Fundamental of Aerospace Propulsion
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Lecture - 21

Let us start this lecture 21, with a very simple message that objective of life is to light the inner fire lying dormant in the recess of our mind.

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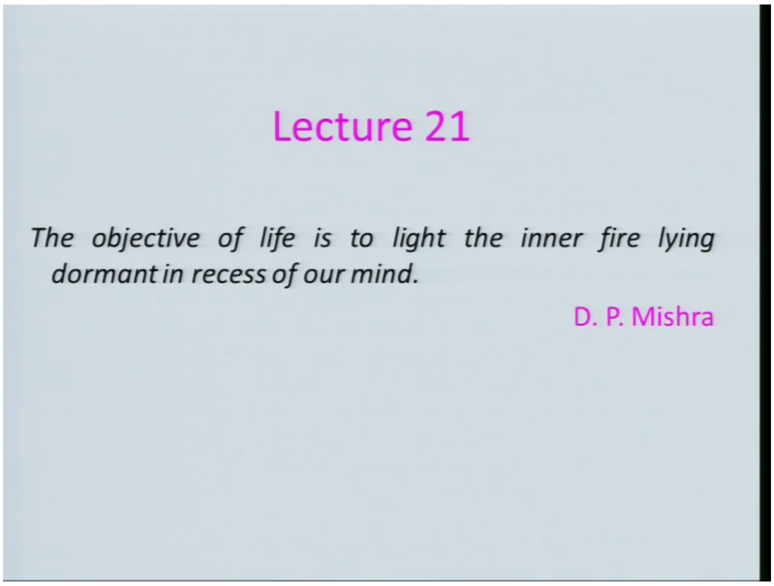

And before we will starting this lecture, we need to re-look at what really we learned in the last lecture. In other words, let us recapture it, if we look I started with taking an example, where I illustrated how to really determine the activation energy from experiment provided both are conducted at two different temperatures. And that was the part of that an example, then we moved into what we call the molecules of reaction, based on that we divided roughly all the reaction into three, unimolecular, bi-molecular, tri-molecular of course, quantum molecular reaction can take place, but which is unlikely to happen.

And then, we also define a term known as order of reaction, and based on that we just touch upon the first order reaction, second order reaction and third order reaction, some of the examples I have taken. But, however if we want to look at in detail, you need to look at the equations and solve it, so that you will see how this reaction rate is varying with time. I did not get into that, some of you are interested you can look at some stranded books and compassion, and you can have a feel what it is.

Later on we moved into chain reactions, which is natural in case of particularly whenever the combustion reaction is taking place, chain initiation, what we call branching, chain carrying reaction, chain termination. If we remember, I consider this chain reaction is nothing but, a human life, like brave is taken bar that is initiated, life is initiated and it will be branching, carrying out like learning and other things, at the end you will be terminated at the death.

So then, we move the kinetics, the multistep chemistry I just show you a very glimpses of it, juts to have a feel how complex it is, not you remember all those steps involve in the multistep kinetics. But, we will be mostly handling with the global kinetics, which is although not occurring nature, it is just a model to overcome the problem of handing multistep chemistry, in realistic problem.

And then, we moved into what you call various modes of combustion, like flame and flameless model, and under the flameless mode I talked about small moldering compassion, to just will give in to little bit idea about it. And then, we have also talked about premix flame and diffusive flame, and as I told that combustion is basically a wave, weather it is a wave or not that we will look at today, it is like your shock wave, it is like a wave.

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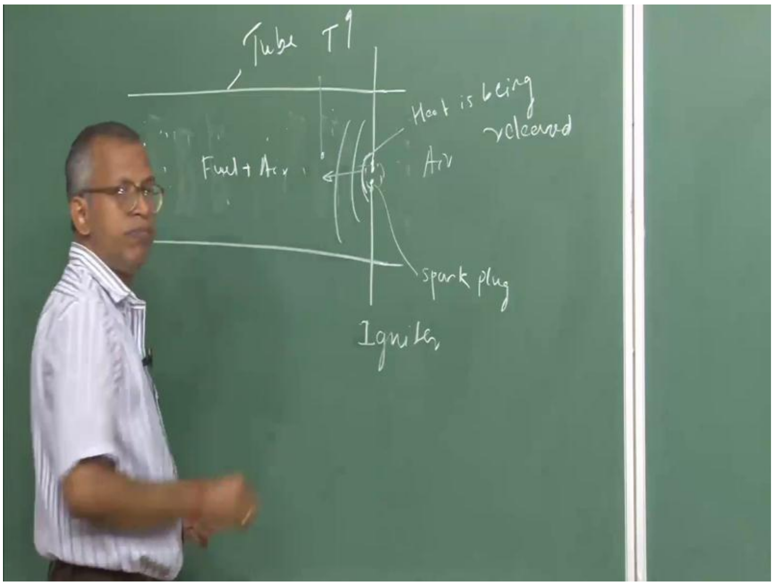

If I consider a tube, which is mixed with pre fuel and A f for example, if I take a tube here and this is fuel plus air which are mixed together, if I ignite these are the mixture particular mixed together. Of course, at a what you call particular fuel air ration in which combustion can take place, because we know that there is two limit between which combustion can take place, beyond this two limit it cannot be, do you know that what is the limit, that is known as claim ability limit will be talking about it just briefly.

