Indian Institute of Technology Madras

NPTEL

National Programme on Technology Enhanced Learning

COMBUSTION

Lecture 40
Flame Structure

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So what we have seen so far is mainly regarding the shape of the Burke-Schumann flame but what about its structure and I have clarified in the past that what it refers to the shape is the overall flame shape but what, what is meant by structure is how do the concentration profiles of the reactants and the products and the temperature profile and how does the reaction rate all those things vary across the flame right.

So we should be looking at that but if you look at how the equations were solved it all becomes like history the sense we just got the flame shape by considering only the mixing field between the reactants the fuel and oxidizer without having to worry about reaction rates and the energy equation which will dictate the temperature and so on.

We never really solved these things strictly speaking now or other matter as a matter of fact we have not solved for a reacting flow at all right so what is what is it what has happened now so how can we actually reduce this well what we what we will see now is we will at least look at qualitatively how these things are going to go and we will worry about quantifying this next in fact many times we just we just goes left unsaid without having to be bothered about explicitly.

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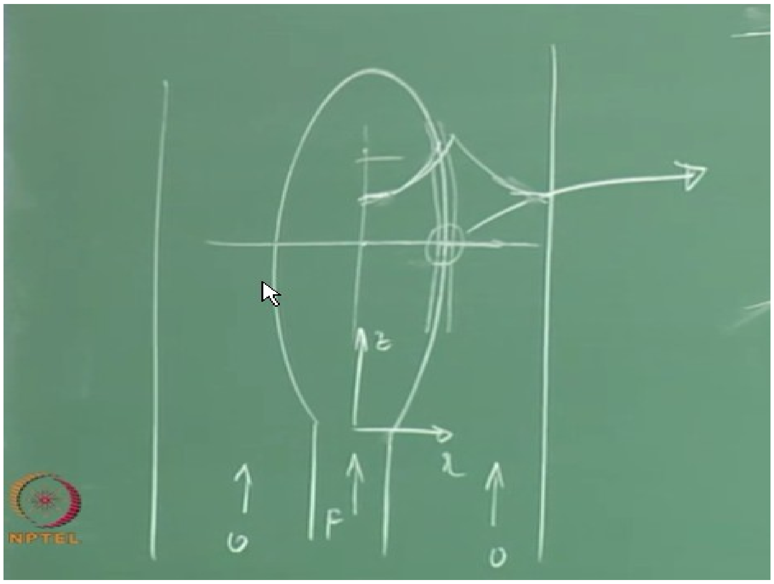

But there are lots of problems like in unsteady cases perturbations and all those things where we need to know what this flow field is or the combustion field is so I did it is of interest in some cases so what we are talking about is if you now have a flame shape like this question is if you now have R and Z go like this in pick a particular Z and then start burying your R from the center line and go radically outward how do the concentrations of reactants and products and temperature and reaction rates vary.

So we have fuel in the middle slot and oxidizer on the outer slot now if you want to actually look at the flame structure we have a little problem here because this is a Burke-Schumann problem, Burke-Schumann flame and the Burke-Schumann analysis assumes a flame sheet that means you now have just a sheet in which all the reactions are taking place infinitely fast right but that is not the reality.

So you are, you are better off actually thinking about the structure of the flame to start with intuitively if you are not thinking about it qualitatively you are better off relaxing the infinite rate chemistry assumption and thinking about a realistic picture and then what we will do is expect what would what would what it would be for a infinite rate case all right the reason why I am saying that is because we will now begin to see a parallel between what we will do for a finite rate chemistry flame and the premix flame.

That we have the structure of a pre-mixed flame that we are already accustomed right and where does that come into picture is what we will see now finite rate chemistry how is that going to actually make the flame look like first of all it is directly related to the thickness of the flame right so when we said infinite feed chemistry that directly went with a flame assumption and therefore what we are expecting is if you now have a finite feed chemistry.

We expect a certain thickness for this flame what is meant by that what is meant by the thickness right so if you want to find out what that what that means we have to now assume into this region and then look at it in a much closer way so let us suppose that you now have a thickness of the flame that is about this thick right what it means to say radically as we are going is this is actually where the reaction rates are beginning to be significant okay so you now have a reaction rate that goes like that.

