Fundamentals Of Combustion (Part 1)
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Lecture – 10
Mixture fraction calculation for diffusion flames

Let us start this lecture with a 3rd process. "Passion is the vital energy that drives the human life to true success".

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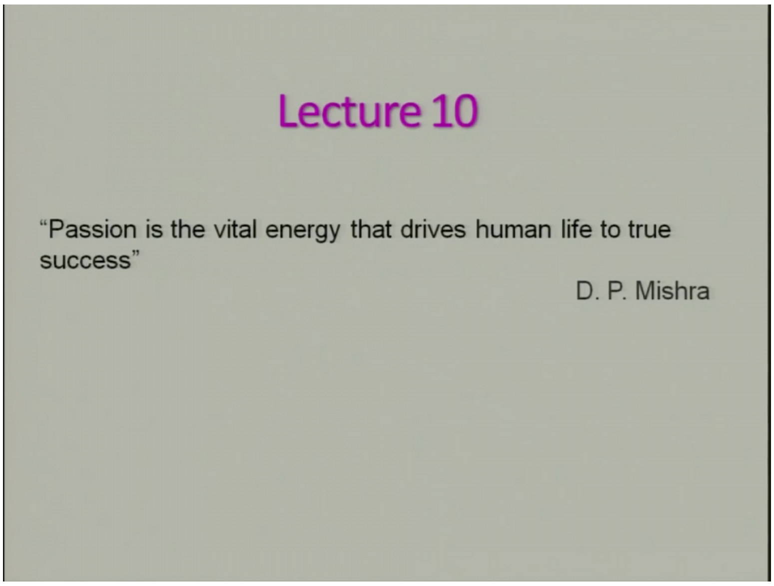

If you want to be successful you should have fire in your belly; that means passion. Are you getting?

So and let us recall what we learnt in the last lecture. We basically dealt with the Stoichiometric calculation, how to carry out a stoichiometric calculation for any kind of fuel, apart from the hydrocarbons which is a you know main fuel in petrochemical era. And as I told we had defined basically a term known as Equivalence ratio which is very useful for premixed flame.

And, so, also the percentage of stoichiometric air and percentage of excess air and we took some 1 example to illustrate how you can carry out this analysis for a generalized fuel, for any fuel as a matter of fact in a carrying out a very systematic manner; the mass balance of for each element.

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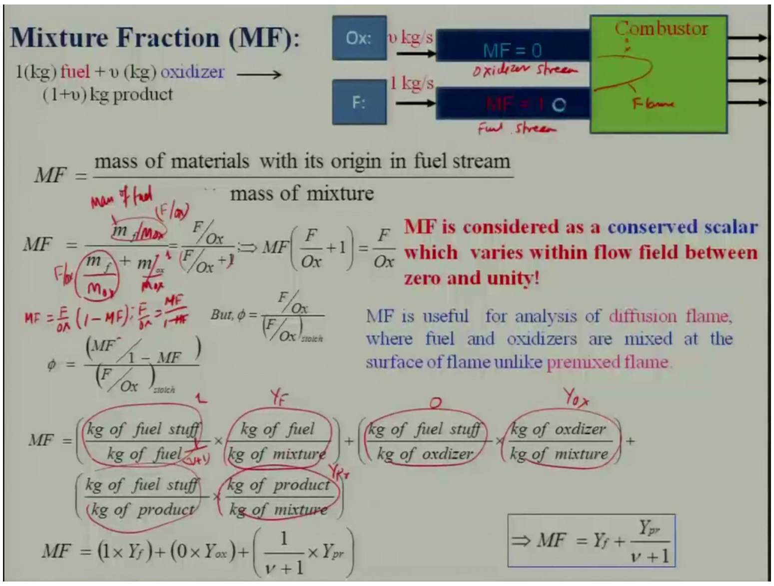

And now will be looking at how to deal with basically the diffusion flame. And for that we will be defining another term which is known as Mixture Fraction. In diffusion place flame particularly at the inlet condition people do use Equivalence ratio, but they call it as a Overall Equivalence Ratio. But that will be only at the inlet of the combustors.

