Fundamentals of Combustion
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Lecture – 53
Turbulent Flames - Part 5
Turbulent diffusion flames

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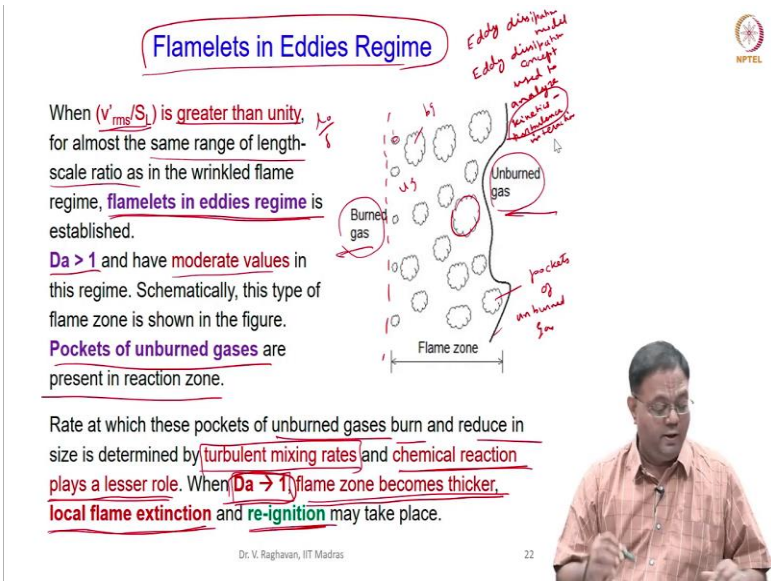

Now, turbulent intensity is increased. The relative turbulent intensity is greater than 1.

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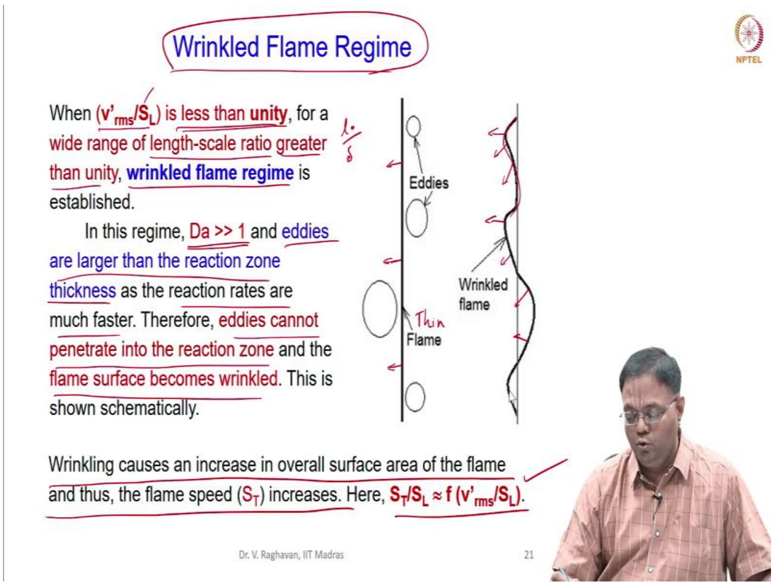

In the first case, what we have seen is less than unity; turbulent intensity is smaller, laminar flame speed is higher. Now, I increase the intensity, so that it becomes greater than unity. So, in that ratio for example, for the same range of the length scale ratio, what we saw in the wrinkled flame regime. The previous regime what will be the range of the length scale ratio. This is this same range what we saw in the wrinkled flame, the same range you get this.

But here difference is the relative intensity is higher than 1; more than 1. So, flame lengths in eddies are established. So, this is the schematic of this. You can see the unburned gas comes from this and burned gases leave here and you have some pockets; what this? These are the pockets of unburned gases. So, here entire is burned gas basically, but there are some pockets of unburned gas. Here, it is totally unburned and here also, everywhere it is unburned; but you can see there are some pockets of gases.

So that means, the kinetic mechanism alone is not able to completely consume the reactants. The eddies are also contributing to that. So, flamelets in eddies regime, Damkohler number is greater than 1 and have moderate value.

So, Damkohler number is not very high here; Da is not much greater than 1, it is only greater than 1; but I have moderate values in this regime. So, you can see the flame, the pockets of unburned gases are present in the reaction zone.

So, this is the characteristic of this particular regime; that means that the flame is not completely controlled by the chemical kinetics nor by the eddies; both are going to be there to control this. So, rate at which these pockets of unburned gases burn and reduce in size. For example, this is larger and this is smaller. So, after this particular length, you can see that only burned gases will prevail. So, to the right of this thick line only unburned gases prevail. In between, you can see pockets of this, this is unburned gas and this is burned gas.

So, both will be present in between this zone. So, how fast this pocket is going to burn and reduce in size will now depend on turbulent mixing rates and chemical reaction.

Actually, chemical reaction will play a role; but not a major role what it has played, it will play a lesser role. Chemical reaction will play a lesser role; but turbulent mixing rates will now contribute to this regime; how fast this is going to burn. Now, in the previous case, wrinkled flame there is no contribution by the turbulent mixing. But in this case, the turbulent mixing rate is going to contribute to the this.

So, you can see that there chemical reaction plays a lesser role; that means, it is not completely gone, but it is going to play a lesser role when compared to this. So, when

Damkohler is greater than 1. But there are situations where the Damkohler number can approach 1; approach a value of 1. In this case, the flame zone will become thicker and local flame extinction and the flame reignition is one of the important characteristics.

