Fundamentals of Combustion(Part 2)
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Lecture – 59
Introduction to Gaseous Jet Diffusion Flame

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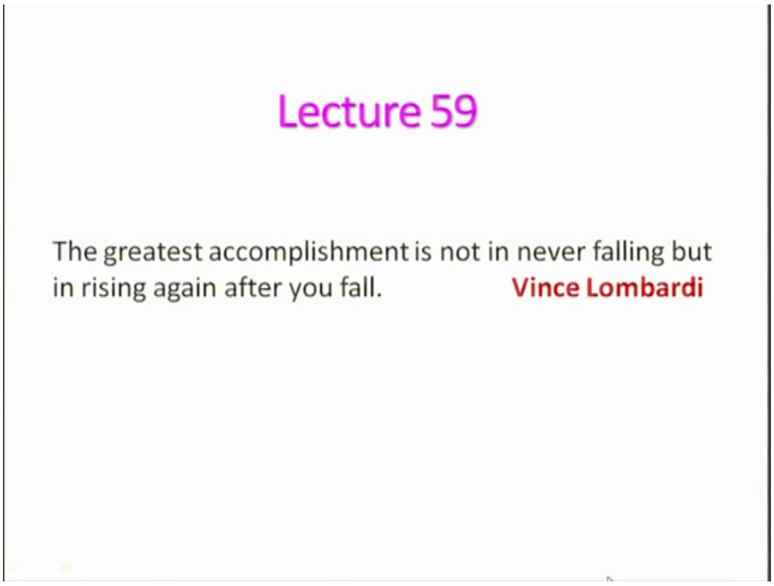

Let us start this lecture with a thought process that greatest accomplishment is not in never falling but in rising again after you fall. And if you look at in the last few lectures, we had discussed about both the laminar and turbulent premixed flame. Today we will be starting a new topic that is a Diffusion Flame.

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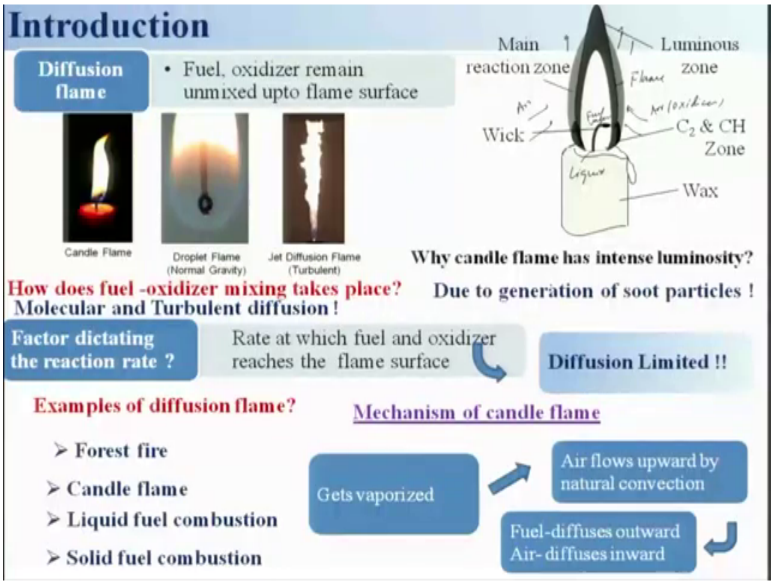

And if you look at like a some of the examples I have given because the candle flame, which is I have shown here. And which is quite common and then besides this is the droplet combustion or the on the normal gravity I have shown and this picture was basically taken in my lab. And jet diffusion flame it can be both laminar and turbulent kind of thing and this is again taken from in my own lab.

So, if you look at the diffusion flame is very important because of fact that all natural flames are diffusion in nature right. That in other words the all the flames whatever nature has produce are basically the diffusion flame. Otherwise, if it could have nature could have produced the premixed flame it could have been catastrophic because, the fuel and oxidizer are mixed and then combustion will take place.

