Fundamentals of Combustion (Part 2)

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Lecture – 45
Structure of One Dimensional Premixed Flame

So, let us start this lecture with a thought process that question can never be silly; it can be a beautiful lily in the garden of knowledge that is a truth, is after age. In the last lecture, we basically looked at, the laminar premixed flame and by discussing about the Bunsen Burner and how the mixing takes place and how the flame is stabilized right and today, will be the dabbling with, the same premixed flame. Let us look at a LPG, air Bunsen flame Photograph, which looks to be a very sharp image here.

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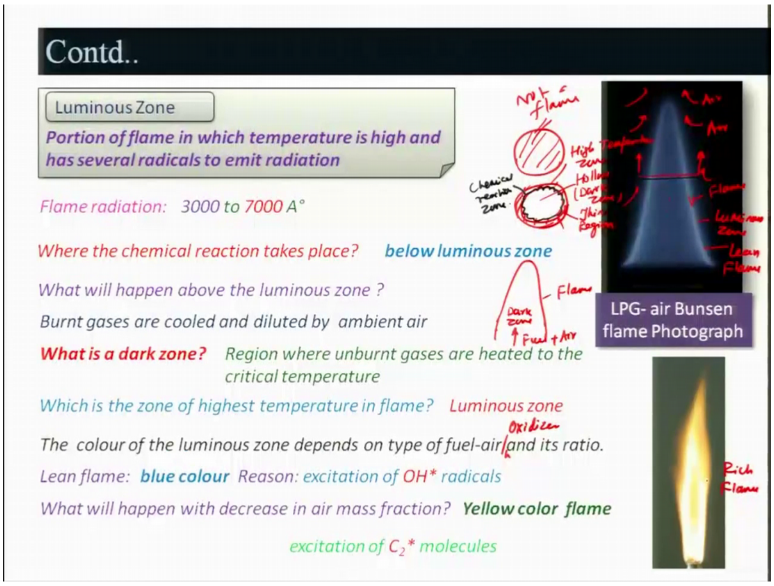

And, if you consider this flame right, is it the whole flame is what that, let us look at it. See is it the entire this thing as a flame, you consider if you take, this is the image that if I take a cross section of this right if I take a cross section of this right, what will be the flame safe? Will it be entire like this? It is, this will be my flame, this will not be my flame right. In my flame would be, this portion will be my flame right. The other portion is hollow there will not be anything you know; that means, in theme region, this is not a flame m I am talking about this cross section right.

So, therefore, flame is a very flame occurs in a very thin region, in which the rapid exothermic reaction takes place. So, if you look at in this thin region right, region, the rapid exothermic reaction takes place and what may call it as a flame are you getting point. So, these you can call it basically, dark zone, this hallow region and this is of course, the light zone right, that you should keep in mind and of course, in this figure, it is taken in such a that, this is the very this region is the flame, which is very-very sharp, but whereas, there is a blue colour is here right and question might be arises, you know why this blue colour coming in the centre?

Also this portion, this portion why? Because you are taking image from the front, so therefore, the flame is there also right, which you cannot avoid it. So, that is coming whereas, if you take this edges that is basically the flame, flame is the this annular region this annular region is a flame. The inside nothing will be there. So, the luminous zone, we call the light zone or the luminous zone right. The portion of the flame in which temperature is high has several radicals to emit radiation, why it is? Because temperature, in this case will be very high temperature, this will be high temperature right zone.

So, there will be several radicals, which will be emitting the light and that we could see, see if you look at you could see a blue colour flame. Now, why blue colour? You can also see a flame which is yellow colour in nature, you can see sometimes purple colour flame right, that depends on the basically, the radiation emitted by predominant radicals right and flame radiation. It will be something 3000 to 700, angstrom kind of things. And however, you know there will be some predom, some colour which will be predominant, some zone and, that does not mean that there will not be other colour.

But those are not, those are being mask by that if you use a spectrometer, you will find various, you know spectrums corresponding to the, particular radiation band. It will be there. So, where the chemical reaction, you know take place is basically, below this luminous zone. This is luminous zone right and just below that there will be chemical. So, if you look at this, if I say this chemical reaction will be taking place here, below this. This is the chemical reaction zone and keep in mind is not that it will be only happening here.

As I as we proceed, we will see that the reaction will be occurring very little thicker zone, but however, the predominant reactions, where the heat release will be occurring will be in a narrow zone and what will happen above reaction, luminous zone that is basically, the burned gases are cooled and diluted by the ambient air. Because, if it is a heart gas right and if it is a, because of buoyancy and also some momentum will be there, but buoyancy will be there at the this thing. Some air will be entraining into this, because this is the open flame. So, this will be air entrainment will be occurring.