For example, there is a gas pocket which is trying to burn, it will extinguish and again it will be reignited. So, this type of small instability will appear. So, we can see the flame will just put off and then again reignite at a particular point. So, that the type of feature will be seen in this. So, in this case, based upon the regime the Damkohler number is greater than 1 and has moderate values.

If the moderate value is tending to 1; for example, at that regime if you try to operate, then you can see there is a flame zone becomes thicker and a local flame extinction, not everywhere, locally somewhere some pocket can put off and reignite, unburned gases which is there in this flame zone can put off and reignite and this can be observed. So, this is the second regime called flamelets in eddies.

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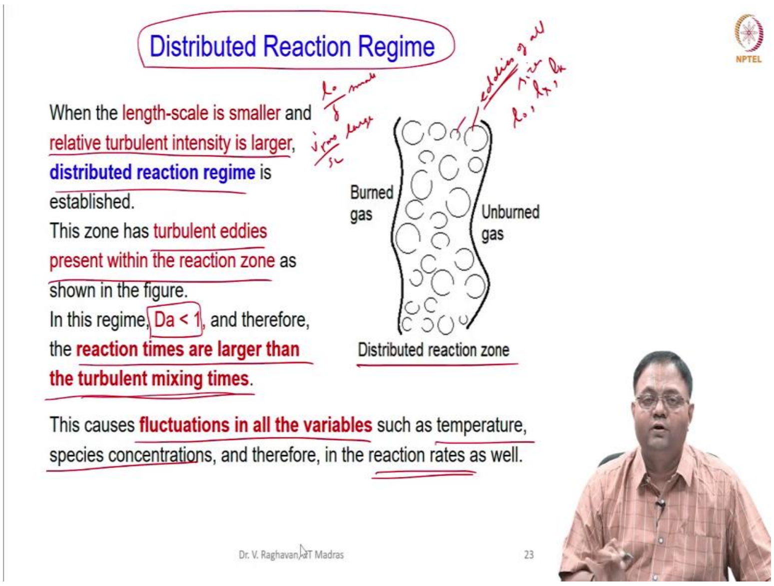

The third regime is called distributed reaction regime. Here, the length scale ratio is smaller and that relative turbulent intensity is large, that is this. Now, we get that distributed reaction zone which is established.

So, here what happens is the turbulent eddies, these are the eddies now; eddies of different sizes. So, you can see eddies of different sizes are present within the reaction zone. So, unburned and burned gas the reaction zone and you see that tremendous amount of this.

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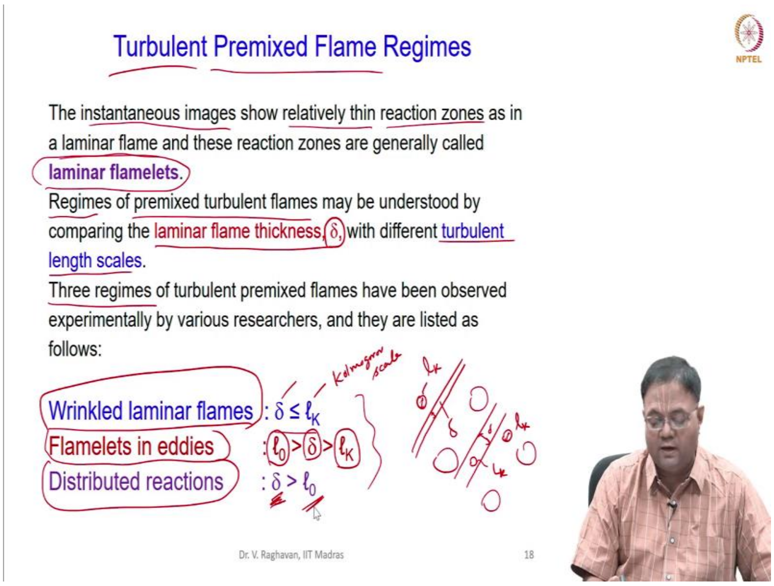

So, this is the distributed reaction zone, $\delta > l_0$. So, you can see starting from the l_0, l_λ, l_k everything, every eddy will be there in this. So, all these eddies will be present within the reaction zone. In this regime, Da < 1 and therefore, reaction times are larger than the turbulent mixing times.

That means that once eddies are present in the reaction zone, what happens is, the eddies break into smaller eddies and smaller eddy grow to a larger eddy and so on, you see fluctuations in the reaction zone. So, fluctuations in all variables like temperature, species concentration and reaction rates everything will be observed in this particular distributed reaction zone. So, here you can see that kinetics is contributing to a small extent, but there are pockets.

So, pockets of this. Some smaller and medium sized eddies can penetrate into this; smallest to medium size eddies can penetrate into this reaction zone which will govern the combustion of these pockets alone.

So, basically outside of this, the reaction rates are controlled by the chemical kinetics only; but in this case, the third case, only eddies are going to take over the reaction zone; the thickness of the reaction zone and how fast the reaction takes place inside and so on.

So, the fluctuations in all variables are observed here. In this zone, completely the reaction rate is taken over by the turbulent mixing and we do not really care for the laminar kinetics, chemical kinetics in this. But in this case, both are important. So, see in the first case, the chemistry is very important. So, you have to use a chemistry to resolve this flame.

And the interaction between the flow field and the chemistry, when you predict the chemistry that is only done by the chemical kinetics and the wrinkling etcetera when you resolve the flow field properly, you will get. So, the increase in the surface area and so on.

But in the second case, there is a good interaction between. So, you need chemical kinetics plus a model like say eddy dissipation model or eddy dissipation concept etcetera are included. So, here I say eddy dissipation model or a eddy dissipation concept. So, you can see that eddy dissipation model or eddy dissipation concept are used to analyze the kinetics turbulent interaction, turbulent chemistry you can say, turbulent chemistry interaction.