And any carelessness we will lead to the explosion right. So, therefore, nature has not really thought about the premixing the fuel and oxidizer. So, in the diffusion flame basically the fuel and oxidizer remain unmixed up to the flame surface that is the beauty of the diffusion flames. But, however, it is having problem you can see that the flame here in the candle flame you can see that it is basically the yellow in color right.

And it is unlike the premixed flame, where the flames are blue in color right. And similarly for the droplet combustion and jet diffusion flame you can see the yellow in color. Now, question might we arising why it is this color is there and another question might be coming to a mind how does the fuel oxidizer get mixed right? What is the mechanism right? As you know very well that the mixing is governed by the two things. One is your molecular mixing flame right other is your turbulent mixing right.

But in case of laminar flame generally the diffusion is being controlled or being governed by the molecular diffusivity right. And the factors dictating the reaction rate is basically the rate at which the fuel and oxidizer reaches the flame surface.

That means if you look at the reaction; is very fast as compared to the diffusion process or the mixing process right diffusion process. As a result this kind of combustion is known as diffusion control; that means, diffusion flames are basically diffusion control. Whereas, the pre mix flame is kinetically controlled; that means, it is controlled by the reaction rate. In other words the diffusion flame; basically the reaction rate will be very fast as compared to the mixing time right.

So, therefore, it is a diffusion control or diffusion limited you can say and examples of the diffusion flames you know the forest fire right. Forest fire of course, is a very catastrophic and the problematic and of course, we are having very less number of forests or the forest area is shrinking.

So, therefore, we are not facing that much of problem, but; however, we are facing the problem of environment degradation. So,; the other one of course, candle flame and then liquid fuel combustion which is very important because of fact that for your transportation system. And any other things we use the liquid fuel for the combustion unlike the gaseous fuel right, because gaseous fuel is difficult to transport.

And also the another important thing is that like; the gaseous fuel is limited in terms of releasing the energy per unit volume and whereas, the liquid fuel one can go for a higher combustion density or the heat release due to combustion per unit volume. And the solid fuel combustion which is a very old as old as our civilization and again that also is governed by the diffusion flame or the diffusion control.

Let us look at very simple case of the candle flame as I shown; if you look at the process involved this candle flame is five complex. First of all this is the works which is solid in nature, it will be converted into liquid whenever the heat will be; you know received from the flame surface due to radiation and due to of course, mainly radiation and also little bit convection may be right.

And we use this wick, wick helps in transporting this is the liquid and this is this will be the liquid you can say liquid kind of things you might have observed. And this liquid will be getting into this wick due to what? Due to basically, capillary action, because, this is the porous and then it will be getting into it will be moving against the gravity right without any force.

And then it will be vaporize and there will be some pyrolysis, which will be taking place right. And because of heat is coming and then it will be some kind of a flame will be occurring and the reaction tune will be occurring. And this is C 2 and C H zone which is there. So, if you look at the mechanism of the candle flame to be more little this thing; specific that melted works force upward by the capillary action with the help of the wick or in the wick itself.

And then of course, the this liquid gets vaporize and convert into gas. And this gases basically, also paralyze and once this combustion take place you know like only it will take place if the oxidizer would coming because, the flame is established then what will happened there will be buoyancy effect. The buoyancy effect means, it will be some of the gases which will be moving you know upwards because, of buoyancy effect.

So, as a result it will be taking this air entrainment right. This is the air which will be entrain because of buoyancy effect of the flame. And air flows upward by the natural convection because, this here the natural convection plays a important role right. Unlike in the combustion system in practical application where the force convection plays a important role. And fuel oxidizer defuse like let us say this is the fuel vapor and this is your oxidizer right and which will be moving towards the flame surface this is your looming flame surface luminous flame right a flame surface, this is your flame surface right.