So, from the ambient and there will be getting cool down the gases, hard gases and the diluted by the ambient here right in the above this. So, the region where un burn gases are heated to the critical temperature in this region right, if you look at, this is my flame. Let us say this is fuel plus air mixtures and this is my flame. So, in these, this is known as the dark zone, in this case what is happening that, the un burnt mixtures are coming right fuel air, that is getting heated right, because of presence of flame and flame will be giving the heat right, due to conduction and, what you call convection and also the radiation, radiation will be more predominant right in this case. So, therefore, that will be preparing the mixture to attain the certain critical temperature.

So, that ignition can take place and that makes the flame to be self sustained even though you initiate the flame are combustion with the ignition energy, but afterwards you just, you know stop this giving providing ignition steel. It is being maintained; that means, this process makes the, flame are the combustion to be self sustained and this dark zone place a very important role. So, which is the zone, of highest temperature in the flame generally, the luminous zone or the just below where the reaction will be very predominant, the temperature will be very high right.

The colour of luminous zone depends on the type of fuel air or fuel oxidizer rather I would put it as a oxidizer right, because right air is one of the oxidizer and it is ratio, ratio means is a equivalence ratio, which will be, basically are the fuel air ratio, which will be dictating the colour of the flame, the lean flame. Generally, it will be blue in colour, this is the lean flame, lean means fuel lean mixture right, that we call it as a lean flame. So, blue colour due to what; because there will be O H radical, which will be more prominent and that will be giving the radiation in the, you know this thing.

So, that is why it is the blue in colour and when you will decrease the mass flow rate of air right, for a fixed fuel flow rate. What will happen, this will be basically the fuel reach, because the air mass flow rate your (Refer Time: 09:58); that means, it is, if it is a stoichiometric and there and then your, decreasing the air mass flow rate, what will happen naturally? It will be fuel reach and if it is fuel reach, you will get it yellow colour flame right, like this you will get. This is a reach flame right and, that is due to the excitation of C2 star molecules right.

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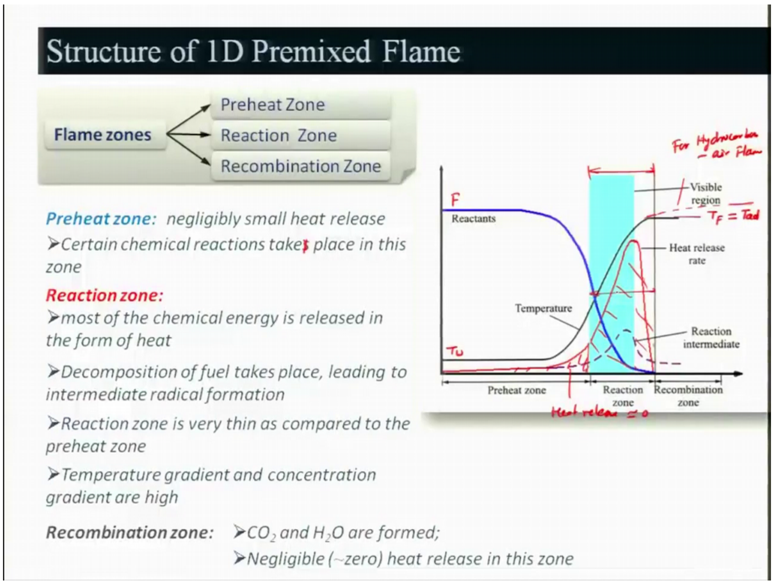

These will be so, having said this thing what will be interested to look at is basically, the look at the structure of a one dimensional flame, see flame looks to be very simple when you look at a photograph, but what is happening inside? We need to look at it and, the flame zones as I told, it can be broadly divided into three zones; one is pre heat zone, other is a reaction zone, other is the recombination zone right. The flame zone where the flame is occurring is divided into three zones.

So, from the, if you look at, the one dimensional, we are considering, but in the case of Bunsen Burner flame is not really one dimensional, it is a two dimensional. You can say if you consider the, it is symmetric, along with the theta direction azimuthally. So, therefore, it is to be, but if I consider the one dimensional right, I will get a structure like this and, if you look at this is basically, temperature profile the T u.

This is un burnt temperature and it remains same almost constant, but; however, it start a slowly increasing and then it goes to a peak temperature and although I made it flat, but in some case of a particularly hydrocarbon, this goes on increase asymptotically increases. This is only for the hydrocarbon air flame, but not for others.

