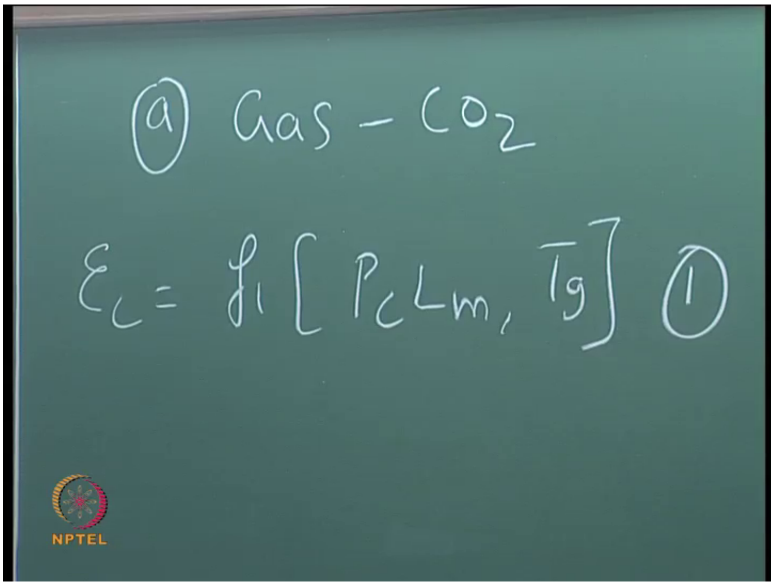

Now, principally, we are considering two gases as… Please look at your charts. So, we will have both carbon dioxide and water vapor. Now, we will start with a – Gas C O 2. So, the emissivity of the carbon dioxide is a function of the product of the partial pressure of carbon dioxide multiplied by the mean beam length and the gas temperature.

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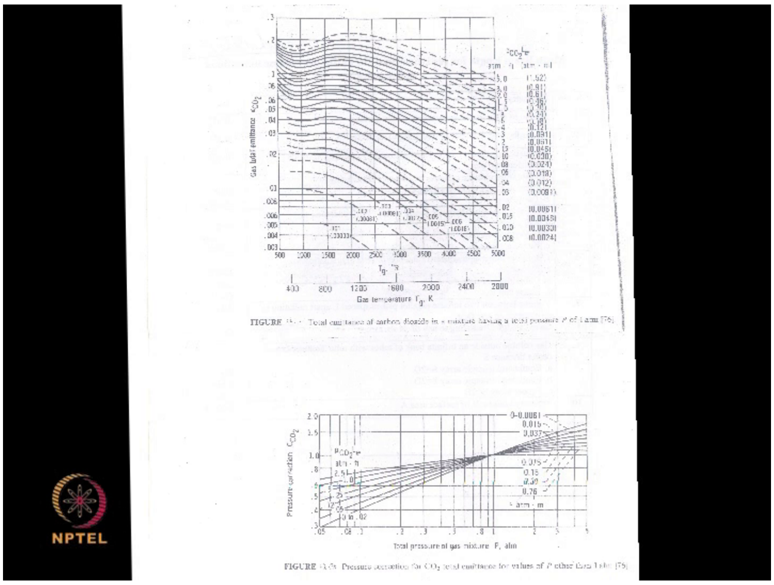

So, it is like this. So, the product of mean beam length into pressure is given in both fps units and SI units on this… Abhinandan, do you have the chart?

Student: I do not have the chart.

You can share.

So, you can see that it will give you straight away the gas emittance. The maximum is only 0.3. So, the first chart what you have to do is – suppose I give you two parallel plates; consider yesterday's problem. If I give you two parallel plates, L equal to?

Student: 11.5

1.5 meter. Mean beam length is 1.8 into L – into 1.5. You will calculate the L m. Then, if I say that the total pressure 2 bar and the mole fraction of carbon dioxide is 0.4, then what is the partial pressure of carbon dioxide?

Student: 0.8

0.8. So, you will multiply 0.8 by that 1.8 into 1.5 and get the P c into L m.

Now, the various curves are available for various values of this parameter. And, T g is the gas temperature, is given in both kelvin and rankine. From this, you will straight away read; based on these two, you will straight away read the value of epsilon c.