So, in this regime where both are going to play a role and, in this regime, only eddies are going to take over. There is no chemical kinetics required here. We can keep off of that and only use the eddy mixing rate as the chemical reaction rate in this. So, first one in this, chemistry is very important to predict the thin flame zone and so, if you want to accurately predict the reaction zone thickness etcetera, we have to go for this.

See it is not a zero thickness. So, if you assume an infinitely fast chemistry or a single step chemistry, then you get a very thin flame zone. When you want to predict the accurate thickness of the flame zone, you have to use the chemical kinetics mechanism in this case. And we will resolve the flow field properly, you can predict the wrinkling.

In the second case, we have to use chemical kinetics. However, we have to also take care of the interaction between the turbulence and the chemistry. So, that is this zone, flamelets in eddy. Third will be the zone where the chemical kinetics can be discarded and the only model like eddy distribution model can be used to just predict, mixing rate will govern the reaction rate here. So, these are the three regimes which are going to be observed in the turbulent premixed flames.

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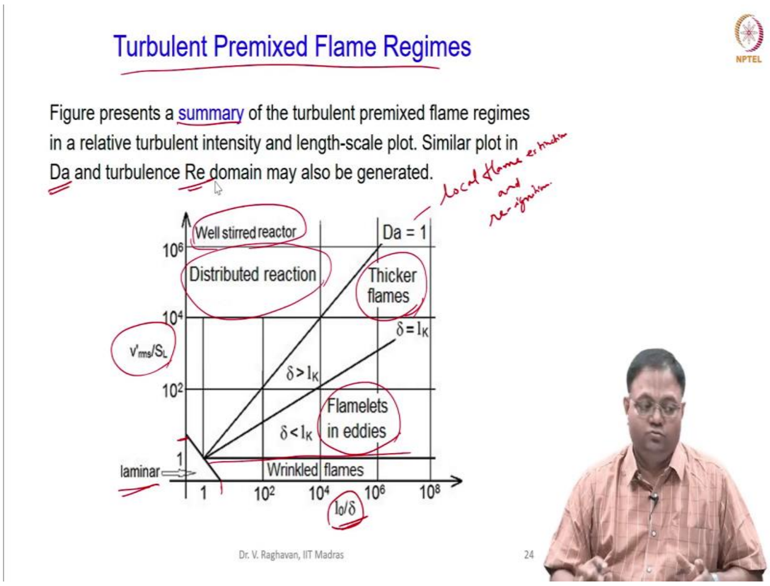

In summary, when we plot a map of the relative turbulent intensity and the length ratio l_0/δ, I know that this is the log of scale, this is say 10. So, when both these quantities are less than 10, you get regime which is laminar, which are phenomenal laminar. Then, the wrinkled flame as I told you the turbulent intensity is very low and for a given range of length ratio, I get wrinkled flame; very low turbulent intensity.

Now, turbulent intensity I have increased to some level, but the same range of length, I get this laminar length ratio same range of length ratio; but some increased value of this. So, if it is now more than 1 you can say. Here a wrinkled flame, this ratio is less than 1 and, in this flame, this is more than 1. To a particular ratio we get this flamelets in eddies. We have a thicker flame, when I see in this case, this is the Damkohler equal to 1 regime. So, here we get the local flame extinction and reignition. So, thicker flame zones are got. Again, this is also like, this it is not exactly the distributed zone. So, in this regime, it is also laminar flamelets in eddies type of regime, where both chemistry and these are important.

Now, if you increase the turbulent intensity and the scale ratio is decreased, you get a distributed reaction zone. So, here also we can have a wider, somewhat wider, when compared to the wrinkled flame or the flame in eddies, this ratio is slightly lesser and we have distributed reaction zone where we can see that the eddies are going to be inside the zone and the eddy mixing rate will control the reaction, overall reaction rate.

For example, well stirred reactor is nothing but where the reactants come in and there is a fast mixing of this, so that reaction complete and the products leave. Such a phenomenon will be there. When the turbulent intensities are higher, then you can see that the flame will be completely controlled by the eddy mixing, the turbulent mixing. So, this is the map of the turbulent premixed flame regimes and this can also be plotted in plot called Damkohler number versus Reynolds number domain, turbulence Reynolds number domain. So, this is a very important diagram which will illustrate based upon the relative turbulent intensity and the length scale, what are the domains what we can have. So, that is the thing.

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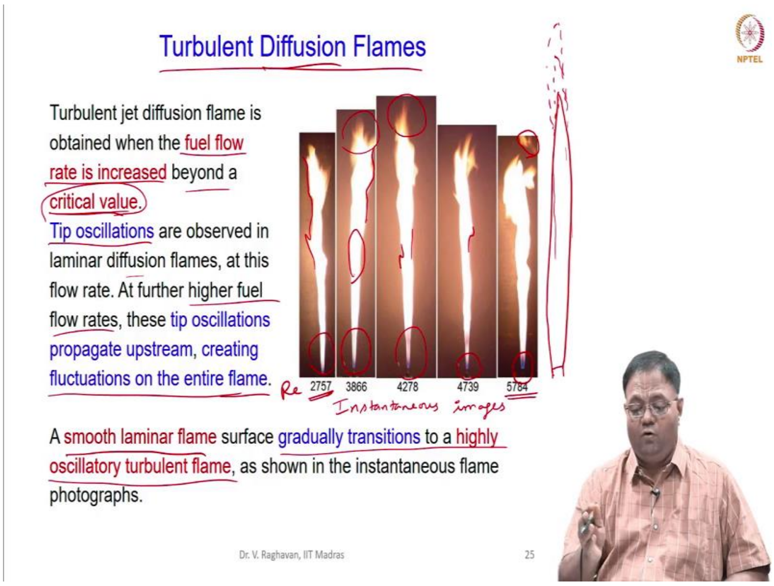

Then, we go for the next topic which is nothing but turbulent diffusion flames. Here, the diffusion flames are analyzed. So, you know the laminar diffusion flame; let us also draw a laminar diffusion flame. Now, it is a very well behaved flame and basically the I will just draw it. Basically, it will be a longer and you can see that based upon the flow rate, the flame length will increase.

