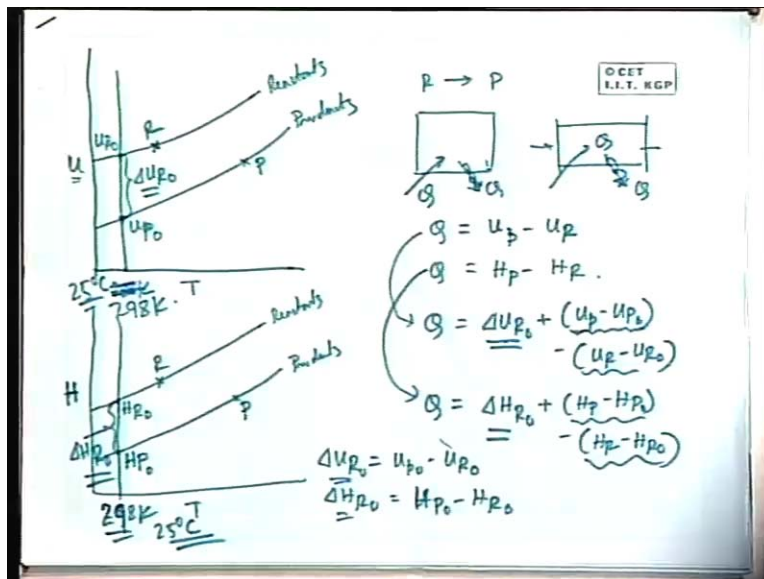


Basic Thermodynamics
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Lecture - 28
Thermodynamics of Reacting System – II

Good morning. In the last class, we were discussing the enthalpy of the reaction and internal energy of reaction and how we can write the first law of thermodynamics to the process of reaction. Recalling this again if we plot a figure of internal energy versus temperature, for certain class of reactions, if we consider the combustion reaction mainly, for those reactions, the reactants have a higher internal energy than the products at any temperature.

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Similar is the case for enthalpy. We consider this type of reactions and recognize how to write the first law if this is taking place in a closed system or an open system. If we write the heat transfer as a positive quantity which goes into the system, convention of the first law of Q is [.] If I consider the initial state of the reactant as R and the final state as P product; the initial state R is a steady flow process and holds good for a closed system

where internal energy is used. In a steady flow process, the enthalpy exactly substitutes internal energy in the first law of thermodynamics.

If we compare the steady flow energy equations with that of the first law; $del Q$ is du plus $del w$. So, we can write Q is equal to U_P minus U_R in case of this (Refer Slide Time: 02:32 min), and in case of steady flow process, U_P is equal to H_P minus H_R . With the definition, if we consider, at a standard state of 25 degree or 288K and if we define internal energy of the product as U_{P0} , and this as U_{R0} , the difference $delta U_{R0}$ is known as internal energy of reaction.

Similarly, in case for enthalpy; if we designate enthalpy of the product as the standard state at H_{P0} and that of the reactant as H_{R0} , then this (Refer Slide Time: 03:16 to 4:20 min) is known as $delta H_{R0}$, which is the enthalpy of reaction. Hence, this is usually written in terms of enthalpy of reaction, by subtracting and adding U_{P0} and U_{R0} . Accordingly, one can write, plus U_P minus U_{P0} minus U_R minus U_{R0} . Similarly, in the algebraic way, by subtracting and adding the initial state values for the enthalpy, we can write this as H_P minus H_{P0} . Importance of heat is that; for all the reactions known, the values are tabulated, and this is the change in the internal energy or enthalpy for product and reactant from a standard state to the state at which they existed. These are also tabulated, as $cp delta t$ type for an ideal gas. The change of enthalpy from one state to other state for an ideal gas is a function of temperature.