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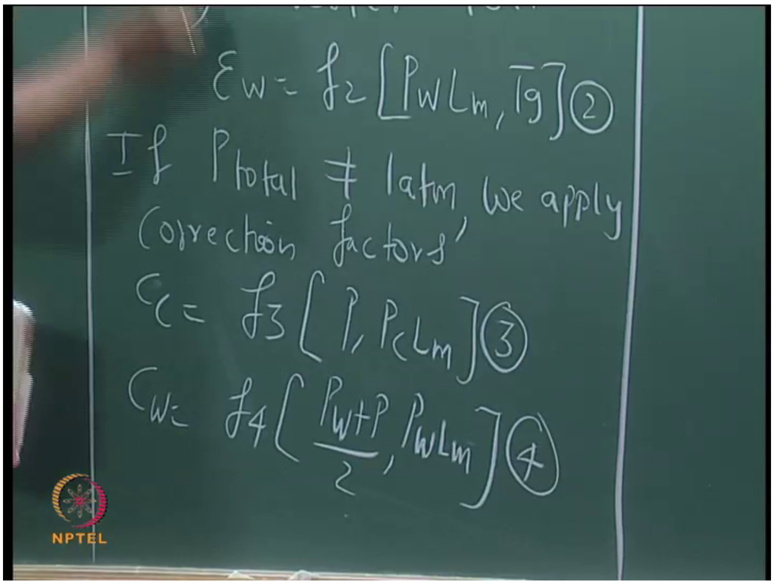

Now, water vapor… And, in exactly similar procedure, you will read the value of emissivity of the water vapor. Now, if the P total is not equal to one atmosphere, then we apply correction factors. The correction factors are… So, these are all empirical. These charts I think… Hopefully, you must have done lot of experiments with varying concentrations; we measure all these quantities and put it in the form of charts. So, what is P w? It is a partial pressure of water vapor plus P divided by 2; P w and L m.

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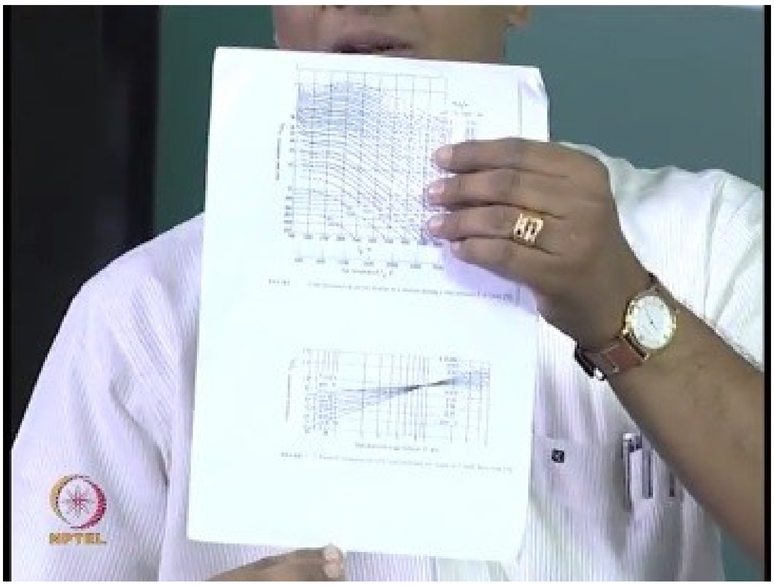

You can see emissivity of carbon dioxide; correction for the emissivity for pressure other than 1 atmosphere.

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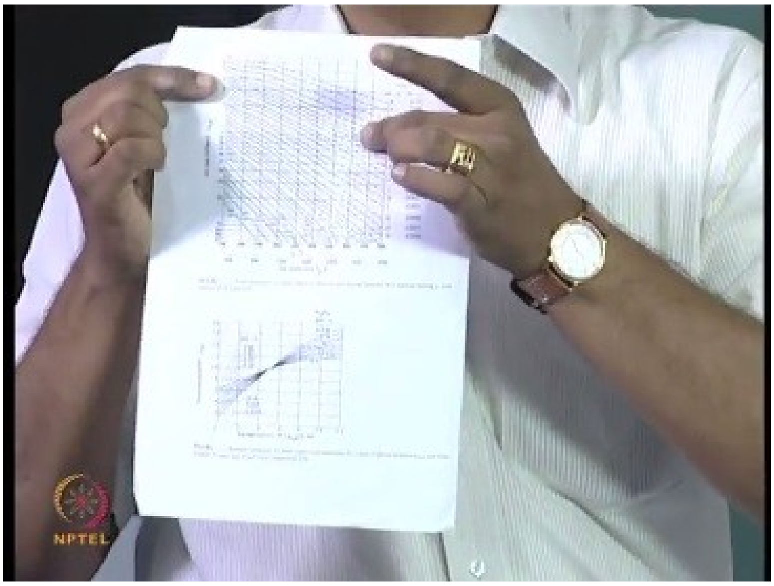

Emissivity of water vapor; correction for the emissivity of water vapor for pressures other than 1 atmosphere. These two charts will not be used if the total pressure equal to?

Student: 1

1 atmosphere.

Then, there are some cross terms, there are certain spectral bands in which the absorption of both carbon dioxide and water vapor overlap. So, we cannot simply add epsilon of carbon dioxide plus epsilon of water vapor. For example, watch this carefully. If you want to get the total emissivity, you may be inclined to believe that it will be epsilon of c plus epsilon of w. Now, this should be valid for 1 atmosphere. For pressure other than 1 atmosphere, you would like to believe that it will be C c into epsilon c plus C w into epsilon w. But, what happens, sometimes the sum of these two will exceed 1. Then, that will be a startling answer; you cannot get an emissivity more than 1. That is because you have not taken care of the overlap. There is an overlap band, which has to be subtracted. So, you have to take care of the overlap.