Now, here the characteristics, you can see this is the smooth flame surface, now you can see the oscillations in the flame surface. So, everywhere you can see the oscillations and other things. The surface is now having lot of fluctuations.

This is instantaneous image. Please understand, these are all instantaneous images. Now, this type of flame is formed when the jet velocity, the fuel flow rate or jet velocity is increased beyond a critical value. So, the laminar flame will transition to this.

Now, how it starts is, first we will see tip oscillations; only the tip portion will oscillate. The tip portion of the flame will oscillate, when you cross this velocity, critical flow rate, and when you further increase the flow rate, the tip portion penetrate into this overall length and finally, the fluctuations are seen in the entire flame like this. Entire flame we will see the fluctuations. When you see near to the base, it will not be fluctuating at all.

But almost the entire length will be fluctuating. So, this is the turbulent regime. So, important thing what you can see is the turbulent regime. The Reynolds number is indicated here, these are all Reynolds number. So, 2700 to say 5700. You can see that the flame length does not change much; flame length is not changing much that we can see.

So, the consequence of turbulence in the diffusion flame or non premixed flame is a smooth laminar flame surface gradually transitions to a highly oscillatory turbulent flame and basically it is shown in the instantaneous photographs, also we can see that there will be some puffing and this.

So, we can see here some flame has just left. So, there will be some puffing and due to the vortex shedding type of phenomena, the flame can puff and go off and again it burns. So, this type of vigorous oscillations are seen in the flame zones. So, other characteristics we will see. The first thing what we can easily observe is the smooth surface is not anymore there and the flame actually is oscillatory.

You can see that after a particular point, this flame tip will move away; it will lift off from this. Also, you can see the flame tip; but when they are attached, you can see that there is a blue flame, bluish flame which is present in the base of the flame. And you can see that there are again same features like a luminous part here and you can see that there is no smoke escaping for this particular Reynolds number range.

But if you increase, you can also see a smoke which is coming out of that and so on. So, the main characteristics is the tip oscillation which starts at a particular flow rate called critical flow rate, penetrates into the entire length and the flame becomes oscillatory.

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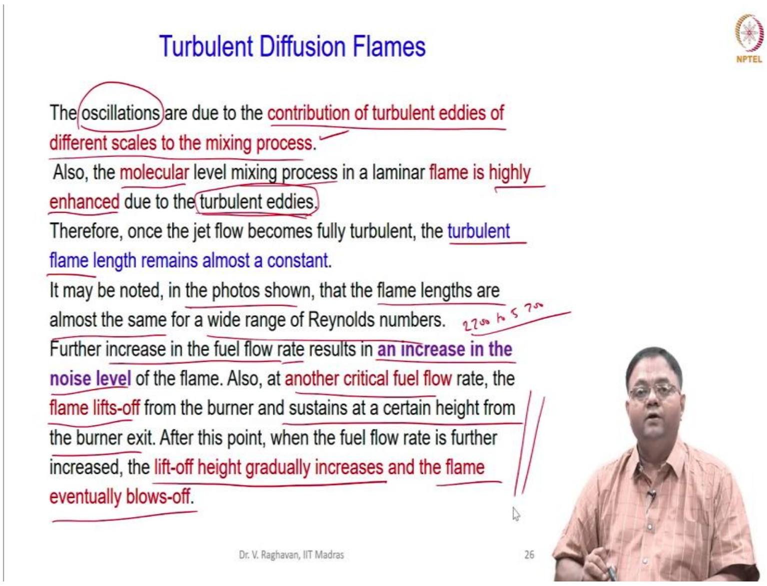

These oscillations are contributed by the turbulent eddies of different scale into a mixing process. So, at the non premix flame basically is set by a proper mixing of the fuel and the ambient air at stoichiometric proportions, where the flame zone is formed.

But if the turbulent flow field is present, the eddies will try to mix this fuel and air and since eddies are fluctuating, the mixing zone itself is fluctuating and such fluctuations are important on the flame surface. So, contribution of the turbulent eddies of different scale to the mixing process will contribute to the oscillations.

Now, molecular level of mixing. That is the diffusion coefficient; molecular diffusion coefficient or molecular diffusivity will be enhanced tremendously, highly enhanced due to the turbulent eddies. So, this is the reason why we can see that the length is almost same. For a Reynolds number of 3000 to say 6000, you can see that the length has not changed much.

This is actually when you take the accelerations are not much here; only the oscillation in the surface are very high. So, you can see that almost if you take the average value of the flame heights, here it will be almost the same; it is not going to vary much.

In the laminar regime, you can see that as the volumetric flow rate is increased, the flame length actually showed a very good increase; but here, you can see that after increasing this to 2700 to 5700, you can see that the flame length has not increased much. You can see increase and decrease etcetera for instantaneous.

But overall if you take average value of the flame height, visible flame height what you see in the photograph, it will not vary much. So that means, the turbulent eddies, they contribute to the mixing and that does not depend upon the jet Reynolds number that is what we saw; both the spreading rate and the axial velocity decay etcetera does not depend upon the jet Reynolds number.