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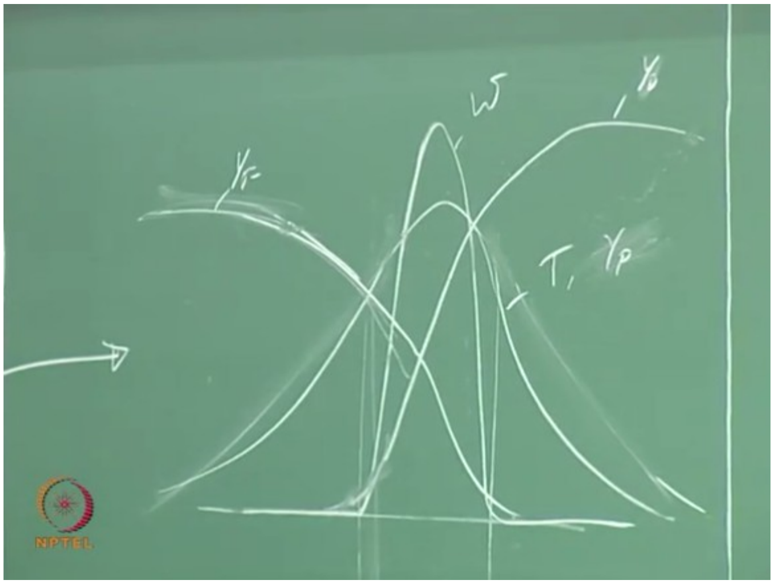

Now why does the reaction rate fall on either side? It is not because you are actually having a fairly low temperature okay it is because you are running out of one of the reactants on either side soon this side in this particular picture you are going to have a fuel rich composition on this side you are going to have an oxidizer rich composition and these are leads this is actually diffusing in and there is a region where they are meeting in stoichiometric proportions right in the middle of this region.

On either side the reaction rate drastically falls down because you are running out of one of the reactants on either side if you now recall when was the last time we actually had a thin region where the finite thickness dope we are week adding appreciable rise in the reaction rates and then a fall within this region this was the reacting reaction zone of the premier premix flame the premix flame we had a preheat zone and the reaction zone.

And the preheat zone you did not have any appreciable reaction rates it is only in the reaction zone you had appreciable reaction rate so the reaction actually rates grew very rapidly and then fell back again because you are running out of a deficient reactant again on the, on the, on the downstream side right so here again on either side you have a deficient reactant because you are you hear your fuel rich and by the time you go there you run out of fuel here your fuel oxidizer rich you by the time.

You come here you are running out of oxidized there is a deficient reactant although neither side therefore we should now anticipate that if this is like the reaction zone right as we had seen in the preheat the pre-mixed flame there must be something like a preheat zone so the preheat zone there was a convective diffusive balance all right and similarly what we are looking for here is if you now have this region where most of the heat is being released right.

Then that heat has to be conducted on either side in the case of premix flame you now have a flow only in one direction and you had hot products on the other side so you do not really have a temperature gradient in the product side for a for adiabatic flame okay so you did not have a temperature variation in the product, product side beyond the flame but in this case the flow is going in this direction right.

Therefore you have hot region over here relatively cooler regions on either side okay so what that means is you are now going to have a region where you have a crushable thermal or heat diffusion that is taking place on either side so the temperature is going to actually rise from all from far away on either side and then locally become locally attain a peek right in fact you should be in fact if you could, you could even expect.

That this is sort of like that you have a curvature just like how in the preheat zone of the pre, pre, pre explain you had a temperature rise with the curvature you can expect the same thing over here now if you are in the middle of the burner you are going to have a certain that a fuel, fuel concentration right and as you now coming closer to this the field concentration begins to fall pretty much like the way.

The, the fuel concentration began to fall as it approached the reaction zone because here you had an upstream product diffusion but here just like if you now and then and then of course when you now look at the product concentration profiles in the in the preheated in the pre-mixed flame structure it mixed the temperature profile in a non dimensional sense or a normalized non dimensional sense right here.

Again that is what is going to happen you are getting lot of products that are being formed right and the products are all being formed in the reaction zone and once they form they look around on either side they now find that they are less in concentration therefore they diffuse so there is a radial diffusion that happens on either side for the products even as a convection is going on in the axial direction.

Therefore you expect a product concentration profile to look fairly similar to the way the temperature profile is right so because you now have a high concentration of products near and then it falls rapidly on either side as you as the fuel is now diffusing into the flame it is progressively getting diluted by a product concentration that is higher.

Therefore you should expect a transport zone for the fuel that is that is coming in like this and in this region the fuel concentration is looking exactly like how it was in the reaction zone or the pre me explain right and similarly for the oxidizer may be at a different starting from a different level if you are plotting in dimensional terms and comes down and as these things come down to nearly zero you have the reaction rate drop, drop down to zero does this how this is happening so this is your W temperature CP its concentration or it can say YP mass fraction.

And this is YF this is YO you can figure so much right but now the question is what if my makes this burnt approach is adopted what if my, my infinite rate chemistry assumption is adopted what does it really correspond to in reality right what it basically corresponds to is in the, in the case of the pre-mixed flame we were talking about a flame that is getting thinner and thinner when the reaction zone is getting thinner and thinner particularly when you have a very high activation energy right.

