Fundamentals of Combustion (Part 2)
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Lecture – 41
Combustion Modes and Classification of Flames

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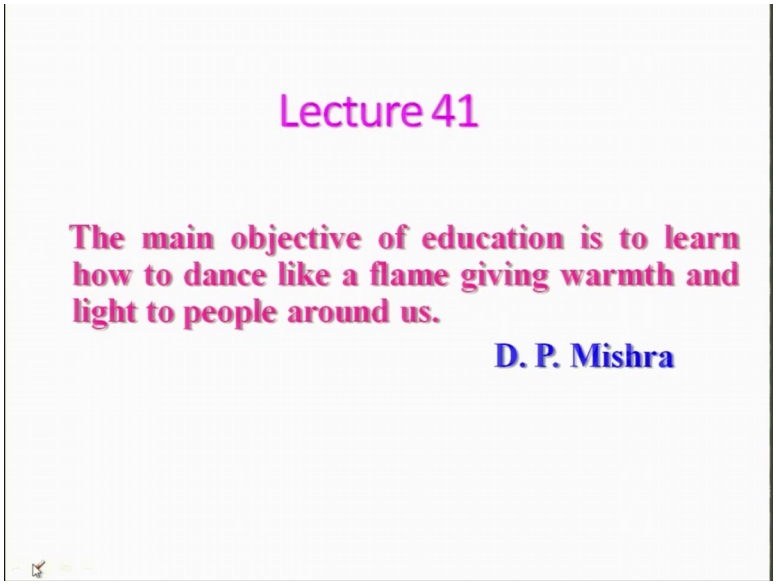

Let us start this lecture with a thought process; the main objective of education is to learn how to dance like a flame giving warmth and light to the people around us. In the last you know part of this course we learnt basically the fundamentals require to understand the combustion in details. And today onwards we will be looking at basically about the combustion. And if you look at the combustion is very important and also the part of the heat generation and utilization of fuel for various application, and the basis of the combustion is basically flame; that does not mean their own be any combustion where you know there would not be any flame, but mostly the combustion is based on the flame.

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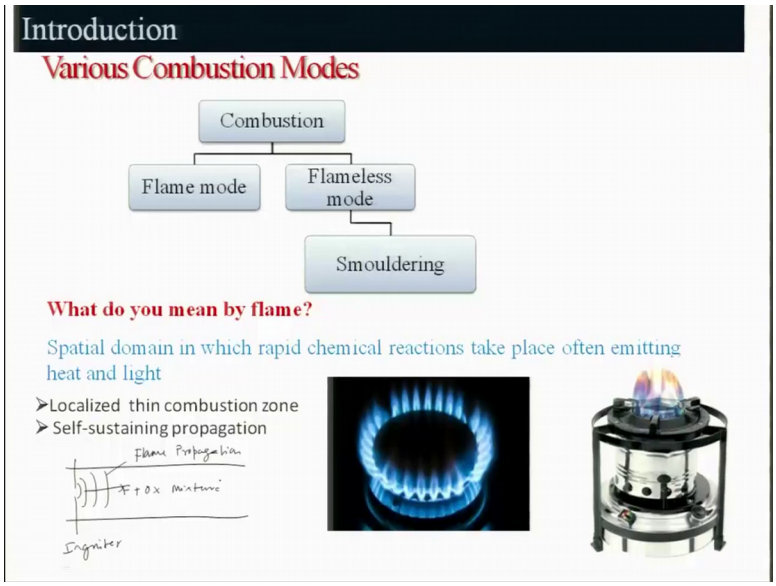

If you recall we had discuss about various modes of combustion. The combustion can be broadly divided into two categories one is flame mode other is flameless mode. And if you look at flameless combustion you know like is basically not very much their, but you can see as a you know example like in other words what are the examples of flameless mode of combustion or what we call smoldering combustion any idea?

Basically cigarette smoking or you can say in sense like a burning in the during the pooja we do, it will be just smoldering the of the you know biomass which will be used for that and even saw dust combustion as I thing. Beside this in recent time there is a man made flameless combustion also like where combustion will be occurring in a very broader zone or a wider zone, wider region then as compared to the flame which will be occurring at a small or a very thin zone right.

