Fundamentals of Combustion (Part 2)
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Lecture – 53
Effect of Inert Additives on Burning Velocity and Flame Extinction

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Let us start this lecture with a thought process. Creativity is like a spark that ignites the flame of innovation. In the last lecture, we are basically looked at the effect of the initial pressure and the initial temperature on the burning velocity. And we have seen that the pressure particularly for certain mixtures or certain range of fuel air system decreases the laminar burning velocity, but that is not true for all the range, and whereas the temperature enhances the burning velocity. And we have looked at semi empirical relationship to basically solve a problem and also how we can handle the semi empirical relationship taking care of the effect of inlet temperature and pressure, and also the dilution effect was embedded in that semi empirical relationship.

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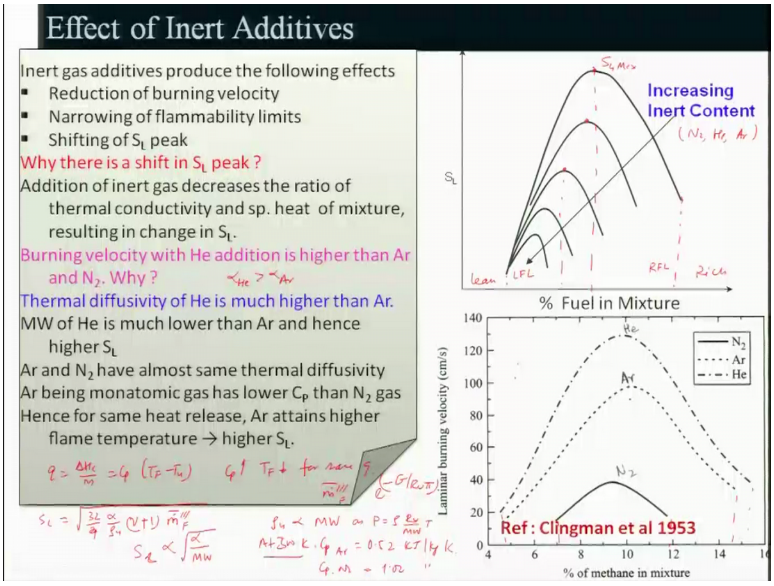

Today, we will be looking at the Effect of Inert Additives or the dilution you can say on the Laminar Burning Velocity. And here I have plotted the laminar burning velocity purchase the percentage of fuel in mixtures. If you look at this arrow, indicates with the increasing of the inert content. Inert content means it will be any gas, which will be act like a for example, nitrogen, helium, argons. So, I can look at that inner gas, this is maybe nitrogen, helium, argon or any other gasses the kind of thing. If you look at inert, then what is happening this laminar burning velocity let us say this inert is zero, like this is the thing. This is having a very high peak temperature here, and sorry peak laminar burning velocity here, and it reduces to the rich this is rich side right, this is the lean side mixtures, and it of course, decreases both the lean and rich side.

But, when you increase these inert content, what you find that there is a reduction in the burning velocity, because the burning velocity as decrease right. And beside these if you look at let us say this is the peak value here, and when you go for you know inert addition, then you know what will happened, it will be here. Then when it will be peak values of the burning velocity it changing, because let us say this is at this fuel air, you know ratio mixture ratio, and whereas here, it is here. So, this is changing that means, it is going towards more linear side that is the one observation you can make and another important things which will be discussing later on.

This is basically known as the flammability limit like this is known as RFL, Rich Flammability Limit. And this you can say basically this is lean flammability limit right. And this is being narrow down like see within these range, the flame having certain fine and burning velocity that means, it is flammable, but beyond these, it is not flammable right, it was the meaning that means, the flammability limit being narrow down.

And as I told there is a shifting of peak S L S L maximum right. So, this is being shifted toward the lean side. And why there is a shift in laminar burning velocity peak? Because, what happened with the addition of inert gases, the ratio of thermal conductivity and specific heat of the mixture, resulting in change in burning velocity. So, we have seen that conductivity plays a very important role and so also the specific heat. And specific heat if you look at if it is being enhance, then what will happened, the basically the temperature will be decrease for the same heat release rate right. So, if the temperature will decrease naturally, the reaction rate will be deceasing. And if decreases the burning velocity, will decrease right, and similarly the thermal conductivity.