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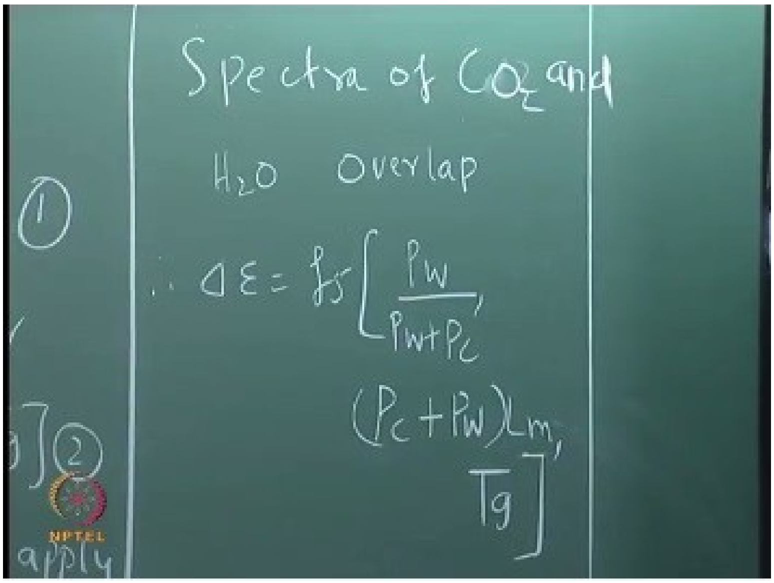

Spectra of CO 2 and H 2 O overlap…

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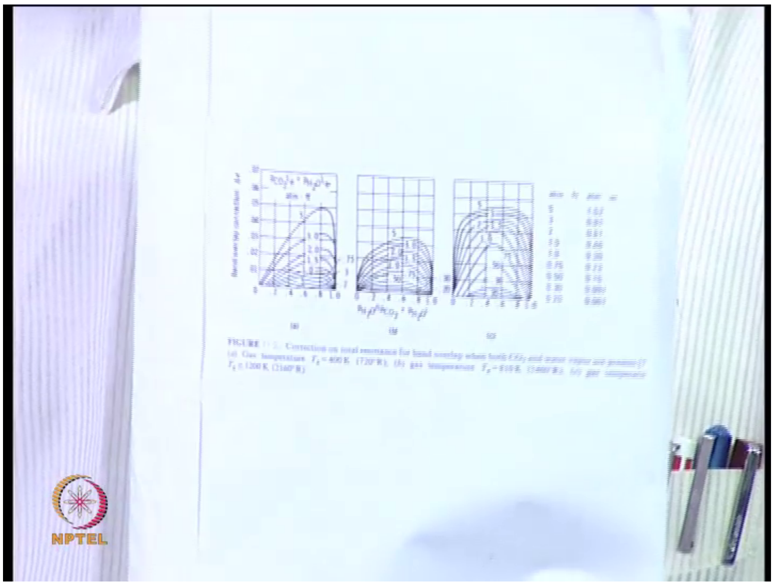

Please go to the last page. This delta epsilon is given; three charts are given for this delta epsilon. Unfortunately, these are available only for three values of temperature.

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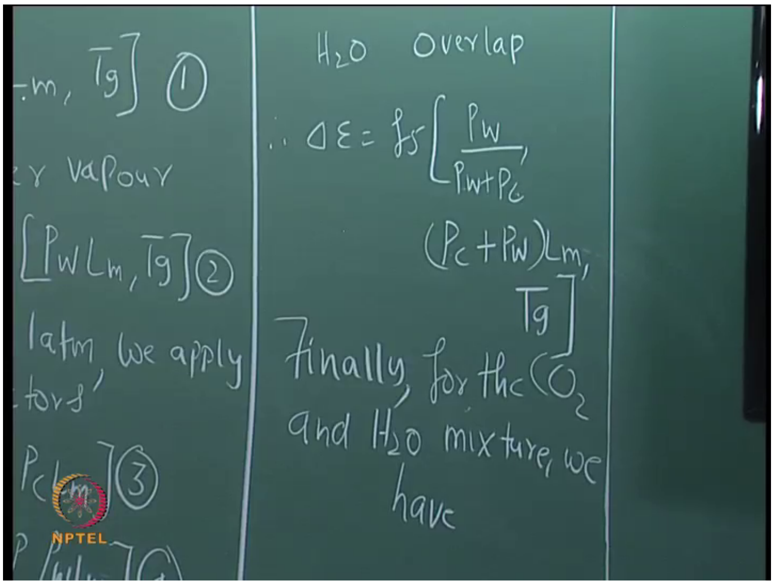

Please note that in order to use this chart, I have to work out these two parameters: partial pressure of water vapor divided by P w plus P c; P c plus P w into mean beam length and T g. Do not assume that P w plus P c must be equal to P total. You can also have nitrogen and other things; inert gases, which are there in the gas mixture. Now, it is available only for three temperatures. Suppose I give you a temperature, which is in between; so, you have to take two charts and do linear interpolation. What are the three temperatures for which correction is available? 400, 810 and greater than 1200. So, if I give you greater than 1200, straight away use the third chart.