So, a question arises what do you mean by flame? You might have absorb the flame in like in your LPG burner which have shown here right and; that means, you could see the flame by its colour right. In this case colour happens to be blue, but in some class it will be yellow, some case it will be combination of both right and there is another let us look at example where you know this is the flame which is consist of blue yellow and purple colour right you can see and this is a flame, which you might not are the same because it is not being use very much for cooking food, but when you I was a kid like we had use

this one or we use to use this kind of stove, this is the weak flame right using kerosene as a fuel.

And if you see that means, as this is being use you know for heating purposes for cooking purposes, then it will be giving heat; that means, flame can be defined as a special domain because a occurs in certain domain right in region, in which some kind of chemical reaction will be taking place giving rise to what heat and light right.

So, we can define then a flame as a special domain in which a rapid chemical reactions take place often emitting light and heat right. Keep in mind there might be some flame which may not emit light for example, hydrogen oxygen flame. It would not really give any light right unless that is a impurities in the hydrogen or in the oxygen.

And if you look at generally the flame will be propagating right, but in these example what I have shown in LPG stove and then this kerosene stove which have shown here in this flame is being stabilize do not propagating and the combustion as I told it occurs in a what you call localize zone. So, therefore, it can be consider as a localize thin combustion zone; that means, the flame can be consider as the localize thin combustion zone, in which the combustion process will be self sustained or in other words if it is propagating flame right, then it will be self sustaining propagation right.

For example, if I say that if that is a thieve which contains fuel plus oxidizer mixture if I ignite it this is a igniter right. Igniter means you are giving certain amount of energy of heat or a spark such that you know it will be giving you some kind of heat initial it and then flame will kernel ignition kernel will be formed and then it may spread to the mixtures fuel air mixture.

It may move we certain velocity right and that is known as a propagation flame. This is a flame which is basically propagating right this known as flame propagation; right flame will be moving at a certain velocity right. And these we call it as also a combustion wave because it is having certain motion, but in case of any application particularly stove or the combustor we try to stabilize the flame otherwise we cannot use it or it will be little dangerous to have that, but however, flame propagation to occur in mixture all right. Now let us look at the how to classify a flame.

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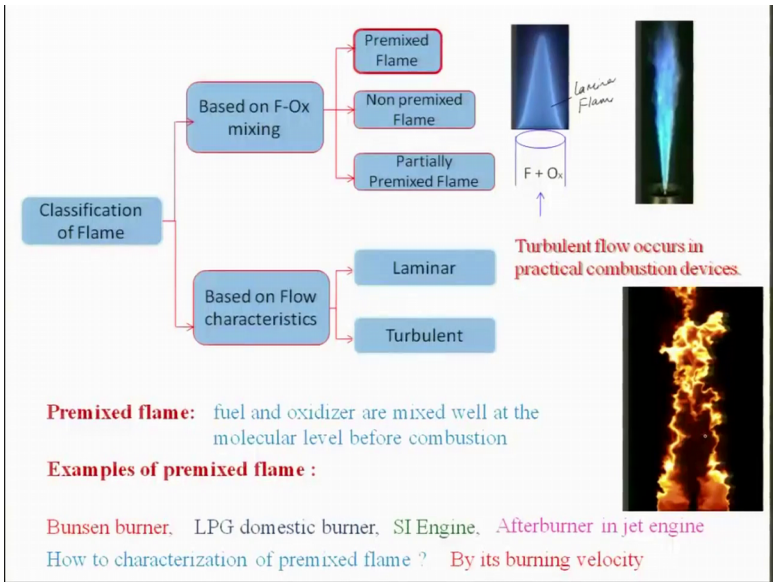

The flame can be you know classified on various basis one is the extent of mixing right the extent of mixing of fuel and oxidizer we can classify, and we can also classify based on what you call the physical state like whether it is a gaseous fuel flame or a liquid flame right or a solid fuel flame kind of things we can do that.

So, based on fuel oxidizer mixing, we can you know divide the flame in to three categories one is premixed flame other is non premixed flame and the third one is partially premixed flame right and based on the flow characteristics we will be also basically dividing the flame like laminar flame and turbulent flame.