And then, that is the fuel air mixture, beyond which no combustion will take place, how when they ignition energy we need to take, if you look at to ignite something, to have a flame, to have a combustion we need to ignite it, without ignition can really combustion take place certainly no, initiation is required. So, naturally we will ignite, if you look at this is igniter, then what will happen, of course this is far I am talking about, but with this spark, you can say this is a spark plug kind of thing.

Spark plug is one kind of igniter, there is several kinds of igniters, as we go along we will talk about it, particularly in solid problem combustion, various kinds of igniter you can think of. So, if I ignite it what will happen here, what will be there in this place there would not be any fuel air mixture, will it be there, there might be, but those are dilution will be taking place. And it will mix some with air maybe below the flammable limit nothing will happen if I ignite it.

So, if you look the flame will be, the cornel will be coming over here, but it will be moving towards this direction, these are flame will be moving, will it be moving or it will remain stationary. Why it will move, because there is a fuel air mixture, and which is there on this side whereas, this side it is simply air, if this is my tube, so this is a simply air which is open atmosphere. But, why it will move at all what makes it to move, because fuel air is there, is it the reason, then how does it really takes place.

Because, what will be happening like, when the flame is formed or flame cornel is being formed, then some heat will be transferred. If it is some heat chemical reaction is taking place, some heat being released yes or not, it heat being released, then it has to go both the side, it can go this ((Refer Time: 07:07)) side, it can the other side as well. That depends upon what is the mode of it transfer, what kind of mode of transfer you can think of, one is conduction, other will be radiation, what else other will be convection.

But, is it convection will take place in this, because keep in mind in the tube, the mixtures are stationary, it not like a pipe which is moving we are just keeping mixtures stationary, will it be convection with air, why not. What about natural convection, there would not be any force convection, but natural will be there yes or no, because if something is hard that gas will go up, because of gravity yes or no. I think you people are not getting, natural convection will be there, radiation will be there, because it is very high temperature.

That radiation it transfer is proportional to the temperature power to the 4, so naturally it will be there, because temperature is quite high, but in the lower temperature I cannot really consider, I need not to consider the radiation file. Because, temperature effect is not very, but at the high temperature I cannot manage to neglect it, so heat will be transfer. If heat will transfer what will happen to the mixture here, it is temperature will go up, if it will go up, go up means this temperature if I put a temperature here, this will be going up temperature of this point will be going up yes or no.

Because, heat is being transfer and then, what will happen transfer, then the mixtures temperature will be going up till, when it is beyond the initial temperature, self ignition temperature, then combustion cannot take place. Then, so it will be going at what you call go on moving like a wave in the direction till it all the gases being consumed. If you look at this example I always give, like suppose this is a food item, let us say there is an insect it will go on eating, because of course, as long as is hungry.

So, similarly in our scheme stable will say that fire is having a hunger to consumed the fuel, so similarly it is goes on moving that, wherever food is there, if look at like leg horses are being put like, if they want to make the horse to move. So, they will give them the what we call food to leave you by food, like you people are being lewd for getting a job to get something. Otherwise, who will study why I let you in class, because you want to get a job that is why you want to work hard, and then do that, it is like that fire or the flame will be trying to go towards the fuel and air, that is a natural way, so therefore it will be moving.

So, if I look at this what is this passes, can you give me another similitude which will help you to think better about a flame movement, this is nothing but, a wave it will be moving this flame front.

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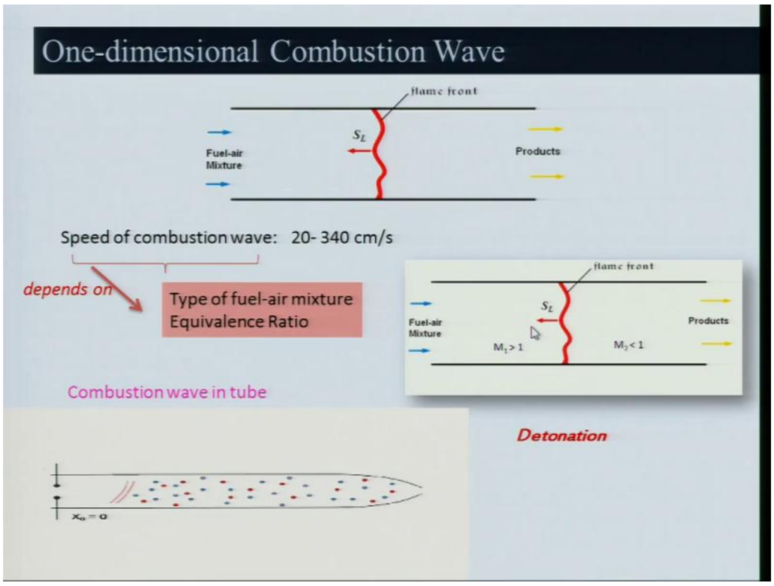

These are flame front, which will be moving, so now let us look at just that, whatever I have told, let us look at visually what really will be looking at, I have taken tube in this case. And there is a tube here, glass tube where we can see visualize the flame, there is this is a fuel air mixtures the ignition, then what is happening this flame cornel is being it is moving towards that, it is goes on moving. But, as it goes if you look at in the beginning it was like a curve little bit and then, this is also fatten like, is a half of a moon christen shape kind of thing, but in a sudden angle.