Suppose I say the gas temperature is 650 or 945, 950 kelvin, then you are in trouble. So, you have to read from both the charts and interpolate. So, finally, epsilon g…

Student: Epsilon of (( )) is not there; it is not a participating medium.

Yes, it is an inert gas. Radiatively, it does not participate. In the atmosphere also, we do not worry; it is not a green house gas. If you do not believe me, then we will do DDP; you take an enclosure and put nitrogen and we will... So, finally, we have…

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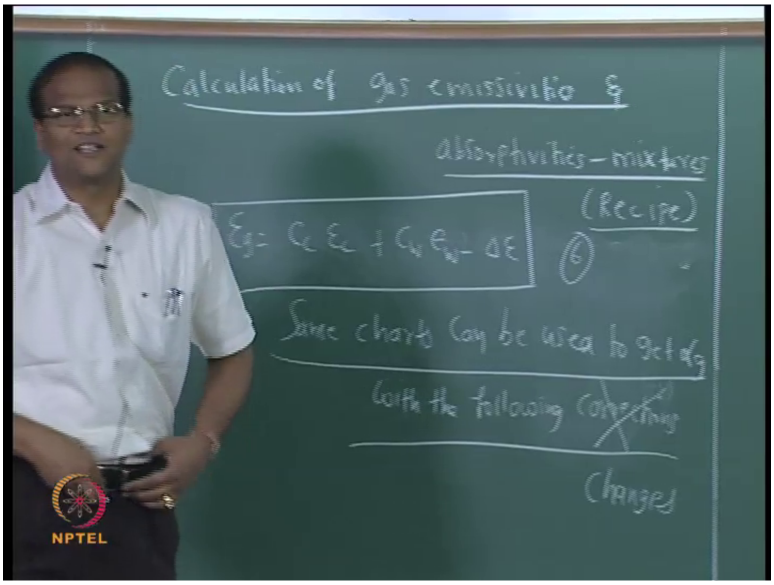

I will write it here. Equation number 6. So, how many charts will you read to get the epsilon g for a pressure other than 1 atmosphere? Five times you have to read the chart. Once you calculate epsilon c; once you calculate epsilon w; twice to get their corrections; and, the fifth time to do the minus delta epsilon. But then, in order to use the five charts, some painful parameters have to be worked out; that is, P c, L m, T g. That is why it is very important that if you write down this properly, you can use it in the exam. So far, it was all analytical, but there is no other way of teaching this; the only way I can. We cannot integrate something and show it; this is the only way to solve the problem of gas emissivities in a mixture in a class room environment. So, it is not very intellectually stimulating, but it works. Why? Which is epsilon w?

Student: Second one; C w into C w.

Yeah

Now, what is the story for gas absorptivity? We cannot use epsilon g is equal to alpha g; obviously, it is not a gray gas. First of all, it is not only a gray gas; it has also different spectral bands for absorption for various frequencies. Therefore, the alpha g has to be worked out. Fortunately, for us, the same charts can be used for alpha g, but with a correction.

What is a correction? For the epsilon g, the gas temperature is very important. For the alpha g, the surface temperature will be very important, because it is absorbing; the gas is absorbing from the neighboring surfaces. So, the same charts can be used for evaluating gas absorptivities, but with the following correction. Let us not use the word correction because already some correction is there; so, with the following changes or following modifications.

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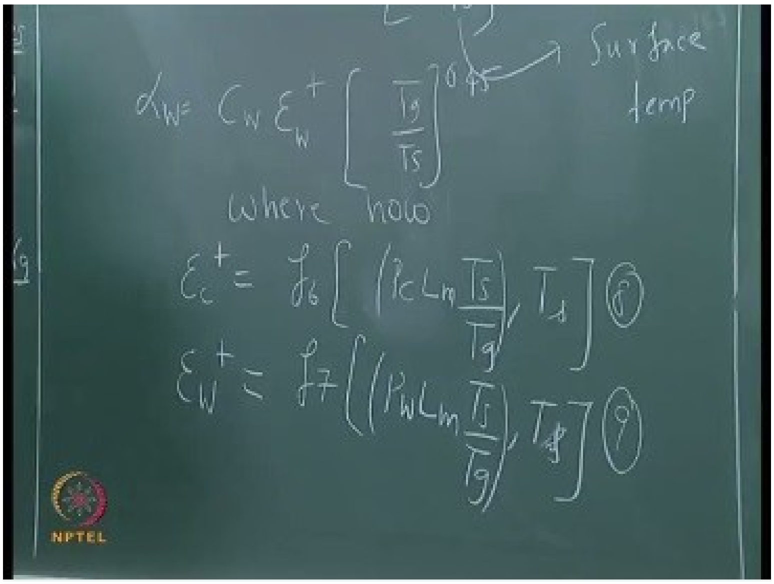

What do you want to do for alpha c? Please note this. What is T s?

