Fundamentals of Combustion (Part 2)
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Lecture – 47
Laminar Flame Theory for Premixed Flames (Contd..)

Let us start this lecture with a thought process from Benjamin Franklin.

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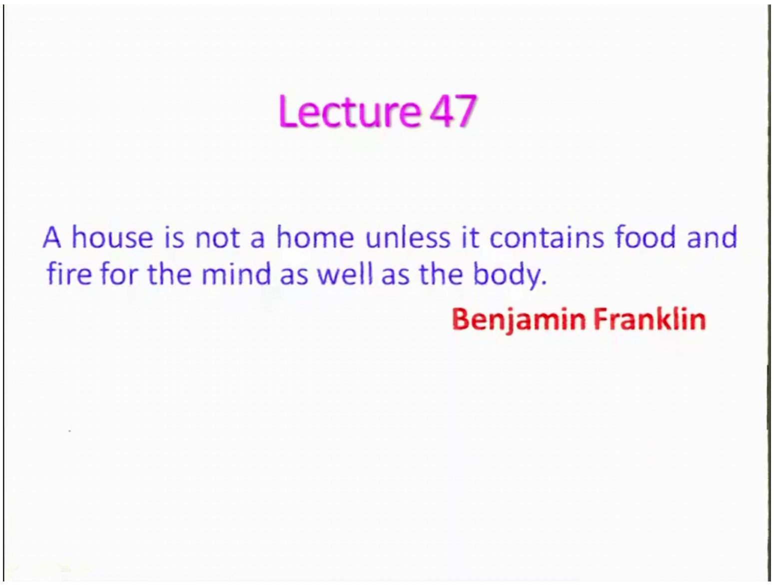

Who says, a house is not a home, unless it contains food and fire for the mind as well as the body; which is quite true and commensurate with the thought process of Indian scriptures. And let us recall what we learnt, in the last lecture we are trying to derive a relationship for burning velocity and in that we invoke basically all the equations of conservation of mass, momentum and energy and spaces. But we looked at the basically the energy equation and mass conservation.

And we have also found that momentum conservation equation need not to taken for 1 dimensional steady flow. Because it is a change in pressure is approximately equal to 0. And if you look at I had derived expression for energy.

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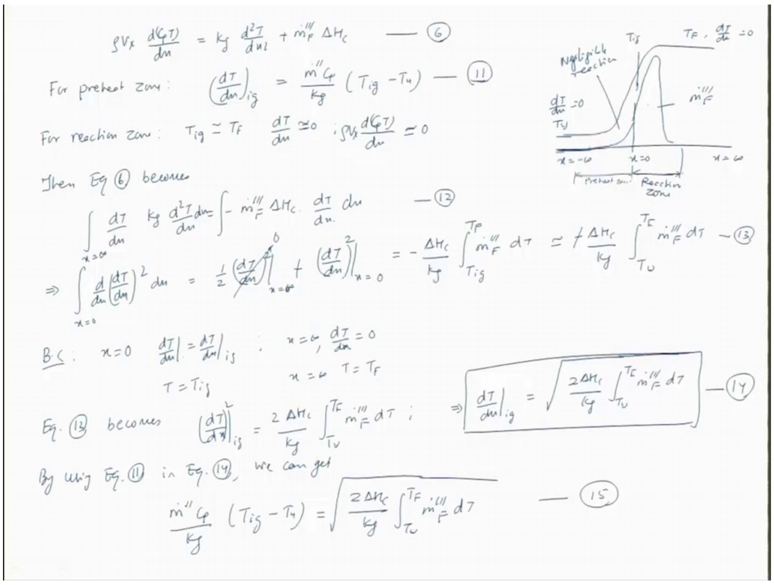

And that is basically rho V x d C p t by dx is equal to k g dT square by dx square plus m dot triple dash F delta H c. This I had mentioned as equation number 6. So, later on what we did? We basically looked at the for the preheat zone. In the case of preheat zone, the reaction rate is 0.

So, therefore, we neglect the reaction rate or the heat release rate. And then we applied the boundary condition arrive at this expression; that is dT by dx ignition is equal to m dot double dash C p by kg into T ignition minus T u. I had given equation 11; if I have not given you can take this as a equation number 11, right to be consistent. Now for the reaction zone we will have to consider, for reaction zone as the name indicates reaction zone means you know reaction will be very important.

And conduction also will be important then which term will be not important, what can be approximately any idea? Let us draw a temperature profile and this is my what we call let us say this is my T ignition. This is T F, this is T u. And this is basically x is equal to 0; x is equal to infinity, minus infinity.