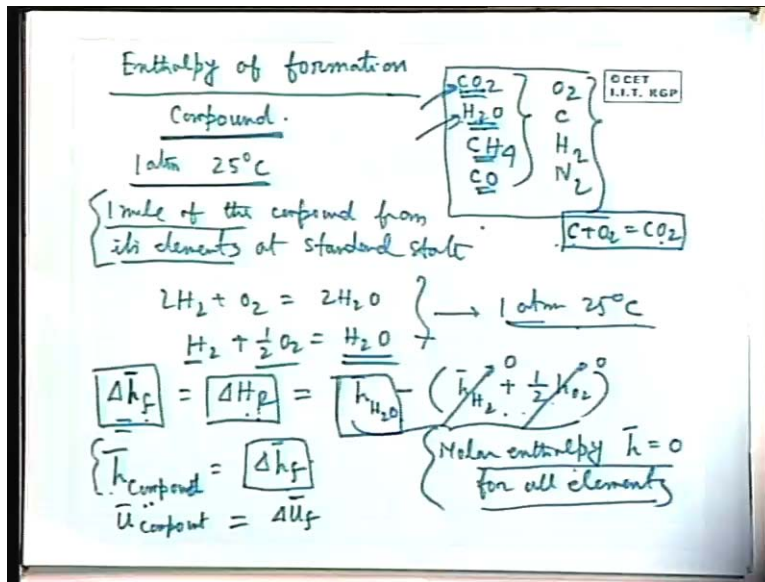
Specific internal energy or enthalpy is $cv delta t$ or $cp delta t$. These values are either evaluated or taken from a table, which gives the change in the enthalpy from standard state of 288 to some other existing state. If we write the equation this way, it is convenient to calculate; and for those equations where $delta U_R$ is negative, this $delta U_{R0}$ is U_{P0} minus U_{R0} , which means product minus reactant. Similarly, $delta H_{R0}$ means, the entire set scalar magnitude is H_{P0} minus H_{R0} . Therefore, for these two curves, where reactants have higher internal energy and enthalpy, these quantities are negative, that is, less than 0. If you put this value, Q becomes negative under usual conditions, if it depends upon this, which means, heat is being rejected from the system.

(Conversation between student and professor not audible: Refer Slide Time: 05:28 min)

25 plus 273 is 298 Kelvin. I am sorry. Very good boy. I am sorry. Extremely sorry. 25 degree Celsius, usually for Celsius, temperature is coated. That is why, people always express SI unit. Both Kelvin and degree Celsius go together, so, it is degree Celsius. Sometimes, for triple point of water as you know; 0.01 degree Celsius comes so frequent. If you add 273.15, which is the exact number, it is just the addition of the Celsius to give Kelvin. Therefore, 273.16 is not that frequent; sometimes there may be a mistake, but 0.01 Celsius will never be made.

Next is the enthalpy of formation. What is enthalpy of formation? It is very important.

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Enthalpy of formation is defined to give the scale of enthalpies for elements and compounds. You can tell that when I know the enthalpy of internal energy of reaction and internal enthalpy of reaction and I am comfortable to find out Q quantity which is our prime interest. Sometimes, instead of giving the internal energy of reaction or enthalpy of reaction, it is coated in terms of enthalpy of formation. So, we have to know enthalpy of formation and this gives you an understanding of the scale for enthalpy of the elements, and the compounds. Let us now understand what enthalpy of formation is. Enthalpy of

formation is always for a compound. For example; consider a compound such as; CO_2 , H_2O and CH_4 , with which we will be dealing in combustion reaction. When these react with oxygen, it gives water vapor and carbon di oxide. Carbon monoxide may be also there for incomplete combustion. So, these compounds do not have the same enthalpy even at same pressure and temperature.

We have appreciated earlier, because of inter atomic bonds the enthalpy levels and internal energy levels are different, because of which, the reaction results in a higher temperature of the products. To attain the same temperature, heat has to be transferred out. These things have been already recognized that they may not have the same enthalpy at the same temperature and pressure and similarly the internal energy. Internal energies are not very frequently encountered, because most of the practical processes deal with steady flow process. I will tell, enthalpy of formation has a similar definition and will go with internal energy of formation.

Similarly, for elements such as carbon, hydrogen and nitrogen; what is the enthalpy of these elements at some reference condition? Enthalpy of formation is defined as the enthalpy of reaction to make the compound from its constituent elements at the standard condition; that is, one atmospheric pressure and 25 degree Celsius at which conditions the elements are at most stable situation. That means it is the enthalpy of reaction for making this compound from its elements, or generating this compounds from its elements at standard conditions, where elements are in their stable states.