Student: Surface temperature.

Surface temperature.

Now, alpha w… Do not ask me why this 0.65, 0.5, everything has come; these are all brute force fit after getting the… There will be two surfaces; which surface… Which surface…

Multiple surfaces are radiating; which surface we have to take? If we take the parallel plates, there will be (( ))

Student: One is 1500; another is 900 (( )).

I do not get your point.

Which is the T s? What is the absorbing surface? Again, multiple surfaces… Then, you have to calculate it separately and use it in the enclosure method. Now, we will start the development, because we cannot straight away go to enclosure. It is the… Radiation is being absorbed by the gas mixture from a particular (( )) surface. We can always start only with one surface; then, we have to use a modified enclosure theory and do it; that is not a problem.

Now, to the power of point this thing, where now…. Invariably, when we use this, we assume that the whole combustion chamber, the furnace is it at one temperature; the furnace is it at one temperature, the gas is it at one temperature. So, these peculiar cases of one wall at 1500, one wall at 1200, all that, this will not work. If the different wall is at different temperature, then the question will come – which T s I should take? Then, this will not work.

For the first cut, you can take the average temperature, something and proceed. But, generally, in these problems, usually, all the furnace walls can be at one temperature and so on. This gives an… (( )) an IC engine or something, the cylinder walls are at one temperature, the gas is at one temperature; what is the radiation heat transfer? This can be used. And, this value will be used in your CFD simulation. This will come as q r – radiative heat flux in your calculation. So, epsilon w square… Note this down very carefully. So, wherever the temperature comes instead of T g, we will have some… Which part? P c L m T s by T g; T s by T g is the normalizing factor.

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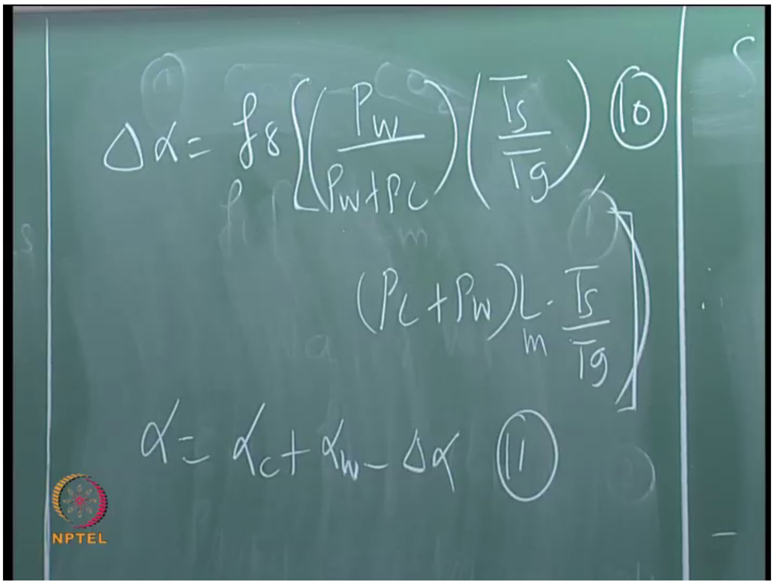

And then, finally, we also have delta alpha. Delta alpha is a fate of… – L m. Now… Which one? Is it there? Yes (( )). Yes, T s is there. The chart has got two… 4 T g. So, use the same charts. Again, you have to use the charts five times. One to again calculate alpha c, alpha w; but, fortunately, C c and C w are the same. So, that you have to read only once. Calculate these two values. But, do not forget to multiply by this T g by T s to the power of 0.65. But, unfortunately, T g by T s to the power 0.45 for alpha w. Get these two correction factors; incorporate them. Get this delta alpha. But, from my experience, for the kind of problem, which you are solving, delta epsilon and delta alpha will be usually 0.001, 0.002, 0.003 and so on. If you get some 0.1 and this thing and which makes both epsilon and alpha become negative, then please check your calculation.

Please check the band correction; last figure. Now, where does it exist? 0.05 or 0.06. So, the maximum correction can be 0.05 or 0.06. But, in the first two charts you can see that the epsilon C O 2 can be 0.3; and, epsilon w can be up to 0.7. So, please remember the order of magnitude; the delta alpha, delta epsilon will generally be much smaller compared to… But, they cannot be ignored. They can be much smaller compared to this epsilon c and epsilon w. So, things will look very vague and ambiguous when we will do something like this. But, once we solve the problem, everything will be clear. So, you have two choices. We will take a problem which is difficult, so that the pressure is 2 atmosphere or you want to solve a problem with a pressure of 1 atmosphere?

