Indian Institute of Technology Madras

NPTEL

National Programme on Technology Enhanced Learning

COMBUSTION

Lecture 41
Mixture Fraction Formulation

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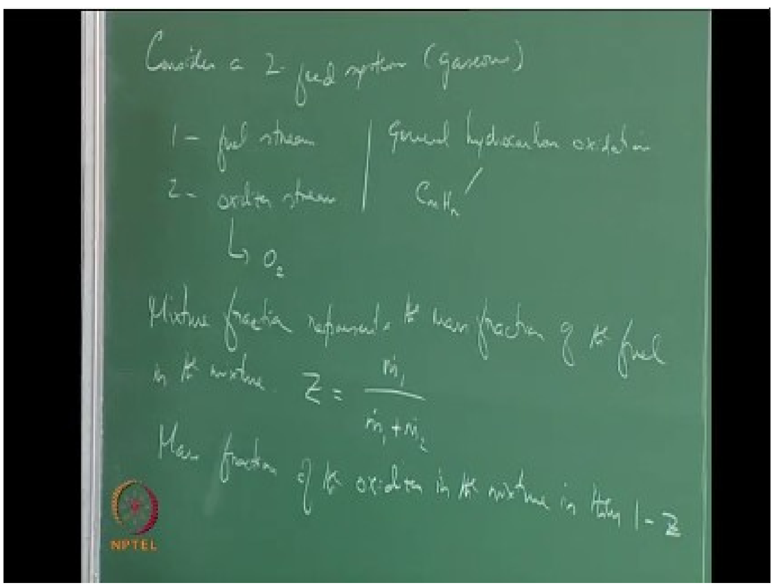

We will adopt what is called as the mixed refraction formulation in trying to describe diffusion flames this is actually a powerful idea for combustion in general and with particular context of diffusion flames and partially pre-mixed flame. So the idea basically is we now try to define this variable called the mixed refraction mixed refraction, extremely useful then in diffusion flames and partially pre-mixed flames. So what we will do is let us consider a to feed system that means we have 2 inlets that are allowing gases to come, so we are looking at a homogeneous gaseous system.

And let us say that 1 represents fuel string and 2 represents oxidizer stream, in fact we will try to adopt this for a general hydrocarbon, fuel hydrocarbon oxidation that means from now say oxidizer we will mainly be thinking about Houghton and for the fuel we might mainly be thinking about a Cn Hn kind of hydrocarbon right.

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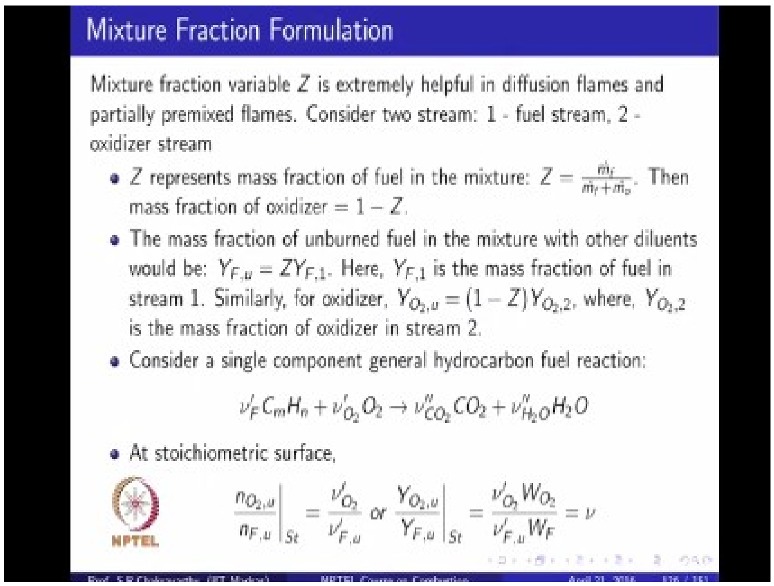

So then the way the mixed refraction is defined is essentially like a mass fraction okay, so the mixed refraction next refraction, represents the mass fraction mass fraction of the fuel in the mixture fuel in the mixture right. That means let us say Z is the symbol given to a mixer fraction then this is basically m.1 / m.1+ m. 2 where m.1 is the mass flux of or the mass flow rate of the fuel stream m.1 is 1λ 2 is the mass flow rate of the oxidizer screen and of course what this means is the mass fraction of the oxidizer then is oxidizer in the mixture is then when it alright.