Why it is so, why it is not moving as a front, like a little bit curve maybe, because of heat losses will be there, and why it is not moving as a one dimensional cameral, now it is almost two dimensional why it is so. Why it is particularly in ((Refer Time: 11:57)) this region, it is what you call curved and then, it is slanted kind of thing why it is so, I already given you answer for this, because of what natural convection. But however, if I want to make these flame stationary what I will have to do, has the flame front is moving, it is like open fire goes on moving, you have seen it is devastated.

But, as an engineer we do not want to the flame to move, we should control the flame such that, we can utilize it, that is the whole gamete of combustors or the gastro when the combustors or the rocket engines, we need to contain the flame inside the combustors. For that we need to talk about flame stabilization and other things.

So, if you look at like I want to look at that, so what do you basically, in these case what you can I ask you give a similitude, what is really happening, if you look at these example, if you are not think about will come to that little later on. Let us now look at how we can make it stationary, it is very simple questions, what will you have to do, I will have to feed these fuel air mixture with certain velocity with which this flame front will be moving, again in this case flame print is moving with a respect to unbound mixture or the bound mixture with certain particular velocity.

And that will be dependent on what, like I call it as S l, S l is the laminar bonding velocity S l and it is defined with respect to unbound mixtures in this case that means, these are unbound mixtures. This is flame will be moving toward this, with respect to this unbound mixtures, then I call it as a bonding velocity. Now, if I make the flow, fuel air mixture to be flow towards or into the flame, like in the opposite direction of flame, flame is moving in this direction and fuel air is coming this direction, if it will be same as that then my flame front will be stationary.

Otherwise, it will be moving either to the left or to the right, depending upon whether the fuel air mixture is less than the bonding velocity, or fuel air mixture is greater than the bonding velocity, this is the basic principle of flame stabilization is very important point, are you remember my point. So, now if I will make this it will be stationary, and if it is stationary it will be very easy for me to, what you call look at this one, look at it and then, analyze it.

It will do that like the speed of combustion wave as I told you, will be varying between ((Refer Time: 15:18)) 20 to 340 meter per second, keep in mind that, if it is a deflagration. That means, what is the meaning of deflagration, the bonding velocity or the flame front will be moving at a subsonic speed, that we call it as a deflagration. And it will be dependent what, it will be dependent on in a temperature, then what else fuel air mixtures, type of fuel air.

Like if it is methane air it will be different, if it is methane oxygen it will be different, if it hydrogen oxygen it will be different, if it is hydrogen air it will be different or any other combination it will be different. Whether it is a like a lime mixture it will be different velocity, pressure also it will be dependent on that, so we will look all those things out; that means, it will be type of fuel air mixtures and other inlet conditions what it would it be.

And as I told you that when this flame front will be moving at at a subsonic speed, we call it as a deprivation, and I can consider this as a one protocol, station one, station two, but if these bonding velocity or what you call flame front, is moving at a more than the speed of sound we call it as a detonation. Detonation is basically a explosion kind of thing, because it is moving at a very high speed, you might have heard in your what we call Diwali or the festivals, people make fire cracker.

Or even like you are is they put some explosion, that is a detonations not a deflagration, and which is always mush be avoided unless, otherwise it is useful for the mankind. But, unfortunately all explosions at other thing is misuse abuse for the people, against the people.

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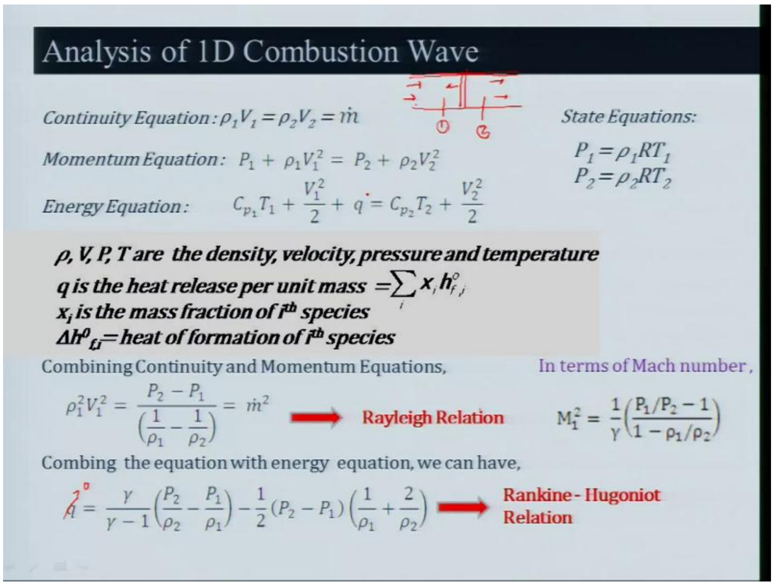

So, now let us look at how we can analyze this one dimensional combustion wave, because as I told you it is basically wave, and what we will do, we will be using the same continuity and all those equation. But, what will be looking at is like I am having, what we call a tube kind of thing, there is a wave here, it is a flame front and I can say this is a 1 and this is 2 keep in mind that. This flow is coming over in such a way, it is moving in such in directions and it is stationary.