So, let us look at three diluents, we are going for methane air mixtures right; one is nitrogen, other is argon, other is helium right. So, different of course, here what we are doing in the upper one, it is same diluent, let us say if I take nitrogen, it will be one nitrogen I am goes on increasing. But, here what is being done, the percentage will be same, but the diluent will be different, in this case nitrogen, argon, helium.

So, if you can look at that the observation that burning velocity with the helium addition is much higher than the argon and the burning velocity for the argon is also much higher than the nitrogen that is the observation you can make. And of course, there is a broadening of the flammability limit particularly for helium like if I consider this with the flammability limit right, and that means, when you go from helium to nitrogen, generally it narrows down the range of the flammability limit, that is another thing.

So, question arises why it is so because what is happening, the thermal diffusivity of helium right is much larger than the argon right. We have already seen this thing like S L is basically root over 32 by 2 32 by 9 alpha, this is your thermal divided by the rho nu plus 1 F, this is we have already seen this formula right. So, this is higher right. And beside this what you can see that rho u is basically inversely proportional to molecular weight is not it, rho u is a proportional sorry rho u is proportionality molecular weight by the gas ideal gas law right. As P is equal to rho R u by M W T right, so, rho is proportional to molecular.

So, therefore, S L if you look at S L is proportional to alpha right and molecular weight right. And of course, this will be root right, root will be there. So, if you look at that way, that molecular weight of the helium is much lower. If it is lower, then therefore there will be increase in the laminar burning velocity as compared to the argon. And similarly, the thermal diffusivity is the higher, so therefore also it will be having effect.

Ah But, when you look at then argon and nitrogen, you will find that it is have almost same thermal diffusivity that means, it is not really changing by that. Of course, if you look at the argon will be having higher molecular weight, as compared to the nitrogen right, is not it.

So, but here what is happening the C p the argon being a monatomic gas, the C p value will be very low right. For example, if I take at 300 Kelvin C p of argon will be something 0.52 kilo joule per k g Kelvin and C p of nitrogen will be 1.02 kilo joule per Kelvin right at 300 Kelvin. But, of course, the argon being monatomic gas, it would not be really changing much with the temperature. But, however nitrogen it will be changing with temperature, it will be increasing with the when the temperature increases.

So, therefore, what will happened the C p of nitrogen being higher, then what will happened to the temperature the burning the flame temperature. If you look at the C p basically if you look at the q, q is equal to delta H c by m is nothing but your C p by T F minus T u. For the same heat, what happen, the C p is higher. So, what will happened with the same heat release at the same heat release per unit mass right what will happened, the C p will be higher that means, the T F if C p is increases, then T F will reduce for the same q right. So, therefore, the temperature will be in case of nitrogen, when you add will be decreasing. And this is having much higher effect. Why, because it is e power to the reaction rate goes F e power to the R U T. So, therefore, these will be affecting much the reaction rate. As a result, that burning velocity will be reduce drastically right. This is the argument, what I am trying to given.

So, therefore, argon attains higher flame temperature as compared to the nitrogen. So, therefore, the burning velocity will be much higher right. So, this argument one can look at it by explaining the experimental data or the observation what we got. And this is the effect of inert additives and depending on that, you can utilize it, for your application.

