Fundamentals of Combustion (Part 2)

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Lecture – 49
Flame Thickness and Burning Velocity Measurement Method

Let us start this lecture with the thought process.

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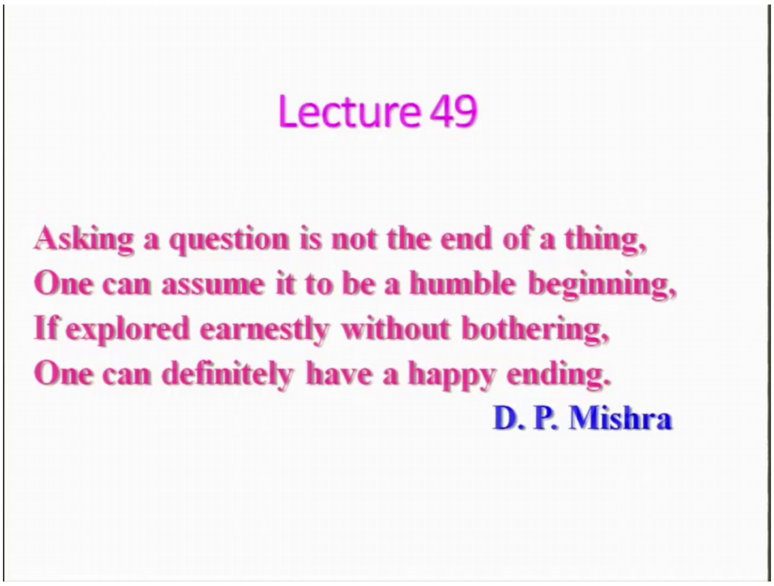

Asking question is not the end of a thing, one can assume it to be a humble beginning, if explored earnestly without bothering, one can definitely have a happy ending. So, in the last lecture we have learnt how to evaluate the burning velocity by making a lot of assumptions and also will have to evaluate the properties properly, otherwise you will land in getting some number which is having not much meaning right.

But today we will be trying to look at and the flame thickness and relate and also try to relate that to the burning velocity. So, later on in this lecture we will be looking at how to evaluate the burning velocity experimental right what are the methods being used generally for evaluating the burning velocity.

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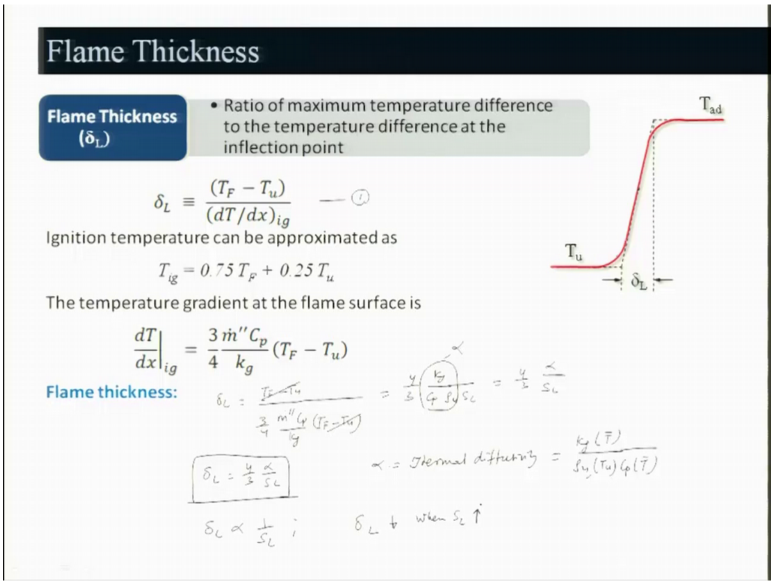

So, flame thickness if you look at is basically a ratio of the maximum temperature difference to the temperature difference at the inflection point. This basically inflection point you might be knowing that where the slope will be changing right of the temperature profile, for example, if you look at this here this is the temperature profile and we of course, will be approximating as a linear profile for our computation in actual situation there will be curvature here kind of things and the inflection point will be somewhere here.

Where the slope we changing from positive to the negative kind of things so, that we will define as the delta L is the flame thickness, this is your flame thickness I will take a tangent and then do that. So, that is nothing, but T F minus T u divided by T at the ignition we can take approximately right and T ignition is can be approximated as 0.75 T F plus 0.25 T u. So, temperature gradient at the flame surface will be we know the T ignition is nothing, but your 3 by 4 m dot double dash C p divided by K g T F minus T u these already we are seen right.

