Fundamentals of Combustion (Part 2)
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Lecture – 54
Simplified Analysis for Quenching Diameter

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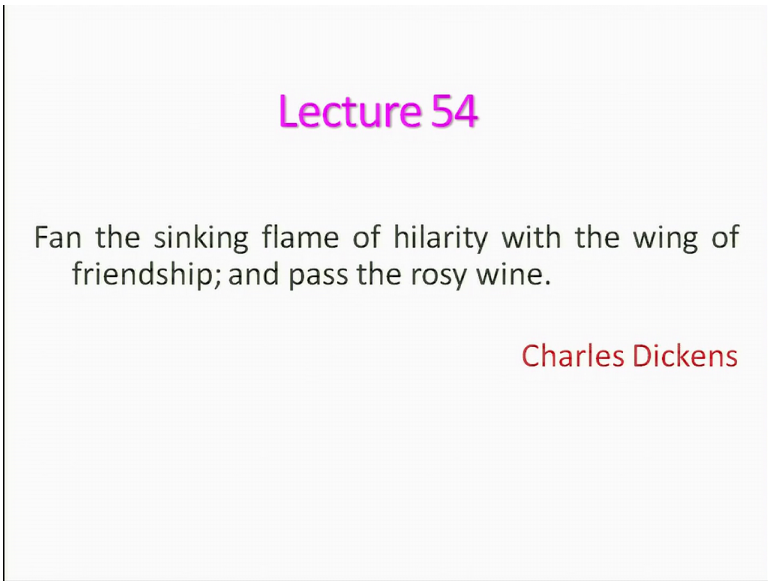

Let us start this lecture with thought process from Charles Dickens. Fan the sinking flame of hilarity with the wing of friendship; and pass the rosy wine. You might be aware he is the one of the great author Charles Dickens. So, in the last lecture, we basically look that flame extinction and its application; and later on we looked at also the flame quenching.

Flame quenching is basically is one kind of extinction flame extinction. And in the process also we define the quenching diameter. And also we have defined the quenching distance right. Generally quenching diameter related to a tube; and quenching distance is related to two-dimensional burner or a kind of things.

So, when you conduct experiment in both the apparatus, one is the let us say tube burner as there is a two-dimensional burner or there is a three-dimensional burner you can say, flame whatever you will be getting from a Bunsen tube right, you will be getting three-dimensional flame. And when you get from the two-dimensional flame in a slot burner right that is known as slot burner, and that will be there will be difference in the data.

Like what I had shown you in the last lecture, the data about quenching diameter is related to three-dimensional flame. But, if you conduct the experiment two-dimensional, and find out the quenching distance that will be different. So, generally the quenching diameter is around something 20 to 50 percent higher than the quenching distance, why, because the heat losses in the tube will be higher, why, it is a curvature effect will be there right. So, therefore it will be much higher surface area will be higher as compared to 2D.

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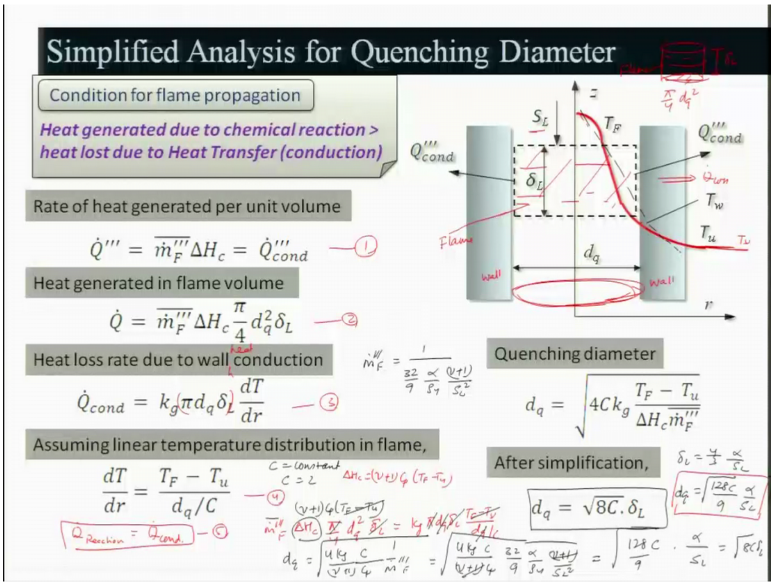

So, now we will be looking at a very simplified analysis to determine the quenching diameter rather we will be relating that laminar burning velocity with the quenching diameter. So, we always talk about a quenching distance kind of thing, where the flame is entering into a tube. These are the wall. So, if you look at this is the wall, right of the tube.

And this is if you look at it is a basically tube kind of things, and the flame; this is my flame with having thickness of delta L. This is my flame right. This is basically flame, this is my flame right, and which is moving at a, you know laminar burning velocity with S L, that means, the burning velocity and particular mixture. Keep in mind that we are assuming it to be one- dimensional in real situation, it need not ok, even inside. So, here we are assuming one-dimensional.