And this is my reaction rate you can say F right. And we know that dT by dx is equal to 0 here. And similarly dT by dx is equal to 0. These are the boundary condition what we have seen. In the reaction zone you can see that T and which is your reaction zone? This portion is your reaction zone right. And this portion is your preheat zone. We have already discussed this, I am just repeating it. So, in the reaction zone, T ig is approximately a closer I can say to T F right.

So, therefore, I can write down dT by dx is equal to 0, approximately right this is not exactly. And this is again an approximation ok. As a result, we can say that C p by T dx rho V x is approximately 0 right. Then equation 6 becomes kg dT square by dx is equal to minus F delta H c and we will have to basically integrate this equation right. This I can say as equation 12. What I will do? I will just multiply by dT by dx here, dT by dx here right.

And I will have to integrate this equation. So, I can say this is dx, dx. So, therefore, I can write down here as dT by dx whole square right d by dx, dx and this is equal to basically what? x is equal to 0 to x is equal to infinity, right. And similarly here and that itself I can write down basically half dT by dx x is equal to 0 minus dT by dx x is equal to infinity, right, is if you look at sorry, this will be infinity and this will be 0.

And by using the boundary condition, if you look at the boundary condition is basically, what is that? x is equal to 0; dT by dx at is equal to dT by dx at ignition right. And x is equal to infinity or I can write down here x is equal to infinity; dT by dx is equal to 0, right. So, if I will use this one, x is equal to infinity this will be 0, right. Yes or no? And we will I will take now the right hand side, right hand side is basically I can say that is delta H c by k g ok. I have taken k g from left hand side to right hand side in the equation 12.

And that is triple dash F integration dT; this is basically T ig right at x is equal to 0 T is equal to T ig and x is equal to infinity T is equal to what? T F, right yes or no? Make sense? And because the and if you look at the whole reaction rate from this region this is the portion of things, reaction rate which is negligible. Instead of integrating from T ignition to T F, I can write down as approximately equal to delta H c by k g T u by T F m dot triple dash f dT. Can I write down this? Because I am saying this is very small quantities as compared to this reaction rate. This is the major one right.

So, therefore, instead of taking from here I can take from there. This is very important this thing you should keep in mind, ok. Are you getting? These are negligible. So, instead of say I can take from here to there from the T u to the T F or the x minus infinity to x is equal to infinity I can say.

Student: By F, how can you say negligible?

Because if you look at the area right because this area is very, very small, and it is why it is so? I will come to later on, but let us also we can discuss now; that is, if you look at activation energy, right E by R U T, we will be discussing that. Unless the temperature is having that higher, you cannot have any term from that. So, therefore, this will be very small term. But however, it will be finite, it is not that exactly 0, it will be approximately 0 or it is as compared to the heat release in the reaction zone is very, very what you call higher in the heat release rate at the reaction zone is much higher as compared to the heat release in the preheat zone that is the thing we have already discussed right.

So, therefore, I am saying instead of taking this T ignition to T ignition to T F integrating I can say that. Making sense? Ok. So now, this if you look at and keep in mind that I can cancel also this minus sign, right then I can say let me tell you this is 13. The by equation 13 becomes right, I am just rewriting that equation that is all, dT by dx ignition is equal to right delta H c 2 delta H c, there is a little problem like 2 square this will be square, delta H c by k g T u by T F m dot triple dash F dT.

So, I can write down this as dT by dx ignition right; is equal to root over 2 delta H c by k g T u by T F m dot triple dash F dT right. This is I am saying equation 14. Now, we have already derived this you know expression for temperature gradient at x is equal to 0 or ignition point right. You can see the equation 11 right. By using.

Student: Equation number.

Equation number 11 right, in equation 14, we can get C p by k g T ignition minus T u is equal to root over 2 delta H c by k g integrated T u by T F triple dash F dT right.

So, I can say this is basically equation 15 kind of things. What we will do now? We will have to now basically invoke the continuity equation right, because here the mass flux is there, that mass flux is equal to basically rho u S L. Why we are doing? Because we want to find out a relationship for burning velocity that is S L right. S L means basically burning velocity for laminar flame, laminar premix plane.