So, if I say this is equation 1 what I will do I will basically substitute these values like flame thickness. So, flame thickness I can write down this as delta L T F minus T u divided by 3 by 4 m dot C p by K g T F minus T u. So, this you can cancel it out and you can write down basically this is 4 by 3 right K g by C p and m dot double dash is nothing, but your rho u S L right and this I can consider this as alpha this is nothing, but your 4 by 3 alpha divided by S L.

So, I can write down this is equal to 4 by 3 alpha by S L and this is alpha is basically thermal diffusivity K g and this is evaluate as the average temperature rho u evaluated at T u right or I can write down add evaluated at T u and C p is evaluated as.

So, what it indicates? It indicate that flame thickness will be inversely proportional to S L burning velocity, the burning velocity will be higher the flame will be thinner and burning velocity will be lower the flame thickness will be thicker right and this flame thickness will be order of m m kind of things. And if equivalence ratio is 1 for a hydro carbon air flame right the burning velocity will be what maximum you can get, but when you will go for the lean side and the rich side you will find the burning velocity is decreasing; that means, flame became thicker towards the either the rich mixture or the rich mixture lean mixture or the rich mixtures right.

So, this kind of things will be helpful because the flame thickness is basically; depend on the burning velocities right, we will be looking at little later on that the other things like your quenching diameter and the ignition energy all can be related to the burning velocities so therefore, the burning velocity is very very important parameter in case of laminar premix flame.

So, if you look at if it is delta will be decreasing when S L delta L basically will decreases when S L increases and vice versa, because it is inversely proportional to the because the flame thickness is inversely proportional to the burning velocity. Now we will be looking at how to measure the burning laminar burning velocity, there are various methods available in the open literature; however, we will be looking at some of them.

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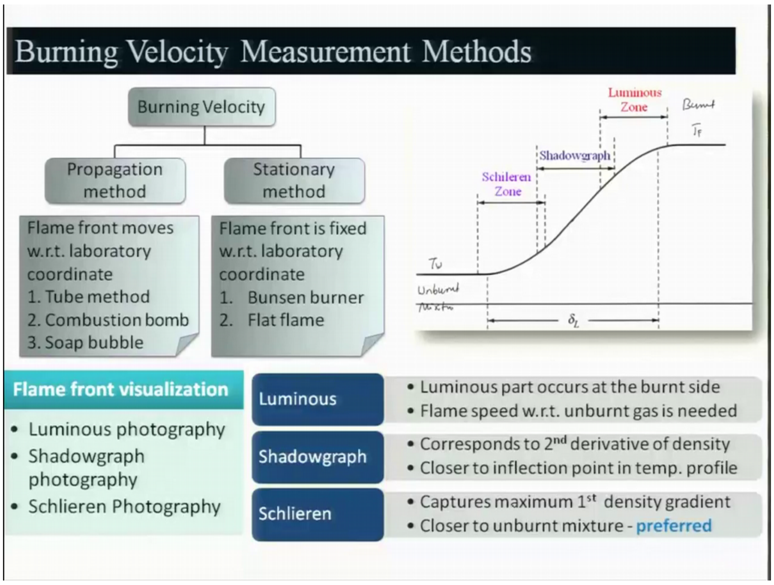

And this measurement methods for burning velocity can be broadly divided two categories one is the propagation method or when the flame will be moving at certain velocities, other is the stationary method like where the flame has to stabilize and then you measure the burning velocity.

And in the propagation method the flame front will be moving with respect to laboratory coordinate system, which is basically fixed coordinate system and there are three of them which will be discussing one is tube method the combustion bomb method and the soap bubble method right and stationary method there will be also two of them like Bunsen burner and the flat flame burner right, there will be several other things also and in this case also flame front is fixed to the with respect to laboratory flame.

So,, but question arises all these in the case of propagation method and also in the stationary method will have to identify the flame surface right for that three methods are being used one is luminous photography, which we directly take and then because of colour you will get a shape of the flame photograph, other is shadowgraph where you will be using some technique shadowgraph which you might have use in a fluid mechanics and Schlieren photography.

And if you look at this if I take this a flame thickness flame zone will be in this region in the initial with respect to basically if you consider this is T u and this is T F and shadowgraph in between right and whereas, the luminous zone in the higher temperature zone where; the luminous photography will be coming.