It would be defined as m2. / m1. + m2 that therefore is 1 – Z, now each stream contains diluents it's not as if like the fuel stream is fully fuel it could have some nitrogen, you could also have the oxidizer stream is like a let us say air and most of it is nitrogen.

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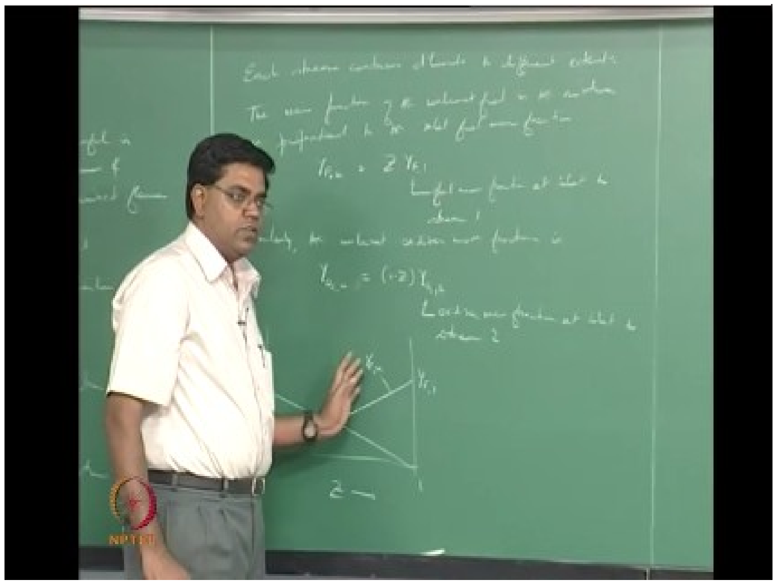

So you have only part of it as oxygen so contains diluents different extents right then what you are looking at is the mass fraction of the unburned fuel in the mixture, what we expect is it should be proportional to the inlet mass fraction of the fuel in the fuel stream times the mixed fraction. So the mixed refraction is a fraction of fuel when compared to the total, so the mass fraction of the unburned fuel in the mixture is proportional to the inlet fuel mass fraction, so that is to say YF , U that is the unburned fuel mass fraction anywhere in the mixture can then be written as Z YF , 1.

So why I have come up 1 is essentially the mass fraction film mass fraction at in at the inlet to stream 1 right, now previously we were using the symbol Y if not for this purpose the corresponding oxidizer would be YO not well this allows for us to actually think about a YF2 which means you could also dope some fuel into the oxidizer stream and vice versa alright. So this notation somewhat is a little bit more general of course it is not too general it is still confining ourselves to 2 streams alright.

But we could say Y of 1 Y of 2 Y of 3 and so on so this is a little bit more general notation then and similarly the unburnt the oxidizer mass fraction the unburned oxidizer mass fraction is Yo2 u is =1- Z times co 2 right. So Yo2 is actually the oxidizer mass fraction at inlet to stream 2, so for example if it were air this number would be like point 2 three or so right with this if you now think about it what happens is you unburnt fuel mass fraction or the unburned oxidizer mass fraction both vary with the mix 2 fractions are linearly okay.

Ron Awards if thought were more your y if you would be more than a place proportional to Y of 1 right if there were more Yo2 unburned will be less correspondingly proportional to Y or 2, so if this is represented in a graph that could go like this, so if you now plot Z along the horizontal axis it goes from 0 to 1 so if your mixer fraction is going all the way from 0 to 1, 0 would correspond to no fuel and 1 would correspond to all fuel all right, no oxidizer.

Therefore as that keeps on increasing then you have a straight line that keeps on increasing from 0 all the way to Y of 1, this is to say in the mixing field at the inlet you would have only oxidizer in the oxidizer stream and you will have no fuel at all in the you would have Y of 1 in the fuel stream and you would have no fuel in the oxidizer stream and anywhere else in the mixing field you would now have a mixed refraction which is having different values and corresponding to that the fuel mass fraction would lie on this line essentially all right.