For example, if I consider that there is a combustor where the 1 kg of fuel stream; this is basically a fuel stream and will be basically in the oxidizer stream. The new kg per second is flowing and it will be reacting in this combustor. And what will be the product then, if complete combustion is taking place? What will be mu plus 1 kg of product? That means, 1 kg of fuel is reacting with mu kg of oxidizer going to the product 1 plus mu kg of product.

Now, we will basically look at a definition of the mixture fraction which is nothing but mass of material with its origin in fuel stream divided by the mass of mixture. So, I can write down in mathematical form as m f divided by m f plus m oxidizer. What is this? This is basically mass of fuel and this is for mass of oxidizer m; m o x is the mass of oxidizer.

Now, if you look at for this stream, for fuel stream, what would be the oxidizer? Oxidizer will be 0; for fuel stream there is no oxidizer. Is not it? Therefore, what will be m f? m f will be 1. For oxidizer stream, what will be the fuel? It will be 0. So, therefore, the m f will be 0. Is not it? Is that clear? Yes or no? Because in the fuel stream, there is no oxidizer.

So, therefore, mixture fraction will be 1 and in the oxidizer there is no fuel. So, therefore, mixed fraction will be 0. In the combustion chamber, what will be happening? It will be between 0 and 1. So, we will be dealing with about that little more; but let us now look at that if I will divide this by, mass of oxidizer. This will basically 1. So, these we know. What is this one? This is nothing but your fuel by oxidizer. Is not it? And this is also fuel by oxidizer.

So, I can write down that is nothing but F by oxidizer divide by F by oxidizer plus 1 and I can write down this, I can take this you know to the left hand side; I can write down MF into F divided by oxidizer plus 1 is equal to F by oxidizer. Now, if I want I can express this basically F by oxidizer in terms of MF. How I will do? It is very easy. What I will do? I will be MF will be equal to F by oxidizer 1 minus MF. So, therefore, F by oxidizer will be MF divided by 1 minus MF. Yes or no?

Now, you might be wondering why I am doing, this I am rewriting the same thing; is not it? I want to relate the MF to the equivalence ratio. Because, we have already calculated that. So, we know equivalence ratio is nothing but fuel by oxidizer divided by fuel by oxidizer stoichiometric. So, what I will do in place of this F by oxidizer, I will put this expression. That will be basically phi is equal to MF divided by 1 minus M divided by fuel by oxidizer; are you getting? So, one can really relate; because if I you know MF with the equivalence ratio provided I know fuel oxidizer stoichiometric. So, these all 3, you know you can relate each other.

And let us look at little more elaborately, what is really MF? If you look at it is basically mass of material with its origin in the full stream. For example, like you know in the combustion, combustor itself inside it can be fuel will be there; product will be there; oxygen also will be there. Yes or no? In these combustors, if there is a flame here let us say, there is a flame.

That can be fuel will be there; oxidizer will be there and also the product will be there. Therefore, I need to find out what will be mixture fraction; each place you know it will be varies from place to place. For example, mixture fraction will be some values here. It may be some values here. It may be some values, different values here. Any location, it will be different; yes or no? Will it be same? It would not be.

So for that, what we will do we look at kg of fuel stuff divided by kg of fuel into kg of fuel divided by kg of mixture. Are you getting? So, plus I can look at now, kg of fuel stuff divided by kg of oxidizer into kg of oxidizer divided by kg of mixture. Now you might be thinking, in oxidizer where the fuel will be coming? Is not it?

That question might be coming in your mind or not. But in this case, it can happen. In this case where, because it will be mixing; it may be oxygen will be there and fuel will be there; all will be there in this case and another case in some situation, we need to add also some kind of fuel into oxidizer; that also can happen.

Now, into kg of fuel stuff divided by kg of product into kg of product divided by kg of mixture; are you getting? In the product definitely the, what you call fuel element will be there like carbon hydrogen; even if carbon dioxide c is there; carbon monoxide c is there.

So, kg of fuel stuff divided by kg of product into kg of product divided by kg of mixture; now, if you recognize for this example like 1 kg of fuel reacting with mu kg of oxidizer going to the mu plus 1 kg of product. In this case what will be this term; any idea, kg of fuel divided by kg of fuel? That will be 1.