And it is also products are going out I can the station one, station two it can be deflagration, it can be detonation, we are not distinguishing at this movement we will be looking, trying to find out what we call the relationship for this. And what are the assumption, will make will make the steady in we should flow, and it is basically one dimensional flow. And it is what we call all compressive nature, flow is compressible because it can take care of both detonation and deflagration and other assumption, whatever we have done for our early studies will be all include.

So, if I look at this one dimensional, so then continuity equation will be like rho 1 V 1 is equal to rho 2 V 2, that we have done several times form the your mass conjugation equation, is equal total mass flask which is passing through, because this is a constant area. So, the momentum equation will be P 1 plus rho 1 V 1 square is equal to P 2 plus rho 2 V 2 square, because it is a compressible flow. And you could in compressible, then you could have use the bundle equation, that is where P 1 plus half rho over V 1 square is constant.

But, energy equation, then here C p 1 T 1 plus V 1 square divide by 2 plus q, q is the heat being added, it can be due to compassion, it can be due to some heat additions, like anything can happen. And C p 2 T 2 plus V 2 square by 2, this equation kind of equation we have derived at least 3, 4 times, so I am just writing here. So, equation of state if you look at what will two for the station one it is P 1 is equal to rho 1 R T 1 and for station two it is rho 2 R T 2.

So, keep in mind that this q is the heat release per unit mass, and this is basically a submission over this x i h i f and y i is the mass fraction of i species, and if you look at the h i f is the head of formation of i s species. And combining this continuity equation and momentum equations, we can get a expression rho 1 V 1 square is equal to P 2 minus P 1 divide by 1 over rho 1 minus 1 over rho 2 of course, that is equal to the m dot square, that is the mass flaks, mass fluoride you know which is going to it.

It is basically mass flaks keep in mind, because area is divided, so it is a mass flaks. Now, if I want to explicit this in terms of mark number, I can do that using the your what you call definition of speed of sound. We know it is root over gamma p by rho or root over gamma R P, so if you do that what you will get is basically M 1 square is equal to 1 over gamma and the bracket P 1 minus P 2, P 1 by P 2 minus 1 divided by 1 over rho 1 by rho 2. And this relationship what you call this relationship is known as Rayleigh relationship, if you look at it is similar to the Rayleigh flow.

Because, all this equations are nothing but, your Rayleigh flow which we have already consider, but we are looking at little from the different angle. Combining equation with the energy equation, like this equation what we call with energy, we can get an expression q is equal to gamma divide by gamma minus 1 P 2 by rho 2 minus P 1 by rho 1 minus half and then, P 2 minus P 2 in the bracket. Of course, into in the bracket 1 over rho 1 plus 2 by rho 2, I think it will be 1 I guess, so what if you look at this is a very important relationship, which is known as Rankine-Hugoniot of relationship.

And if this heat addiction will be 0, what we will get you will get basically soft wave relationship that means, if this q will be 0, so then form this you get a relationship for a soft wave which you have already derived, because if energy equation if q is 0, you can get that.

So, and let us look at for a what you call, ((Refer Time: 23:27)) this expression what we will do, we will be looking at and for a particular pressure, inlet pressure P 1 and intensity rho 1.

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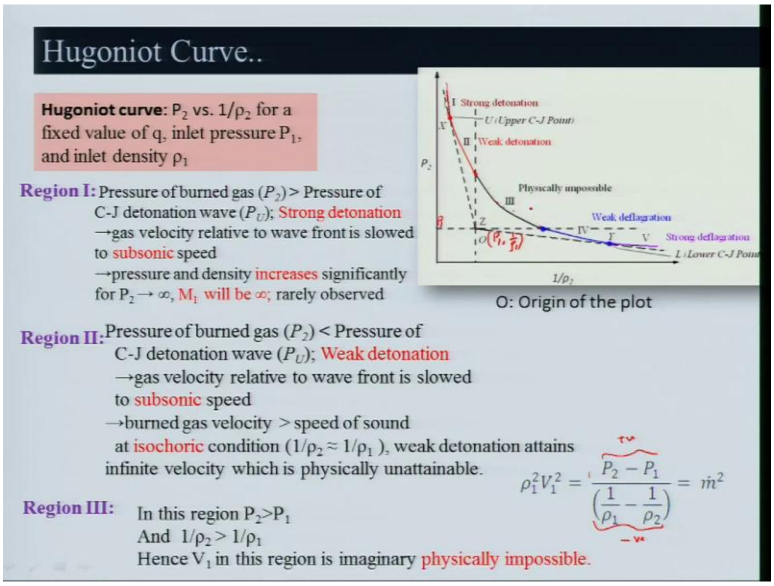

And for a particular heat addition like kind of things, if we will plot this by wearing the density P 2, then we will get a curve which is known as Hugoniot curve, that Hugoniot curve is basically P 2 is being plotted 1 over rho 2. And for a fix value of q and inlet pressure and inlet density, the curve will be looking like that, so if you look at this curve will be looking in this way. Now, what is this or this in if you look at, this is basically P 1 1 over rho 1, if I draw a parallel line two this what do you call 1 over rho 2 axis. This is the 1 over rho 2, and this is P 2 axis, and it will cross at a point here.