So in the case of high activation energy the reaction, reaction rate actually begins to be very, very low for a long distance within the preheat zone and then suddenly shoots up to very high value within the pre heat within the reaction zone over a very thin, thin, thin region and the thinner the reaction zone region is higher is the higher the value to which the reaction rate goes because all of the reactions have to happen within that small region right.

So essentially what was what it meant for a high activation energy situation was that the, the reactions were waiting for the temperature to be raised to a fairly appreciable level before which they would become significant and once they became significant they would rise very rapidly with any additional increase in temperature right so as I said at the time the activation energy then is a marker of the sensitivity of the reaction rate a temperature higher the activation energy the reaction rate becomes more sensitive.

In the sense it is it becomes the variation becomes more and more nonlinear it remains fairly low for wide range of temperatures at a lower level and then with a with a temperature rise beyond a certain level which is which is very high then it is even a slight increase in temperature will cause a huge increase in reaction rate right and correspondingly your reaction zone would be very small we are very thin so that is exactly what we are expecting over here as well right.

And as you see what it means is if this reaction zone is now going to become thinner and thinner then we expect the reaction rate curve to actually go shoot up to the sky right so that essentially comes to a limit where if you have a thin reaction zone that is a flame sheet that it should correspond to a infinite reaction rate right so from here we should now be able to deduce if you now have a flame sheet assumption the frame sheet assumption should correspond to a infinite reaction rate.

That is your right strictly speaking you should you should keep drawing this line vertically up and up and up to the X you again right it is infinite then she knows what happens to the rest of the curves right and then what is meant by what are we talking about like the fuel and oxidizer should be at stoichiometric proportions the answer is if you now look at the temperature what it means is we have basically squished this region right and that means this particular curve does not really exist.

Okay or in the limit of high activation energy into to a higher order if you now relax this thinner system plain field assumption you will see this thing happening in a very, very small region okay but outside in a larger picture it essentially is like our picture is starting in essential from somewhere here and then you get to see one the preheat zone counterpart okay which is the transport region or four for the temperature.

So you now get the temperature to go like that so in this case for example you can now say the temperature reached reaches a peak somewhere, somewhere here and then falls back again right and keep in mind in this in this picture you need to have the temperature go to a zero slope over there for symmetry consideration we tasked me probably go to a zero slope if you now have an antibiotic or an insulated wall right so you have to keep those things in mind and trying to construct these temperature profiles in the global picture and this is actually what is called as the outer zone picture in the vicinity of the flame sheet right.

And this is actually a inner zone picture so you now have two or three levels into which you have to go to this is like the global picture this is the outer zone in the vicinity of the frame sheet this is the inner zone of the flame gene that is how we have to think about it so if you now think about so the product concentration as I said will the temperature so you can say this is your T and Y P then look at how they are the reactant concentrations would look like what it means is you this is going to be there.

Because the product concentration is decreasing as you go away from the flame sheet so as you go in near the flame sheet toward racially the fuel concentration is getting contaminated by, by the by the product right therefore you are going to have this part of the curve intact so it is going to go like this and what happens then does the fuel fill concentration cross cut across the, the flame sheet where the where the reaction rate is infinite no because all of the fuel is getting consumed there right.

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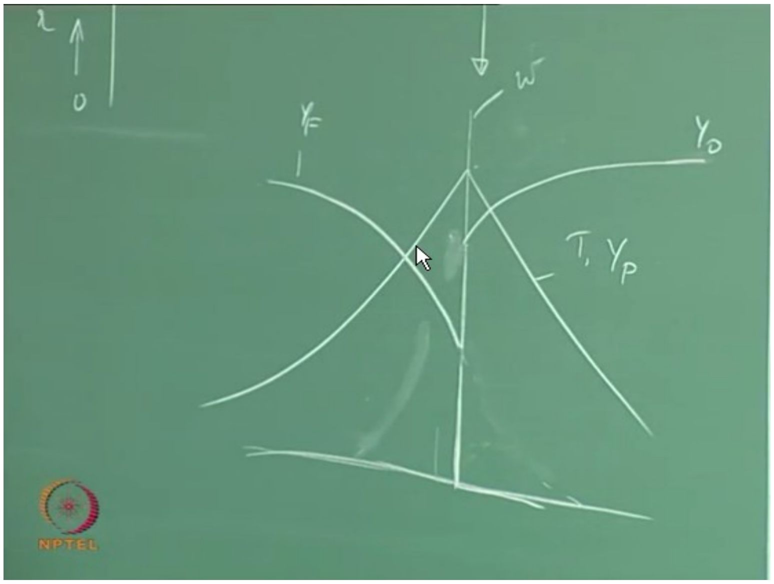

So you now have a step jump into the fuel concentration so first of all we notice that you had a slope discontinuity in the temperature the temperature is continuous all right ,right but it is, but it is having a slope discontinuity what does it really mean it means that heat is actually being released over here and this heat is heading on either side depending upon the slopes you have a temperature slope on either side corresponding to a heat conduction of a on either side okay.