So, luminous part occurs at the burnt side as I told and flame speed with respect to unburnt gas is required so therefore, some correction has to be done, because always we define the burning velocity with respect to the unburnt mixture because this is your unburnt mixture right and this is burnt side.

And shadowgraph correspond to second derivative of the density because if it changing temperature is changing so also the density will be changing. So, closure to the inflection point like somewhere here right so where the slope will be changing.

And Schlieren capture the maximum first density of the gradient and closer to the unburnt mixture therefore, it is more preferred will because you need not do any correction it is just basically with respect to the unburnt mixture and which is according to the definition of the burning; laminar burning velocity, but however, for the optical systems and other things are very you know cumbersome in case of Schlieren people generally go for the luminous kind of things is if because easier to do that and also it capture the flame because flame will be not in this region because no reactions will be taken this is coming under pre heat zone Schlieren right. So, therefore, there is a confusion but generally people go for luminous images more and some people go for Schlieren also.

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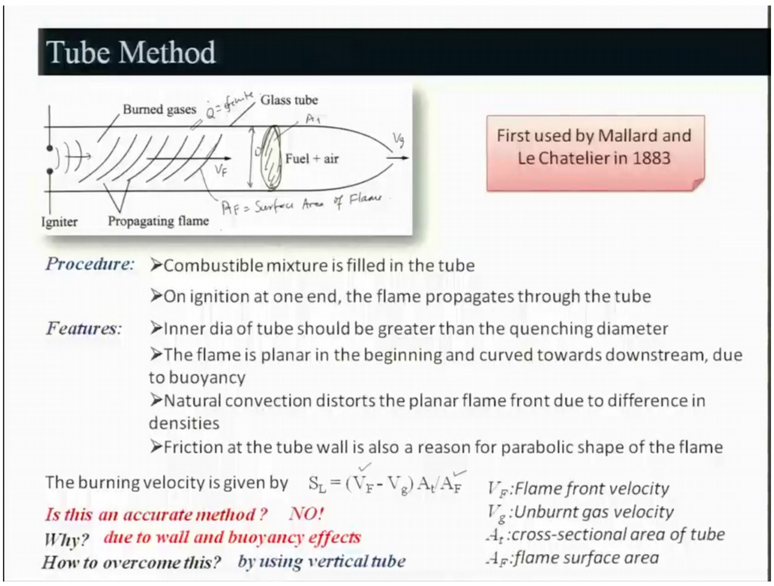

Let us look at a tube method what you can do? Tube it is a horizontal tube which a you feel with the fuel oxidizer mixture to start with and then of course, there is a some kind of nozzle you can say through which the you know mixture can move when the flame front is moving right.

So, when you ignite the there will be a kernel right small one will becoming then it will be growing it will be moving in the direction, after that it takes some certain shapes right and this need not to be one dimensional basically it is a two dimensional why because of there will be some buoyancy effect as a result the flame takes a different cell. And; and this was basically developed by Mallard and Le Chaterlier in 1883 and they have also given the thermal theory which we have already discuss that, but it is little modified version than the Mallard and Le Chaterlier later on it was modified that we have discuss for finding out expression for laminar burning velocity.

So, what will have to do basically combustible mixture is filled in the tube and on ignition at one end flame propagates through the tube and keep in mind that you know the diameter, this if you look at this is the diameter these diameter should be greater than the quenching diameter you might be asking question what do you mean by quenching? As the name indicate that if the diameter is small then heat losses will be very high if heat losses is higher than the heat release then flame will be quench it own propagate.

So, that diameter, inner diameter should be greater than quenching diameter generally; what happened around 50 m m diameter is being used, because it little bit 2 bit then what will happen buoyancy effect will be much higher, because even though arisen really some of the gasses will be having higher lower density then it will go up and the flame will be distorted.

So, that also has to be taken care and the flame is planar at the beginning and curved towards downstream due to the buoyancy effect as I this I have already discuss. So,; and if the diameter is larger then the natural convection distorts the planar flame front due to difference in densities of the mixture right. And of course, the friction at the tube wall is also a reason for something parabolic shape that is another reason because there will be some heat loses and also the friction between both the actually wall of the tubes so, that will make the shape of the flame to a parabolic.

