Fundamentals Of Combustion (Part 1)

Dr. D. P. Mishra
Department of Aerospace Engineering
Indian Institute of Technology, Kanpur

Lecture – 14
Adiabatic flame temperature and its effect on various parameters

Let us start this lecture with a thought process. Patriotism is a feeling of unbreakable bond with the land of your birth, which indicates your own personal sense of worth and respect for your common heritage and culture right.

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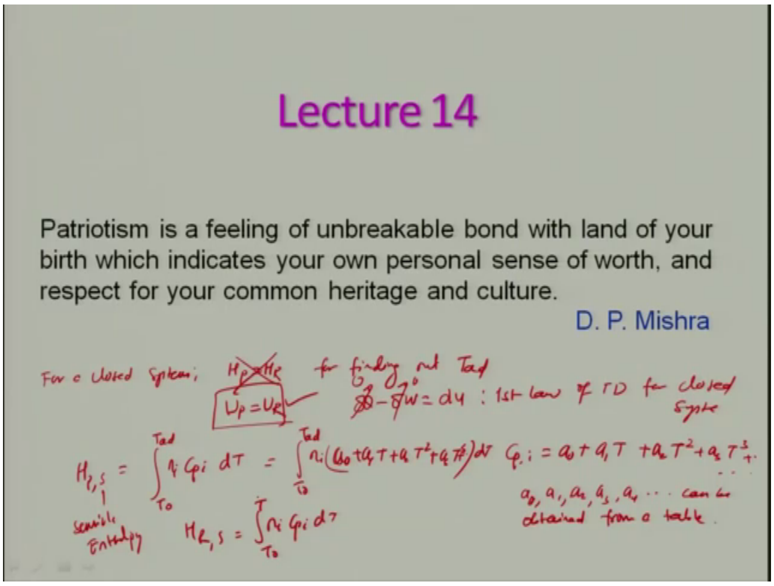

Lecture 14

Patriotism is a feeling of unbreakable bond with land of your birth which indicates your own personal sense of worth, and respect for your common heritage and culture.

D. P. Mishra

For a closed System; $\cancel{H_P = H_R}$ for finding out T_{ad}

$\boxed{U_P = U_R}$

$\cancel{\delta Q} - \delta W = dU$: 1st law of TD for closed System

$H_{P,S} = \int_{T_0}^{T_{ad}} n_i C_{pi}\, dT = \int_{T_0}^{T_{ad}} n_i (a_0 + a_1 T + a_2 T^2 + a_3 T^3)\, dT$

$C_{pi} = a_0 + a_1 T + a_2 T^2 + a_3 T^3 + \dots$

sensible Enthalpy

$H_{R,S} = \int_{T_0}^{T} n_i C_{pi}\, dT$

$a_0, a_1, a_2, a_3, a_4 \dots$ can be obtained from a table.

You please mull about it because you know like we are in the August month and is a Independence lot of work being done by our ancestors to get freedom from the British rule.

So, let us recall what we learnt in the last lecture. In the last lecture we had initiated a discussion about the how to calculate adiabatic flame temperature right and if you recall that I had asked one question right. What is that question? That question is that if it is not a flow system; that means, if it is a closed system where chemical reaction is taking place which happens to be a geothermic; that means, combustion is taking place you need to calculate the adiabatic flame temperature. How we are going to do that? Is it the same thing will do whatever we are done for the burner or a closed system that is H P is equal to H R right.

For a closed system; Can I write down H P is equal to H (Refer Time: 00:00)? H P is equal to H (Refer Time: 00:00), for finding out, for finding out T adiabatic. Can I do? Certainly no, this will be wrong this is not right. Then what it would be ? It will be.

Student: (Refer Time: 02:16)

U P is equal to U (Refer Time: 00:00), this is right. What is that U? U is basically internal energy of the product is equal to internal energy of reactant are you getting is not it. What is that? We know that delta Q minus delta W is equal to du this is your first law of thermodynamics for closed system right. So, work done is 0 is the adiabatic process that is 0 that is nothing but du, du is nothing, but U P is equal to U R product the internal energy of product is equal to internal energy of reaction ok. That is I please keep this in mind, because I have seen lot of people always say H P is equal to H R just you some of you told, but that is not true.

