Fundamentals of Combustion (Part 2)
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Lecture – 56
Ignition in Premixed Flames

Let us start this lecture with a thought process.

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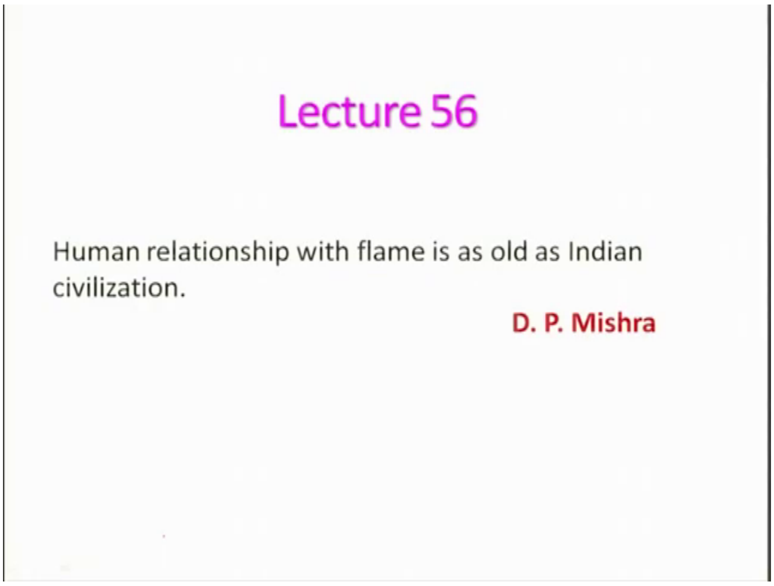

That human relationship with flame is as old as Indian civilization. And Indian civilization is the most oldest or the oldest civilization of the entire world has recently been talked about. So, in the last lecture if you recall that we basically that the flammability limits. Then we moved into the flame stability we discuss about various regimes of lifted flame, and then blow off, and the flashback and stable flame.

And also there will be some oscillation oscillating flames right we talked about. And we also derived a expression that that is basically the velocity gradient at the rim right, which will be dictating particularly for the Bunsen flame, whether the flame will be stable unstable or blow off will be occurring or not right. And today we will be discussing about a very important one that about ignition.

Question arises what do you mean by ignition? Ignition is basically a process by which the combustion is initiated; that means, how we can do that we basically have to provide some external energy. And that should be sufficient such that not only initiate the combustion, but it must also such that the energy released by the combustion should be much higher than the heat loss, such that flame can be self-propagated.

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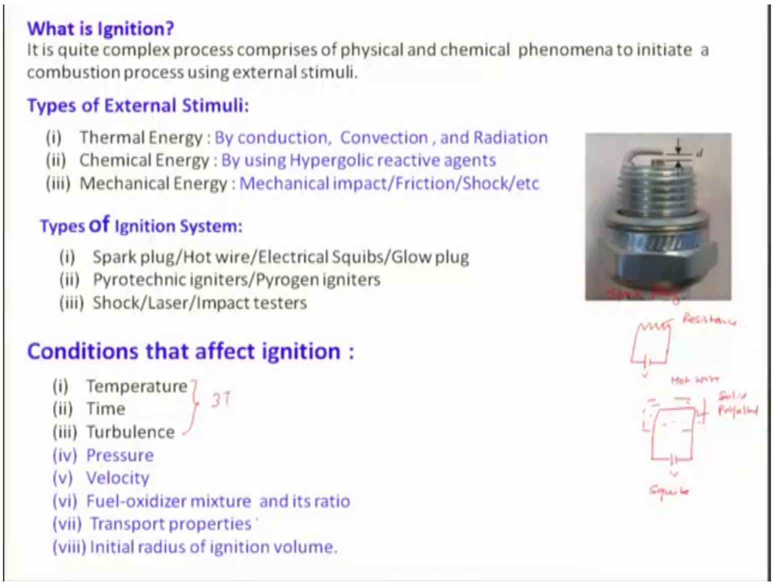

So, if you look at the ignition is a quite complex process comprises of basically physical and chemical phenomena. Like means there will be mixing will which will be occurring. And also there will be the kinetics of the chemical kinetics, the chemical reaction will be taking place to initiate a combustion process using external stimuli.