And, and obviously you need to have the temperature go like that because you will not have heat go this way as well as that way and that will correspond to having like a cusp in the temperature profile that is a slope discontinuity but as far as the fuel concentration is concerned you actually have a value discontinuity as well because you, your car having the fuel concentration arrive at a particular level.

And similarly you can think about for example let us say that is your oxidizer so this is this is your YF and let us suppose the dots your oxidizer and comes in like this and then we are not squished did this region right so it comes in like this so what is meant by and there and then it drops to zero because within this narrow region it just drafted falls to zero but now we have even squished this narrow region to a sheet.

Therefore it has to fall to zero within that sheet so what is meant by saying you, you, have a few let out fear and oxidizer and stoichiometric proportions the answer is very simple this is the value of the fuel concentration at the flame sheet this is the value of the oxidizer concentration at the flame sheet and if you now look at the ratio between these two it would be a stiochometric that is how it has to turn out right.

But how did we figure that by just doing the mixing analysis without a flame strictly speaking the answer was if you did if you did not have a flame you would not have this curve you would not have to worry about the temperature or the products so you are still going to have something that goes like that something like that, that, that goes like that.

The moment you found them at stoichiometric proportions you now said that is my flame surface and that is where the flame is but if you now go back and look at look at look at it in the rigor in reality this is how it turns out to be so you do not have these things the fuel and oxidizer get consumed these are some of the some of the issues that you do not find very explicitly stated in textbooks and you get confused.

These are some of the some of the issues that you do not find very explicitly stated in textbooks and you get confused what exactly is happening in the diffusion flame as you now move far little bit farther away from the flame on either side or how did we get to locate the flame using the stoichiometric surface assumption and just solving the mixing feel.

So this is the connection between the mixing problem and the combustion problem in the context of a final infinite rate chemistry which is actually a idealized high activation energy or infinite activation energy a version of the realistic finite rate, chemistry case you see, so we will, we will see later on next lesson what is how do you, how do we how is it possible for us to actually get these get these profiles but right now what we want to do is to stick with the theme on finite rate chemistry.

We want to now look at the situation with respect to finite rate chemistry here because that is what we started doing the question we have to ask is are we going to have this kind of a very thin in fact this is an exaggeration this picture is an exaggeration it is not even as thick as this right, is it going to be like this everywhere right.

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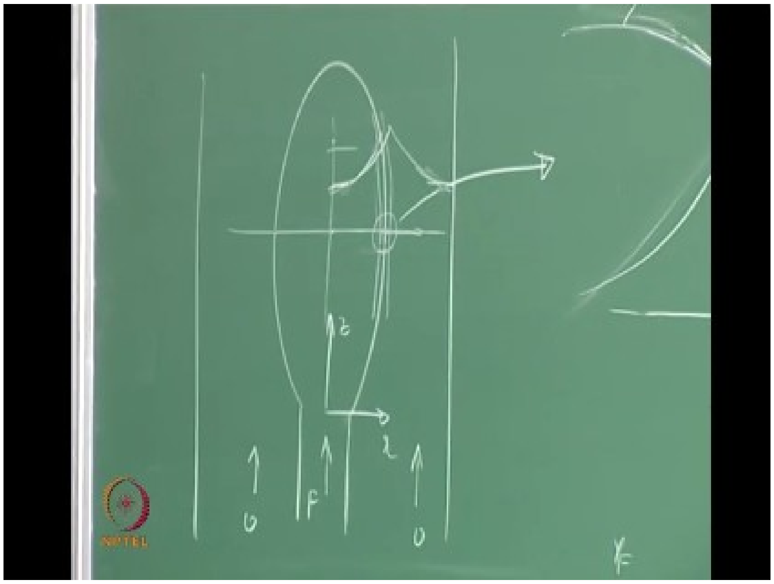

The point was the flame sheet assumption or the infinite rate chemistry assumption essentially meant you have mixing rates that are rate determining when compared to the reaction rates, so you did not have to worry about how fast the reactions are happening because they were just waiting to happen they instantaneously happen, once the mixing happen and the mixing was the one that was slower therefore we are waiting for the mixing to happen.

So when would we have high mixing rates and when would we have sorry one would we have low mixing rates or lower high mixing rates men would we have low or high reaction rates right. Mixing rates depend on concentration gradients reaction rates depend on temperature and of course CA of course none zero concentrations okay. So given reactants given that they are available if the temperature is low the reaction rates are going to be significantly low right.