So that means, the turbulent eddies which are in the field, they are going to contribute to the mixing, keeping the turbulent flame length almost a constant. So, that is very important characteristics of turbulent flame length. The laminar regime flame length increases, but in turbulent regime flame length are almost constant; we are talking about jet flame here. So, when you mix, the transfer processes are enhanced to a high value. So, significant increase in the mixing rates will contribute.

So, when there is a higher jet momentum coming out, for the Reynolds number say 5700, you can see that mixing is also enhanced appreciably so that the fuel is consumed within the same height. So, the flame lengths as shown in the photographs are almost the same for a wide range of Reynolds number say 3700 to 5700. So, this is the range of Reynolds number which are considered and this has been seen by several researchers also. Now, we can see that when you increase the fuel flow rate beyond this, the flame will be noisy. You see some noisy flame and there is another critical flow in which the flame will lift off from the base. As I told you here, the lift off will happen, the flame will now stand. If this is the burner, the flame will stand at a particular height and burn. So, we have already seen the instability which is the only instability which you will observe in the non premixed flame that is lift off.

So, the flame lift off is observed in the turbulent diffusion flame as well and the flame will sustain at a certain distance from the burner exit. When you increase the flow rate further, the lift off height will gradually increase and finally the flame will blow off. So, these are the characteristics of the turbulent jets, jet flames.

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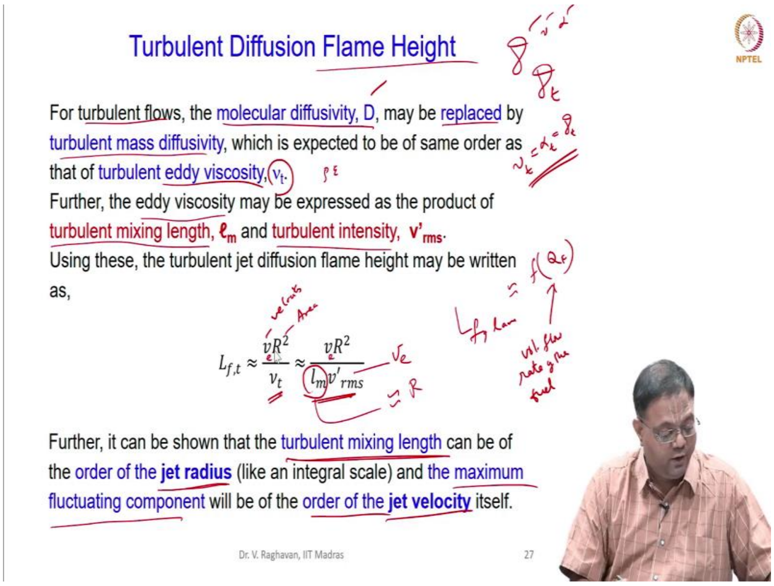

Now, turbulent jet flame height, we have seen it to be constant. Let us do the scaling analysis. We have done the scaling analysis for the laminar regime, where we have clearly seen that the flame height in the laminar regime is a function of Q_F; this is the volumetric flow rate of the fuel.

Now, in the turbulent regime, let us see how we are going to get the relationship between this. Now, in a turbulent flow molecule diffusivity can be replaced by the turbulent mass diffusivity, that is D can be replaced to turbulent diffusivity which is equivalent.

So, we have already seen that the momentum coefficients are the same in turbulent flow. Because it is controlled only by the eddies. So, the fuel properties like this ν and α in the laminar regime become flow property in the turbulent regime. So, ν_t, α_t and D_t, so, we can say the molecular diffusivity is nothing but the turbulent eddy viscosity, it is ν_t or we can say ρε, which we have already seen.

So, we can replace this to the eddy viscosity. Now, what is eddy viscosity? We also see that eddy viscosity as I told you, it depends on the turbulent mixing length and the turbulent intensity. So, you can say $l_m \times v'_{rms}$ will be ν_t; here, this is the velocity and this is the area. So, these are the factors which are affecting the flame length. Now, if you take the turbulent mixing length, this can be of order of jet radius R.

So, this can be of order of R and this velocity, rms velocity fluctuation can be as high as the jet exit velocity itself; v_e. So, the maximum fluctuating component can be of order of jet velocity; the turbulent mixing length can be of order of jet radius. So, I can replace l_m by R and v'_{rms} /v_e. So, this is also v_e; please understand this is also v_e.

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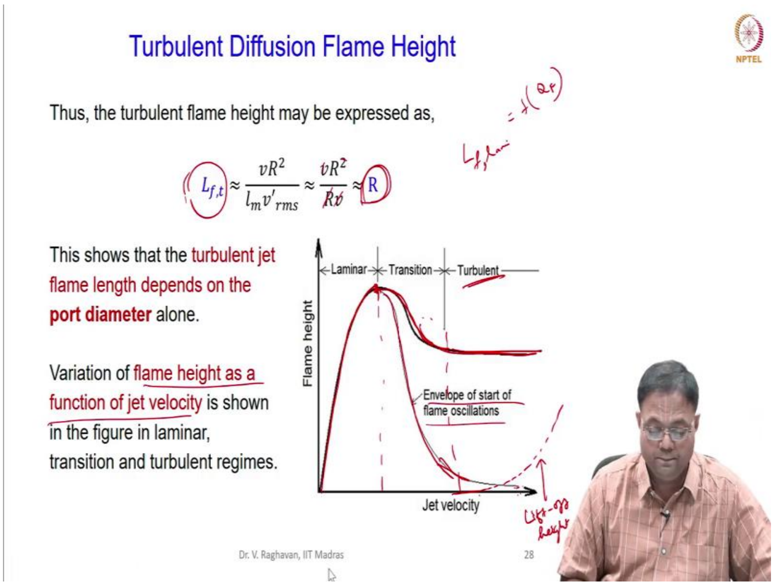

So, when I do that, v_e I substitute. So, this cancel and I get R. So that means, the turbulent flame height will depend only on the port radius that is what we have also seen there. So, in the turbulent case, analytical solution what we have seen here. You can see that the epsilon is function of v_e and R and here also you can see that there is no velocity decay or the spreading rate does not depend on the jet Reynolds number.