And beside this also we looked at in the last lecture the C p value of the product and the reactant plays a very important role to find, for finding out accurate value of the adiabatic temperature right. And what we did in that case? We have taken some average values or a constant values and calculated the adiabatic temperature in the last examples right, that is pentane, you know one mole of pentane reacting with the air and giving to the of course, excess air right if you would recall that example.

But in real situation you know we have looked at a sensible enthalpy if you look at this is C p i and i right, dT, T naught to T adiabatic right. This is your (Refer Time: 04:26) What I will do? C p is a function of temperature I need to integrate; that means, I need to find out C p basically I is a function of a naught, a 1 T plus a 2 T square plus a 3 T cube right and plus some more constant will be there. And this a naught a 1, a 2, a 3 a 4 that may some more things will be coefficients can be obtained from a table. These are data you should get and then put that thing here and then integrate it; that means, I will have to get n i, c a naught plus a 1 T plus a 2 T, T square plus a 3 T 3 squares like that it goes on right dT.

And this is of course, for what you call enthalpy of the product you can say and sensible s is for sensible enthalpy. And if I want to handle that when the reactant when it is not the same as the 298 Kelvin therefore, I will have to again take care of the sensible enthalpy of the reactant H n i, C p i dT T naught by T, T can be any temperature it may be 500, 600, 300 anything right, that way. So, that you will have to take care of that.

So, now of course, as I told that in the product side the constituents need not to be known you need to invoke the equilibrium you know condition to find out the what will be the product you know number of moles there in the products of each constituent or the products and then you can calculate. If you do that then you can use basically iterative procedure what we are going to discuss in the subsequent lecture, but if you do all those calculations then you can get a temperature data right. As I told that adiabatic temperature is a function of what? Equivalence ratio of the fuel air mixture right; And it will be a function of what? Pressure, it will be function of phi pressure initial pressure, initial temperature right.

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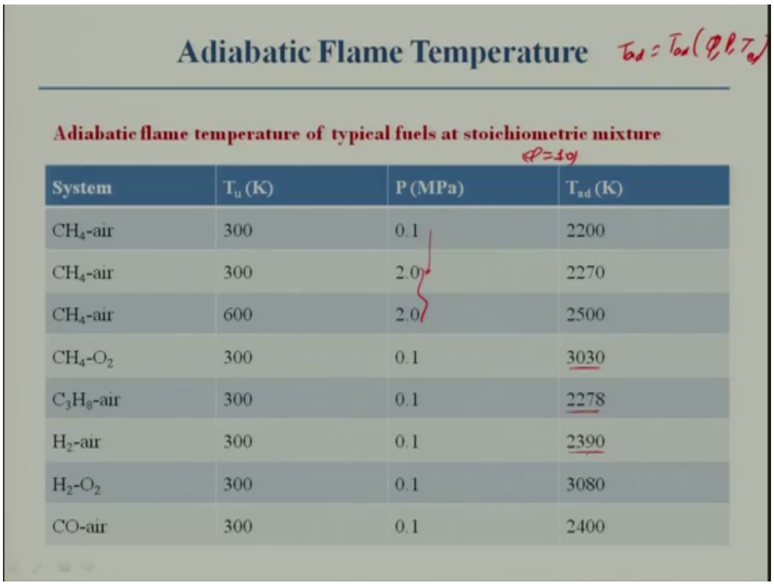

Adiabatic Flame Temperature $T_{ad} = T_{ad}(\phi, P, T_u)$

Adiabatic flame temperature of typical fuels at stoichiometric mixture

$\phi = 1.0$

System	T_u (K)	P (MPa)	T_{ad} (K)
CH_4-air	300	0.1	2200
CH_4-air	300	2.0	2270
CH_4-air	600	2.0	2500
CH_4-O_2	300	0.1	3030
C_3H_8-air	300	0.1	2278
H_2-air	300	0.1	2390
H_2-O_2	300	0.1	3080
CO-air	300	0.1	2400

So, adiabatic temperature of a typical fuel at a stoichiometric mixture what we are looking at right. This is at phi is equal to 1, stoichiometric mixture means phi is equal to 1. If you look at methane if the initial temperature is 300 Kelvin of course, I am saying 0.1 mega Pascal's you will get something 2200 Kelvin right. But if I increase this to pressure; that means, it is a you know 0.1, now it is 2 mega Pascal's right, sotemperature is 2270 Kelvin very very less temperature difference you could see right.