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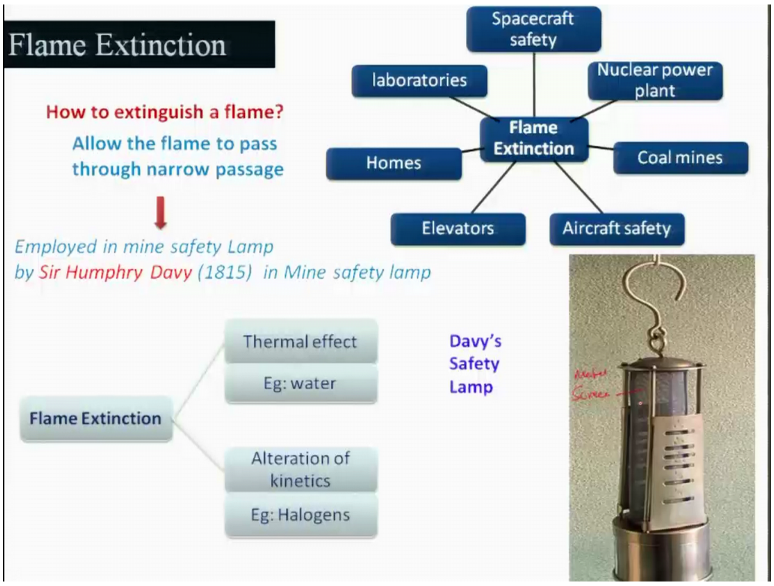

Now, we will be looking at basically the flame extinction. And question arises, what do you mean by flame extinction? Extinction means you will be basically dowsing a flame right or dampening a flame or you will make it you know extinguish right. So, and it is having several applications, because the flame is the dangerous thing, one has to handle it carefully right. So, the however, we will have to contend the flame, wherever possible, so that it should not affect the life and also the materials.

So, flame extinction is very important laboratories, in the of course, the spacecraft safety purposes, safety is very important. So, also the power plants, nuclear power plants right, and the coal mines, and of course, the aircraft safety, and your homes like you know now a days in IIT, Kanpur, we are having all the places fire extinction because of the safety (Refer Time: 13:15) you know issues. And the elevators, now days elevators are being used very much in the high rising buildings as skyscrapers right. And there the fire safety is very important; therefore you will be using some flame extinction.

And apart from that, several other places will be using, but this concept of the safety due to fire hazard is basically started long time back by Humphry Davy. And when what he did is basically trying to extinguish the flame, it is not extinguish the flame, it is not allowing the flame to come out of a land right. In this situation what will have to do, basically flame will be there, but it should not go beyond certain limit. What I will have to do, I will have to basically use that would not allow the flame to pass through the narrow passages, which will be discussing about that like what are the size of the narrow passages through which the flame wont propagate. Although, the fuel and oxidizers within the flammability limits available that means, fuel oxidizer mixtures within the flammability limits are available, but flame would not go, that is the idea.

Ah So, this idea was basically employed long time back for the mine safety, and by the Sir Humphry Davy. And he has developed a safety lamp, and keep in mind that is a controversy, actually this person is a very scientist is a one of the scientist. And there is another person who is not scientist, he was a uneducated person, but he made that lamp previously, before the Humphry Davy. But, of course, he lost the battle, and then people know that he is the person, and I really do not know what is the truth right, whether that fellow did or this fellow did. But, any way he could not explain to the royal society at that time, how it is working right, but he this person Davy could you know explain.

If you look at this is the lamp, and this is the a kind of a net kind of a screen, which is available metallic screen like metal screen you can say. And that would not allow the flame to propagate, although the around this thing will be the fuel air mixture will be the particular in the mines, you know there will be some gases due to paralysis and other things will be taking place and some oxygen will be there right.

And that mixed and that may you know if a if a taking a lamp in to the of course, at that time, if you take a lamp there was a which is burnt you know which is basically made out of a kind of a weak flame or the flame devise or the combustion devise, the naturally what will happen, it will spread the fire. So, that is the very important, you know break through what happened, and then it is being done. And this is the screen, which will help. And if you remember that we basically use this kind of a screen metal screen particularly to stabilize the one-dimensional flame, I had discussed earlier right.

And the flame extinction is a very important, but question arises how we can do, there are two ways, it can be done. One is of course, the thermal effect, because we know the flame is self propagated because of fact that heat been transfer to the pre heated zone. And then, pre heated zone will be attaining the self ignition temperature. As a result, the combustion will be self extent right. So, if you reduce the heat, if you allow the some heat transfer to take place that means, you know heat loss will be much higher as compared to the whatever the heat being release, then flame will be extinguish that is one way.