So, what do you mean by this premixed flame? You know that found the name itself when the fuel and oxidizer are premixed before the combustion takes place, we call it as a premixed flame and this fuel and oxidizer basically mixed well at molecular level. The example see you might be knowing the Bunsen flame and it is the Bunsen who made this premix flame in to a just an see in this world otherwise most of the flames are you know nature are basically the diffusion flame ok.

But the man made flame is basically premix flame in other words the premix flame is a man made and it is having also the good properties and it is having certain also bad properties, let us look at the fuel and oxidizer when mixed and ignited from a thieve as shown here you will get flame like that, which is looks to be having a conical set right and this is your flame zone you can say and that is a also the dark zone kind of thing,

which will be discussed in little later on and keep in mind that this is the premix flame. And this premix flame will be very useful particular in modern times due to the you know like a concern for the environment.

So, what are the examples of premixed flame any idea? You know I already shown you LPG stove burner right that is nothing, but a premix flame right you might be wandering like I am just giving you giving the fuel I am not giving air. Are you giving whenever you are switching on the LPG line to initiate the you know or to ignite the flame in a burner do you supply any air? No, but from where does the air comes and how does the premixing occurs in a Bunsen burner in a LPG stove is the question which you need to explore.

So, the Bunsen burner of course, I have told he is the first person to design this burner and stabilize the flame and LPG domestic burner not only LPG even CNG are any other you know kind of a gas you can use and the spark ignition engines, which you we call it you know basically auto engine as such auto cycle engine in that case the fuel and oxidizer are oxidizer means air are mixed in a carburetor right and then it is being fed in to engine and the flame, which is garneted inside the piston cylinder inside the cylinder is basically premixed the nature.

Beside these after burner in jet engine is nothing, but a your basically premix flame and these are all if you look at after burner in case of a after burner what we use the as a fuel is basically liquid fuel are the ATF aviation turbine fuel we use which is nothing, but a modified kerosene. And, but in case of SI engine what we use gasoline? Gasoline will be in which form will it be in the liquid form or a gaseous form?

It will be in basically liquid form to start with after that it will be evaporated and then it is being mixed properly before it fed in to in to the cylinder of the engine it is basically gaseous form the therefore, it is a gaseous mixed. And LPG domestic burner nothing, but your what you call gaseous fuel and these are premix. But is there any example which where the you know fuel and oxidizer will mixed in the solid form any idea we do use it for not for.

Student: (Refer Time: 13:13).

Ah rocket engines what you call that.

Student: Propellant.

Propellant is fine, but what kind of propellant?

Student: (Refer Time: 13:24).

What kind of propellant? Double base propellant we use right.

Student: Key band (Refer Time: 13:35).

Ah.

Student: Key band or s band.

S band what?

Student: Polybutadiene (Refer Time: 13:43).

Polybutadiene no.

Student: Hydrogen.

Not hydrogen a liquid fuel those are not we are talking about liquid right hydrogen is liquid not solid you are talking was CT BT.

Student: (Refer Time: 13:57).

The cyclo terminated polybutadiene right that is not the case it is basically the double base propellant which is being used and that is example of a solid premix you know kind of propellant, where claim would be you know premix in nature and,

So, how to characterize a basically premixed flame, because we need to understand whether it is a good or it is a bad or a how it is you know how will approve characterize? We will be using a you know a parameter known as burning velocity right which will be discussing further because the velocity with which the combustion wave will be moving with respect to the unburnt mixtures is known as the burning velocity which will be discussing about little later on. Now let us look at based on flow characteristics as I told the it can be laminar, it can be turbulent, it can be also transition in between laminar and turbulent right.

So, if these flame is basically if you look at its laminar flame, you can see it is looks to a very smooth and then we have already discuss about the nature or the you know laminar and the turbulent flow. And if you and then this is a burner which is shows that it is like a turbulent, which is having a some structure and it is having a flame let us which will be over lapping each other right in this case turbulent. And this is another turbulent flame which is having very nice structure looks to a very artistic in nature and this we have seen already this is basically a (Refer Time: 15:56) body stabilized flame diffusion flame right and why you know turbulent flame is important because it will be giving you higher heat release rate.

So, therefore, turbulent flame are being use very much in practical combustion devises. And keep in mind that in this course being the first label we will be mostly discussing about the laminar flames, but however, I will be trying to give a flavor of the turbulent flame as way right.