But; however, this is asymptotically increases for hydrocarbon, this is for hydrocarbon air flame, but for our purposes will be considering that it is just flat, that is this is basically T F, this is the flame temperature and if I consider this as a adiabatic then that is equal to adiabatic temperature, but you right. So, it will be approx or rather adiabatic temperature, considering that there is no heat loss from the flame, but real situation, there will be heat losses. So, there will be lower temperature than the adiabatic temperature.

Now, what is happening, if you look at reactants, this reactant is fuel plus oxidizer. It can be air, it can be any other things right. It is, it both profile will be similar. It not same; that means, one can be fuel profile, other can be oxidizer profile right. Rather I would suggest that, you know profile will be similar right. I can say this is a basically, fuel right and it will be goes on and then it decreases and it remains, in almost 0. It is 0 at the recombination zone and the heat release is occurring here in this region and there will be intermediate reactions, which will be occurring in these regions. Keep in mind that this is the zone, which is very important. This is known as reaction zone.

And this reaction zone will be heating up this pre heat zone therefore, we call it as a preheat zone and recombination, where there might be some of the products, which will be going on like you know going on and then it is; so, if you look at, this is you can broadly divided into four zones like; pre heat zone, reaction zone, recombination, recombination, some re some heat being released here, also in actual situation, but for our analysis case, we will be talking about only three zones ok.

Keep in mind that and there will be zone, where there will not be any rise in the temperature. So, if you look at the human life also divided into four-four regions or the zones, you can say, the human a particularly according to, our Indian, what you call scriptures. The life is divided into four parts one is the Brahmacharya, other is the Grayastha and other one is Banaprastha and Sanyas.

So, it is similar to that; that means, in the Brahmacharyar what you do? You depend on the society or your father mother will be empowering you to contribute; that means, you will be pre heating zone right; the pre heating zone corresponding to your Brahmacharya. You are not earning anything, you are not contributing anything, you are just, you know taking and then empowering yourself then afterwards in the reaction zone that is the dashed zone, where you will have to use your energy and, lot of, things will be doing if contributing and in the (Refer Time: 15:51) zone, you will be little slow down and you will be, steel activities will be going on, but you will be not really very much, productive or something, but in the Sanyas zone. You will say look good enough I will only talk about the god and other things.

So, beautifully the, Indian way of life being defined and it is the similar to the flame are you getting, are you getting my point, it is very important point I am saying. So,, therefore, we need to follow those region to contribute for the society, not for ourselves. So,. So, also the flame, flame is always the fuel oxidize gate burnt and give the heat to the others right. So, pre heat zone, if you look at there is a interesting thing that negligibly heat release. There will be some heat release. You know heat release, if you look at consider here, this portion right, this is, this heat release is, this is basically heat release right, is approximately equal to 0 as compared to the heat release. This portion, this is very high large amount.

So, if you look at the this region you know if I consider, this are the region, where heat will be released, it will be very high and it is occurring in a very thin region keep in mind that this I have exaggerated this portion. If you look at I have exaggerated this is a reaction zone, but in, in real situation it will be order of may be less than 1 mm right and these will be much larger, but I have exaggerated just to make the point clear to you.

So, the reaction zone in this case what is happening like, in the pre heat zone certain chemical reaction, actually take place in this zone. It can be several reactions, I mean certain thing, which is initial, phase, but; however, the heat release will be very-very small and most of the things like pyrolysis and other things occurs in these zone; that means, and some may be, exothermic reaction will be taking place in this region.

But generally the fuel gate pyrolise, pyrolise means endothermic reactions right. Some heat will be coming and the hydrocarbon higher hydrocarbon converted into the lower hydrocarbons and other, molecules which can be consumed and the reaction zone most of the chemical energy is realized in the form of heat. In this due to the chemical reactions, keep in mind that several reactions will be occurring as I have told earlier that for a methane systems, which is a very simple hydrocarbon where something order of 100 reactions takes place right are you getting. It is in this thin region, there will be some 100 reactions will be taking place right, involving may be 20 species right and which is quite complex in nature.

And decompose of fuel takes place leading to intermediate radicals, formations will be taking place and reactions are very thin as compared to pre heat zone. I have already talked about it and temperature gradient. See if you look at gradient is very high here, in this reaction zone and so also the concentration gradient right. This basically reactant is a concentration gradient will be very high. So, recombination zone and carbon dioxide and water are formed particularly in the recombination zone and of course, later on, there will not be much things, will be taking place rather the heat losses will be more, at the, you know recombination zone and other zones.