What is this term; any idea? Kg of fuel divided by kg of mixture. It is mass fraction of fuel. It will be Y F. But in this example, kg of fuel stuff and the kg of oxidizer, what it would be? It will be 0 and kg of oxidizer kg of mixture is nothing but Y oxidizer. And this will be, in this case what it would be? Kg of fuel stuff divided by kg of product; what it will be? 1 divided by mu plus 1 and kg of this thing will be nothing but your Y product.

So, if I will write it down that is basically MF, 1 into Y f, the same thing I am just writing down 0 into Y x 1 divided by mu plus 1 into Y product. Because kg of fuel step is 1, 1 kg product is mu plus 1. So, that became 1 divided mu plus 1. So, therefore, MF is equal to Y f plus Y product divided by mu plus 1. Keep in mind that this mixture fraction is a very useful term; because it can be considered as a conserved scalar. What is a Conserve scalar? We will be discussing little later on. But it is a very useful term particularly for dealing with the diffusion flame.

And this MF will be varying in the flow field; particularly in the combustors not in the stream between 0 to 1 and as I told that Mixture Fraction is very useful for analysis of diffusion flame; because of fact that fuel and oxidizer in this case are not mixed as in the case of premix flame rather it is mixed at the interface of the flame. So, therefore, this will be very useful term which will be again revisiting whenever, we will be deriving you know certain equations for this and also when we are dealing with diffusion jet diffusion flame I will be discussing about this mixture fraction.

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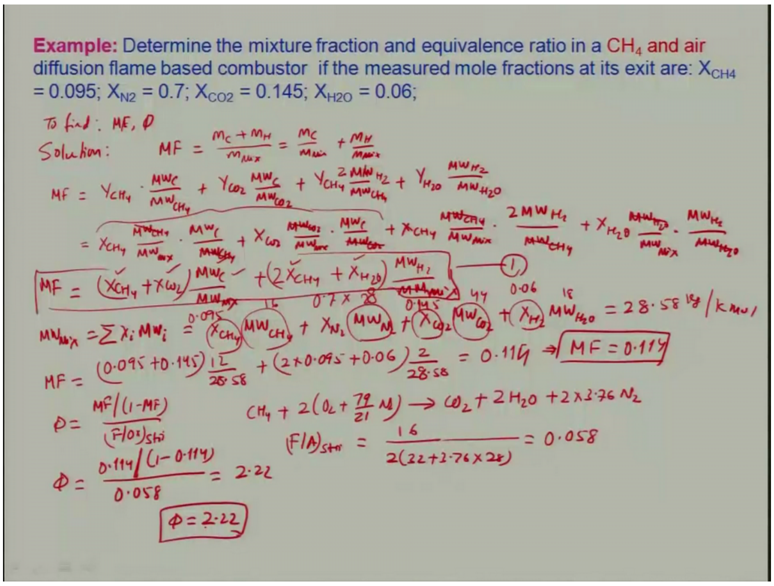

So, let us take an example. So, that things will be clear to you and we will have to determine the mixture fraction and equivalence ratio in a methane air diffusion flame based combustor. If the measured mole fraction at the exit is X CH4 0.095, X N2 that is nitrogen 0.7; X CO2 is 0.145; X water is 0.06. Now, what we need to find out? If you basically to find these are all given to find mixture fraction MF and equivalence ratio; we need to find that.

So, what we will have to do? Basically if you look at the, in the fuel stream, what it contains? In the carbon and hydrogen because is a methane. So, therefore, I can write down basically MF M C plus M H divided by M of the mixture. Are you getting my point? This very clear, is the mixture. And then MF, I can write down as for the carbon, I can write down this as M C by M mixture plus M H divided by M mixture.

Now in the carbon, I will, where the carbon is containing? Carbon in your methane, carbon in your carbon dioxide; these are 2 product which are given in which we will be calculating and for that, what we will do? We will have to basically look at Y CH 4 into M W C by M W CH4 plus we will have to look at in carbon dioxide Y CO2 MW C divided by MW CO2. Is not it?