Stimuli means basically you can think of giving some energy right. A question might be arises what are the kinds of stimuli, generally we give to initiate combustion, any idea? That means it is a form of energy right, energy as you know it is basically various form right. It can be as the name suggests the chemical energy, it can be thermal energy, and it can be mechanical energy. When you talk about the thermal energy is basically can be transferred with the help of 3 modes; one is heat conduction, convection and radiation.

It can be combination any one of 3 or all of them right. In principle basically in practical systems all 3 of them would be there as a heat loss. And also heat gain like; that means you will have to give some heat through this medium by this method or transfer the heat rather by this method. And there is a another way of giving this external stimuli is the chemical energy by using hypergolic reactive agents right.

I can give some kind of a spaces or a very mobile radicals and give that so that reaction can happen. And there is a another way of which is being used is the mechanical energy, that is mechanical impact. I can give some impact you know like kind of things and or the friction or the soft waves. So, that some heat can be generated, you might be wondering; what is this why this impact comes into picture.

You might be knowing like particularly some kind of a you know explosion when you have they give some impact to occur, you know you might have seen in movies or some other places right. And shock of course, is also being given because if you give an impact it may lead to a shock and then you can do that also right and friction is very rarely used. So now, how we can use these basic principles to device igniter is the question right. So, what are the kinds of igniters you are aware, any idea? Which all of you know.

Student: matchstick.

Matchstick is; you can say that you are giving basically some kind of chemical energy right, along with thermal both thermal and chemically will be right and what else?

Student: (Refer Time: 05:27)

Student: Piezoelectric.

Piezoelectric.

Student: And lighter.

Lighter basically it will be generating a spark right. And in your like in your LPG, stove other thing we do use, any other thing? In your icing in you know like you must be aware in your motorcycle or the moped right; you use or in a car you sparkplug right is not it and types of igniter if you look at it can be varieties, but some of them I have just jotted down. First one is the spark plug which is very commonly used in the for initiating combustion LPG stoves or any gaseous fuel stops or a spark ignition engine even your gas turbine engines and other places and furnaces you will use. I have shown you a typical spark plug right this is the spark plug.

And if you look at this is a one electrode, cathode and anode and this is subjected to a very high voltage. And this voltage will be order of something 10000 to 20000 volts and there is a gap it is not connected right.

This electrode and that gap creates a breaking down of these gases which will be there here in this between having certain (Refer Time: 07:09) with that is the d right. And this is very critical and this when the voltage is applied across this very high voltage, that will be broken down like very iron and then space is high spay you know velocity space is which will be moving at a faster rate and then trying to bombard with the other mixtures. And then, it will be some reaction will be taking place releasing certain amount of heat energy and the by that the combustion initiated.

And of course, there is a hardware right, if you look at if I take a resistance and connect to some kind of a voltage source right, this is nothing but a hardware. And electrical squibs are being used right not in generally, but in rocket engines, where you know there will be a propellant right. This is the electrical squeal and this is the basically where this will be propellants will be there. Propellant means solid propellant generally people use it. And you will have to give a source as a voltage and this is a squib. And keep in mind that these wire are coated with a some very high reactive propellants laid as I it is another things right.

So, that that will be you know some heat will be passing through this because this is having some resistance. And then those things will be reacting to start with and then it will go to the propellants and then you will ignite. And that is basically known as a pyro technic igniters it is a pyrotechnic igniters used in a solid propellant.

And the Pyrogen igniters is the nothing but a small or rocket engines, which will be giving you hot products to that like a to the bigger rocket motors, and that is pyrogen igniters. Beside this there is a glow plug which is similar to the spark plug, but the thing is that it will be not in this surface it will be a bigger one. And then there will be a flame will be there bigger flame will be there glow plug, which is used in your basically piston engines in whenever it is used for the aircraft applications right.

And beside this in recent times people are talking about lasers and other things which is as a source and we had done some work on this laser ignition. And as I told earlier one can use also shock; producing a shocked impact testers for basically initiating the explosion react explosive reactions kind of things.

But what we will be discussing in this lecture basically the spark plug and then how to analyze that will be doing. Now we will have to look at what are the conditions that affect the ignitions, or in other words what are the variables that affect the ignition. And, whenever you talk about that, people talk about basically 3 important things for the initiation of ignition. And also the other things will be affecting the minimum ignition energy that is required for initiating the combustion.

And what are those that as the name indicates so like basically temperature time and turbulence because the temperature is very important; that means, when you give certain amount of energy to initiate the combustion. You will have to raise it is mix temperature to certain higher level beyond the self-ignition temperature.