Similarly if you want to think about how D so just this is this is the plot of YF, u similarly if you want to look at the plot of you to come on you that is another straight line that starts with the value of u to come on you, let us say at the oxidizer steam Inlet why you do not have any fuel and goes all the way to 0 and the fuel Inlet where you do not have any oxidizer anywhere in the mixing field your mass fraction of the oxidizer lies on this line corresponding to whatever is the mixed refraction locally right.

So this is regarding how the unburned fuel and unburned oxidizer mass fractions work out what we want to now do is to further proceed and see if we can actually get mass fractions of burnt products right and where you have burned where you are in non stoichiometric proportions you will have excess fuel and excess or excess oxidizer, depending upon which is in excess whether you're in fuel rich of your lean conditions and we would like to also find out what is the burnt fuel concentration and they burnt oxidizer concentration depending upon whether it is excess or not. So for which we need now have to actually go through what happens when you have a reaction.

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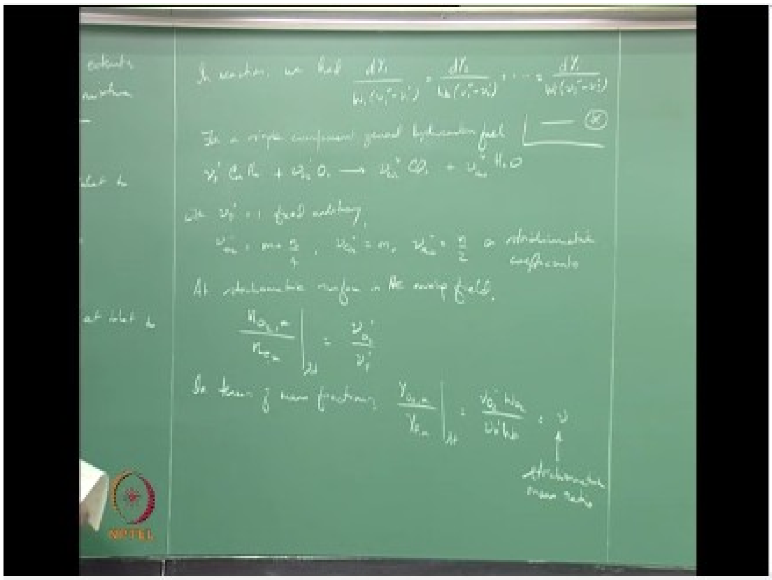

So in a reaction we had this is long ago maybe came up with this3 y 1 / W 1 times 1double prime - nu 1 single prime etc the you could also write of course 1 more dy2 / W2 times µ 2 double prime - µ 2 single prime etc and the general species you could say dyi / w i times µ i double prime - µ i single prime I am sure you re call this, so let us suppose that you can call this set of equations star we will pick at least 2 of these in order to integrated at different times therein the near future.

So for a single component general hydrocarbon that is to say you do not have different mixtures of hydrocarbons for example if you take liquid petroleum gas it is actually a mixture of hydrocarbons butane and propane, so instead of that if that is supposed to be our considering only 1 hydrocarbon at a time hydrocarbon fuel and let us suppose that we write this equation as knew of single prime Cm Hn for the generalized hydrocarbon the P considered + µ o 2 single trying o to gives µCO2 double prime, C02 + µ H_2O double prime H_2O right.

With new F single prime =1 fixed arbitrarily let us suppose that we just say we are interested in 1 mole of this hydrocarbon right we could get new single trying =M + n / 4 new co 2 double prime =M and μ H_2O double prime = n over 2 as psychometric coefficients, that means these values correspond to the reaction happening stoichiometrically right the means you do not have any of the fuel or oxidized the leftover as part of the products.

Now at the stoichiometric surface in the mixing field, we then have the number of moles of oxygen unburnt / the number of moles of fuel unburnt at stoichiometric =μ o2 single prime / nu f single prime right as given above. So in terms of mass fractions so this is this is mole fractions so in terms of mass fractions whether bars in terms of moles not moles fractions I am sorry but of course you can divide by the total number of moles and get the mole fractions as well so here we are going to be looking at the mass fractions Yo2 unburned / Yf unburnt at stoichiometric is nu o μo2 prime molecular weight times molecular weight of oxygen / you fill the fuel single prime x WF.