But now instead of 300 Kelvin initial temperature I have double it 600, so you are getting 2000 of course, the pressure is same this pressure is same. So, you are getting 2500 Kelvin right.

Now, instead of air I will use oxygen what will happen? This will be getting 3030 Kelvin. Why it is so? Because nitrogen is a inert gas so that will be taking a large amount of heat which will be absorbed in the product, when will product is not you know is not really dissociated. So, therefore, that will be taking rather therefore, the temperature reduces. And if I go for propane air, instead of methane will go for propane air will get 2278 Kelvin right, 2200, 2278 you know not much difference.

And if I go for hydrogen air right equivalence say you will get 2390 Kelvin and in somewhere you may get 2400 Kelvin we keep in mind right. And hydrogen oxygen you get again the same order 3080 Kelvin in this one atmosphere or 0.1 mega Pascal's. And carbon monoxide of course, you get that 2400 hundred Kelvin see carbon monoxide, generally it is not being considered as a fuel, but; however, if you use some producer gas right kind of things and then you will get CO, air and also coke oven gas and other gases. It is very high temperature as compared to the hydrocarbon.

But if you look at hydrocarbon air on an average it will be something 2200 to 2300 Kelvin you know roughly all hydrocarbons most of the hydrocarbons right hydrocarbon air keep in mind ok.

Student: Sir, we can always assume if (Refer Time: 10:03) numerical contains the hydrocarbon.

Student: We can always utilize.

Yeah yes, yes.

Student: (Refer Time: 10:09) 2000.

Yes, 2000 and then you can do that 2200 you can guess and then find it off provided it is stoichiometry. If it is not stochiometry, if it is a lean mixture it will be lower. If it is a rich mixture what will happen? It will be definitely also lower because fuel is not been you know consumed not all heat being released because less oxygen is there right. So, therefore, it also be less; that means, peak temperature where it will be occurring.

Student: Stochiometric.

Stochiometric, not strictly we will see now, that let us look at the effect of equivalence ratio on adiabatic flame temperature right.

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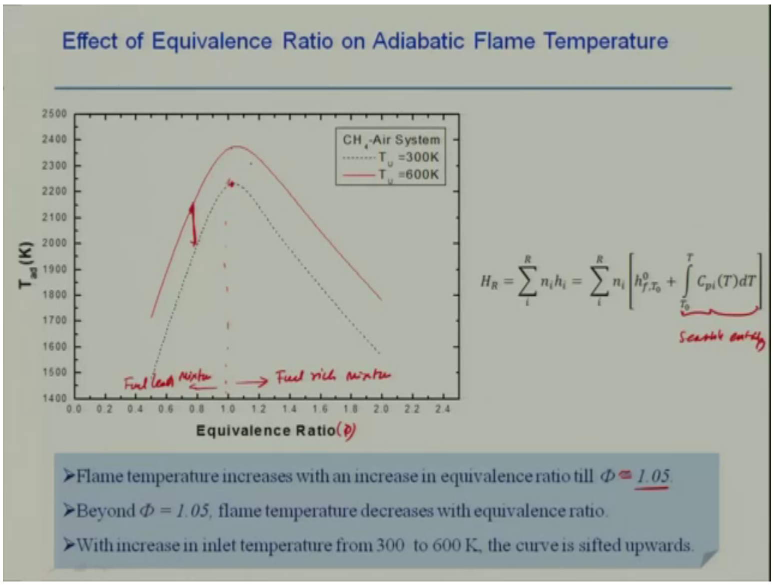

Effect of Equivalence Ratio on Adiabatic Flame Temperature

$$H_R = \sum_i^R n_i h_i = \sum_i^R n_i \left[h^0_{f,T_0} + \underbrace{\int_{T_0}^{T} C_{pi}(T)dT}_{\text{Sensible enthalpy}} \right]$$

- ➢Flame temperature increases with an increase in equivalence ratio till $\Phi \approx \underline{1.05}$.
- ➢Beyond $\Phi = 1.05$, flame temperature decreases with equivalence ratio.
- ➢With increase in inlet temperature from 300 to 600 K, the curve is sifted upwards.