The burning velocity you can write down basically S L is equal to V F minus V g right V F is this one flame front movement and V g will be some gas will be going out because of the flame front then there will be some expansion of gas, expansion will be trying to push some gas out and this is V F is the flame front velocity and V g the unburnt gas velocity through this which will becoming A t is the cross sectional area of tube.

So, if you look at this is we have; A t and A F is the flame surface area if you look at this area will be flame surface area right. And this area you which will be getting from the flame photograph right, basically that you will be measuring rest and also V F you can measure by locating the flame and then you know taking with the respect to time then you can find out what is the L and then how much it has move?

So, V F we can find out this is from the experiment will have to finding out, these and this is already known tube and V g you will be also estimating like how much gas is going out, that is little difficult to evaluate right what you can do you can also put some balloon and see that how much it is going out this measurement of V g is not that easy and sometimes you can neglect that also and then approximately you can measure.

So, therefore, if you know this V F and V g A t of course, it known already because you have taken the proper tube so you can estimate the burning velocity by this method laminar burning velocity of flame. And this is not a very accurate method because there is a lot of involvement, but is the simplest method one can think of so therefore, it is being used to the to estimate the you know laminar burning velocity. And this is as I told like this is basically there will be heat losses from the wall right there will be some heat loses it is some finite values right and also the buoyancy effect will be there which is not taken care in this formula or expression.

So, therefore, one has to be very careful about this measurement system to how to overcome this problem, but you can use a vertical tube instead of that right, when you use the vertical tube then particular at the buoyancy effect would not be that it would not disturbed the flame right and it can be flame can propagate upward and flame can propagate downwards right. So, that also if it is flame is propagating downward then buoyancy effect will be coming and when you upper get you did not really worry because hot gas is already there.

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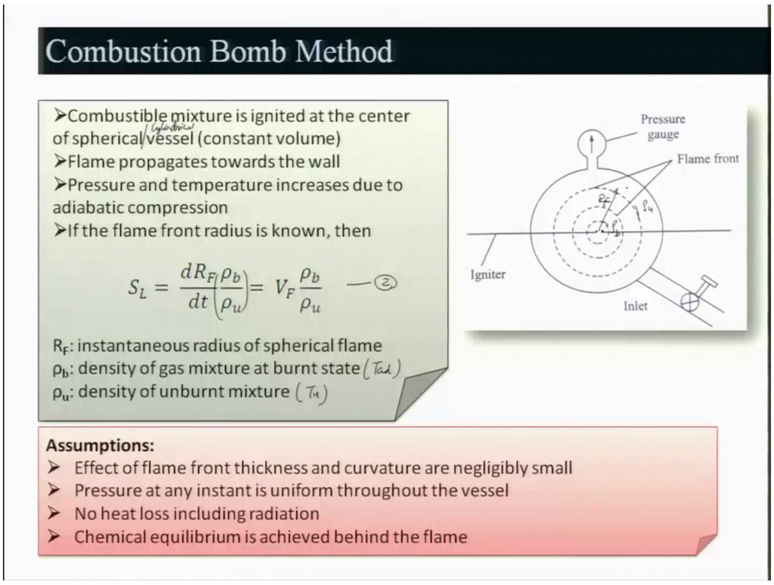

So, that as to be taken care and then the combustion bomb which is being use like you can have a; chamber you know combustion bomb where you can mix this fuel air and then ignite at the center and in this generally the flame kernel will be coming right if it is ignition and then flame front will be moving keep in mind that if the chamber is large again buoyancy effect will be coming in to picture right, but however, if it is a small then the flame front will be suffering the curvature effect because the curve it is not really one dimensional also right and some strain will be experiencing and the strain let has to be looked at that is also an error.

So, generally when it is a larger you know like you the strain effect will be reduced so you can really measure the burning velocities and you can use a cylinder you can use a spherical bomb depending on that what is the generally cylinder is more preferred than the spherical because of fabrication problem and also the strain rate in case of cylinder will be low.

So, as I told the combustible mixture is ignited with the center of spherical vessel or a constant volume or a cylindrical right and flame propagate toward the wall and pressure temperature increases due to adiabatic compression because with the flame will be moving it will be because of hot gas at the center it will be expanding right, density being lower. So, it will be compressing toward the wall when the flame front will be moving and if the flame front radius is known then you can find out basically how much the flame is moving if I take this as a center this is basically R F and I can tracked the R F with respect to time and then I will have to look at because the rho b is the at the center this is rho b and rho u will be after the you know flame front kind of thing you can say, if I am considering this as a flame then this will be rho u of the mixtures.