Which lets us say we call as nu which is the stoichiometric mass ratio, so what we want to do is we want to see if we can integrate this equation for a situation where you have a stoichiometric reaction, so that we can we can make use of the fact that you are not going to have any of the reactants left over alright. So for a stoichiometric reaction for a stoichiometric reaction both filled and oxidized that are completely consumed right.

Therefore we use this to integrate the this equation here star at any mixture condition relative to the unburned mixture because you are not going to have any of the reactants leftover, so you can you can you can now say we integrate.

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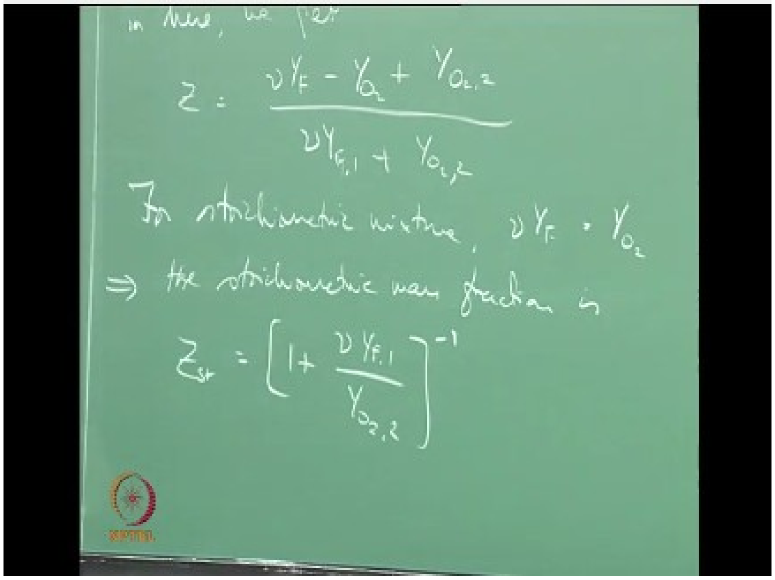

Star at any mixture condition that means giving a look at any intermediate mixture condition mixed condition relative to the unburned condition right the piece the limits of integration go from unburnt values to any value, so during the reaction has Yo2- Yo2 ,u / μ Oh 2prime Wo2 right you strategic and you can just pick let us say oxidizer and fuel then you would get YF /Y a few developed by new prime WF or rearranging this all this means is new YF - y μ 2 equals new YF Yo2- u.

So what this tells us is this is sort of a preserved quantity right you started out with unburnt values Yfu and Yo2 will do you at a point in the mixture mixing filled in a proportion with a new here right, where should I should I have yes new that is right he caught this μ so and that is the same even during the reaction between the 2 that is essentially the idea okay. So whatever are the unburnt values that difference is what is preserved, so what you can then do is we are interested in writing everything in terms of the mix diffraction.

So we had the Yfu in terms of mixed refraction and the inlet mass fraction, so here I will do you in terms of mixed refraction and the inlet mass fraction of the oxidizer, so substituting the expressions for expressions for Yfu and Y to you in terms of Z in here we get and then of course rearrange, so you say that = μ x YF – You 2 + yo2 , 2/ μ Y F , 1 + yo 2, 2 so you can see that you to come out to these things are showing up from the inlet mass concentrations mass fractions of the oxidizer and fuel in the respective streams.

So for stoichiometric mixture for stoichiometric mixture μ F new wire I am sorry should be =Y o2 in fact this is what we had also got for the Berkshire moon solution where we said γ is =0 means β is =0 that means α F - α o is =0 right and that amounted to exactly this, we say Y_F / y o2 is more rather why yeah should be = μ and that should be the same as Y_F y Y_F / y would YF you right the unburnt mass fractions should be in stoichiometric proportions just as well as whatever is in the reaction.

So from this what we can do is this will actually, now tell us what should be the stoichiometric mass fraction right. So the stoichiometric mass fraction stoichiometric mass fraction is 0 C =1 + μ Y, 1 / Y, 2 3 – 1.