If the concentration gradients are high the mixing rates are going to be relatively high, whereas the infinite rate chemistry assumption is primarily based on low mixing rates and high reaction rates okay what we need to examine is, when would we have a situation corresponding to high mixing rates and low reaction rates does that happen anywhere, in the flame it is not too difficult for us to figure out starting from looking at the mixing rates.

As I said mixing rates are depending upon concentration gradient and as the fuel comes in and the oxidizer come comes in at this particular lip you have a high concentration of fuel here a high concentration of oxidizer here and there is a steep gradient of concentration of the field and a steep gradient of concentration of the oxidizer right. It is almost like a step and it is almost infant infinite concentration gradients there, so if we have infinite concentration gradients they are going to try to rapidly mix right there.

Further down a little bit maybe you have the concentration gradient smoothening out and therefore the mixing becomes sluggish all right, but right there you have infinite concentration greens pretty much and therefore the mixing must be very rapid okay but maybe the constant with the reaction rates vary even drop more rapid okay. So many times you know and you are looking at these mathematical limits it is a question of two things go and infinity which one goes to infinity faster right.

But is that right we are now going to have you to see me never worried about the energy equation right; therefore we never have to worry about the boundary conditions to the energy equation if we have to worry about the boundary conditions to energy equation what would you do? Of course we pointed out that this is this temperature profile should go to a horizontal slope there because you are going to have a debate equal but that is that boundary okay and then of course you have a symmetry boundary those are the boundary conditions in our for the temperature.

But what about these are boundary condition right, so there is a boundary condition that you would apply is I am going to have cold reactant sintering this domain, that is what I would do if I just open my top for my for my field to come in on my oxidizer to come in right. I am not going to heat the fuel and oxidizer to the flame temperature and send them in, so I am going to be sending it at cold temperatures, so mighty not is going to be less than my flame temperature.

So ask the fuel and oxidizer are coming in and rapidly mix what would happen they are still cold they are just beginning to get heated up from the flame, therefore their reaction rates are pretty low no compared to what suddenly the mixing rates. There are the mixing races certainly high, so right there you have a gross violation of the flame assumption. Even if you had infinite early infinite activation energy right because the temperature is a fairly low and the concentration gradients are infinite.

So both of them are actually working against each other in satisfying the assumption that was made, so what happens then right so what we want to do now is look at this region that bit more carefully, so let us do that so if you are now going to look at only that region and I am going to now say.

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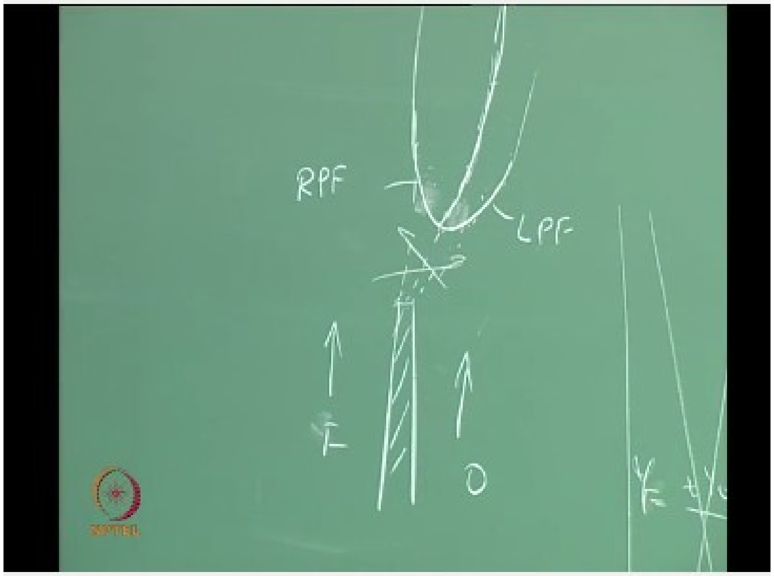

Let us have like a thickness of the burner wall right the inner pipe and so that is not at the moment that is not very significant but we could think about using the thickness at some stage soon but at the moment what we are interested in this you now have a F coming this side and o coming that side right. If i were to worry only about the mixing problem the way i was trying to do the book Sherman solution i would now be able to locate my stoichiometric surface going like that, this is the stoichiometric surface in the mixing region right.

So on this side of this the surface you are going to have a fuel rich region on that side you are going to have a oxy riser rich region. Alright course this is actually for a delay boundary condition in the deaf ear and oxidizer concentrations right, you could allow for flux boundary conditions when you permit axial diffusion to happen in which case this curve does not have to actually come here could be somewhere here little bit of a so on okay. But in this in this region you have a stoichiometric surface emerging out from the domain upstream boundary somewhere right.