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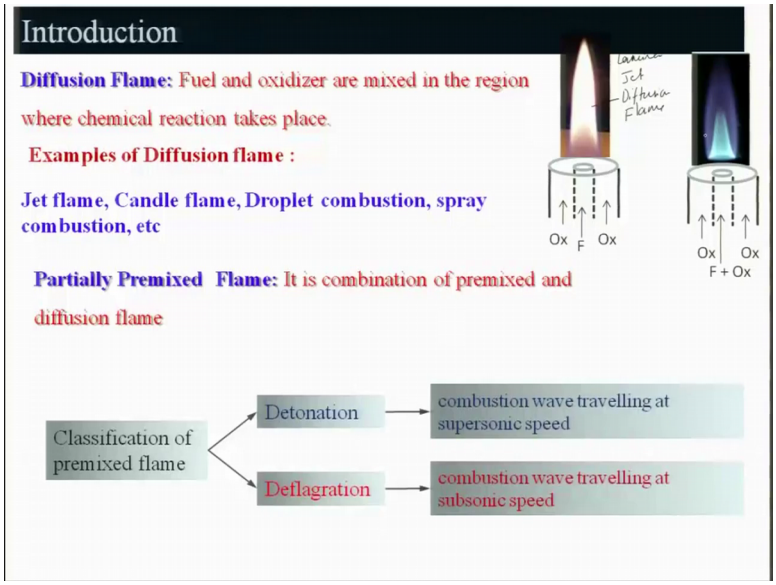

Now, the diffusion in case of diffusion flame the fuel and oxidizer are mixed in the region, where the chemical reaction takes place right. In other words fuel and oxidizer are mixed on the surface of the flame itself right. As I told earlier it is like your marriage I had related that you know fuel and oxidizer basically you can consider one is male and female like you know, and then the marriage will be occurring; that means, you know

arrange marriage right; that means, you will be trying to understand each other while you know experience going on or interaction going on.

So, where as the premix flame you mix together before and then you know you get marriage and which is inherently unstable premixed flame basically inherently unstabled in nature. And the examples are I have shown you that is basically fuel and oxidizer, both are not mixed their getting out from this concentratic tubes and then flame is farmed you get a diffusion flame right and keep in mind that this is diffusion jet diffusion flame, and keep in mind at this is laminar like I can say laminar jet diffusion flame.

And examples you might be knowing the jet flame this is nothing, but a jet flame, candle flame, droplet combustion right and which will be discussing, and spray combustion right and other places you will get and even the burning of your wood right is also example of all diffusion.

As I told earlier most of the diffusion flame will be you know most of the combustion takes place in nature are diffusion flame right and where as the premix flame is a man made and it is in nature, it does not occur as such. The partially premixed means it is the combination of premix and diffusion flame, let us look at an example of the jet flame here the oxidizer are there on the what you call concentrative tube outer jet and whereas, the inner jet is the fuel and oxidizer; that means, it is premix already right.

So, you will get a two flame structure kind of things and that gives rise to a you know combination of both premix and diffusion. In this case you can avoid the suite formation. The problem with the jet diffusion flame when it is operated on the diffusion flame mode is having a suit which is a great concern now this right and where as you can avoid the suit in premixing and so, also their a machine level. Now if you look at we will be now basically initiating a discussion on the premixed flame and premixed flame as I told it is nothing, but a combustion wave and this is can be classified in two categories one is deflagration other is detonation.

So, the detonation is combustion wave travelling at a supersonic speed right as I told the there will be the combustion wave, the flame will be moving certain velocity and that is nothing, but a combustion wave kind of things and that speed happens to be the supersonic speed and then we call it as a detonation. And deflagration is the basically a combustion wave travelling at a subsonic speed right it will be very low values; subsonic

means less than the velocity at which the combustion wave will be moving right will be less than the speed of sound. And what will be looking at now is basically the combustion wave and will be discussing about that.