Let us see H_2O . For generating one mole of the compound from its elements of the compound at standard state the enthalpy of reaction is the one which makes the compound from its elements for one mole of the compound. (Refer Slide Time: 10:35 min) Let us consider H_2O . Now, 2H_2 plus O_2 is $2 \text{H}_2\text{O}$, or I can write H_2 plus half O_2 is H_2O ; that means, for one mole of H_2O , we require one mole of hydrogen and half mole of oxygen. I define the enthalpy of formation ΔH_f° with a bar, hence forth I will use the molar enthalpy per unit mole as bar. This is the enthalpy per unit mole, which is the enthalpy of formation is the enthalpy of reaction. The enthalpy of reaction ΔH_R , is the enthalpy of H_2O for one mole, that means $H^\circ_{\text{H}_2\text{O}}$ that is molar enthalpy of H_2O .

Because, this is the enthalpy of products minus enthalpy of reactants, the enthalpy of reactants is H_2 plus half HO_2 , corresponding stoichiometric coefficient. This is the enthalpy of reaction, and by definition is the enthalpy of formation.

Enthalpy of reaction is the enthalpy of the product minus enthalpy of the reactants at standard condition which is maintained. Standard means isobaric or isothermal or it may be same initial or final state. That means if the temperature and pressure is same, then the difference of the enthalpy of the reactants and the products will be same. This will be negative or positive, depending upon whether it is more than this or less than this. This is the definition of enthalpy of formation. Conventionally, the molar enthalpy of all elements in thermodynamics of reactive systems is declared 0. That means molar enthalpy will be designated as h bar. For specific enthalpy, it is 0 for all elements.

If we declare that scale, then the enthalpy of formation becomes exactly equal to the enthalpy of reaction, which is nothing but the molar enthalpy of a compound. Therefore, molar enthalpy of a compound is equal to its enthalpy of formation; or the enthalpy of formation equals to the molar enthalpy of a compound. (Refer Slide Time: 13:23 to 13:52 min) For all the compounds, if I know the enthalpy of formation, this is the molar enthalpy at standard state. The standard state molar enthalpy values are fixed, which the enthalpy of formation; that means is, when this compound was formed from its constituent elements it might be negative. But it may be more negative for CO_2 then H_2O depending upon the internal energy or enthalpy of reactions. We define enthalpy of formation or enthalpy of internal energy of formation as the molar enthalpy or molar internal energy.

Similarly, molar internal energy of a compound at the standard state is the delta enthalpy of formation of ΔU_f . So, it is clear that enthalpy of formation of a compound is the enthalpy of reaction in which one mole of the compound is formed from its constituent elements at the standard state. We declare molar enthalpy as an reference scale for all elements is 0; which means, if I get enthalpy of formation of a compound, I can use the value as the molar enthalpy of the compound.

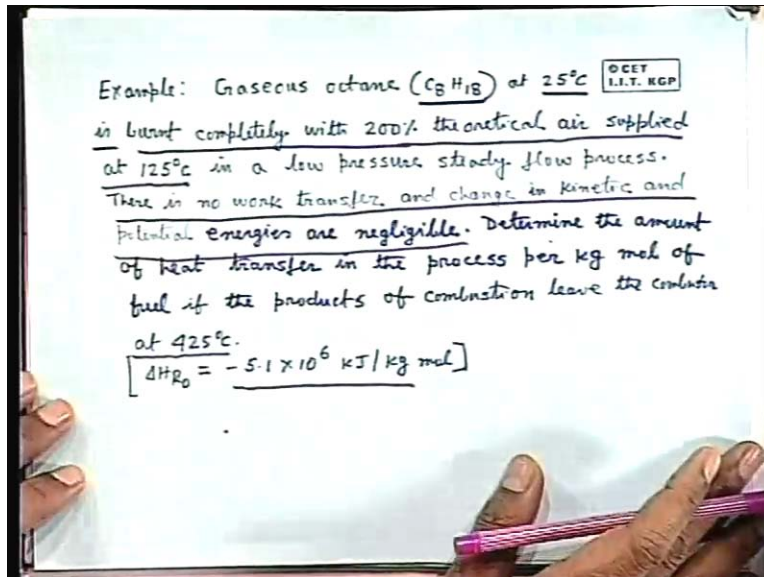
I get the internal energy of formation of some compound and I use that as the molar internal energy of the compound. This is the definition of the enthalpy of formation. Similarly, for CO_2 , you can write $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$. The internal energy or enthalpy of this reaction is the internal energy of formation or enthalpy of formation. When we write the enthalpy of reaction, we will make the enthalpy of C and O_2 is 0. Ultimately, you will see enthalpy of formation of CO_2 will be its molar enthalpy. Thus, it is irrespective of the stoichiometric coefficient.