And similarly, if I draw a parallel line through this origin O, to this P 2 axis, it will cross a point and then, if I take a tangent a draw a line which is tangent to this curve, you will get a point x. Similarly, if you draw a tangent to this line you will get a point y, you might wonder why I am doing this what is the requirement, because we want to look at various reasons. What really happening for example, and this point a axis is known as upper chap Hugoniot point seizer point, and any region above this point is known as the region 1.

The region 1 what is really it is, if you look at if I take a point here, what I will get basically it is a P 2 which is much higher than the P 1, because my P 1 is here yes or no, it is much higher. And if you look at it is moving almost parallel or kind of thing that means, it is infinite, these values are infinite and this pressure P 2 is greater than the P U, two what is that P U. P U is the chap Chapman Hugoniot pressure that is P U here, it is greater than that, if it is greater than that then at leads to what, it leads to detonation, hence strong detonation.

What is the meaning of that meaning is that, if my downstream pressure is very high what will happen, it will be trying to move this wave, at a very higher rate, as a result the MAC number will be moving towards infinity. The gas velocity relative to the wave front of course, is slowdown to the subsonic speed, what is that M 2, M 2 will be vary, because if my M 1 is very very high, what happens at the back of a normal shock, always I mean just suppose it, if it is M 1 is very high, M 2 will be very very low; so the similar thing happening in this case.

And as I told you pressure and density like increases significantly, as a result P 2 is tending towards infinity, it is going very high value little bit changes, and M 1 will be infinity and which is really observe. And that is known as strong detonation which is wont be occurring, it only in nature it cannot really occur, because strong things, very very strong thing is a mathematically it is possible, but in reality it is not that. For example, like if there is a lot of saw what happens, then a person like if your too much of stressed you will extinct.

The nature always wants that you should be here, you may get a little bit stressed, so that you will perform well, so similarly the nature always is behind to the people, all the species around and so also the detonation. So, strong detonation generally would not be occurring at all, but however if the pressure you know which is lower than that, this is the region to where this pressure of the burnt gas will be less than the PC. Keep in mind that this P 2 in this region, region two will be greater than the P 1, P 1 means here, but however, it is less than the P U, P U is the Chapman Hugoniot wave.

In this region it is weak detonation wave will be formed, because if you look at it is a slow piece smaller as compared to this region, region one, so the aim two will be M 1 will be supersonic, but it wont be very very high, as compared to region one. So, gas of course, if you look at other way around that is M 2 gas velocity let wave front is slow to subsonic speed, that similar thing happen, but it would not be that subsonic wave as compare to region one.

So, one gas velocity that is your M 1 will be greater than the speed of sound, that is why it is detonation and weak detonation is likely to occur in a nature, in the form of explosion what we see, or what we always encounter. And we are encountering explosion not as, because of terrorist activities on other places, so which is not good as a result like because, they are abusing the technology. So, at isocracy condition this is very important, where one density this is the point 1 over rho 2 is approximately equal to the rho 1. Then what happens that means, it is a very weak detonation and infinite velocity will be occurring, and which is quite physically unattainable write this point.

But, if you come to this region, see this point actual where if you look at, it is almost 1 over rho 1, if you look at this vertical line, vertical line where 1 over rho 1 or rho 1 is equal to rho 2. That means, if I look at your equation I will come to that, that you will say it will become 0, let me you remember that equation we got from the momentum equation rho 1 V 1 square is equal to P 1 minus P 2 divided by 1 over rho 1 minus 1 over rho 2. So, then if it is rho 0 than denominator is going towards very small value at 0, then it will be infinity, that is not possible.

So, therefore, this region from onwards is not possible physically, let us look at why it is not possible in the region three, P 2 is greater than P 1 and 1 over rho 2 is greater than 1 over rho 1. Because, in this region any point here, in the region three 1 over rho 2 is greater than 1 over rho 1 and P 1 is greater than P 1, because P 2 is here and it is P 1 is here, P 2 will be any point till of course, this point where P 2 is equal to P 1. So, therefore, it is not possible why you look at this expression, because I am saying P 2 is greater than 1 that means, this is a positive quantity.

Whereas what happen to this, this is negative quantity this will be a negative quantity, am I right, because 1 over rho 2 is greater than 1 over rho 1, so that will negative and this is the positive quantity. So, if I take a V 1 what it will be, it will be an imaginary mathematical also like of course, one can think of, but reality it will not. So, therefore, this region is impossible to get that, and I have already told you this is physically impossible this region.

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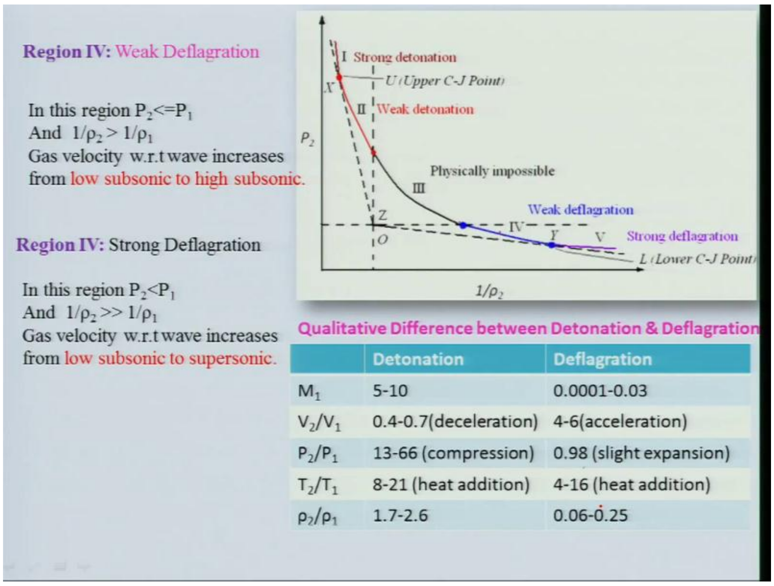