So, this is your z direction. And this is your r direction. And we are saying that at the centre the temperature will be maximum that is T F, because you know heat loss, whatever it will be passing through this, like heat losses right. It would not be the centre may not effect that is a assumption, otherwise it will be little lower. So, temperature profile will be like that and this is your T u. Keep in mind that this will be asymptotically decreasing to T u, but we will be doing some assumption in that.

So, with this assumption what you will do? We will basically look at the condition for flame propagation. Flame will be propagating provided the heat generated due to the chemical reaction in the flame is greater than the heat loss due to the heater transfer. And heat transfer can take place basically due to the radiation, and due to the convection, but here we are talking about the wall, you know through the wall it is taking place though heat conduction, which will be more important because even though the flame will be touching here.

So, therefore it will be you know some kind of radiation also will be coming conduction will be coming. But, once it will come to the wall, it is a heat conduction wall right. Of course, at the outer surface there might be some kind of radiation will be taking place, because temperature is high right. But, we are not considering that, we will be basically considering the heat transfer due to conduction only. And this is a simplified analysis, therefore we are taking that.

So, for that the flame will be quenched, when the heat generated due to chemical reaction will be less than the heat loss due to the heat transfer right, that is the condition will be applying. But, in principle actually it would be that means, the critical condition is what, when it is equal right will be finding it critical condition right. But if it is less, definitely flame will be quenching.

So, re rate of heat generated per unit volume right what it would be? It will basically Q dot triple dash is m dot F into delta H c is equal to Q dot conduction, this is my equation 1 right. And this is the condition, critical condition under which we are saying look flame would not propagate, because whatever the heat being released, it is being lost. So, will it the flame will propagate, flame will not propagate right, so that and then that diameter in which it is taking place, we call it as a quenching diameter right.

And why we are considered diameter, because that will dictate the heat loss. If the larger the diameter, then what will happen? The heat loss would not be that much, because a surface area will be you know not that big. But, as it is a smaller and smaller, the heat losses will be more. And volume the heating being release is reduced right, and heat loss is increasing, so therefore we consider as a diameter.

So, the heat generated in the flame volume. What it would be? It would be basically Q the into m dot F delta H c into area, what is the area we are considering surface area? This is pi by 4 d square, this area right into the delta L. So, this is the surface area, what will be considering. If you look at like this is my flame right, which is considering this is the surface area, what we are considering, and this area is pi by 4 d q square right. And this is your nothing but your delta L. This is a flame, you know in which is (Refer Time: 07:47), this is my flame rest of the things, I am not considered. Although there will be some losses ok, but that we are not considering in the flame volume.

So, heat loss due to the wall conduction. What it would be? Due to the heat conduction wall heat conduction, basically it is a Q dot conduction K g into d T by d r, this is basically the surface area pi d q into pi d q is the perimeter, right into d L that is a surface area and this is the right. Now, if you look at, if I will put this thing in equation 2 and equation 3 in equation 1, then I need to determine this d T by d r right, which is quite difficult you know, because to at this condition I will be looking at here, how much kind of wall it is. And the profile if you look at to find out this gradient at r right at different r (Refer Time: 08:57) I can look at, but I will be more interested in here. How I will do that? We will doing an approximation.

What we will assume that will say this is basically will consider a linear temperature profile right, because this is non-linear, but however, we will be considering linear right. And then, we will find out d T by d r T F minus T u and d q by C. if you look at C, when it is 2, like it will be linear right. If C is equal to 2, then it will be linear kind of things. But, otherwise you see if I will take something, you know it will be different right. But, however this an approximation for to get this d T by d r, you will have to invoke the conservation of energy equation. And then, you will have to solve it numerically or analytically, and then do that, which is quite difficult.

So, what will be doing, basically we will substitute this let us say will be substituting this equation 4, 3, and 2 in 1 right. I can get all those things. So, what will be a doing, will be basically looking at this is that is Q dot due to the heat reaction right is equal to Q dot due to conduction. This is the thing, what we are need to come put it, so that let us say this is 5.

I will substitute these values here, that is heat of reactions you know heat generated in the flame volume is basically m dot triple dash F delta H c pi by 4 d q square delta L is equal to k g pi d q delta L into T F minus T u d q by C. So, if I look at this delta H c, what is delta H c? Delta H c we know is equal to mu plus 1 C p T F minus T q right, are you getting?

So, in that case what I will do, I will basically you substitute this here in place of this, I will be writing mu plus 1 C p T F minus T u right. So, what is happening then? This is of course average right, this is average. So, this pi will cancel it out right. And this d q will cancel it out. This T F and this will cancel it out right, what else this delta L also will cancel it out right, easy so delta L will be also cancel it out.