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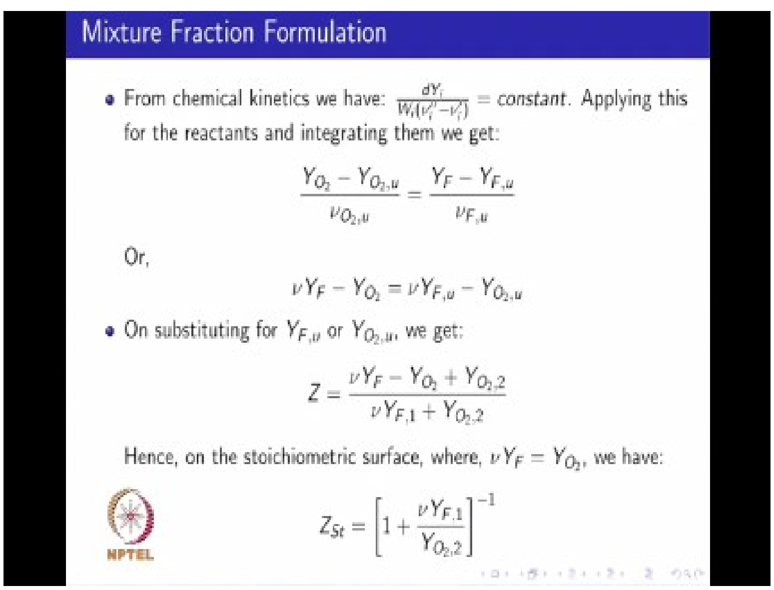

I should be able to show that right if you, now say this is going to go away right then you rearranged what this tells us is there is a particular value of Z which is the stoichiometric mixture fraction naturally and it is related to how the inlet stream mass fractions of fuel and oxidizer work out right.

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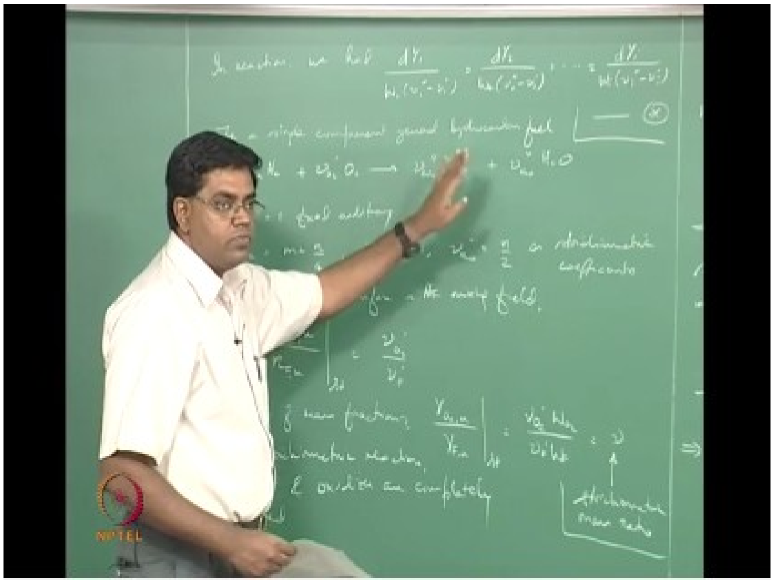

So if Z is less than Z less T right we are less than fuel, so as that keeps on increasing you have more and more fuel that is essentially the idea, so if Z is less than Z less T we know clearly that it is fuel deficient right deficient or fuel lean whichever way you want to write then YF burnt is going to be 0 this is this is, now the mass fraction of fuel in the burnt products. So you are not going to have any excess fuel in the in the product therefore you can now substitute Yfb =0 which terminates a combustion right.

So the combustion essentially does not proceed simply because your grant ran out of fuel you do not have any more fuels plug in plug this in third exhibition right and use definition of Zst you should now get if we now plug in the expression for Z Yfb is =0 then from there you now rewrite you should get why would 2 , be =Yho - come on 2 times 1 - Z / 0 for that less than or =0-3 similarly for fuel rich mixture right combustion terminates when why would to be =0, so you not plug this in the expression for Z and rewrite for Yfb.

You now get an expression Y_F, B =Y_F, 1 times Z - the dusty / 1 - and this is this is valid for sub greater than or = 0-3.