Plus now, we will have look at M H. M H by M mixture; this portion that will be methane Y CH4 M W H divided by MW; M W H divided by CH4 plus Y water MW H MW water. Are you getting? I can say basically if you look at, I can put it as a hydrogen here and I can put it hydrogen here and keep in mind methane, it is basically 2 S2. So, therefore, I can multiply it by 2; is that clear? Please look at it, if you are having doubt, let me know.

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So, now if you look at what is given here is the mole fraction. But here, I have written mass fraction. Now, I will have to convert this mole fraction into mass fraction; what is that? That is basically X CH4 into molecular weight of CH4 divided by molecular weight of mixture into molecular weight of C divided by molecular weight of CH4 plus X CO2 molecular weight of CO2 molecular weight of mixture into molecular weight of C CO2 plus X CH4 into molecular weight of CH4 divided by molecular weight of mixture into 2 molecular weight of hydrogen divided by molecular weight of CH4 plus x water molecular weight of water weight of mixture into hydrogen molecular weight of water. Keep in mind, I can cancel this out; is not it? I can cancel this out; I can cancel this out, similar way I can cancel this out.

So, I can write down MF is equal to X CH4 plus X CO2 into M W C by M W mixture. I am clubbing this term, 2 terms plus this is hydrogen. So, X CH4 that is basically 2 right plus X water into M W hydrogen divided by M W mixture. Now I need to find out molecular weight of mixture; yes or no? Because that is not known; I know the molecular weight of hydrogen; I know this you know mole fraction of water is given. This is given this is given; this is given. X CO2 is given X CH4 is given. And of course, M W C, I know molecular weight of carbon I know, but mixture I do not know.

So, I will have to find out molecular weight of mixture, nothing but Xi into molecular weight i; i can be whatever the space is given. If you look at this is basically X CH4 molecular weight of CH_4 plus X N_2 molecular weight of N_2 plus X CO_2 molecular weight of CO_2 plus X water molecular weight of water. If you substitute these values, you will get it is something 28.58 kg per kilo mole.

You should substitute these values; these values are given, all are given. Keep in mind that or if you want I can write down maybe this is a water is basically what? 18. These values is 0.06 and this is 44 and these values is what? What is this value? Carbon dioxide. Carbon dioxide 0.145 and this is your 28 X N_2. X N_2 is 0.7 and similarly, this is your 16 and these values is 0.095. So, you will get this.

Now, if I look at this is my expression. Oh my god like this is. Let us say equation 1; what I will do? I will substitute these values molecular mixture there and other values I will get this thing, that is X if you look at 0.095 X CH_4, X CO_2 is what? 0.145 into M W C. What it would be? 12. Molecular weight of carbon will be 12 divided by 28.58 plus then, this term 2 X CH_4 2 X 2 into 0.095 plus you are having X water that is 0.06 into hydrogen; hydrogen is 2 divided by 28.58. You will substitute these values, you will get MF is basically 0.114; that means, MF is equal to 0.114.

So, now I find out MF, but I need to find out equivalence ratio. So, what is that equivalence ratio phi is equal to MF divided by 1 minus MF into fuel plus oxidizer stoichiometric; for methane air is given. So, therefore, you can find out what will be the stoichiometric ratio. So, stoichiometric, how we will find out? That is very easy; you have already done that. That is 2 plus oxygen 79 by 21 N_2 going to the carbon dioxide 2 of water plus 2 into 3.76 N_2. Is not it?

So, the fuel air stoichiometric will be what? 16 molecular weight divided by 2 into 32 plus 3.76 into 28. This happens to be 0.058. So, now, I will substitute these values phi is equal to MF; MF is equal to 0.114. This divided 1 minus 0.114 in to 0.058. So, that happens to be something 2.22. So, therefore, phi is equal to 2.22. It is a very rich mixture; you can see from here.

So, with this I will stop over here. And in the next lecture, we will be discussing about basically, how to take care of heat of reactions and heat of combustions, how to calculate all those things; we will see.

Thank you very much.