Then only it will be self-sustaining otherwise you know right it will not really ignite. So, and the duration of the heat or the energy what will be giving for initiating combustion important. Even in your numerical calculations you know; like you will have to also give certain amount of energy to initiate right. If you give less amount the naturally it will not really initiate the combustion time is important and if there is a turbulence, then what will happen the heat will be dissipated out right. So, very quickly so, therefore, you will have to give certain more amount of energy yeah you know whenever the flow is turbulent.

So, this is generally known as popularly is 3 T right? T you know starting with the temperature later T so temperature time enter. Beside this the pressure will be affecting the ignition energy and so also the velocity right, because the flow in a certain a practical application the flow will be not stationary. It will be not a questioned atmosphere, it will be moving so the velocity. And also the ignition will be affected by the fuel, type of fuel oxidizer mixture for example, methane here right. If you will have to give certain amount of energy, but if you move to the hydrogen air for the same equivalence ratio you will have to give the smaller amount of energy because hydrogen air is more reactive.

And beside these the transport properties which will be plays a important like thermal diffusivity, and then mass diffusivity those things will be. And there will be some minimum ignition radius through which you will have to give the amount of energy in to initiate the combustion.

Suppose the, it is a too small then what will happen? It will be less than the quenching diameter what will happen? Naturally it will be quench at all the heat will be lost instead of initiating the combustion. So, therefore, this is the initial radius or minimum radius of the ignition volume plays a very important role.

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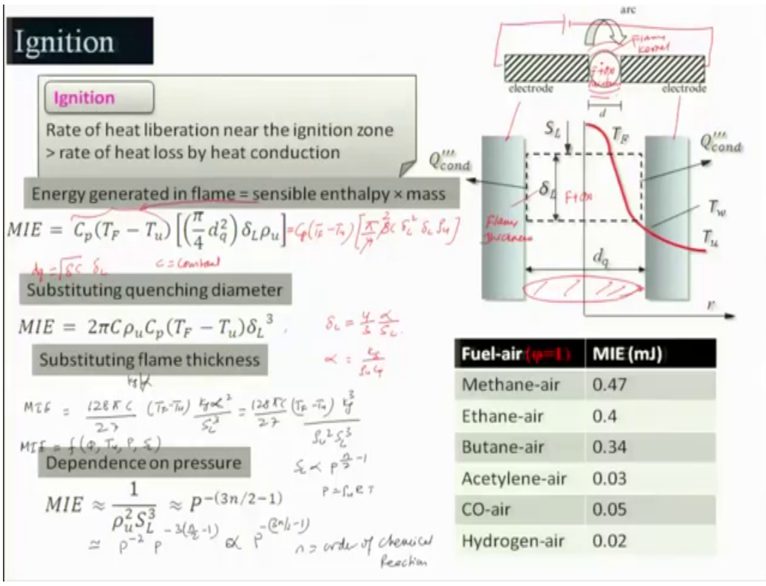

So, ignition if you look at this is I have shown you a spark plug and the you know electrode is there you can connect these thing to a very high voltage source right. And then when it will there having certain diameter and this would be the critical diameter. Generally, it will be much higher rather it will be higher than the, what you call quenching diameter. And then what will happen?

Then there will be a arc which will be produced because the voltage there I will breaking down of the mixtures which will be their fuel and oxidizer mixture right. And then this will be the ions will be produced and then there will be some spaces which will be moving at a higher velocities. And it will move around and bombarded with the fuel oxidizer mixture and then flame kernel may be formed right.

If I say this is ignites there will be a flame kernel right flame kernel right initiation then it will be going through that and then you know after that flame will be self-sustained. So, this is the ignition what the spark we will talk about. It so therefore, when you say this thing; that means, the rate of heat liberated near the ignition zone must be greater than the heat loss by the heat conduction, and convection, and radiation to just now the analysis what we are going to do we are only considering heat conduction due to the presence of electrode.

But in real situation there will be radiations there will be convection that we are not considering. So now, when you do that what we are considering is basically let us say this is the electrode right. These are the electrodes and then the flame is inside this in between electrode. And keep in mind that this is the minimum diameter what you are talking about is quenching diameter. Because it should be greater than that, but let us say we are interested to evaluate the minimum ignition energy therefore, we are taking the quenching diameter.