Conversation between the professor and the student- not audible- (Refer slide Time: 15:33 min)

Do not go on the allotropic form, whatever form it is there in one atmospheric pressure. I am not sure and which form it may react. Accordingly, we define the enthalpy of reaction of carbon dioxide, but there may be difference in the reaction. In that case, there will be microscopic differences. If different allotropic forms make a difference in the heat transfer reaction which we have to make a different enthalpy scale for different forms of the carbon, that microscopic details are not necessary. Then you have to find out the different allotropic forms of carbon and make identical state whether the heat transfer values are different or not. You have to think whether the scale 0, for carbon at standard conditions will be valid for all forms of carbon or not? Only then you can conclude and vary accordingly the internal energy of reactions in enthalpy of reactions will vary along with scale.

We should see a problem so that your concept will be clearer.

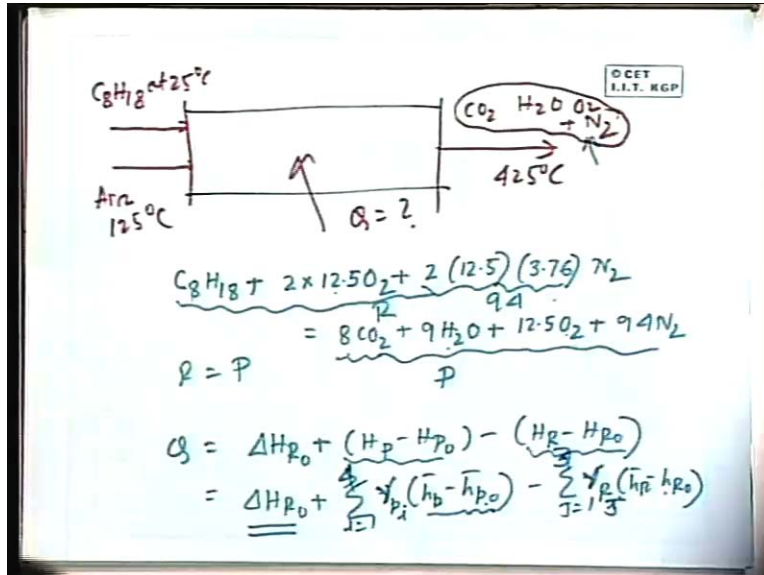
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Gaseous octane, C_8H_{18} at 25 degree Celsius is burnt completely with 200 percent theoretical air supply at 125 degree Celsius. That means, both the reactants are not at the same state, one is at 25 degree and air is at 125 degree. There is no work transfer and change in kinetic and potential energies are negligible, it is not very important. Now, determine the amount of heat transfer in the process, per kg mole of fuel, if the products of combustion leave the combustor at 425 degree Celsius.

The temperature of the products of combustion, enthalpy of reaction is given; I will write the reaction; because C_8H_{18} at 25 degree Celsius, and is 200 percent air at 125 degree Celsius, as given in the problem. This is one side of the steady flow process and the exit side is the 425 degree Celsius products of combustion. When excess air is added, that is 200 percent theoretical air, which is double the stoichiometric air. The products of combustion will be carbon dioxide and water vapor. There will be complete combustion.

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In this case, C_8H_{18} at 25 degree Celsius, and air at 125 degree Celsius, I get the products: CO_2 and H_2O at a temperature of 420 degree Celsius. Now, I will have to find out Q.

Conversation between student and professor not audible: (Refer Slide Time: 19:20 min).