So, what I have taken here? This is methane air system and this is your peak value right, this is your 1. Is it peak for 300 Kelvin? This graph is for 300 Kelvin can black one, this adiabatic temperature here and this is equivalence ratio, this is phi. Is it peak here? No, peak is somewhere here right, peak is here this values.

Now, for the lean side right what is happening? This is your fuel lean, this side is furl lean mixture lean mixture, this is side is fuel rich mixture. Again the temperature also is dropping down both the side, but the drop in the lean side is lower the slope is stiffer and it is a little swallow as compared to lean side in the this side.

Keep in mind that the flame temperature highest flame temperature generally for a hydrocarbon you will be getting around, this is again approximation around 1.05 right. In some case it may be 1.03, in some case may be 1.04, but approximately 1.05 you will be getting. And of course, I have already told if there is a increase in temperature what will happen? The nature of the curves remains same; that means, you know the adiabatic temperature will be lower on the fuel lean side and this side also it will be lower, peak will be around equivalence ratio 1 right, it will be peak values here. But there is a increase in this if a particular equivalence say will say, there is a increase in temperature right, increase in adiabatic temperature right, both the lean and rich even at stoichiometry.

And as I told why it is so, why it is happening? Because here if it is 300 Kelvin or 298 Kelvin you can say right this term will be 0, but if it is 600 Kelvin. That means, this is the contribution from the sensible enthalpy which will be reflected in your adiabatic temperature right, because already you are having and certain heat being released you know then naturally it will be added to that.

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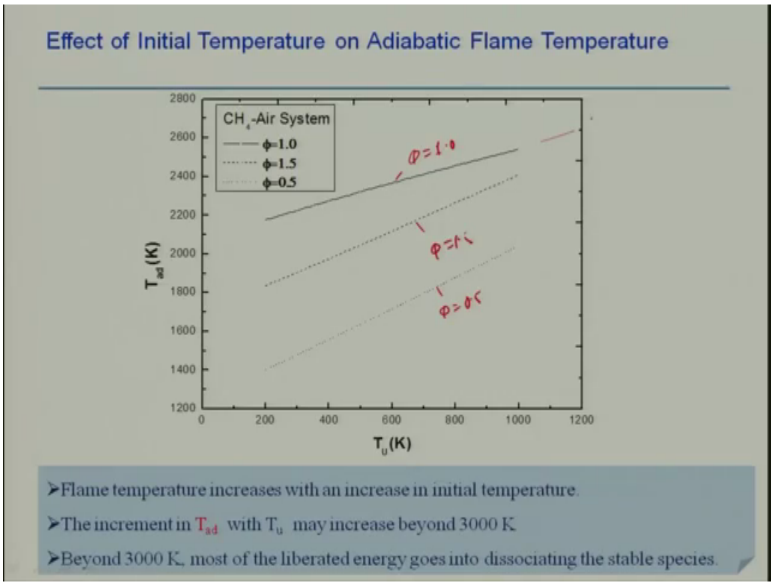

Effect of Initial Temperature on Adiabatic Flame Temperature

- Flame temperature increases with an increase in initial temperature.
- The increment in T_{ad} with T_u may increase beyond 3000 K
- Beyond 3000 K, most of the liberated energy goes into dissociating the stable species.

So, now look at this effect of initial temperature of adiabatic I am just elaborating little bit more further, that you can see that this are the corresponding to, what you call this is phi is equal to 1, and this is phi is equal to 0.5 and this is phi is equal to 1.5. And it goes on increasing with the temperature right.