So, if you do that, what you will get? you will get basically 4 d q is equal to 4 k g right, and you will get 4 k g by mu plus 1 C p right, you will get nu by C p, what else any other thing then m dot triple dash F 1 over that right, C is coming, C will be in the up. So, this is C, and this will be root over. Yes or no?

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C is a constant; you can see is basically a constant. This is a some arbitrary, we have taken, otherwise if I take is a linear profile, I will take C as 2 right. So, after simplification, because we know that m dot F, F is basically 1 over 32 by 9 alpha by row u mu plus 1 by S L square. I will substitute over here, right if I will do that, what I will get 4 K g C mu plus 1 C p right. I will get 32 by 9 alpha by row u mu plus 1 S L square.

So, if you look at mu plus this will cancel it out, and this is right. So, I will get basically if I look at this, that I will get as root over 128 by 9 32 into this. And K g by K g by row u C p right, row u C p is nothing but your alpha. So, I will get alpha by alpha square, I will get alpha square as the, I will be getting alpha by S L right, so but we know that what is your delta L?

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Delta L With the flame thickness is nothing but your 3 by 4 by 3 alpha by S L.

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C should come ok, 128 by C right. So, if I will substitute over here right, alpha by S L is nothing but by 3 by 4 right. I will get this is nothing but your root over 8 C delta L. So, this is the relationship, what you will get that means, the quenching distance or quenching diameter in this case is proportional to the flame thickness. And the other things what you can see, there is the another formula, what we have just now see, that it is d q is equal to 128 C by 9 root over.

D q is equal to root over 128 C by 9 alpha by S L that means, the quenching distance or quenching diameter as a sorry the quenching diameter is inversely proportional to the laminar burning velocity, that means, burning velocity will be higher, what will happen to the quenching diameter, quenching diameter will be small right. So, therefore if you look at, it is very difficult to quench the hydrogen air flame or hydrogen oxygen flame, because laminar burning velocity will be very high.

And using this, we can arrest the flame. Flame arrestor can be designed by using the quenching diameter calculation right. For example, you are operating hydrogen oxygen and hydrogen air flame or methane air flame; you want to arrest the flame. What you have to do, you will have to basically put some small tubes or a porous plugs or something that you know flame want travel. And this is a similar thing what actually humphry davy did without understanding much, you know like you could manage to do that put screen, we use screen for arresting the frame.

So, this small knowledge and also the relationship can be very useful designing the flame arrestor. So, as I told that quenching diameter is basically is proportional to the flame thickness that means the flame thickness will be higher than what will happen d q will be higher. If it is a smaller, then that will be the quenching diameter will be smaller.

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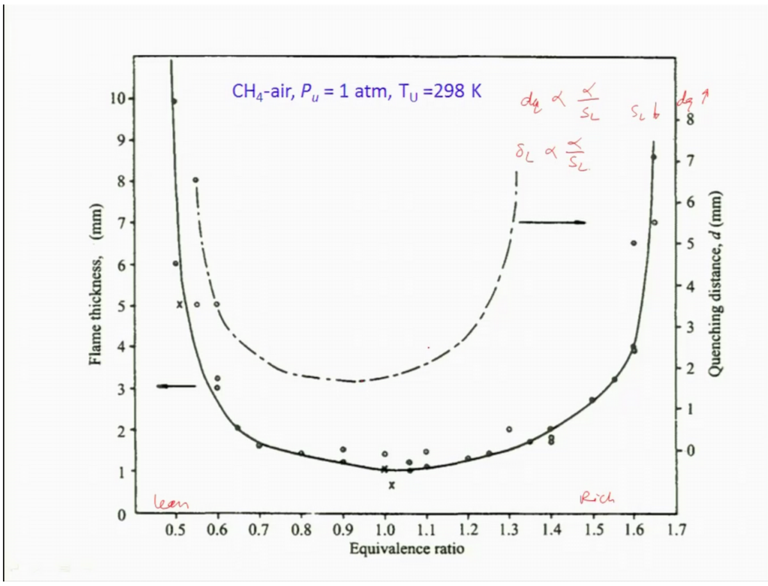

So, let us look at some experimental data, for that if you look at this is the flame thickness right, and this is quenching diameter, and this is verses equivalence ratio. If you look at this is happening, you know equivalence ratio one around are this range right, there is a little shift, but it is having minimum quenching diameter right. As you go towards the reach mixtures right. And the lean mixtures, this is the lean side. This is the reach mixtures side that means, the quenching diameter increases, why laminar burning velocity is basically decreasing, so because of fact that this d q is inversely proportional to basically alpha by S L.

So, S L is decreasing means, d q will go up right. And keep in mind that the your flame thickness is similar in nature flame thickness is increasing towards the both the rich and the lean mixture, because we have seen delta L is proportional to alpha by S L right. So, therefore it is the similar to that the quenching diameter is similar to the flame thickness the in ok. So, this is very important point, what do we need to look at it. And we will be in the next lecture, we will be looking at flammability limits right. And then we will stop over here ok.

Thank you.