Yes, that will also come; Nitrogen. I have not shown it. Let me write the equation.

Then only you will understand.

Let me write the equation; C_8H_{18} plus 2 into 12.5 O_2 , is the theoretical air. 3.76 is the ratio for nitrogen to oxygen. Balancing 8 CO_2 plus 9 H_2O as professor Das has mentioned 12.5 O_2 that means 100 percent excess remains plus the entire thing. If you multiply, this will be 94, actually I should have written these things. I have just mentioned the species CO_2 , H_2O , O_2 and N_2 have the excess here; this will be the actual product. Thus, reactant is equal to products.

I will use the equation heat Q is equal to ΔH_{R0} , H_P minus H_{P0} minus H_R minus H_{R0} . I can write this as ΔH_R . This is with the corresponding stoichiometric coefficient that is new for P molar H_P minus H_P bar 0 minus gamma minus r into h_r bar minus h so that Sigma of the mean for product and for the reactants.

I have to know the enthalpy of reaction at standard condition; also, I have to know the differences of the products for all the constituting components of the products and reactants depending upon their existing states.

Conversation between student and professor not audible: (Refer Slide Time: 22:20 min)

Summation will be over for four components. I have not given anything. Here 1,2,3,4; four components. Here, I have not written any suffix, that is why, I have not written that. If you give J; then J will be equal to one to four, just the simple general summation for the product; it is 4 and for J it is 3. Automatically, it will come from the reactions. You just write the summation form.

The problem becomes much simpler when you get this table

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Temperature (K)	298	398	698	Constituents
Molar enthalpy ($\times 10^{-3}$ kJ/kgmol)	0	29	11	N_2
	0	30	12	O_2
	-393	-389	-375	CO_2
	-242	-238	-228	H_2O

$$Q = \Delta H_{R_0} + \sum_{i=1}^4 \gamma_{P_i} (h_{P_i} - h_{P_0}) - \sum_{i=1}^3 \gamma_{R_i} (h_{R_i} - h_{R_0})$$

$$= -5.1 \times 10^6 + 8(-375 + 393) \times 10^3 + 9(-228 + 242) \times 10^3 + 12.5(12) \times 10^3 + 94 \times 11 \times 10^3 - \{ 25 \times 3 \times 10^3 + 94 \times 2.7 \times 10^3 \}$$

$$= -3.99 \times 10^6 \text{ kJ/kg mol of octane}$$

OCET I.I.T. KGP
 298K: $8H_2 + 27/2 O_2 + 94 N_2$
 398K: $= 8CO_2 + 9H_2O + 12.5O_2 + 94N_2$
 698K:

Temperature is given, and you can see the constituents and at different temperatures. These are the three temperatures concerned. This is 0, 25 degree Celsius and this is 398 minus 125.

Q is equal delta H_{R_0} plus sigma $P_i (h_{P_i} \text{ bar} - h_{P_0} \text{ bar})$ and i is equal to 1. Products will be four minus sigma $r_{R_i} \text{ bar} - h_{R_0} \text{ bar}$; and i is equal to 1 to 3. Let us now solve the

problem. The given data is minus 5.1×10^6 kilo joule per kg mole of C_8H_{18} . The equation is $C_8H_{18} + 12.5 O_2 \rightarrow 8CO_2 + 9H_2O$ plus $12.5O_2$ plus 94; this is the reactant. Thus, minus 5.1×10^6 per kg mole is ΔH_R . We are analyzing per kg mole only. Now, tell me one by one; 8 into CO_2 , means the molar enthalpy of CO_2 at existing temperature 698 K. Existing temperature of this is 298 K and existing temperature of the state is 398 K. So, neither of the states, either for reactants or for product [.] so one of the components of the reactant is in the standard state. It may not be also, we may heat C_8H_{18} earlier and it may be introduced at some 300 K or 320 K, which does not matter. Here one of the components of the reactant is at standard state; other component is not at standard state.