But in some book people do calculate this what is the critical diameter, but I have assumed it as a quenching diam. And having a flame thickness del L of course, we are considering this laminar. And this will be moving with certain flame laminar burning velocity SL right. And this mixture this is the fuel plus oxidizer mixture right? In these volume right and this is the circular in nature right.

So, if you look at this is a circular in nature cross section, and there will be some heat conduction here, and there is the unbound temperature this is the flame temperature; that means, the mixture has to raise to the flame temperature right. This is the amount of energy minimum amount of energy what will have to give.

So, we can say that energy generated in the flame with this volume right is equal to sensible enthalpy into mass right so; that means, the minimum ignition energy is nothing but your sensible enthalpy; so this is your sensible enthalpy. And this is your mass which is consider pi by 4 dq square right into delta L into rho u. Rho u is the density of the unburned mixture right delta L is the flame thickness right, this is basically flame thickness.

Now, if you look at we have already seen that dq we can express in terms of in terms of flame thickness right flame thickness. So, that is nothing but your 8 C delta L right, we have already derived. Now what I will do? I will just put this thing here like Cp T F minus T u into pi by 4 in place of dq I will put 8 C delta L square right, and delta L will be there and rho u right.

So, this is nothing but your 2, so therefore, the becomes substituting this quenching diameter I will get 2 pi C is your constant right. Put values will be varying like you can say a constant right that is nothing but your delta L cube right. We know that delta L cube right I can express in terms of flame, laminar burning velocity right 4 by 3 alpha by SL right. So, if I will write it down here that is 2 pi C rho u Cp T F minus T u into l cube means it will be 4 by 64 by 27 alpha cube by SL cube. So, we know alpha is the basically k g by rho u Cp. So, in place of this right I can write down what kg, I can write down that I can write down kg by alpha right, can I not write down?

So, this we can cancel it out. So, I can get basically M I E is equal to 128 pi C by 27 TF minus Tu into kg alpha square by SL cube right. This is alpha square by SL cube, is it fine? The C is already there right; that means, what he says minimum ignition energy will be dependent on basically, what? This will be dependent on the fuel air ratio because TF will be dictated by the fuel air ratio right. And then it will be dependent on the burning velocity right SL.

And SL is a function of initial temperature, initial pressure right; that means, M I E is basically function of phi right, function of initial temperature right T u pressure and then it will be properties like kg and alpha all those things will be there.

So, and also it will be function of SL right. And keep in mind that these analysis what we have done is meant only for the quiescent atmosphere; that means, there is no flow, are you getting? How it this minimum ignition energy depends on the pressure?

So, if you look at this is basically alpha you know that kg by rho u cp. So, I can write down that 128 pi c by 27 TF minus T u. And this will be kg cube right by rho u square SL cube right. So, I can say that minimum ignition energy is basically rho u square SL cube. And we know that that SL is proportional to what p n by 2 minus 1 or it will be 2 it will be 1 right n by 2 that we have already seen.

So, that is nothing but your 3 n by 2 right minus 1. Am I right or wrong? Or let me just do it if we are not getting let us say this is basically p power 2 the rho u is nothing but your rho u is?

Student: p.

Basically p square right rho, p is equal to rho u R T. So, therefore, minus it will be 2. And p power to the this will be 3 n by 2 minus 1. So, that is nothing but your or is proportional other p is equal to minus 3 n by 2 minus 1 right. So, this will be minus right is coming. So, you will see that it will be basically depends on the pressure by this coefficient. And where n is the order of chemical reaction right.

So now, let us look at how does it basically depends on equivalence ratio and also type of well. And if you look at for the equivalence ratio 1 I have taken this data the minimum ignition energy is 0.47 millijoule it is a very small amount of energy right, are you getting? And ethane air is 0.4 and butane air little bit low 0.34. And if you look at acetylene air is 0.03 and hydrogen air even much lower 0.02 millijoules.

Why it is. so because; SL or the laminar burning velocity is very high in case of hydrogen air and the acetylene air and also CO air. That we have already seen in the data right. So, the and whereas, right so therefore, this is the in under the cohesion atmosphere and phi 1. If phi is low then what will happen if it is a lean let us say mixtures phi is equal to 0.6 or 0.7. So, what will happen to let us say methane air minimum ignites will it increase or decrease. It will definitely increase because the laminar burning velocity is getting lowered down with the change of the equivalence ratio, either towards the lean side or the reside right so, that we will be looking at it.