So, let us look at the region now, I V like this is a weak deflagration which will be occurring, in this region what is happening P 2 in this region, P 2 is very very less than the P 1. That means, closer to P 2 is closer to P 1, because this is your what point P 1 and when you are saying, this is not changing, because slope is very very small is the flattening out. So, and whereas, the 1 over rho 2 is greater than 1 over rho 1, because it is your this point is your 1 over rho 1, and this point is much higher.

So, as a result what will happen gas velocity with respect to wave increases from low subsonic to high subsonic, but then what will happen the pressure ratio, a pressure change across this combustion wave will be very very small. And this is known as weak deflagration, but however, in the case of the region five, it is a strong deflagration and P 2 will be I mean little what you call a rather P 2 is less than P 1. But however, the in this region the weak deflagration region P 2 is very closer to P 1 as compared to the strong deflagration.

And 1 over rho 2 is far greater than, then the 1 over rho 1 and gas velocity with respect to the wave increases from low subsonic to the supersonic is it possible, because the area duct is constant. If it is constant, then you cannot add heat to a extent, that it will go from subsonic to supersonic, we have seen the Rayleigh flow, thermal chocking will be occurring. So, therefore, it is not possible, so there is a strong deflagration in generally not possible in reality, so what will be happening that means weak deflagration is possible that is the blue line, and weak detonation is possible that is the your red line from this region.

Now, let us look at qualitatively, what is the difference between the detonation and deflagration, so M 1 if you look at the MAC number for the detonation 5 to 10, whereas deflagration is very very small, you may be thinking why it is small, keep in mind that this MAC number is with respect to the burnt gas. So, that your speed of sound if you consider very high velocity and V 2 by V 1 is 0.4 to 0.7 and whereas, this is a declaration kind of rho detonation it occurs, that is why that impact will be more kind of things.

And whereas, the deflagration it will be 4 to 6, keep in mind that the P 2 by P 1 is 13 to 66, because this is the compression it will be compress, that is why it is effect is very very higher impact. Whereas, the deflagration it will be 0.98, and little slight expansion will be taking place across the deflagration wave and T 2 by T 1 of course, the heat addition and in the case of deflagration heat addition will be there. And of course, you can add more heat in the detonation, therefore nowadays people are talking about pos detonation they like, so that you can manage.

Of course, one of the biggest problem ((Refer Time: 37:56)) detonation is the noise, one has to worry about and I guess there people will overcome that, and it will be future power plan for the anchor as well I guess. So, rho 2 by rho 1 is 1.7 to 2.6, whereas for deflagration the density variation is just at the a rho of 0.06 to 0.25. So, if you look at these are the qualitative difference between the detonation and deflagration, so now let us get into basically premix flame.

Because, this wave we need not to worry about like, whether it is a flame is there not, we are not worried about what is the structure of a flame how it is affecting, what is the bonding velocity, here we are looking at whether, what is the characteristic of deflagration and detonation, without bothering into inside what is happening.

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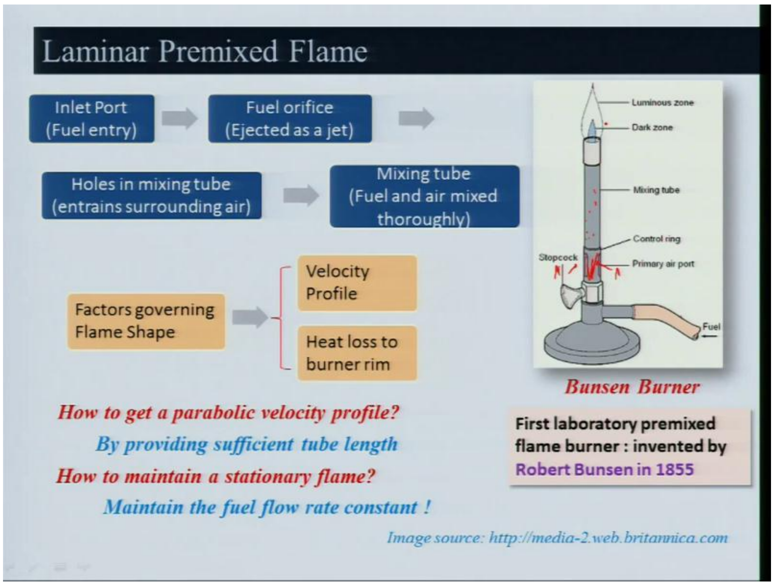

So, now we will be getting into the laminar premixed flame, if you look at the first premixed flame was invented by Robert Bunsen in 1855, and it is a man made flame. There is no premix flame in the nature except of course, in a issues and flame there might be small region which is premix flame, very very small region and that to nature does not support premix flame, as a matter of fact. But, however might be small region, so if you look at how we achieve that this Bunsen you might be knowing, like how we achieved it because you have use that, burner that is known as Bunsen Burner.