And keep in mind that if you go on increasing the temperature like what is happening, the temperature is increasing. But if it will go beyond let us say something 3000 Kelvin you know like some higher temperature you are increasing, now what will happen? There will be dissociation which will be occurring, as a result the temperature would not be increasing further right, which I have not shown in this diagram, but it will happen because of some heat energy will be utilized for dissociating the product right stable spaces, and as a result temperature will be dropping down right. Nowadays people are basically using this energy right, from the product site and then bringing to the reactant sites such that you can utilize it that is known as the recuperative burning right. Are you getting?

Suppose there is a burner here and the products some of the things will be going out. Let us say from the engine exhaust right and that will be at high temperature. So, instead of that and then inlet temperature is lower. So, you take those product and then have a heat exchanger heat will be exchanged between the exhaust gas from the exhaust gas to the inlet. So, that you will reuse those things which are going to the atmosphere or the some sink right. So, that is known as recuperate therefore, a lot of interest is going on to you know preheat the fuel air mixture before combustion takes place right is known as preheating combustion right, preheated combustion.

So, let us now look at what happens to the pressure.

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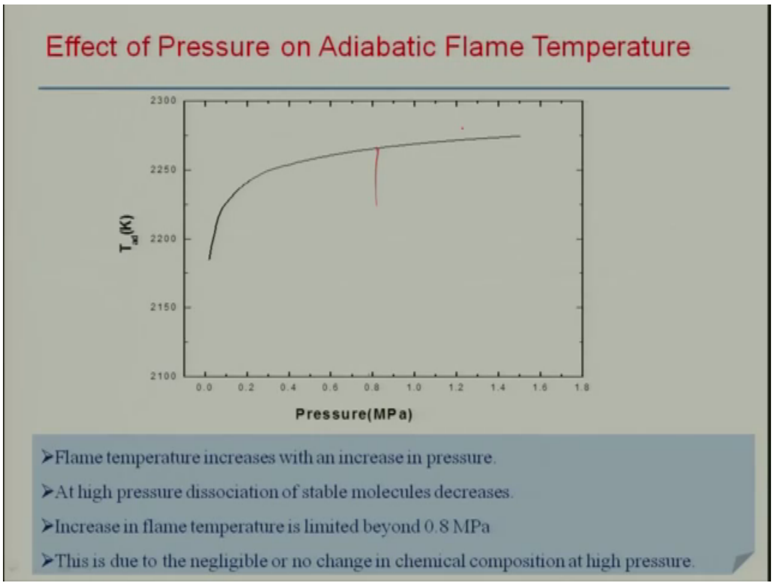
Effect of Pressure on Adiabatic Flame Temperature

- ➢Flame temperature increases with an increase in pressure.
- ➢At high pressure dissociation of stable molecules decreases.
- ➢Increase in flame temperature is limited beyond 0.8 MPa
- ➢This is due to the negligible or no change in chemical composition at high pressure.

Like if at a pressure if you look at initial pressure of the this reactants there will be steep increase in the pressure here right. The adiabatic being plotted with respect to the pressure this is being increased and of course, this will be very steep, but however, with when it will be reaching something around 0.8 right mega Pascal there would not be much change; of course, there is a slight change, but this is much higher level right. And this is because of fact that the change in the chemical composition at a high pressure will be negligibly small, so therefore, the changes would not be occurring in this region right.

So, therefore, it is very important to take care like a effect of pressure, effect of initial, temperatures right, you one should know. You might be wondering why should we look at the effect of pressure because you know most of the practical engines the combustion occurs at a higher pressure, in case of your gas turbine engine, for aero application, for power generation, internal combustion engine right at a high pressure. Now, you should know what is happening the, what will be the adiabatic temperature.

And keep in mind that adiabatic temperature is a theoretical one. In actual situation it is not possible to have a adiabatic system right, some amount of heat also will be transferred even if you are insulating it even if you are doing that. In case of IC engine you might be knowing like we cool the engine wall right, so also in case of gas turbine combustor. So, therefore, lot of heat will be lost right. You want to be achieving that temperature what is we will be calculating, even right even realistic situation. So, you would not get that.