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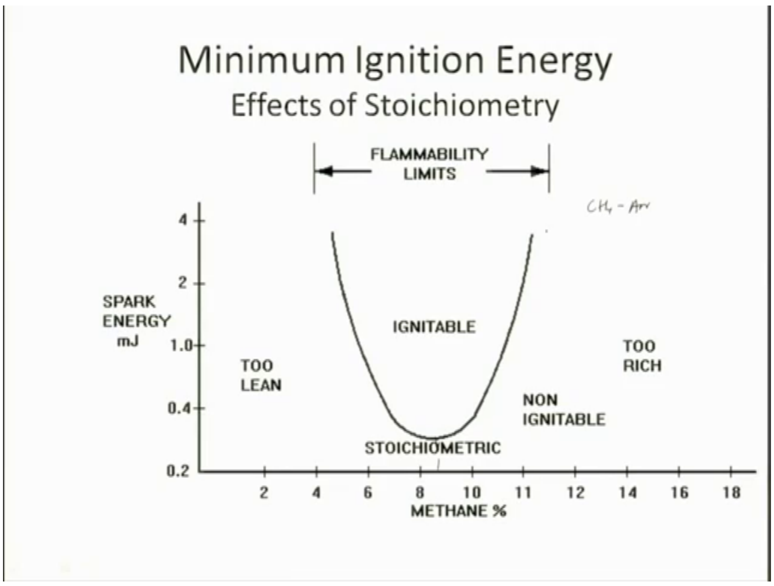

So, if you look at this is the you know data which I have shown spark ignition energy versus methane air percentage of methane air methane. And this is for methane air system C H 4 air flame.

You can see at stoichiometric, it is a minimum values and then it goes up both the lean side fuel lean and the recycle. And keep in mind that these mixtures right what you want to ignite must be within the flammability limit. Otherwise you cannot ignite. Whatever the amount of energy you may provide so, that, you should keep in mind.

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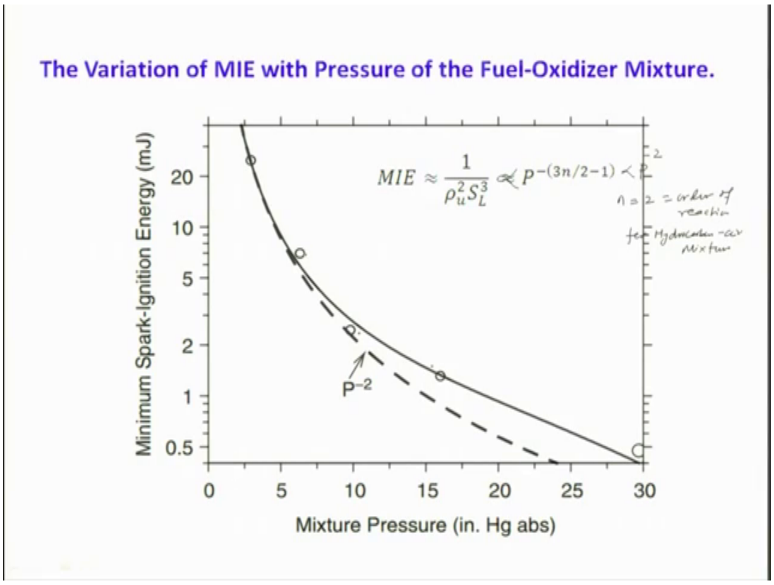

And let us see that variation of minimum energy ignition minimum ignition energy with pressure for fuel oxidizer, we have seen that the minimum ignition energy is proportional to power pressure basically, P power 3 n by 2 minus 1. If I take the order of reaction is something 2 right. This is your order of a reaction right for a hydrocarbon air mixtures if I take certain range right.

So, what you will see? You will see this is around, what? This will be 2 if I will say this is nothing but your proportional to P power t minus 2 right. We will see how it is you know there with this experimental data, these are experimental data's right. And this is the variation minimum spark in here by the P power 2. So, in the low pressure it is almost matching of course, high pressure it will be deviating, because as I told you earlier the order of reaction will be dependent on the pressure, I have shown you right.

So, therefore, you keep in mind that this is very important point because as the pressure decreases the ignition energy is increasing tremendously. You keep in mind that this is in you know log plot the values is very high. And that has to be taken care particularly for the aircraft engine when it is operated at high altitude; that means pressure. So, you will have to provide the more amount of energy right. So, with this I will stop over here, and we will see in the next lecture some of the aspect of the ignition energy in. And later on we will move to the turbulent premix plane.

Thank you.