So, this will be a getting diffuse a fuel diffuses outward and then oxidizer air will be diffusing inward towards the and as a result on the flame surface it will be getting consumed and then you will get. And as I told that it is yellow in color not only the candle flame, but also the other flames other generally jet diffusion flames will be yellow in color. What might be the reason any idea? This is basically, if you look at as I told the pyrolysis will be occurring.

And this will be starvation of the oxidizers and then there will be formation of suit. And when the suit will be passing through the high temperature zone it will be radiating the heat radiating the not only the heat, but also the light and which is yellow in color.

So, as I told that because of a large amount of suit particles are produced in these candle flame or the week flames. You might be knowing that this suit particles which will be there will be order of nanometer right. And you might be aware that even the person who is uneducated they collect this suit particles for what? For Kazal, right to use that and people find that if we use that it will be very healthy for the eyes and other things right.

It is a not that today people are talk about nano material, nano materials were being used even in a the of the beginning of the civilization right which is as old as our civilization.

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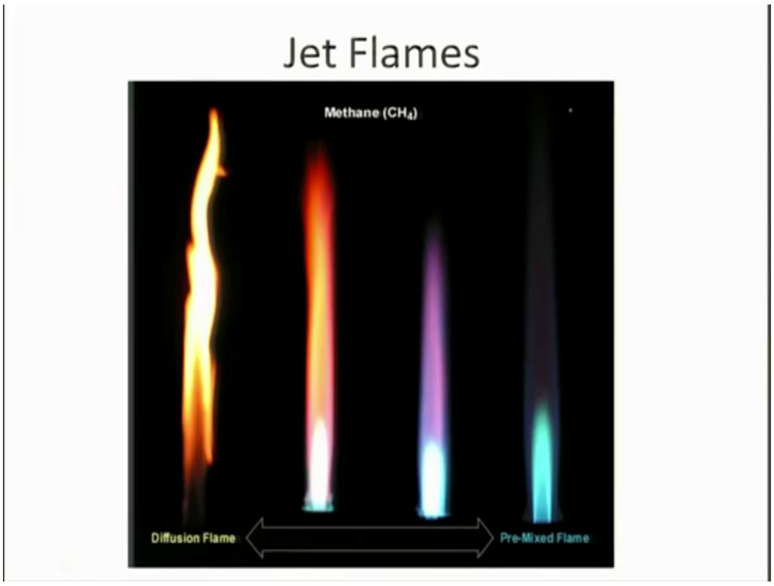

So, therefore, this is people use it and for various purposes. And so let us look at the jet diffusion flame and jet flames and here the fuel and oxidizer is basically mixed right. This is the fuel plus oxidizer right, oxidizer are mixed together and you will get a blue flame. When you oxidizer will be basically reducing you will be getting into that and then this is the diffusion flame mod. And in between this is the partially premix you can say right kind of things.

The color you know if you look at is a blue color and this is the purple color kind of things of course, some blue color is there and then of course, this is having yellow color some portion is a fully yellow it is jet diffusion flame. And which will be discussing about that jet diffusion flame.

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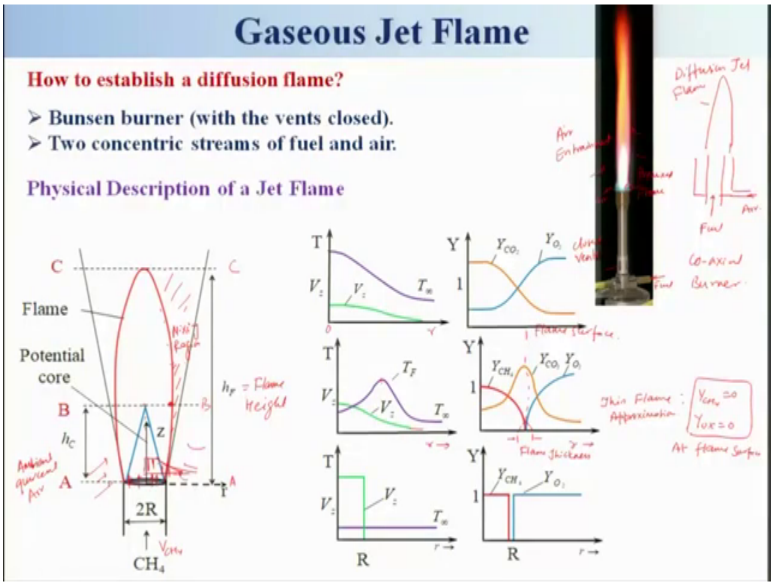

And question arises how to establish a diffusion flame or as jet diffusion flame? Rather because we will be talking about now gaseous jet diffusion flame.