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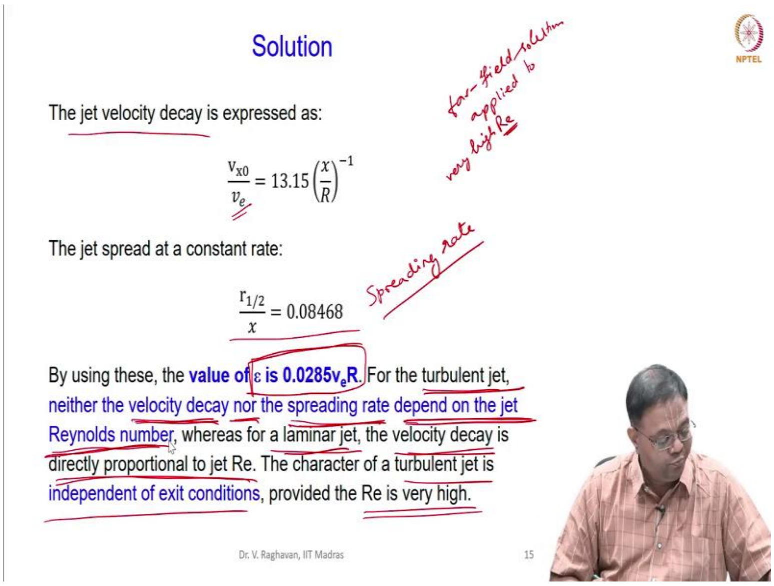

Whereas, in laminar jet the velocity decay is directly proportional to the Reynolds number; but for turbulent jet neither the velocity decay nor the spreading rate depends on the Reynolds number, it is not depending on the Reynolds number.

So, that is what here also we are getting. You can see that here the flame height is only dependent on the port radius. When you want to increase the flame height, then you have to increase the port radius, that is what it is. So, it is directly proportional to the radius. So, nothing else affects that.

So, this is the actual curve. We can see that in the laminar flame and the laminar regime, we can see the flame height with the jet velocity increases and in transition regime it drops basically to some particular value; then, in the turbulent regime it is constant. So, now in this, the critical velocity, where the envelope flame starts flame oscillation. Envelope of the flame will oscillate now and oscillations penetrate; the oscillation penetrate to the entire surface.

So, when it becomes turbulent, almost all this is turbulent regime, almost the entire surface will be oscillating. So, envelope of start of the flame oscillations is this. The tip oscillation starts and penetrates into the entire length and when it becomes turbulent, almost the entire flame will oscillate. Somewhere here the lift off also will start; somewhere after a particular flow rate, the flame will lift off. So, if you say lift off height, lift off height will be 0 here and after a particular length, the lift off height will start. So, this is the lift off height.

So, these are the characteristics of the entire jet flame, where in the laminar regime, you see an increase in the value, it reaches the maximum. And then, transition regime starts, where the flame height decreases as the Reynolds number or the jet velocity is further increased and then in turbulent regime it becomes a constant that is what we have seen. Because only the turbulent mixing is going to take place there. So, the mixing is enhanced by eddies present there.

So, the flame height variation as a function of jet velocity is shown for the three regimes. So, this is very important to understand that the laminar flame, flame height of the laminar flame will be function of Q_F; as Q_F increases or velocity increases and keeping a constant burner diameter, velocity increases, the flame rate increases, transition zone decreases and in the turbulent zone, it is almost constant.

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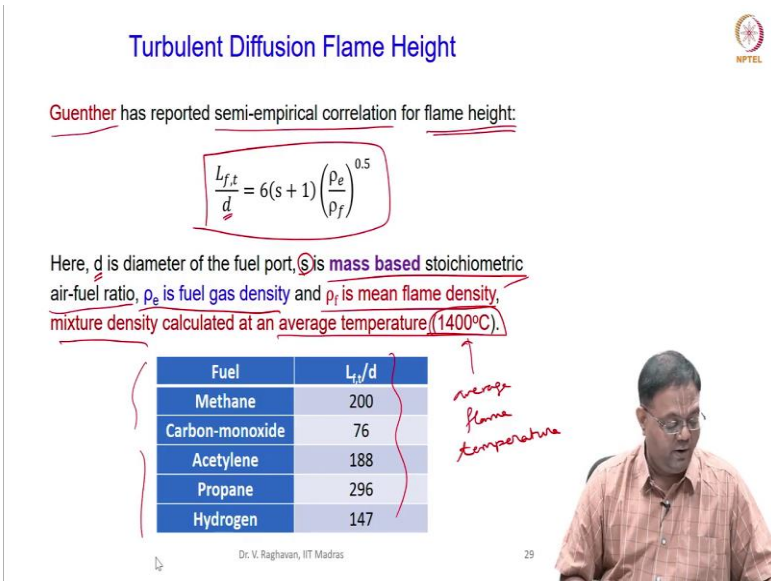

Now, Guenther has given the correlation which is semi empirical in nature; some theoretical plus empiric experimental data has been used to arrive at the correlation for the flame height in the turbulent regime; flame height of the jet diffusion flame in the turbulent regime that is $L_{ft}/d = 6(s + 1)(\rho_e/\rho_f)^{0.5}$; where, d is the diameter of the fuel port here. So, it is normalized with that; then, s is the mass based stoichiometric air fuel ratio.