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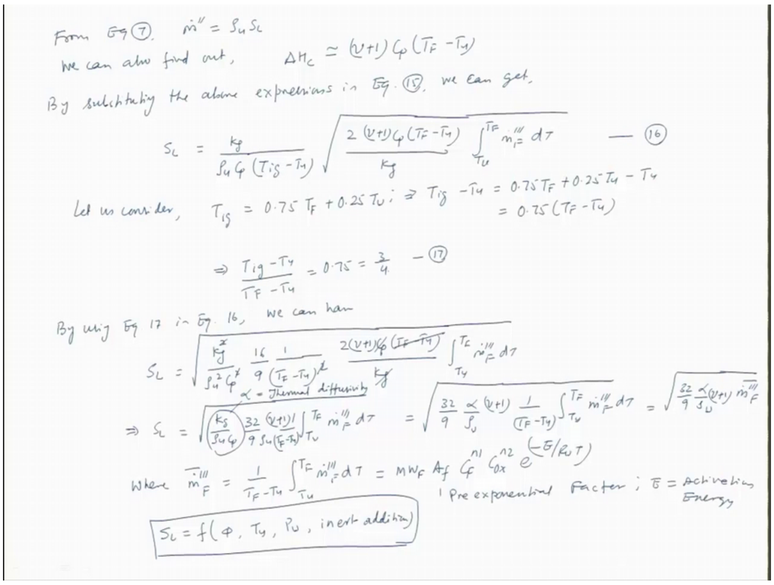

So, from equation 7 right that is the continuity equation, we know that m dot double dash is equal to rho u S L right. And we can also derive, we can also find out delta H c is approximately equal to nu plus 1 C p T F minus T u right. That I think I have given as an assignment you can do that it is a very simple thing right.

So, by using by substituting the above expressions in equation 15, we can get S L is basically is equal to kg by rho u C p T ig minus T u right root over 2 nu plus 1 C p T F minus T u, divided by k g T u T F dT, is it fine?

Now, keep in mind let me tell this is 16. Keep in mind that this we will have to simplify little further also right. I can say that I can assume that T F, let us consider the T F is equal to 0.75. Let us consider T ignition as 0 point T F plus 0.25 T u. I can write down this as T ig minus T u is equal to 0.75 T F plus 0.25 Tu minus T u; which is nothing but your 0.75 T F minus T u right. So, by that I can write down that T ig minus T u divided by T F minus T u is equal to 0.75 is equal to 3 by 4. This is an again an approximation because I want to relate the T ignition with the T F and T u, right.

So, if you substitute these values in equation 6, 16, right. So, I can say this is 17. Using equation 17 and equation 16, we can have S L. What I am doing in this expression? Basically, I am taking this term right into the root. What I will get is basically, k g square into rho u square C p square right. In place of T ignition and T u, I will be putting basically 16 by 9 1 over that is T F minus T u whole square right and 2 nu plus 1 C p T F minus T u k g T u T F m dot F dT.

Now, these will cancel it out, kg will cancel it out, C p will cancel it out right. So, I can write down that as S L is equal to basically k g by rho u C p I can write down 32 by 9.

Student: Why sir?

Just hold on, I am coming, nu plus 1 right and rho u T u T F m dot F dT. Keep in mind that these I will be considering as a alpha. What is alpha? Thermal diffusivity, I must also tell that k g will be evaluated at the average temperature right, kind of things which will take an example and do, but T u will be evaluated at the ambient inlet temperature, right and C p will be evaluated at the average temperature. I will take an example to illustrate that point right. So, I can write down this as alpha.

Student: T F minus T u.

Yes, yes you are right. I will consider this as basically 32 by 9 alpha by rho nu plus 1, right 1 over T F minus T u T u by T F F dT. Keep in mind that this I can write down as 32 by 9 alpha rho nu plus 1 m triple dash F average. So, where the triple dash F average is equal to what is that? 1 by T F minus T u T u T F m dot triple dash F dT is equal to basically M W F A f C F n 1 C oxidizer n 2 e power to the R u T, right.

And this is from the Arrhenius relationship. I can say this portion the average mask conjunction of fuel per unit volume is nothing but that right. And if you look at we can get this you know A f is your pre exponential factor. And C F is the concentration of fuel, C oxidizer is the constant oxidizer, E is the activation energy, R u is the universal gas constant, T the temperature, right.

So, from these what you can get is basically S L is a function of what? What is its function? It is function of basically phi or the fuel air ratio or the right. Because nu is coming, nu is the nu you know, like 1 mole of fuel is reacting with nu moles of oxidizer going to the product of nu plus 1 of product ok.

So, therefore, the equivalence ratio comes over there. And it is also a function of T u, because rho u is there, this is you can say rho u, right rho u and it is also a function of P u; unburnt pressure right. Of course, in this case pressure is remaining almost constant right. And it is also you know depending on the inert addition. Like suppose, you are replacing nitrogen with argon or helium or other things.

So, these are the things which we will get from the simple you know expression and which will be looking at particularly looking at the considering the experimental data later on. And in the next lecture, I will be taking an example how to calculate the burning velocity.

Thank you very much.