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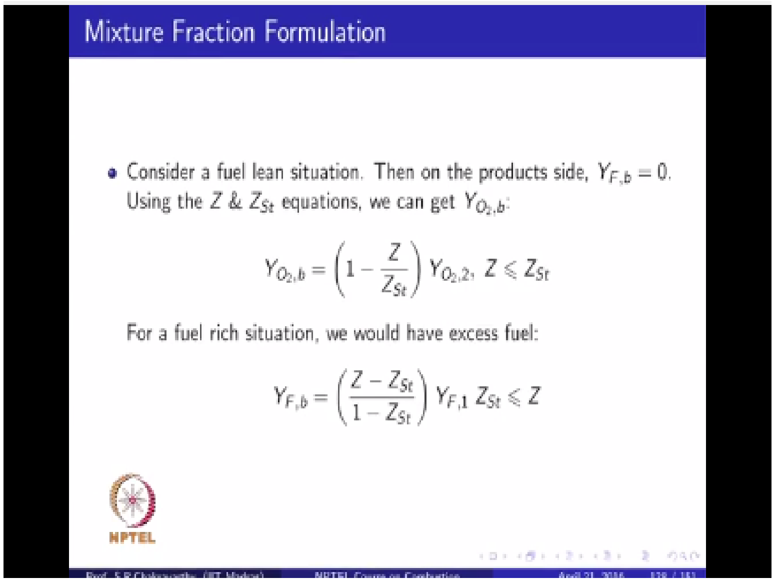

That means we can now draw a picture similar to this is for the unburnt fear that unburnt oxidizer in the mixing field but we can now anticipate how the unburned, sorry the burnt fuel and burped oxidizer should look like if you now halves up going in the horizontal axis from 0 to 1 somewhere and there you should now be able to locate Z = Zst now that that become that becomes an important thing but there are we on this side of Zst or that side of zealously because this is going to correspond to a fuel in situation that is going to correspond to an oxidizer lien situation.

Therefore you are Yfb is valid only for greater than right on this side B is =0 therefore you come and this is also linear enzyme okay, so this goes so your Y_{FB} is going to go all the way to from 0 to Yf , 1 right as a matter of fact when you go to this corner when Z is =1 your YF is =YF1 you know and so this or Yza goes to 1 so YF b goes to Y F 1 alright and this is what we were looking at the last class were at the flame, you now have the fuel concentration go all the way to 0 and then stay flat on the other side okay.

So here the fuel is going to go all the way from the fuel Inlet screen all the way down to 0 at the stoichiometric surface and then lie flat on the oxidizer regicide right and similarly you now, have a straight line that goes from 0 here backwards to Yo2 in the mixing feed, so essentially if it is possible for us to now go back and redo the Berkshire 'men problem in terms of Z instead of β which is not very different if you think about it alright and it is also possible then you can actually look at contours of Z several contours of Z and dependent upon the contours of values of Z.

You now try to actually look at what the values of Y_{FB} and Y 2 be should be you now can map how the fuel concentration and oxidizer concentration should show up, this is still for the excess field a side to the products and excess oxidizer the products or fuel rich side and fuel inside. So have not talked about the actual products of combustion right like Co2 and H2o so for getting the product concentrations we should do something similar to what we have here in order to obtain your new Co2 double Prime and new h2o or double Prime all we have d1 by saying we are balancing this reaction is to basically conservatives week. We compared carbon atoms hydrogen atoms oxygen atoms and then came up with these things.

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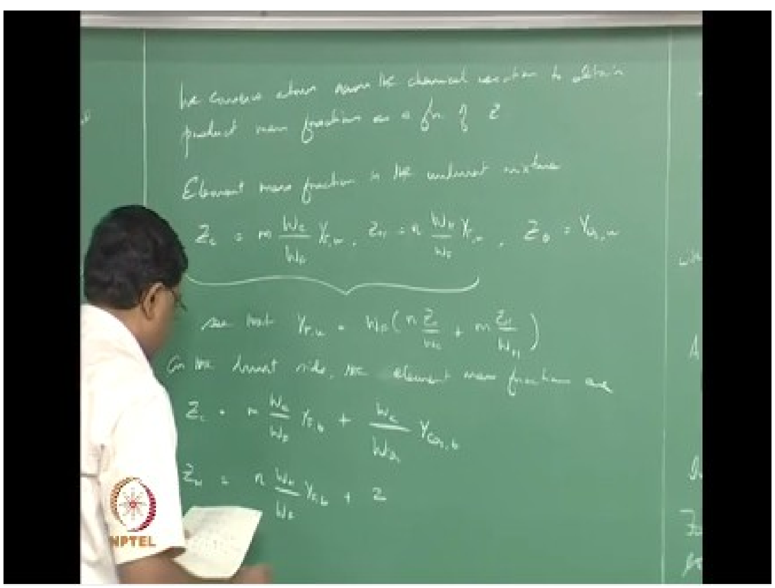