Please understand that in the Roper's correlation, it was molar based and in the Guenther correlation, it is mass based. So, you have to keep the difference in mind and ρ_e is the fuel gas density; ρ_f is the mean flame density. So, there the fuel temperature was used; the oxidizer and fuel temperature, here the flame density is used and the flame density is actually calculated as a mixture density at temperature of around 1400. This is the average flame temperature.

So, at this temperature, the mean flame density is calculated and used in this correlation. These are some values of fuel jet which is coming out. So, it need not be the Reynolds number. So, why it needs a Reynolds number because it is only a constant, almost a constant. So, for methane $L_{ft}/d = 200$; for carbon monoxide it is very small, so reactivity is high; similarly, hydrogen also is smaller than this and so on.

So, these are some of the values of the turbulent flame height. So, like this lot of correlations are available. So, here I have just presented a simple correlation which is available for the turbulent flame height.

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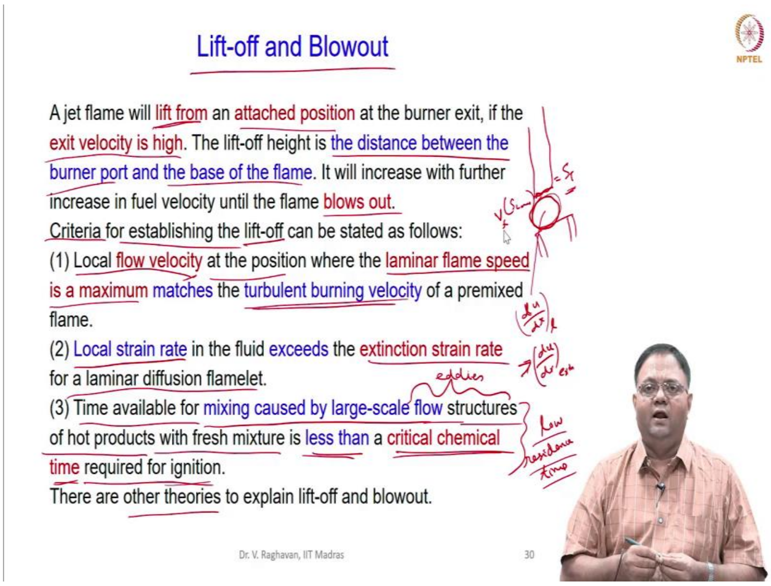

Now, some notes about lift off and blow out basically you can see that the flame will lift from the attached position if the exit velocity is high. So, exit velocity is high. Why it is? how can we judge the lift off height etcetera that is what we are going to discuss here. But we have seen that the flame lifts off after a particular velocity.

So, critical velocity is crossed, then we can see. So, it can also occur at a very small orifice, say 0.4 mm orifice which we illustrated earlier, even in a laminar regime, the flame lifts off. However, in the turbulent regime basically after a particular flow rate, the flame actually lifts off. And the lift off height is the distance between the burner port and the base of the flame. So, partially premixed flame base. Then, further increasing the flow velocity for the fuel will cause the blowout.

So, that we have seen. Now, what are the criteria, some theories to establish the flame lift off? So, there are three arguments; the first one is the lift off, local flow velocity at the position where the laminar flame speed is the maximum that will match the turbulent burning velocity. So, that is the lift off position. When the flame was lifted off, where it will stand? It will stand at a location where the local flow velocity at the position matches the flame speed.

So, there is a position, there is the flame lift off. So, this is the base of the burner rim I can say and the flame was lifted off here. So, the local flow velocity at the position, where the laminar flame speed is the maximum. So, we can say, where S_L is maximum at that position so that the x location matches the turbulent burning velocity S_T. So, this will be equal to S_T. There we can say lift off, but this is actually complicated. So, these are one of the theories.

If you can come up with some theory or empirical correlations to get turbulent burning velocity S_T and try to see the velocity, where the maximum S_L will occur etcetera, then if you can match this; then that will be the lift off location. Then, second one, second concept is the local strain rate exceeds the extinction strain rate of a laminar diffusion flamelet.

So, till this point what happens is, where the flame has this local strain rate, that is strain rate can be a velocity gradient like this. So, velocity gradient, something like that. So, this local strain rate basically exceeds the extinction strain rate. So, this is greater than du/dx, extinction. I will say extinction strain; that means, at the strain rate surely the flame will not be anchored there.

So, the local strain rate is greater than the extinction rate in this regime, where I have circled so that the flame cannot anchor there. So, in this position, where the flame base is anchored, this will match; the local strain rate is matched or maybe it will be lesser than the extinction strain rate. So, the flame establishes there. A simple theory is mixing caused by the large-scale flow structures that is eddies flow, these are eddies of all products with the fresh mixture.

When they mix, time available is less than the critical chemical time, then flame will not be anchored there. So, this is the low residence time we can say. So, here time available for mixing caused by the large-scale eddies which mix the hot product with the fresh mixture, why we need hot product to be mixed with the fresh mixture because it will auto ignite.

So, when the mixture come, the mixture is formed in stoichiometric ratio, it should be ignited by some hot products which are already existing, existing flame should reignite this. So, the hot environments should reignite it. There is no pilot or anything there. So, in this case what happens is the flow structures which is actually causing the hot products to ignite the fresh mixture, the time available for that is less than the critical chemical time for reaction to complete and cause the ignition.