Student: 2 atmosphere.

We will, so that we will just do one problem and be done with it. Problem number?

Student: 41.

Problem number 41. Hopefully, this is the last problem for radiation. Problem number 41 – a furnace having a spherical cavity of 0.5 meters diameter contains a gas mixture at 2 atmosphere and 1400 kelvin. The mixture consists of C O 2 with a partial pressure of 0.6 atmosphere, N 2 with a partial pressure of 0.9 atmosphere and the remaining is water vapor. If the cavity wall is black, what is the cooling rate required to maintain its temperature. What temperature do you want for ease of… It should be lower than the gas temperature; is not it?

1000 is too much. I have put 500 in the problem. You take 500; some pain is there – at 500 kelvin. He wants 810 kelvin that is too dull talk no? What is the cooling rate required to maintain the temperature at 500 kelvin? Now, Pradeep’s question, which T s? So, I am carefully drafting problem such that there is only one surface. The whole spherical cavity is at one temperature; gas is at one temperature. Gas is very hot; wall is cold. So, heat transfer is from gas to wall. Now, we have 20 minutes; we can solve this problem. For the end semester examination, there will be a solid question on this. Bring your charts; 20 minutes; 15 to 20 marks. Let us see; we have 18 minutes; you should be able to solve.

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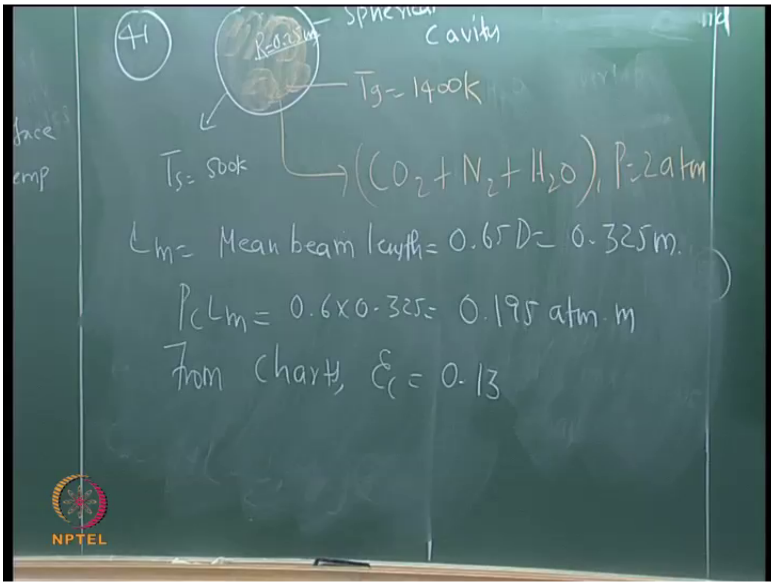

Let it be like this. So, what is this R equal to?

Student: 0.5; 0.25

Did I give 0.5 meter?

Student: Diameter.

What is the first step?

Student: Mean beam length.

Mean beam length. Very good. First step is mean beam length.

Student: 0.65.

0.65?

Student: D

D. Very good. Next step is to write out all the factors. So, P c into L m; so for some people, if you feel that this atmosphere meter is not convenient to work with because basically the charts are given in atmosphere feet, you can take one meter as 3.3 feet and proceed. But, I feel it is not such a great thing.

Both are there. Both are there; then, you can. Give me the first value epsilon c. Is it correct? Can you show this?

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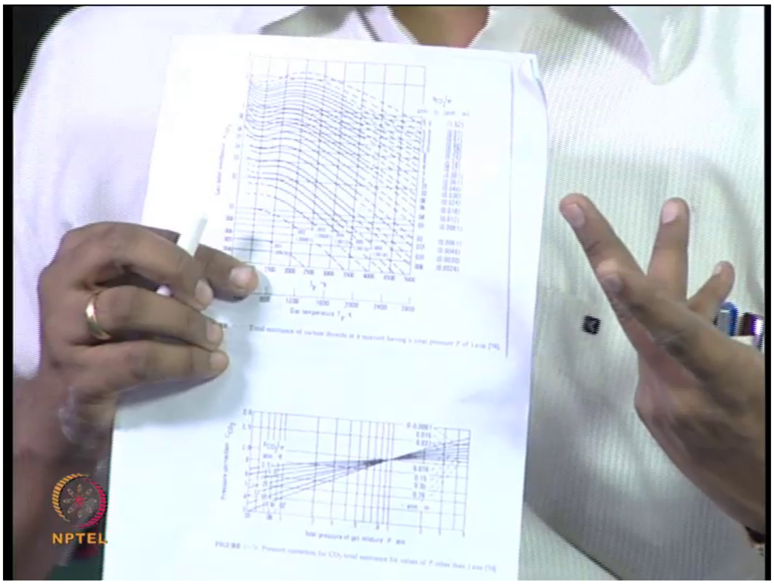

We have already found out the P c into L m. P c into L m is basically 0.195. It is somewhere here in the middle. And, then…

Student: 0.15.