How we can do which is a very simple one we have already seen the Bunsen burner right. And Bunsen burner if we can close the vent right, there is a vent here right which will be closing. If it will close what will happen? Only the fuel this is the fuel line right, which will passing it will be no air will be entering into this zone right these are the vents close vents right; that means, no air will be entering into this.

So, only the fuel will be there and you will be getting a jet flame which is a very simple one to get. And keep in mind that all though this is a diffusion flame this portion is basically premixed flame. You will see I mean like a you can observe that there is a little bit pre mixing will be there because of ambient air right you know, this is the air ambient air which will be moving into that fuel will be mixed.

So, that will be premixed flame rest of the thing even and besides these you can also have a two concentric tube. One is let us say this is your fuel and there is a another tube which I can into air right and I can have a flame.

This is basically diffusion flame jet flame. And this is known as coaxial, coaxial burner in the case of single tube or the jet burner generally, what happened air is not being controlled you do not have a controlled over the air. Because, the jet fuel jet which will be issued from this tube will be dictating how much air entrainment will be taking because, the air will be entering into this zone right this is air entrainment.

And that will be decided by the jet velocity whereas, here it is not only the jet velocity of the fuel, but also the air can dictate the frame shape and size right the this is known as coaxial burner. But two concentrate of course, there a several varieties one can thing of. And keep in mind that this gaseous jet flame is being very much use in furnace and other places.

And although it is a quite suity in nature right and it is very much essential particularly, whenever you are heating the metal in a furnace and other thing why it is so any idea? I need to produce more suit. If you look at a gas turbine applications or the IC engines or other things, where, the suit is a deadly thing; that means, suit that should be avoided.

But in case of a furnace and the where the metal heating and other things are to be carried out they are the suit is essential, why? Because I think you are not getting. Because the suite will help to enhance the heat transfer to the metal because, what do you need? The heat has to transfer to the metal quickly in case of a furnace or a processing furnace right, are you not getting? Because suit will be there so that it will radiate that.

And radiation is a you know is a very high the temperature power of the four it will go and whatever temperature it will be metal will see. And then it will be melted very easily or the whatever annealing process whatever the process is involved it can be carried out easily. That is a reason why the jet diffusion flame particularly suity jet diffusion flames are preferred. The physical description of a jet let us look at it and if you look at here, this is the fuel is a tube having two R as a diameter D.

And when this having certain velocity let us say V C H 4, this velocity right kind of things which is moving right. What will happen? Of course, depend on the weather you are using a tube, if it is a using a tube it should be long enough such that the fully developed flow is attain. Otherwise you can use a nozzle where uniform velocity profile will get it. Whatever it may be then what will happen? When it will give then you will see that if I say this is the centre line is the jet direction that is and the R is this thing.

And of course, I am not considered the effect or the azimuthal directions right it will be seen the same.

Now what will happen when the flow is taking place, then; it will be trying to entrance some air here right is not it? And why it will be entraining because, it is having momentum right this is having these are ambient air right, these are ambient quiescent air right.

So, it is a almost steel layer. So, when it is moving at certain velocities it will be having certain momentum. And this momentum will be a utilize to entrance some amount of air to this flow. It is like similar to your leader right in a country or in your institute who will be driving the rest of the people with his own ideas not through the power right.