So we conserve atoms across the chemical reaction to obtain product mass fractions as a function of Z still we are interested in what happens at the function of the mixture fractions are and that is a hero for the day it makes the fraction so we keep on looking at everything as a function of Z, so element mass fractions so look at what happens in the unburned mixture element mass fraction in the unburned mixture, so look at the fracture of carbon atoms so you had m carbon atoms in the hydrocarbon right.

So this is M times molecular weight of carbon atom / the molecular weight of the fuel right times why I have come on you, so this is the mass fraction of the unburned fuel times this fraction is what is going to give you the carbon fraction. Similarly if you now look at H that is going to be n times Wh / W fuel times y fu for the oxygen it is mainly coming from the oxidizer screen so you might as well just write 0 =Y or to you.

Whatever is the mass fraction of the oxygen in the oxidizer stream unburned right is easy to 0 of course from here we should now be able to also write C see that Y of U is =W F times n . C / W C + M or did I make a m0h by wh all right on the bond side on the bond side for the products are the element mass fraction or for the carbon we have c =m w c / wf YF , b that is actually for if you have excess burnt fuel right + if carbon is also there in carbon dioxide that is what we are more interested in WC were 2 times c were too burnt and this is what we are trying to find out in terms of Z okay.

And hydrogen is going to be like n times Wh/ wf YF , b + twice because water contains 2 hydrogen atoms so Wh/ w h2o x yh2o , b there is also the next thing that we are trying to find out in terms of that currently, so and finally we have to conserve oxygen atoms so that o from the products would be twice Wo / Wo 2y o2 , b + twice Wo /W co 2 because there are 2 oxygen atoms in carbon dioxide Weiss you were to come a week + 1 Wo / w h 2o Yh2o , B right, So now if you know equate these,

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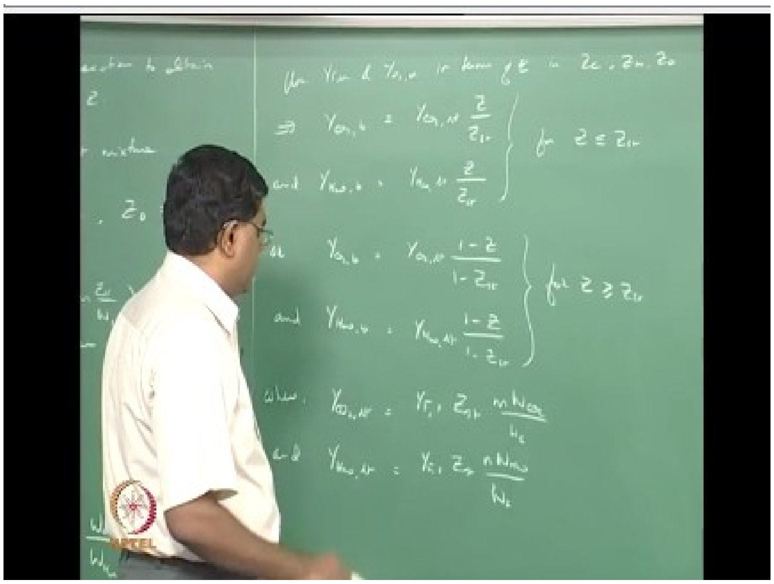

So use YF u and Yo2 you in terms of Z in that C. H 0 and rewrite okay, so you then get y co2 B would be y02 stoichiometric times Z / Zs t + y h2o, b = y h2 or stoichiometric times Z / Z stoichiometric.