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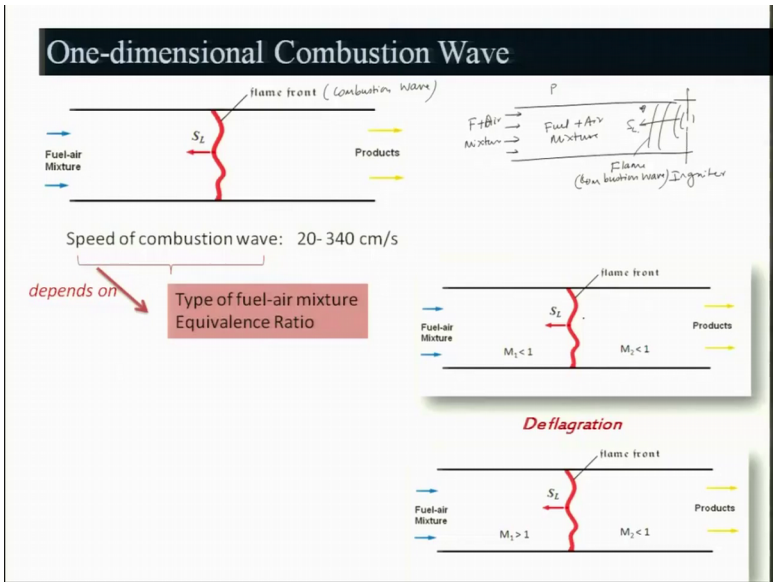

And we will be considering one dimensional combustion wave and as I told earlier let this fuel air mixture is their in the tube right. And as I told earlier if we ignite it what will happen? That means, the flame front will be moving towards the what? For example, if I take let us say this is a fuel air mixture air mixture filled in this tube, and I am trying to ignite it here let us see. Igniting means I am giving some kind of energy here and as I told there will be ignition kernel it will be spreading it will be moving towards here why because fuel and oxidizer. You will did not move toward this these also if there is a mixture it will move towards these also, but after that this will be only air so, it cannot really propagate.

But as it is you know fuel oxide fuel and air mixtures are their it will be moving right in certain velocities right. Now this is a propagating flame right I can call this as basically flame or a combustion wave, flame is nothing, but your combustion wave right and that is moving with certain velocity. Now I want to have a you know fixed what? A flame at a particular position what allowed to do? This is the fuel and air mixture is stationary in nature right.

Now I want the flame should be like this here somewhere located what I will have to do? I will have to supply the fuel air mixture with a certain velocity. If I give supply this fuel air mixture right fuel plus air mixture will certain velocity then in such that which will be same as that of the burning velocity right then I will or you can say this is instead of this I will say this is burning velocity, then the flame will be remaining stationary in the front are you getting?

So, therefore, this fuel air mixture will be supplied same velocity as that of the what you call burning velocity otherwise what will happened? It would not remain at a particular position, it will move depending on the mixture velocity. In mixture velocity is higher than the burning velocity flame will move from left to right. If it is lower then flame will move from right to left in the tube right.

So, that you should keep in mind and this is we call it as basically a combustion wave and this is flame front I can say it is a basically combustion wave, which will be having certain velocity and we call this SL as also the flames speed right which will be using later on flame speed. And this will be always moving towards the, what unburnt fuel air mixture is not it? The direction is always toward that of course, regarding this is very much you know talked about in our basic literature towards what the [FL] will move you know that way.

Now, the speed of combustion wave will be basically order of something 20 to 340 centimeter per second right of course, this is form depending on whether the fuel air or fuel oxidizer. If oxidizer is there then burning velocity or the combustion wave speed will be higher right. And that depends on the type of fuel mixture if it is methane air it will be different, if it is carbon monoxide air it will be different and if it will be what you call the hydrogen air or hydrogen oxygen it will be different.

Hydrogen air will be lower velocity as compared to the hydrogen oxygen mixture and that depends on also the ratio equivalence ratio, fuel air ratio whatever it is it will be depend on that. We will be discussing more about it, but now this if it is the speed of the combustion wave will be subsonic, then we call it as a deflagration right. If it is the speed of this combustion wave speed is greater than the sonic speed, we call it as a detonation.

Keep in mind that this will be discussing further and keep right and we will be you need to analyze this thing in the next lecture, we will be discussing how to analyze this

combustion wave considering is to be one dimensional wave kind of things right and I will stop over here, and we will look at this thing in the next lecture.

Thank you very much.