So and negligible are the 0 heat release occurs in this recombination zone right. There will be a little bit, but that is negligible as compared to the reaction zone. So, when you talk about we talk about basically, comparatively right.

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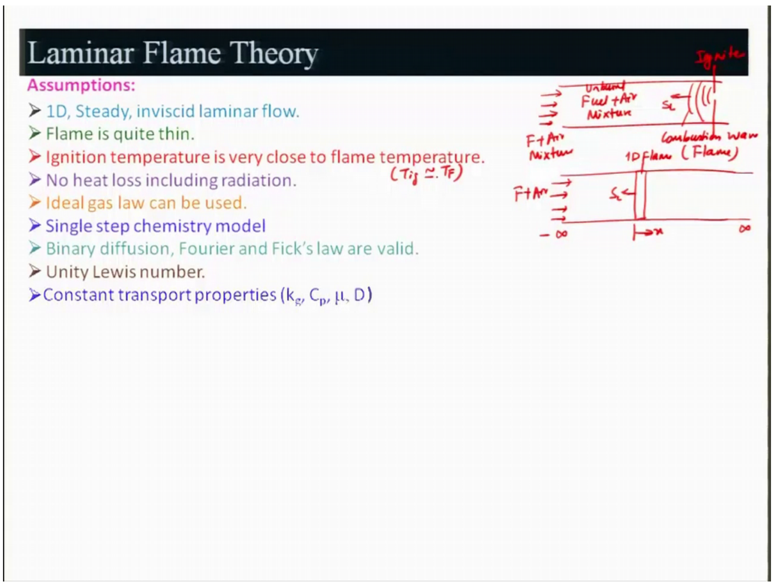

Now, we will be, trying to analyze this, laminar, flame right considering the thermal theory and, there are, there are several theories are there and this is basically, we will be considering the simpler one and we will be making, certain assumptions right for before making some assumption. Let us look this is my, let us say fuel air mixture filled in this tube and we are just igniting it right. What will happen?

There will be a flame kernel will be taking place and it will be taking a shape and then it will be moving right, moving towards the un burnt this is Un burnt fuel air mixture with a certain velocity that we call it as a burning velocity S L. The S L is the movement of the combustion wave, this is a combustion wave, what we call, it is a flame in, you know in current situation and, this will be moving with respect to un burnt mixtures and these velocity is defined as a speed with which combustion wave will be moving with respect to un burnt mixtures right.

Now, this is a propagation of the flame, but as I told earlier, what we will do? We will supply this fuel air un burnt mixture right. Fuel plus air or fuel or oxidizer, I need not to confined fuel air, only oxidizer mixture with certain velocity such that the, it will be equal to the S L. So, that my flame will be stabilize here, somewhere right.

So, if I look at; that means, my flame I am considering this as a one dimensional flame, 1 D flame right and keep in mind that fuel air is supplying fuel plus air supplying at certain velocity, which is equal to the S L. So, that my, this is fixed. So, I am considering this as my X, in the fixed co ordinate system. Now, the flame is fixed did not moving, because I am putting this, reference frame with the flame right basically, we can put that way and then it fixed.

So, with these this and then this side; what I will be considering is a far away, it is infinity and this is minus infinity right are you getting and this is we are considering one dimensional flame. So, with this, what will be doing will making some assumptions. So, assumptions are we are considering one dimensional steady in visit laminar flow. The flow is laminar and it is steady, there is no viscous effect right. Hypothetically, we are considering, but I can have establish a flame, which is just lifted one dimensional flame like which is stabilize in burner, I will see, I will show you a burner one dimensional by which you can really establish that in the lab, I have done that, may be 25 years back myself.

So,, of course, it is quite difficult to, design that and developed. So, flame is quite thin right that we are considering and the ignition temperature is close to the flame temperature; that means, in this case what we are considering the ignition is approximately equal to T, for very close, there is not much difference. You can say and, the no heat loss including radiation, but in actual flame radiation, you cannot avoid, but flame temperature is very high and ideal gas law can be valid and single step chemistry model will be using as I told the in the flame.

There will be several reactions will be taking place, you know involving where several kinds of places even for dimple hydrocarbon for methane here, binary diffusion and Fourier's and fixed laws, like you know are valid, we are considering binary diffusions, because fuel and oxidizer only right and, the unity Lewis number will be using it. So, constant transport properties we are considering will be considering constant properties and with, these are the assumption will be considering, but with this will stop over and we will discuss in the next lecture, and also trying to derive a relationship for burning velocity the next lecture.

Thank you very much.