It is not very important that it is actually coming right from the lip for the discussion that we are doing now but this is just a mixing field okay and you are having a mixing going on the gases are as they mix trying to get heated up from a flame, so that they give reaction rates will become appreciable and they can constitute the flame right what is the flame it is essentially where the reactions are happening reactions are happy reactions happen where the reaction rates are significant reaction rates of significant when the temperature is high.

So the heat is getting released and then it now starts heating up those reactants that are cold, so that that temperature can be raised up to the flame temperature and therefore they can react right this is how this is how it is going on. So therefore we are expecting them flame to be there somewhere with a standoff distance okay and reaction rates are not very appreciable within this region because the temperature is just warming up to wherever the wherever it is wherever it is reaching the flame.

So this dynamics of heating up the reactants right to the temperature at which they need to exist for the flame is going to dictate this town of distance right, physics essentially based on a thermal balance between of course you can now begin to factor in some amount of heat going to the burner wall by heat conduction, there are also analysis that have been done where you take into account radiation losses. So again you again you can think about these things but even without that even if you were to consider this to be an adiabatic wall you have to still heat up the reactants in the first place.

From their original room temperature let us say to the flame temperature, that much bit is going to require a certain distance over which it can happen as the flow is getting conducted right, so as this flame is now going to be there and heating up the reactants the reactants are mixing and they are mixing pretty fast here because the concentration gradients are very high right. So when they mix by the time they reach this flame, what is that flame? That is no longer a diffusion same.

What is going on very cheating ourselves, what kind of a premix flame are we going at half right it is stoichiometric right, there along that surface okay because we have the start of distance, now you can see why was not really worried about whether this stoichiometric surface comes all the way back to here with a with a traditional a boundary condition or whether it would go somewhere else for a flux boundary condition, that is not that is not very important for this discussion.

Because you have a standoff distance over which you have to figure out how the flame is going to look like right, so it is the premix there is a premix thing going on right it is not quite like a pre-mixed flame it did they say if they pre-mixing flame, so typically people begin to talk about this as oats or partially pre-mixed same right and what happens here is you have a stoichiometric mixture here, so you would expect the premix flame to propagate at stoichiometric speed but as you go little bit further out your striker Marti drops drastically into a field which fraction and on that side you are drastically going on as you go further out you are drastically falling into oxidizer rich.

So we have to think about a pre-mixed flame propagation into this what you have to think about is like a mixing fan, where these edges of these contours might correspond to a rich flammability limit and flammability limit for a pre-mixed flame beyond, which you are not going to have the prime explain exist this is pretty rough because we are talking about it is rough in many ways and we will we will see why this edges do not really have to correspond to that very precisely as we build a build up the scenario.

But at the moment if you are now thinking about I Prime explain that is propagating there we could think about like edges to this because beyond which it cannot propagate and essentially what we are talking about, now is a pre-mixed flame that is trying to propagate against a reactant stream in a what is called as a strained at must ambience what has been by strained is you, now have a pre-mixed flame propagation with a concentration variation across. That is to say if you now went back to your one-dimensional prim explain picture, we have this premix flame all right.

But that was for a particular mixture ratio question is what would happen if your mixture ratio continued to vary across, can I now have what is called as a mile stratification that means can I now say well this is supposed to be a YF plus YO right but can I now say that roughly my YF was like this a profile like this the beans I had progressively more feel here and less fuel there and like my YO was like that we had progressively more oxidizer here but what would happen to that plane right.

So if you had a given uniform mixture ratio between fuel and oxidizer for a prime explained it would propagate at a particular speed and that speed would be the maximum if this uniform mixture were to be stoichiometric, on either side of equivalence unity equivalence ratio you are going to have the flame speed drop right. So if you now think about a moon fuel rich situation here more oxidizer rich situation here the flame speeds for the flame are not going to be the same everywhere right.

Somewhere in here you are going to have a stoichiometric proportion in which they exist and that is where the flame speed is going to be the maximum, therefore the flame is now trying to actually propagate the fastest along the stoichiometric surface and it progressively is slowing down as you go further out. This is similar to how you were looking at a few lean pre-mixed flame established in a Bunsen burner with entrainment of air further out or even as a matter of fact if and even if you think about a fuel rich flame if you know entrainment there.

You now have a mixing region and the flame speed varies because of the constant because of the reactant concentration variation spatially right, so here what is going to happen is the flame is now beginning to bend right, this is of course a very blown a picture strictly speaking we should now go back to our G equation kind of approach where we now thought of a pre-mixed flame as a flame sheet, which contained all this information about the structure and all that information was packed into simply as flame speed variation right.

So if you had a flame speed variation then how would that look like if you if you had a stratified flame SL, now is actually a local function of the equal equivalence ratio or CASL is now a function of the local equivalence ratio and it is now having a maximum over here.