T g – what is the temperature? 1500. So, it is in this region.

Student: 1400

1400. So, it is somewhere in this region. What is the answer? 0.13. Got it?

Then, straight away you can get the C c. So, that is a correction factor. For the correction factor, you go to this chart. Total pressure is 2 atmosphere and partial pressure P c into L m is again 0.191. So, what is the correction factor? Wait. 1.1?

Student: 1.2.

1.2. So, C c equal to 1.2. There is nothing great in what I am doing, you have to do it patiently; that is all. You should know how to read the charts.

Student: Point (( ))

Point?

Student: 1.2

Which is point…

Student: 0.13

You are not getting? Why, what are you getting?

Student: 1.25…

0.13 – how many of you did not get? Everybody has got. What are you getting? You are not understanding me?

See this is tabulated in terms of P c into L m. Please look here. This chart is tabulated in terms of P c into L m. Identify the P c into L m corresponding to 0.195 atmosphere meter. Follow that line and let it cut with the T g – 1400 kelvin.

Student: Sir, this is an atm feet we have to convert.

Right side atm meter is also given. Please look at the chart carefully.

Student: It is coming 0.035.

No 035

You have to go along that line. You have to go along that line. It will meet one line no? That; so many lines are there no? We have to move along the… That line is going up and down; do it carefully. 0.13 how we will get? 0.1 is there 0.0… So, 0.1 to 0.2 so many point are there no? OK. Leo, you got it no? It will come just check this. Correction factor is 1.2?

Student: OK sir.

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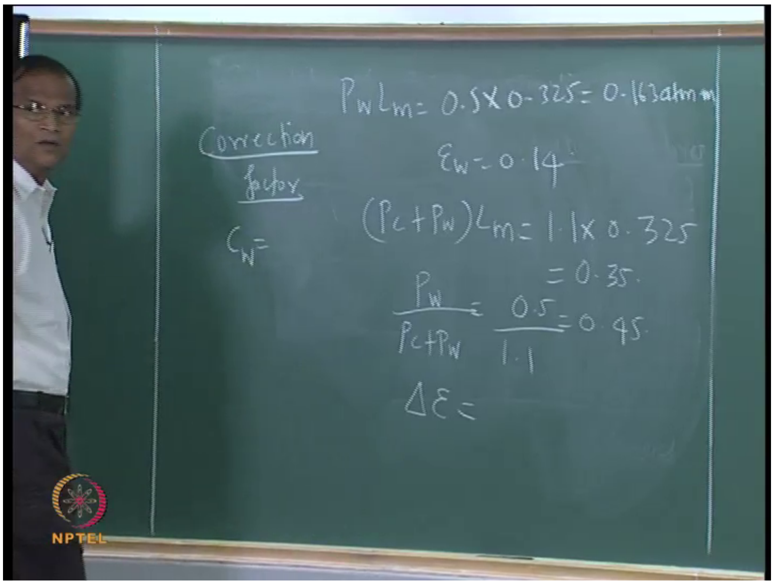

Now, P m into L m…

Student: Sir, one problem; the calculations that you have taken in rankine; follow the green rankine from the...

No.

Student: Kelvin is there; there is no rankine…

You have to go along the line.

You got it finally? Do it patiently you will get it. Do not be in a hurry.

It is not an impossible problem.

Student: No, sir. But, the thing is that we are following 1400 rankine, not kelvin.

No, I am following 1400 kelvin, which is in the bottom.

That is not going…

It is going; that line is going up and down. Do it carefully. Vikram, is it OK?

Now, what about P w? What are the partial pressure of water vapor? 0.5. What is this? 0.163.

What is the value of epsilon w?

Student: 0.1

0.1

Student: Sir, 0.14

0.14? You got it?

Hang on. I have worked this problem out, but, I took CO 2 – 0.6; N 2 is 1 atmosphere and remaining water vapor. Just 2 minutes back, I deliberately changed it to 0.9. So, that is a partial pressure of N 2. So, my answers will be different. So, I got 0.10. And, now you are getting?

Student: 0.14

0.14; it is OK.

Now, P c plus P m into L m. What is P c plus P w? 1.1 into 0.325. What is this?

Student: P plus P w.

No. P c plus P w; I am calculating and keeping it for something else.

Student: Overlap spectra.

Overlap spectra; how much is this? 0.36?

Student: 0.35

0.35. Then, delta epsilon is? Get me delta epsilon. So, the delta epsilon… No, I did not do something.

What is it, correction factor – C w? How much was this?

Student: 1.7

1.7?