Now, typical Bunsen Burners shows your air comes over here and there is a hole in this primary air hole, there is a tube this is known as mixing tube, and you will get a flame there is a dark zone and glooming air zone. How really this air entering into this fuel, and why it is entering, how it is being mixed, these are the questions which might bother you, when you people are using Bunsen flame, in your laboratory particularly plus level. Can anybody tell me what is really happening, because we know there fuel will enter, when fuel is entering you need to supply the fuel at a higher pressure, than that of the ambient.

Higher the pressure better it will be, then what will happen, the fuel or if it is will be ejecting the fuel jet, as a jet for example, there will be a jet, so it will be like this something. When jet is coming, a jet what is happening, it will be trying to enter the air, because if I out a jet here at a simple air what happen it takes the ambient air into it, it is like your leader. Leader is having a large amount of energy it takes the other people who is having low energy level, that is why today we do not have a leader in this country, because people are do not have real energy, they may show to have certain energy, but that is not genuine energy.

So, the momentum is very very low, so people are not coil or similarly in this case the jet plays a very important role, if there is a dirt in the your oarfish, you see that is not working. And if it is mixed then interment will be there, so holes in the mixing as I told this air will be entering here, and in this place there is mixing will be there, and as it mix together, like you will get a through mixture over here, and you will get a flame.

Suppose sometimes I close this control ring, what will happen can I get a flame or not, certainly yes, why not I can get a flame which will be sooty in nature and yellow in color and that is a diffusion. If I open this control being or the air will be entering, and it will be premix and you will get a blue flame provided it is mix purple, generally this Bunsen Burner is being designed first to clematis mixtures. So, if you look at I will get a flame there is a Luminas zone, there is a dark zone and I may get another flame where there is a two zones.

Like oxidizing zone, reduction zone all those thing you might be knowing, so if you look at the flames same will be dependent on what, various shapes you may get, it will be dependent on what, it will be dependent on the inlet profile. What you can have, it will be dependent on how much heat losses there, it will be dependent on of course, what is the fuel air mixture you are having. So, if you look at that way, it will be dependent on heat loss from the burner rim, it will be dependent to the velocity profile, question here is how to get a parabolic velocity profile in a tube, is it possible to get that.

If it is so, how we will get it, is it desirable to have a parabolic profile, to have a stable flame burnt, why not we will use just like that. And if you look at whether the Bunsen Burner can give us that, we provide that means, is very simple you should have a fully developed flow. And that fully developed flow can be achieved provided you will give sufficient length, which is required for the flow to be fully developed, what do you mean by fully developed flow, where the burnt layer in a tube from the surfaces will be merge.

Such that, it would not change with the length after be getting merge is certain length that is the, so how to maintain stationary flame, because we always want to have a stationary flame. How to maintain that, because you have seen that flame is fluctuating and whenever the flow air or the fuel air mixture will be fluctuating, then naturally it will be fluctuate, or there is a external disturbances. For example, if some air is blowing or you put the flame on, then my flame will be extinguish or it will be was letting you, if it is away from the flame or if there is a door is open or something, you may get a assaulting flame or a assaulting you know it will be doing here and there.

So, therefore, it is very important to have a flame where to maintain the fuel air, constant fuel air fuel rate flow rate, in case of Bunsen flame and in case of premix flame, not only the fuel, but also the fuel air mixture must be kept constant to have a constant or a stationary flame. And the burner is designed to have stationary flame, there might be propagating flame as I showed you in the beginning of this lecture, it is the tube fill and then, you will ignite the flame will be moving.

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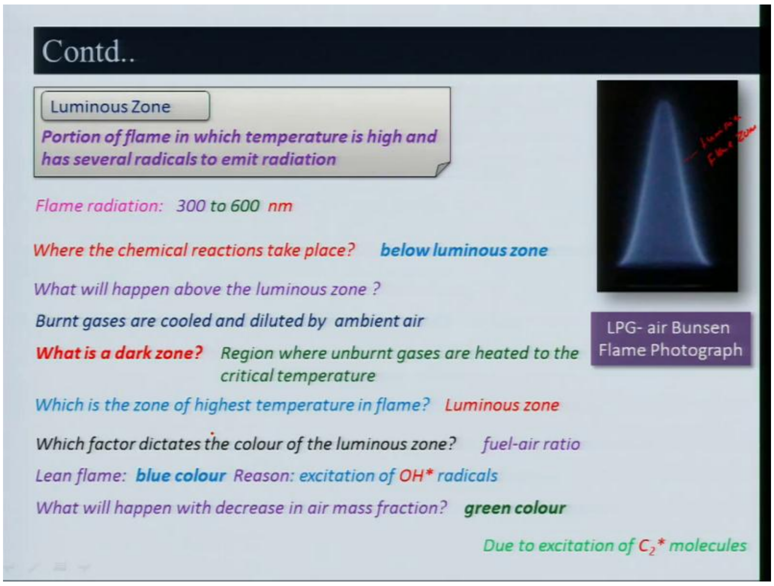

So, now let us look at a typical LPG air flame photograph I have taken, if you look at these zone I can call it as a flame, is a luminous flame. What about this region it looks to be having some color, this is the premix you can consider basically little protocol, maybe around stoichiometry, but in the lean side stoichiometry. That means, 5 is equal to may be 0.9 kind of things, and if you look at what are the zones, this is the luminous zone a luminous flame I can call it as a zone, flame zone.

