**Fundamentals of Combustion (Part 2)**

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**Lecture – 67**
**Droplet Combustion (Contd.)**

Let us start this lecture with a thought process from Mahatma Gandhi, the best way to find yourself is to lose yourself in the service of others and which is not we are which is not being followed today by majority of people. So, let us recall, what we learnt in the last lecture basically, we are trying to analyze the one dimensional spherical droplet under (Refer Time: 00:41) atmosphere and we have derived the relationship considering or eliminating the source term considering the both the fuel and the temperature or the energy equation and there, we have already once integrated and if you look at, we get this equation D, can be rewritten as.

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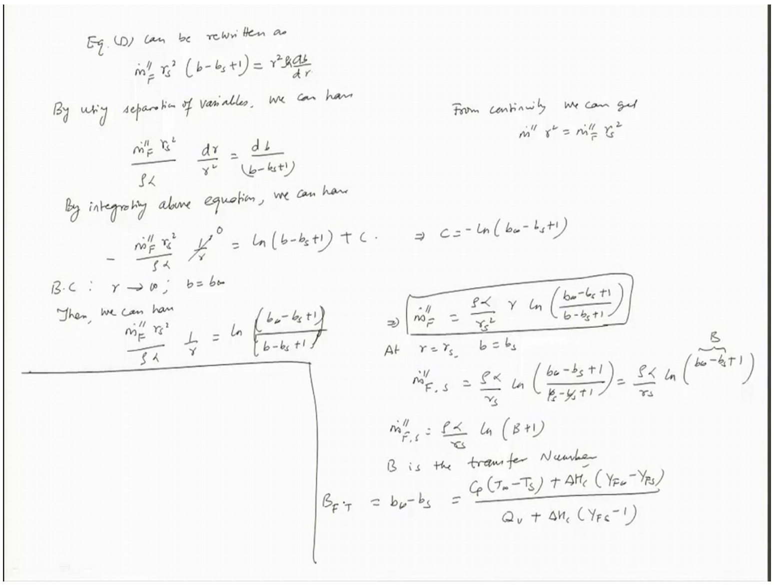


Equation D can be rewritten as r s square b minus b s plus 1 is equal to r square rho dv by dr.

So, if I can separate the variables and then we can integrate it by using separation of variables, we can have r s square by there should be alpha right rho alpha is d r by r square is equal to db by b minus b s plus 1 right.

If you look at continuity equation from continuity, we can get mass flux of r s square is nothing, but your F r s square; that means, whatever the mass is being generated at the surface of the droplet will be conserved across, the along with the radial direction. So, that way we can use that, is that make sense.

So, you would do that then we can integrate the above equation, we can have alpha 1 by r it will minus is equal to ln b b s plus 1 plus c and we will have to apply the boundary condition that boundary condition, we are having r is tending towards infinity b is equal to b infinite; that means, in this equation right if r is equal to infinity, what is happening? This is basically 0 this will be 0 right and c will be what then? C will be then ln minus it will be b infinity minus b s plus 1.

So, then we can have that basically m then, we can have 1 by r is equal to ln b infinity b s plus 1 divided by the I can make it this bracket bs plus 1, in other words you can write it down basically as, F is equal to rho alpha, if I take that rho alpha by rs square r ln b s plus 1 b minus b s plus 1.

So, we will have to now apply a boundary condition again right at r is equal to rs, what is that? That is basically b is equal to b s right. So, if you put that thing here right, I can get simplify this one right m dot F because I want to find out, what is the mass flux at the surface? Because, this is a general term right, this is a mass flux at different r any r you can have, but you want to find out mass flux f s right at the r what it would be it will be rho alpha by r s ln by v s plus 1 and this will be basically 1, because b become b s minus b s plus 1 this is 0. So, this is nothing, but your alpha by r s ln b infinity minus b s plus 1 right this much you are getting.

So, keep in mind that, this is I can say this is basically, I can write down that mass flux right F, I can write down that as a surface is nothing, but your alpha by r s ln B plus 1, because this itself, I can take B right and B is basically is the transfer number, which can be estimated using various expression right. For example, if I say B F T right, we have basically considered B F T it can be extended for any other thing that is nothing, but your b infinity minus b s which is nothing, but your Cp T infinity minus Ts plus delta HC Y F infinity minus YF s at the surface right divided by Q v plus delta H C Y F s minus 1. And similar expression you can get for b fuel oxidizer and your oxidizer and temperature. So, you keep in mind that this thing is known like delta HC will be known to you Y F infinity will be known right.