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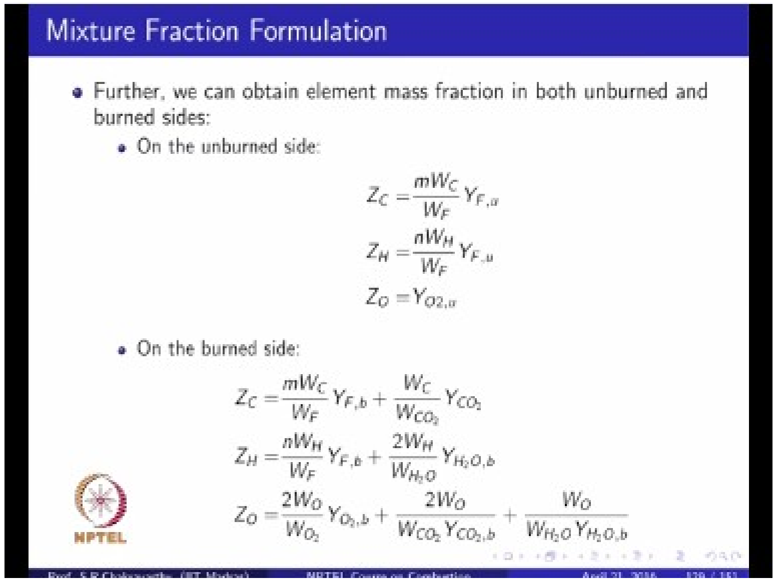

This is for Z less than or = Z0 C or why see what to , be =YC were to strike geometric times 1 - Z / 1 - Z stoichiometric and h2o , be =Y h2o stoichiometric times 1 - Z / 1 - Z this is for Z greater than or =Z of T, where we have to say what is yco2 stoichiometric and Y h2o stoichiometric so why co2 stoichiometric is why F , times M W 0 2 / W F and why h2o , striker metric is why F , 1 0 Y 200 / W F alright.

So what do you what do you expect we can still see that why co2 is still going linearly as dud Y h2 is going linearly Z, so long as zealous lessons are s t white sea water is still going linearly but decreasing with Z Y h2o is decreasing linearly with Z as Z is greater than right. So let us think about plotting this.

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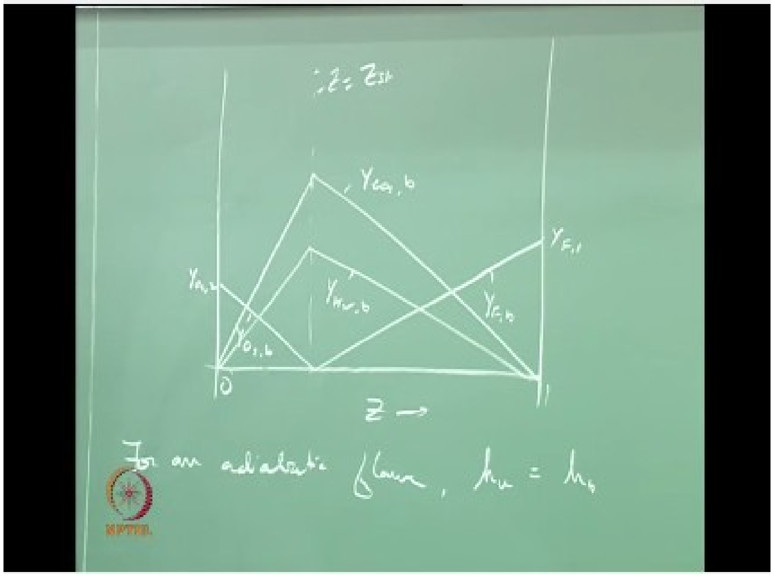

There is no half third along the horizontal axis going from 0 to 1 and we know locate it is like a metric surface at somewhere in between and we noticed earlier from that picture just to reproduce your Y_F , B goes from 0 at these are equal is that stoichiometric to Y_F , 1 when Z is =1 this is the excess burnt fuel and you now have Yo2 , B going all the way up to Y ,2 – that is not =0 but what we are looking for now is how this varies Yco2 goes to a peak value ads are equal as a discrete and then comes all the way down to 0.

So this is your Yco2 , B and similarly of course depending upon the numbers they should now get a similar set of lines for Yh2o , B so it reaches a peak value you get the same expression same numbers I should say from both the expressions at Z =0. So you can plug that and then let us see what I got right, now we are still interested in the temperature so for temperature all these things are essentially like looking at an equilibrium you see. So for the temperature where we now say for an adiabatic flame right for an adiabatic flame we have the unburned enthalpy = the bond enthalpy and it is probably a good time to stop just stop.

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