But, there is a dark zone as well, in the last slide I showed you dark zone, but why this dark zone will be there, can I see that dark zone, how I will see it is a very simple way of doing. And what really happens in the dark zone, is it some reaction takes place, when does this reaction take place as i told you that layer flame is a very thin, the combustion all combustion occurs in a very thin region. What I call it as a flame that means, it is a like a surface one can say, flame is like a surface of course, it is not a surface like, but if at a cloth, it is like a plain surface very thin.

That means, all the reaction will be occurring in this thin region, am I right or no, wrong we will see that as we go along, and below that what will be happening there is no light why this light comes. So, that I can see it is it so, there is some flame which you cannot see like as I told you, what makes the flame to be visible, so if you look at the portion of flame in which temperature is high, and has several radicals to emit radiation. Because, of radiation we could see and which is invisible region, but if it is outside that we cannot see.

But, however, it will be radiating, so the flame radiation occurs roughly 300 to 600 nanometers, and you of course, somebody can say it is not 300 it is 295, that is this some wrong number I have given. That means, what is saying it is something ultraviolent to the visible or the infrareds, somebody's will be there in the flame as well, but particularly wedge radicals it comes around 300, n kind of thing nanometers which is like a ultraviolent kind of thing.

So, where the chemical reactions take place that is of course, that is a question which i ask, it is basically below this luminous zone or below this luminous. And below this luminous zone what it will be, and above the luminous zone what will be happening, because the reaction is taking place, just below the luminous zone. And what happens above the luminous zone, there must there would not be any reaction, the burned gases are cooled and diluted by ambient air, because some internment will be there.

Why there will be internment, there is no momentum no momentum is being lost, but why it will be, because of ((Refer Time: 48:32)), hot gases will be going out when it will go it will be taking some amount of air. And it will be cooling that is a natural, what is the dark zone as I told you region way unbound gases are heated, to critical temperature such that, it can attain the self ignition temperature to take place.

And not only that here also pyrolysis of the fuel takes place, pyrolysis means like where it will be decompose of course, not in the true sense pyrolysis, but decomposition of the hydro carbons will be taking place into the lowest temperature. So, and how will I identify dark zone, you can conduct a very simple experiment you take a postcard, post card you know earlier days people use write in a postcard, hard paper and slice over a what we call a flame see that, what you will get you will see that a flame.

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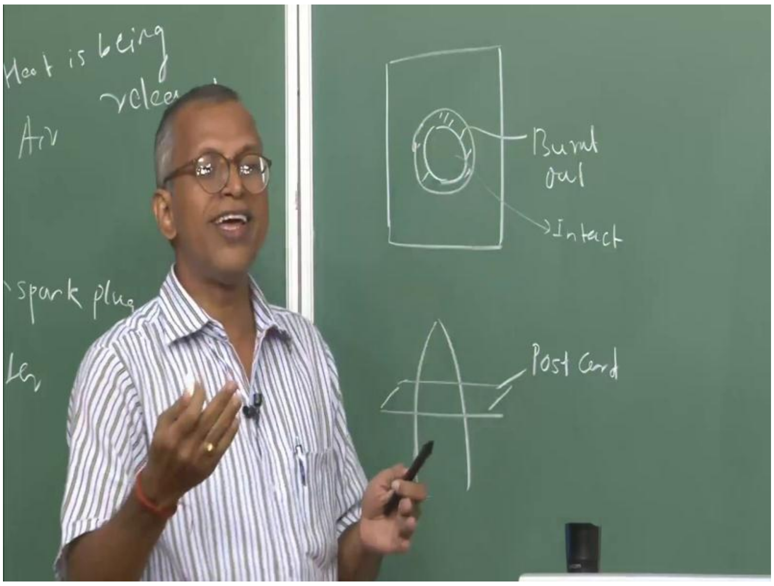

If I take a postcard and it is my flame hear, I am putting my post card in this region, this is my postcard, so if I will take this out what I will get in this region, I will be getting this region is being burnt out, black one I will get. Whereas, ((Refer Time: 50:05)) this region center will be intact that means, this says that flame is occurring at a, what you call in a rim form as a seat.

And in inside there is nothing no is this thing and it will be dark in nature of course, if I take a some kind of image, I will see it is no emitting any light, because at a low temperature. If it is high temperature it could have burnt it all, paper this you can burn easily, so which is the zone of the highest temperature plain that is the luminous zone, and which factor dictate the color of luminous zone, the radicals. And which will dictate is basically fuel air ratio, and depending on fuel ratio you get radicals being form, and the lean case flame you will get a blue color.

And that is due to what we call OH radicals and what will happen with decrease in air mass flow rate, you will get a green flame sometimes you get, and that is due to the excitation of C 2 star molecules, star is basically cumin luminous, molecules which is radical. And then, if you cumin there will be shoot formation, which will give the yellow flames you might have seen that is due to the carbon particles and they long, so with this I will stop over.