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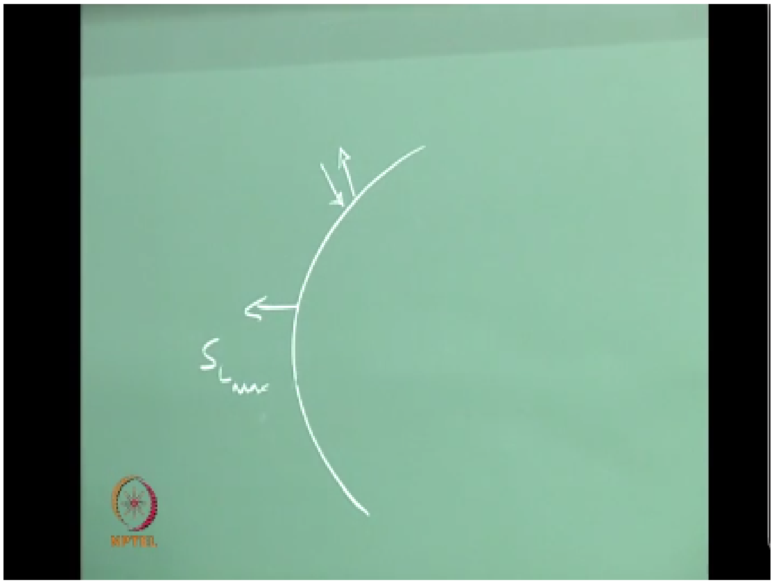

And elsewhere it is now trying to propagate perpendicular to itself at a lower flame speed and therefore it is now going to shape itself in such a way that it is balanced by the local normal component of velocity, whereas the maximum flame speed is going to counter the full velocity right there right that. Is exactly how we are thought we would have thought about shaping things like premiere Bunsen burner flames and so on and that is something that can happen over here as well?

So now we know how to progressively go back to rubbish where we started right, so in this picture which is here we will now like to think that you had a pre-mixed flame that was like this right, if we now had a pre-mixed flame and add this particular point you are going to almost like zero flame speed so you should actually expect this betrayal off and DK right as more almost like extinct it became becoming exchange and what happens on this side, this is a fuel rich prime explained right.

So this is rich pre-mixed flame and this is a lean pre-mixed flame, so when you have a rich creamy explain you have a fuel excess fuel as part of the products right and when you have a lien pre-mixed flame you have excess oxidizer as part of the products which can now diffuse to form this diffusion flame they are pretty hot right. So the way diffusion flame now no longer has to wait to get ignited right, so you can now have a diffusion flame that is actually emerging out of the stoichiometric surface where the premix flame is trying to propagate against the flow the fastest.

And then trail off all right, so this is the diffusion, so this kind of a structure has now been variously called originally it was it was called by Buck master is what is called as a tribe tracheal flame meaning that it is a flame with three branches all right but subsequently most of the literature refers to this is a triple fling and the literature basically sides, the first time a triple flame was published was in 1962 in an experimental work, where you are where you are looking at a diffusion flame with kind of a geometry but essentially with a very mild stratification.

That means you have a mixture of fuel and oxidizer of varying proportions, that the aflame is subjected to and that gives rise to a triple flame structure. So if you now go back to this picture we now have to expect that this is happening somewhere here right, now that looks very small when compared to the rest of the rest of the diffusion flame no wonder book and Schumer never have to worry about this right because if you are thinking about like the height of this flame forget about this you do not even worry about this right.

So the flame sheet assumption leading to the flame shape for a diffusion flame is fine for certain purposes of looking at the big picture of you right, so that is what we are expecting for the flame to look like. So if you now go back and look at a candle flame very carefully let us suppose you had a romantic candlelight dinner with your girlfriend right and then you of course forget about the girlfriend and look at the candle right.

Now you know why I am a professor right, so you now look at the candle very closely and you look at the base of the flame and you see that to be blue and sort of like a bulb and how would we try to sort of exaggerate this picture like, how do we get to see this more and more the answer is the closer this part is to the burner you can see as it comes further and further closer the mixing fan is actually narrower right.

So if you were to have the stabilization happen somewhere here it is going to be much smaller, so it means it is not going to be very apparent right so correspondingly if you now go back and see it is going to be somewhere here so it is not going to be very apparent all right. So what you would want to see you do is to take a good for example a Bunsen burner and then shut off the oxidizer supply from the base and now allow for the diffusion flame to be established and then keep on increasing the fuel flow velocity.