And another way is of course, you can add see this thermal effect is basically you can look at some water, you can take some water addition, and then what will happen the C p of the water is very high, so that it will be taking out of the heat water will be alleviated. So, that is the way, it will be a flame will be can be extinguish and that is which is a common way of doing it. Beside these, there is a chemical reaction, which is going on right. And that can be the chemical kinetics during the chemical reactions, you know can be altered by adding some halogens some other constituents, which will be you know affecting the kinetics or the chemical reaction.

So, by these two ways, one can think of basically using extinguishing a flame. So, you might be knowing that like wherever there is a flame, we use also nitrogen gas right that is basically it will be acting as a diluents or the thermal effect, and whereas some halogens some other constituents you know you can use.

And this is the flame extinction, there will be also flame enhancement, which is just opposite right that means, the it will be other burnt, you will have a minimize the heat loses from the flame right, that is the one way. And another way that you add some additives, which will be help in enhancing the chemical reactions right, so that is just if you look at one is positive aspect by enhancing the combustion rate, like we do use some additives, like metal powders, and other things are being used in your liquid propellants or the liquid fuel to enhance the reactivity of the propellants. So, similarly in solid propellants and another place people do use it.

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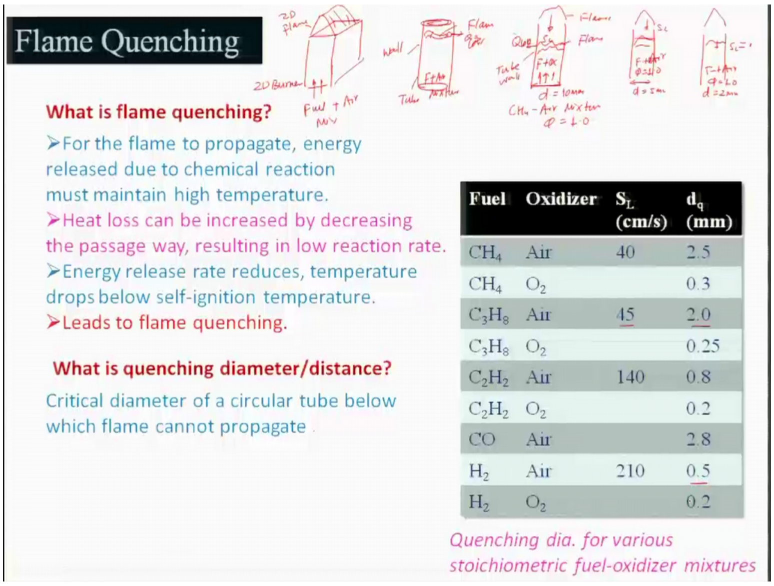

And now, coming to this thing, we need to understand the flame quenching. So, as the name indicates quenching means what, like basically it is the dowsing influent or dampening it right. And how we can quench the flame is a very important question, we need to ask. For that, we need to understand what is happening inside the flame. For we know that the for a flame to propagate right, certain energy being released due to the chemical reaction, and that maintains a high temperature. In other words, theses heat transfer heat release during the chemical reaction will be transferred to the pre heat zone, and then the fuel air mixture will be basically enhance and reach the auto ignition temperature, such that the combustion will be taking place.

And if heat loss can be increased by decreasing the passage way right, because if a in a tube let us say there is a tube here right, and there is a flame, which is moving right. And then, this is the wall right, and this is your tube, fuel and air mixture, it can be oxidizer also right; it can be oxygen. So, these loses, heat will be loss to these right, something heat loss. If this can be enhanced right, then what will happened, the reaction rate will be reduced, because the heat release you know whatever it is being generated heat being released during the chemical reaction of fuel air mixture will be heat will be released reduced because of heat transfer through the wall right, heat loss you can say. So, as a result, like there will be resulting low reaction rate right.