What will be Y F infinity? Will be 0 right and Y F S at the surface you need to find it out right and how you will find out that is a very important one right and of course, you should know the surface temperature T infinity always you will be known and Q v is heat of vaporization we will have to evaluate already we have looked at the formula for Q v and all these things, if you know then you can get the BFT and if you know this rho and alpha and then r s will be known to you can find out mass flux consumption, how much mass is being consumed or being vaporized during the combustion process right.

And let us see how we can really get this; how we will get this T s and YF s? That is the very important question one has to ask right and for that of course, the simplest way of doing is that you can take look, you can take the tea boiling, but you know then and then do that.

But there is also another way of doing it what we can do? We can basically estimate that b we need to know either this T s if I know T s, I can find out Y F s right and if I know the partial pressure also I can find it out that and for these purposes, what we will be doing we will be using this various this transfer number and then all transfer number will be same then, we can simplify.

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## Liquid Fuel Combustion (Contd.)

The transfer number, B is given by

$$B_{F,T} = \frac{C_P(T_\infty - T_s) + \Delta H_C(Y_{F\infty} - Y_{Fs})}{Q_V + \Delta H_C(Y_{Fs} - 1)}$$

$$B_{Ox,T} = \frac{C_P(T_\infty - T_s) + \Delta H_C(Y_{Ox,\infty} - Y_{Ox,s})f}{Q_V + f\Delta H_C(Y_{Ox,s})}$$

$$B_{F,Ox} = \frac{(Y_{F,\infty} - Y_{F,s}) + (Y_{Ox,s} - Y_{Ox,\infty})f}{(Y_{F,s} - 1) + f(Y_{Ox,s})}$$

Values of transfer number, B for some typical fuel:

| Combustion in air | B | Combustion in air | B |
|---|---|---|---|
| Iso-octane | 6.41 | Kerosene | 3.4 |
| Benzene | 5.97 | Gas oil | 2.5 |
| n-Heptane | 5.82 | Light fuel oil | 2.0 |
| Avation gasoline | 5.5 | Heavy fuel oil | 1.7 |
| Automobile gasoline | 5.3 | | |

Let me talk about this transfer number as I told this transfer number is the given by B is equal this thing right already being discussed and then BO x t will be given like this and this is BF Ox right and. Values of typical transfer number B for typical fuel is given right, something Iso-octane 6.41 benzene then heptane all those datas are given and kerosene gas oil light fuel, all those are you can see that octane is a little higher number and then this is 1.7, keep in mind that this is in the logarithm.

So, therefore, changes in this transfer number would not really affect the mass burning very much right. So, we will be seeing that, but now question arises how we can basically estimate properties at the surface? Like YFS and TS that is the thing we will be doing that.

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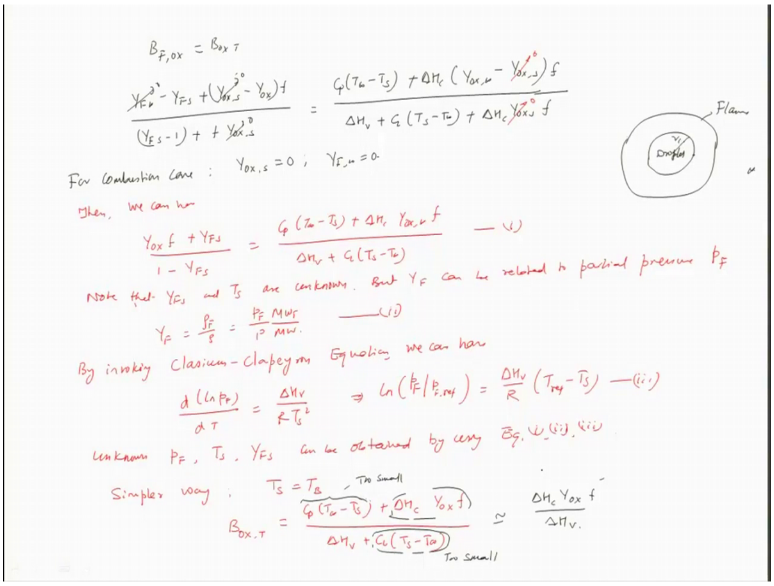


So, for that estimating this, what will be considering B the transfer number of F and oxidizer is equal to p oxidizer and T right and if you look at that I can say that in the combustion case right.