And keep in mind that this rho u evaluation is not that easy why? Because the it will be some heat will be transfer and it is radius and this will be so, not ambient temperature when you start the experiment right, it will be attending some values. So, therefore, this is evaluation is a very important point and of course, what temperature you will be talking about that also another thing rho b, rho b generally people consider to be there corresponding to adiabatic temperature and rho u is the unburnt, but it need not unburnt.

So, therefore, this V F d R F by d t you can get from the defining the R F with respect to time and you can measure that V F and rho b and rho u are to be evaluated to determine the laminar volume velocity.; As I told that rho b density of gas mixture burnts state generally you can evaluate at T adiabatic here and this is T u is suppose to be evaluated, but, but; however, it need not to be T u it might be little higher than the unburnt temperature.

So, assumption what is being made here that effect of flame front thickness and curvature are negligibly small, which is a assumption in this equation right. And curvature effect is negligibly small in this case and pressure at any instant is uniform throughout the vessel, that is again assumption being made no heat loss including radiation which is not real the case, but it should be particularly when the flame front will be moving towards the wall heat loss will be definitely there, but when the flame front in the middle of the this thing, then you can say flame is far away heat loss will be not that much and then generally flame will be moving at certain velocity.

So, therefore, it is a very fast process than the whatever heat loss could occur and chemical equilibrium a achieved behind the flame which you need not to be the case, because this is a very fast process right these are the assumption being made for this.

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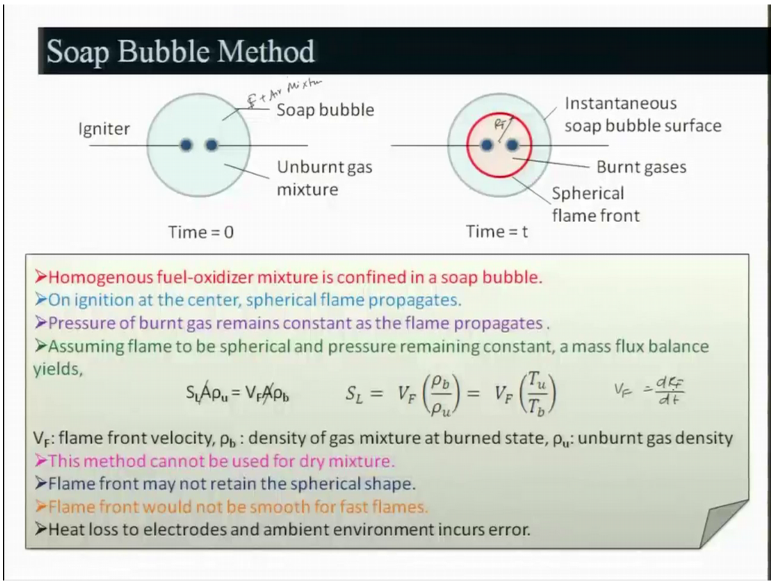

So, soap bubble what is being done basically this is the soap bubble right, this is the fuel plus air mixture in a soap bubble and if you look at is the igniter this unburnt mixtures and at the time t when you ignite certain time the flame will be moving in front and towards that and then you will have to track this flame and look at it. So, this is you can assume it to be spherical flame front and this is the of course, the when flame will move it may go little expand also soap bubble surface, instantaneous flame surface.

So, homogeneous fuel air mixture is confined in a soap bubble on ignition at the center spherical flame propagates and pressure of burnt gas remains constant as the flame propagates, assuming flame to be spherical and pressure remain constant mass flux you can say S L is equal to A rho u V F in to A and this A is cancel it out. So, you will get basically S L is equal to V F rho b by rho u and V F you can evaluate basically in the similar way this is your R F and V F is nothing, but d R F by d t you track that values and then find out.

So, this method cannot be used for dry mixtures, because when you are using soap bubble there will be a some kind of a water coming in to picture because you will be putting in to that and a flame front may not retain the spherical shape and flame front would not be smooth for the first flames right and heat loss to the electrode and ambient environment also incur error right.

So, this is a thing and with this we will stop over here. In the next lecture, we will be taking discussing about mole methods, how to evaluate the laminar burning velocity?

Thank you very much.