And if it will may such that that it would not be self sustained the naturally, there will be flame extinction. In other words, the energy release rate reduces due to the drop in the temperature right, when the temperature drops below the self-ignition temperature right, then there would not be any heat release right and that leads to the flame quenching.

That means, if you look at if you summarize, basically what is happening. If you enhance the heat loss from the flame to its surrounding, like such that the temperature will be below the self-ignition temperature, so that it would not be self it would not be self-sustained. Because, combustion means what, even though you are taking out the ignition energy source, still combustion is going on. Ignition is just mean to initiate the combustion, after that it will be self-sustained right. So, therefore, the heat loss place a very important role, for quenching the flame right.

Question arises how we will conduct this experiment to find out quenching. For that, we what we do, we will define a definition that is a quenching diameter or the distance, and that will dictate, whether the flame will be quench, when it will pass through that. For that, will have to conduct experiment, what will do, we will take a tube right of diameter something let us say d right some diameter, and this is fuel plus oxidizer mixture, and there is some kind of a flame is established right. What will do? You will now suddenly close this wall that means you stop.

So, if you stop this wall flow right, which is going through this, what will happened, the flame will trying to travel inside this tube; this is a tube right. So, it will be coming inside the nut, flame will be moving inside with certain velocity. So, when it will move inside, then you know it will see this wall like flame may be somewhere here right, it may be flame will be here. As a result, that heat loses will be there right, there will be some heat loss. And these loses will make reduce the laminar burning velocity.

If it is a coming towards zero right, then what will happened, flame will extinguish right. What I will do, I will take this diameter, and see that flame is coming in, and this of course, when the flame enters in to the tube, we call it as a flashback right. This process we known as flash back. And let us say d you have taken let us say 10 mm right for a methane-air mixture right at phi is equal to 1, of course the initial temperature 298 Kelvin pressure is 1 atmospheric pressure and know we are conducting experiment.

Then what I will do, I will take a small tube like let us say I will reduce into 5, deem is 5 mm right. And again, I will conduct this experiment right that is fuel plus oxidizer and phi is equal to 1 right, I can select air will better right. Then again, flame is coming, and then it is propagating right with a certain velocity S L, so it is passing through it that means, it is not quench right, it is not quench.

Now, if I reduce to let us say it is something d is equal to 2 mm right, flame is established here. But, however when this fuel and air phi is equal to 1 is stopped, then flame is entering here, but it may be moving to some extent, but the S L is coming towards 0, after that it would not move, you know flame is extinction. That diameter at which flame would not propagate right inside the tube metal tube where the heat transfer will be taking place. Why I am insisting and metal, because heat transfer will taking place. Then it would not propagate, it cannot propagate, that diameter we call critical diameter or the quenching diameter that means, the quenching diameter is the critical diameter of a circular tube below which flame cannot propagate right.

And similarly, I can conduct these experiment in a two-dimensional burner right. For example, if I take this is a tube right, tube means it is a something like this tube right, and the two-dimensional means, it will be like a burner like this, tube like that right, where the fuel and air mixtures right.

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This is basically 2D flame, this basically two-dimensional flame. And similarly, we can define a quenching distance right for a two-dimensional flame. This is a two-dimensional burner. Are you getting the circular and the two-dimensional? Right, flame will be like this, these are the basically flame surface.

So and let us look at the quenching data for various stoichiometric fuel air mixtures. If you look at that the methane air, where the S L is around 40 centimeter, the quenching diameter is 2.5 mm, and of course when it is replace by air is replace by oxygen, it become very small. Why, because the burning velocity is very high.

And similarly, for a propane air, this is 2.2, because burning velocity is higher, so it is lower than little bit. And if you consider the hydrogen air right, it is the burning velocity is very high 210, and it is a very small value. And if you go to oxygen, it is again reduce for the, because the burning velocity will be higher. So, with this, we will stop over. In the next lecture, will be looking at how this quenching diameter will be related to the burning laminar burning velocity, using a very simplified analysis right. So, we will do that in the next lecture.