So and we talked about this we said as the fields flow velocity is increasing in diffusion flame the length of the flame is going to increase but in addition to that, you are know also going to have this push top and when this gets pushed up you are having a mixing fan that is actually broader right and therefore you are going to have a larger region value we are going to have this flame, so in the literature when you now are getting down to something very close you do not really see these three flames separately.

In fact you can again think about these three flames if you now go back and think about how we got these flames right the three flames this is from the G equation right the G equation kind of approach, the G equation kind of approach is assuming a flame sheet and aflame sheet for a pre-mixed flame is valid typically in an infinite activation energy kind of higher activation energy limit and this diffusion flame is like a sheet again because of an infinite rate chemistry kind of idea right, in reality does not let it happen like that.

We know we saw that it is actually take in reality right if you now translate that it is now going to be like this and then it is going to come like that, that is like where reaction rates are going to be appreciable right and if you now allow for this to actually come progressively closer and closer these two branches now begin to close more and more right and of course there is no reason to expect that they will close. Simultaneously together so there are conditions where you have stratification only on one side for the oxidizer or the fuel where you can get in towards go to the double flame structure or a hockey stick kind of flame shape.

And they call it double flame right where one of the branches is actually merged with the diffusion flame the other branch is still sticking out, but eventually when you get closer and closer you are going to have both the branches essentially merge with the diffusion flame and it is essentially going to look like a bulbous region of high reaction rates. And that is that read that kind of a flame structure in general is what is called as a edge flame because it is actually relating to the edge the leading edge of the entire flame.

So this entire flame you see when you had a fully diffusion flame you never really had to worry about propagation of the flame because it exists wherever you have an interface of fur and oxidizer at stoichiometric proportions it does not propagate any where right. But the moment you have to worry about a mixing region in which you are having a pre-mixed flame that is propagating right you worry about propagation of the entire flame, so it is as if like this flame is trying to eat into the reactant mixture with a certain speed at which the reactants are coming at.

It is exactly the same kind of thinking as in the case of a prim explained with curvature effects and so on, as a matter of fact all the all the things that we talked about for flame curvature effect and flow divergence effect or valid in this region, so you can think about here as you now look at a flame sheet that is that is therefore the pre-mixed flame you see the reactant that is going here is actually partially refusing and partially convicting. So you are now sending out heat this way to a reactant that is not necessarily participating in the in the reaction.

Therefore this region is not necessarily corresponding to adiabatic flame temperatures at all you will have a two dimensional heat loss in this region and if you now get closer and closer to the burner you are also going to get heat loss to the burner right and therefore the this that is another reason how this flame could actually shrink, the region could shrink further and further as you go closer and the second thing is as you now have a flame that is curved like this and the flow goes like this you can see that it is it is it would tend to actually go up and then converge.

Because it is actually convex phasing the reactant flow, so since it has to converge it locally diverges and then converges this is what we saw for a for a flame says in fact go back to this but what we saw was we should expect this to happen. So since it is a subsonic flow in reality what happens is you now have aflame tube this is now a faster flow that can be handled by a curve plane because it is actually diverging locally decreasing its velocity right. So relative to the far upstream velocity this is actually slow so it the flame tends to slow down the flow as it as it approaches.

So that it can get established right that is the flow divergence effect similarly you have a fairly huge flow divergence effect and you will if you now solve, like the momentum balance associated with the flame you will now find like a small pressure hill around which the filter the lead if the flow has to go around which has been created by the flame right. So effectively what that means is this flame can propagate against a much higher velocity than even stoichiometric premix fling.

Because it curves so steeply and it causes the flow to diverge and then converge and therefore the far upstream flow is that actually a much higher velocity when compared to the flow at which it is stabilizing. So it is not the local stoichiometric velocity that matters it is actively far upstream velocity that matters which has been altered near the flame by the flick flow divergence effect on the flame Kerr, which all those things that we talked about for prime exclaims is valid and as we as it gets closer and closer to the burner you are getting into what is in general called an edge flame.

And the other thing that we can also point out is if an edge flame will correspond more and more to a infinite concentration gradient at the splitter plate well as if you had a smoothly varying concentration gradient you will have more and more of a triple flame right. So even for the same distance from the burner lip if you if you were to rig up the concentration gradient in a smooth manner you will get a triple flame structure, whereas if you had a very drastic variation in the unity in the concentration gradient then you will have more like an edge flame right.

So the edge flame then it is a more general picture of which a triple flame is a particular structure right and this is typically the stabilization mechanism for diffusion flames in general. So the diffusion flame is essentially getting stabilized because of this and then of course because of this reason it goes through what is called the lifting process right, as you now keep on increasing your velocity at some stage the frame the de stabilization mechanism does not work over here in this region and then it lifts off. And you now get a diff you a diffusion flame that is far away with a fairly broad pre-mixing region and of course its turbulent and you have to worry about those aspects also will stop here you.

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