1.5

So, the second chart gives the… People who are all at… See first page gives the emittance of carbon dioxide; first page – 1 a and 1 b; 1 a gives emittance of carbon dioxide; 1 b gives the correction for carbon dioxide. Page 2 a – emissivity of water vapor; 2 b – correction for water vapor. 3 a, b, c – delta epsilon and delta alpha for three temperatures.

Now, to calculate for the water vapor, we proceed to chart number 2, page number 2. 2 a – we already got the value – 0.14. Now, I am applying the correction factor. Tell me the correction factor.

Student: 1.57

1.6; 1.57. Delta epsilon is? Delta epsilon you have to interpolate, because 500 kelvin is not there. Attention please; charts are not available for 500 kelvin. So, you just write in the exam – charts are available for 400 kelvin; I am using 400 kelvin chart. Please use the 400 kelvin chart do not waste time interpolating in… Please use the 400 kelvin chart. What is delta epsilon? If it is 700 or 900, use 800 chart. But, if I give something plum in the middle like 600, you have to interpolate.

Which one?

Student: T g is gas temperature.

1400 chart…

No. My funda you can use it for getting the delta alpha. So, this is gas temperature. Anyway, 1400 – you can use chart number 3. We can straight away use chart number 3. What is the correction? 0.01; something will come. And, what is the correction?

Tell me the corrections.

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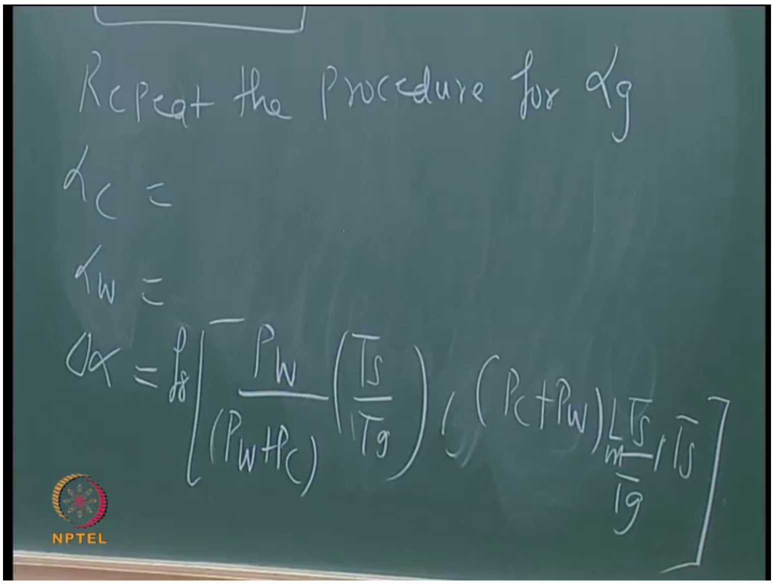

So, epsilon g is equal to 0.13 into 1.2 plus 0.14 into 1.57 minus 0.03.

Student: 0.03

0.0?

Student: 0.03

0.03?

0.035

Student: 0.04 sir.

Does it matter? It should not be 0.3; that is all.

So, what is epsilon g? We will get around 0.5 or 0.6 when you struggle and all this. What you get?

Student: 0.36.

0.36. So, it takes about 10-12 minutes to get the one gas. You have not got the enclosure problem actually. You first got epsilon g. Then, you have to get alpha g. Epsilon g is not equal to alpha g unfortunately. We are not talking about single gas, gray gas and all that.

Now, repeat the procedure for alpha g. But, you have to apply the correction T s by T g and all that. The two correction factors are the same. The C c and C w are the same for alpha, but… First, we will do the delta alpha. Delta alpha – it is based on? Delta alpha... So, in the correction factor, the last three charts, instead of T g, you should assume that the charts are for equivalent surface temperature.

Please look here. Do not say, sir, the charts are only for T g, I do not know what is for T s. We are using the same chart for calculating the alpha also. So, assume that these three charts are for three temperatures. These three temperatures can be the gas temperature or the surface temperature depending on which property you are seeking to evaluate.

Now, how many of you have already given up? So, tell me at least one.

Student: 0.005.

Which one, alpha c? Is delta alpha 0.005?

Student: One more 0 sir.

One more zero? Absolute zero? Then, leave it. Then, it is safe for us. Calculate the other things: alpha c and alpha w.

I think we cannot start conduction tomorrow, but I thought of completing this. So, the first 15 minutes, we will solve this problem. Keep these values; I do not have these values, because I have different numbers in my… We will spend another 10-15 minutes; close this problem. And then, we will start conduction. I will just have a simple power point for introduction to conduction. Next week onwards I will go to regular chalk and talk.

Whatever power point I am using in tomorrow's class, it will be available on model. We are not able to use the model too much this semester, because anyway, it is all very intense; I am not showing any slides. Tomorrow, introduction to conduction, I will show some slides. So, we will solve this problem first 15 minutes and then start conduction.

Thank you.