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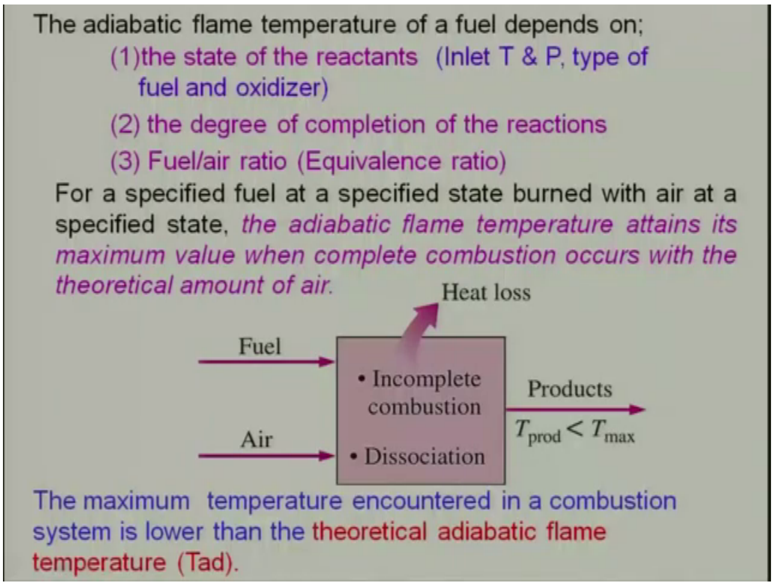

The adiabatic flame temperature of a fuel depends on;

(1)the state of the reactants (Inlet T & P, type of fuel and oxidizer)

(2) the degree of completion of the reactions

(3) Fuel/air ratio (Equivalence ratio)

For a specified fuel at a specified state burned with air at a specified state, *the adiabatic flame temperature attains its maximum value when complete combustion occurs with the theoretical amount of air.*

The maximum temperature encountered in a combustion system is lower than the theoretical adiabatic flame temperature (Tad).

Now, to summarize about this adiabatic flame temperature; as we already know that adiabatic flame temperature of fuel depends on what equivalence ratio or the fuel air mixture. It will be depend on the initial pressure, it will be dependent on the initial temperature and also the type of fuel and oxidizer. It will be also depend of degree of completion of reactions; that means, extent of reaction is going on like whether it is completed or not if it is not complete it naturally it will be different right. And it will be also, as I told earlier that it will be dependent fuel air ratio or the equivalence ratio.

And if you look at for a specified fuel right let us say for methane air system or a propane air system at a specified state burned with the air right the adiabatic flame temperature attains its maximum value provided right, complete combustion is taking place with the theoretical amount of air that is the ideal situations right.

And there is a heat loss what is happening right? If the heat loss and there is also incomplete combustion which will be taking place and then dissociation may take place also right, that dissociation means like the product will be getting to the reactant as well right which may take place also. Then, what will happen? The product temperature what you will be getting will be less than the T maximum right. And this maximum temperature encounter combustion system is generally lower than the adiabatic temperature; that means, adiabatic temperature what you will be getting is basically the theoretical one right.

So, therefore, you should keep that in mind and there would not be any combustion system where you will be measuring some temperature higher than the adiabatic. If you are then something is wrong ok, in your measurement or your calculations right you cannot get beyond that. So, therefore, it is a thumb rule which is to be used or a indicator for you to judge whether it is your calculation is right or wrong, your experiment is right or wrong or how it is varying like that way you will get some values and some calculation for initial calculation you can use.

In the next lecture we will be basically looking at how to handle the compositions right at equilibrium condition, because unless you know the equilibrium conditions and also its composition you cannot really calculate the adiabatic flame temperature in real situation right. It is just we have done those calculations in the last lecture basically which can be carried out in a classroom right.

But it is, it would not be the right one to say oh that is adiabatic temperature, no right for that you need to calculate equilibrium composition, and what do you mean by equilibrium combustion, and when the equilibrium can occur and all those things we will be discussing in the next lecture. I will also illustrate maybe subsequent lectures how to calculate adiabatic temperature while calculating the composition right. So, we will stop over here.

Thank you very much.