So, there are set of reactions which will cause ignition. So, the critical time required for causing the ignition, chemical time, that is reaction time, the time available for mixing is less than that. So, it is not able to mix properly. I will say low residence time for this. The mixing cannot be complete within that particular time, where the reaction rate or the chemical reaction rate is required. That time is actually more than the mixing time.

So, the products have not mixed properly with the fresh mixtures to cause the auto ignition there. So, there are the theories, but there are several other theories also, which will explain the lift off and blowout. Basically, you can see that the mixture can be formed, but the mixture has lesser time to ignite or the mixture has a higher strain rate or the mixture has this local velocity, that is higher than the S_T and so on.

So, these are the causes, where the flame cannot survive and it lifts off and further, it goes and sustain at a higher position from the base or the rim of the burner. So that it has this criterion satisfied. After a particular flow rate, it will blow off.

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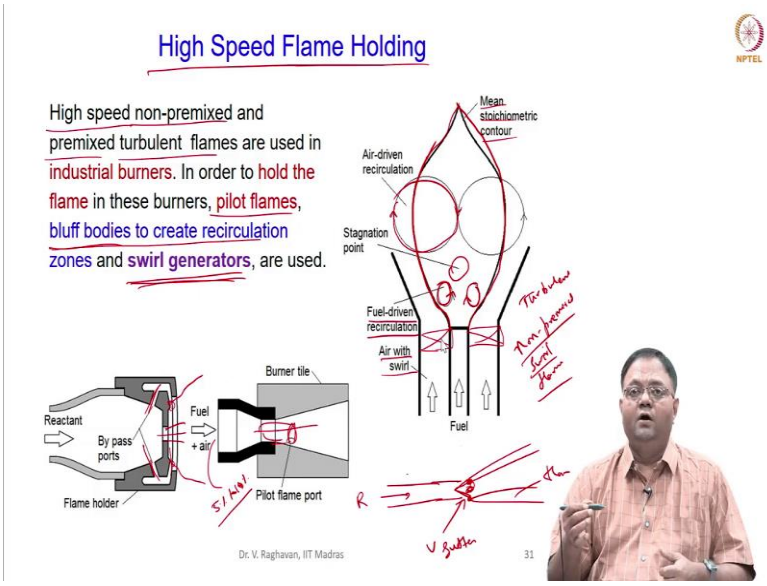

Now, flame holding; So, we know that we want to burn more fuel in industrial applications. So, when I go for high-speed flows, I get the lift off instability in both the premixed and non-premixed flames. So, high speed reactant entry or the fuel entry is unavoidable. So, you can say non premixed, where from the different ports you supply the air and the fuel or you have a premixed turbulent flame which are of high flow speed. Then, you need to somehow control the speed, where the flame can be held then. So that means that you have to keep the flame at a particular location and allow that to consume the incoming high-speed reactants or the fuel, and this fuel and the air should be mixed at a proper proportion to sustain the reaction zone. So, there are several methodologies. I have given three methodologies here. Using pilot flames; a small pilot flame which will give extra source of energy to ignite the mixture.

Then, we can also have bluff bodies to create recirculation zones, then we can have swirl generators. So, for example, if you take some schematics what I have given here. So, the reactant mixture comes in. The reactant mixture goes through this port as well as from bypass ports here so that it will have some time extra time to go in and burn here.

So, you will see a flame which is coming out of this. So, this bypass ports basically will create some time and some reaction zones can be formed here. This will help in sustaining the major reaction zone which is there in the front.

Similarly, when the fuel plus air enters in, there will be a pilot flame. So, some of some parts very small parts say 5% to 10% of this can be of the reaction pressure can be supplied through the pilot flame port, where a flame will be formed here and incoming reactants will be burnt or ignited continuously.

So, the extra energy provided by the pilot flame will ignite the incoming mixture. So, this is the typical non-premixed swirl flame. So, here you can see the fuel comes from the core port and air comes from the annular port, but these annular ports swirl the air. So, either you know you can have a swirl vane here; swirl vane and the swirl component, swirl component can be imparted here. Now, if you see the structure of the flame, shape of the flame basically is like this. The flame actually goes and radially it enlarges.

Basically, you can see there will be two recirculation zones here; one is the fuel driven recirculation zone, fuel driven recirculation zone which will be like this and the second one is the air driven recirculation zone which is present here like this.

So, there is a stagnation zone also in this. So, we can see that we can have a higher speed for fuel and air supply to this and due to the stagnation region recirculation zone etcetera, you see better mixing takes place. This is turbulent flame, actually turbulent. The swirl component normally imparts a turbulence in the flow field.

So, the flame shape is actually represented by the mean stoichiometric contour. So, you can see that the flame is having higher radius and because of the swirl component, the tangential component, it has sustained. The same thing can be done for premixed also; this is for non-premixed, where the fuel and air enter from the separate ports coflowing, but with swirl component. We can also do the same for the premixed flames also, we can impart swirl components.

So, when I do impart swirl components by swirl generators or pilot flames or we can have some bluff bodies to hold, see you can also have a bluff body to hold this. So, if you have a flame coming out of this port, we can have a V gutter. So, this is called V gutter and the reactants are flowing in this direction and the flame will be held like this. So, this will be the flame basically. So, this is the flame. The flame actually will anchor to this V gutter. Because there will be the recirculation zone in this position so that will reduce the velocity and the resident time will be increased so that the flame anchors in the V gutter and then, we get. So, bluff bodies can be used; this type of bypass ports can be used and the pilot flames are used or swirl components can be used.

So, when we have higher speed, then we cannot control the lift off etcetera, we have to use some of these techniques to do that. So, this is the turbulent flame characteristics.