So, this is having momentum to drive. So, that and keep in mind that when it is doing you will find, that interestingly you will find that this velocity will be not changing although there is entrainment in this region that is a potential core. That means, if I will look at the centre line, till that point the velocity will be remaining same. Let us say if it at the inlet it is 10 meter per second we just for the example.

Then that 10 meter per second will be remaining along with this direction till these kind of things into the blue color whatever I have shown in potential. That means, potential zone or the core zone is not affected by the entrainment that is not affected by the entrainment.

But, however, once it potential I will the velocity profile will be changing right I mean of course, here if you look at if i draw a velocity profile here. So, it will be remain same and then after that will be reducing right. This is the velocity profile what I am drawing right. It will be reducing I mean it will go I will just show you in maybe velocity profile that is better. So, let us say this is the velocity profile uniform profile when R is particular of course, the T is infinity. And you can consider and this is the considering the A A cross section I am talking about.

Then what will happen to the methane, methane will be one I am like in mass fraction will be one because, only methane in this region am I right. So, whereas, the oxidizer will be in this region right of course, these have it could have been the same location I have given some gaps has to make it difference otherwise it will be same right.

Now this region between the flame, this is the flame this is known as mixing region mixing region. What is that? These are the mixing region right, mixing region which will be taking place. And if I will now, look at this velocity profile, temperature profile, mass fraction profile, B B I will get like this. That means, this one if you look at this is the maximum velocity whatever it will be having right and it will be decreasing.

And temperature of course, it is here temperature here is a smaller one and then peak at this point, this point will be peak along with R keep in mind that this is R direction right. And similarly what will happen? The mass fraction of methane will be 1 at the centre line at R is equal to 0. And it will be becomes 0 at flame surface and this is your flame surface. And similarly oxidizer will be 0 and oxidize will be some finite value far away from the flame surface right.

And this kind of flame where the both the oxidizer mass fraction and the fuel mass fraction is 0 we call it as a thin flame approximation this is basically thin flame. We will occur only when YCH 4 will be 0, Y oxidizer will be 0 at flame surface; this will be occurring at flame surface.

But is it really possible? Actually in reality it is not right. So, therefore, will be some kind of a oxidize you know fuel which will be coming over here there will be some cross over here. And this will be having null set in finite and this is your flame thickness right. Flame thickness I have exaggerated it will be order of mm may be half mm one mm kind of it is not be that big whatever I have shown here right. Are you getting? But however, we will be looking at this thin flame approximation. Now; let us look at the a all this profiles at this location CC you will get that VZ has been changed VZ is being reduced from here to there as it going of course, there will be two effect will be there. One is the buoyancy effect because this is the hot; however, a because of mixing it will be reduced peak temperature will be occurring at the centre R is equal to 0 this is 0 right.

And after that it reduce that is the peak temperature whatever you will be getting at the centre. Whereas, the here the temperature is occurring at this point and this point all this point will be peak temperature, because at the flame surface temperature will be peak. Similarly, you will get that this is oxidizer is here and there is no fuel is being burnt out and oxidizer of course, will be something getting into that and of course, the carbon dioxide will be maximum here.

And then it will be minimum as it goes towards that this is flame is located here. So, therefore, carbon dioxide of the product will be the maximum here. And keep in mind that if I want to say that the what is the flame height which I have told this is basically flame height.

And this h F how we will have to define that is the one question might be coming into my mind and this h F plays a very important role; because of fact that it is one of the properties that govern the characteristics of a jet diffusion plane. It is similar to that a laminar burning velocity in case of premix flame. We have seen that laminar burning velocity is coming in all other places like your blow of and then your quenching distance, your flame thickness a minimum, ignition everywhere you know laminar burning velocity is coming into picture.

Similarly, the flame length or flame height or the flame length whatever we call like is very important for the jet diffusion flame. And we will be looking at this aspect in little detail and so, with this I will stopover. In the next lecture we will be basically discussing about how to derive a phenomenological analysis, how to derive a relationship for flame length using phenomenological analysis ok.

Thank you very much.