We will be considering, where it is combusting, but let us let me write down the equation over here that is F O x is nothing, but your Y F infinity minus Y F s plus Y oxygen at the surface minus Y oxygen f right divided by the YF s minus 1 plus F Y oxygen s is equal to C p oxygen and temperature we are talking about T infinity minus T s delta H C Y oxygen infinity minus Y oxygen s into f H v and in the in place of Q l I am just writing the full term now, T s minus T infinity plus delta H C Y oxygen s f right.

So, at the for combustion case keep in mind that, these transfer numbers are valid for vaporization and combustion, for combustion case what is that? That is basically Y oxygen at the surface of the droplet, what it would be? It will be 0 right at the surface of the droplet; you know if you take a droplet right and there is a flame here. So, at the surface what will be this will be oxidant cannot be penetrate into the through the flame. So, therefore, this will be 0 at the surface right if I say this is r s. So, this will be 0 and if it is far away let say some infinity what will be the fuel? F infinity will be 0. So, if that is the case I can say this is 0 right oxygen at the surface it is 0 right and similarly Y F s Y oxygen s will be 0 right and Y oxygen at the surface this will be 0 right.

If you do that, what I will get then? We can have Y oxidizer F plus Y F s divided by 1 minus Y F s right from this side left hand side then I will get Cp T infinity minus Ts plus delta H C Y oxygen infinity f divided by of course, I can write down this is basically this will be oxygen at the surface this will be 0 right. So, I will be getting delta H v plus C l T s minus T infinity.

So, this is let say equation, I am saying i right and then if you look at I need to find out this Y F s and Y F s and T s are unknown two are unknown right, Y F s and T s are unknown. So, what I will do? I will basically Y F can be related as. Note that Y F s and T s are unknown, but YF can be related to partial pressure, pressure PF partial pressure right. So, YF we know is nothing, but your rho F by rho is nothing, but your P F by P molecular rate of fuel divided by molecular rate missed right.

So, then you know still we have not solved. So, what we will have to do? We will have to basically use the, you know relate this partial pressure with respect to what temperature? And for that we will have to invoke the Clausius Clapeyron equation by invoking Clausius Clapeyron equation, we can have ln P f dT is equal to delta H v by R T s square right.

So, you can get this thing very easily that is ln P F by P F reference right, some reference you will take reference is equal to delta Hv by R into T reference minus Ts. So, this is 3. So, all these 3 equation can be solved because 3 are unknown right and therefore, you can get those things right very easily because, what are the unknowns here? Unknowns are P F right partial pressure and Ts and then your basically Y F s by solving these all 3 equation can be obtained by using equation i, i 2 and i 3 right.

And, but generally for the simpler way to do is that simpler way, you take T s is equal to T B boiling right and then it will be very easier thing to do right, kind of things and keep in mind that, this we will be doing basically, this a thing and the another thing I would like to also draw your attention that if you let us say, if I will take Bo x T right is nothing, but your C p T infinity minus Ts plus delta H C Y Oxy for the surface I can look at this term right delta H C into f is equal to delta H v plus C L T s minus T infinity right.

So, if you look at this term, this term in the minute is too small compared to what? As compared to delta H v so, you can neglect it right, similarly this term that enthalpy change is also too small as compared to heat release, because that will be what is that T infinity to Ts will be very very small because, heat release will be much higher. So, this is also too small as compared to this term right, see always comparison.

And then I can say this is basically delta H C Y f into delta Hv, which is very easier to find out, because all are known. See we were eliminating lot of thing, Y oxidizer you will be knowing, f you know delta s you know delta H, we know are you getting this is of course, approximation you will be. So, now, we will stop over here and we will be discussing about, how we can use this relationship for finding out basically burning rate and droplet diameter, how does the diameter of the droplet is changing with respect to time. And once, we know how to find out that then we can find out what is the droplet lifetime. That means, how much time it will take to completely consumed during the combustion so, that we can look at in the next lecture.