The products are also not so, therefore we see that, it is h_p minus h_{p0} . What is h_p minus 375? So, minus 375 minus h_{p0} means plus 393 and this is 10 to the power 3 kilo joule minus 10 to the power 3. Next will be 9 H_2O minus 228 plus 242. This value is the molar enthalpy of carbon dioxide and water vapor. These are the enthalpy of formations. Then 12.5 plus O_2 , the scale is 0. So, 10 to the power 3. Next is 94 n_2 11 minus this. Again, you first take C_8H_{18} ; this will be 0 at 298. That is why, CH_4 C_8H_8 is not given.

Conversation between student and professor not audible: (Refer Slide Time: 27:28 min)

Air comes at 398, but it is for the products. I have not gone to the reactants; it is only the part of the air at product state. For C_8H_{18} already this is taken care of, there is no h_R minus h_{R0} ; because C_8H_{18} is at standard state of 298, which means, h_{R0} for C_8H_{18} is 0. That means, here, it will be 2 into 12.5; that means 25 into 398; that means it is three into 10 to the power 3. Here, it comes minus; this minus is already 394 into n_2 which is 2.9 into ten to the power 3, if the octane could have supplied at 50 degree Celsius.

We equate the value 50 plus 273, which means 323 Kelvin, which is the required value of the enthalpy for octane. Since octane was supplied at the same state h_R minus h_{R0} is zero, because initial state of octane is h_{R0} . So, the difference.

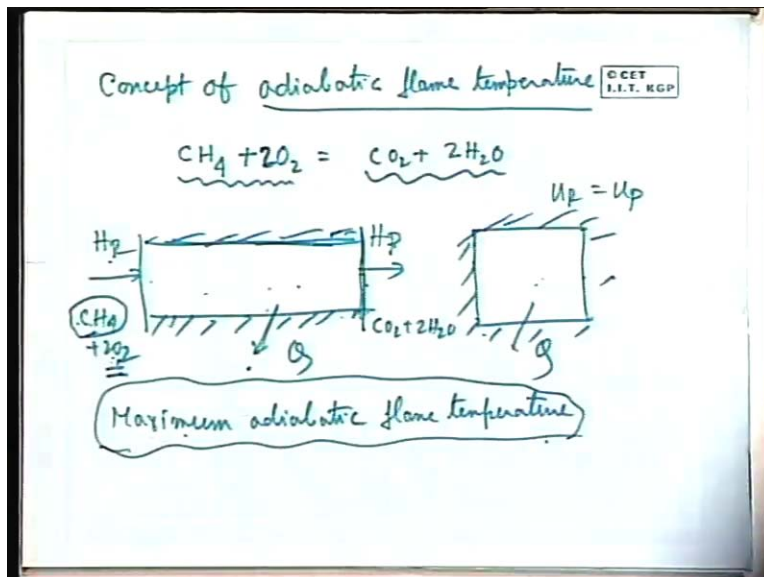
Conversation between student and professor not audible: (Refer Slide Time: 28:58 min)

Standard state means fifty degree Celsius and the enthalpy of formation; both the things are needed. We make the difference h_R minus h_{R0} . That means in the same table, another row will be added for C_8H_{18} . But, this is not added, because it is already given at standard state. So, enthalpies of octane are not required.

Next part is two level calculations; that is minus 3.99, which is the answer. I am writing 10 to the power 6 kilo joule; that means, this much amount of heat will be coming out from the system. This is the analysis for a steady flow process. For a non-flow process in a closed system, same thing holds good. Instead of enthalpy, it will be internal energy, because internal energy and enthalpy are identical. Things will play identical role when we deal with closed system or open system.

Next is the concept of adiabatic flame temperature.

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If we consider a combustion reaction or an exothermic reaction; for example: if we make a combustion reaction of CH_4 plus O_2 , it gives CO_2 plus H_2O . The equation must be balanced. This is the stoichiometric equation for one kg mole of CH_4 . That is why, it is a type of reaction which is the peculiar; which means, in this case, reactants always have higher internal energy or higher enthalpy than that of the product.

Make the reaction an insulated tank, either closed or an open insulated pipe. Then temperature will rise. If you want the products at the same temperature as that of the reactants, then heat has to come out. This is a characteristic exothermic reaction which means the internal energy or enthalpy of reaction is negative. This type of combustion reaction is made in an adiabatic system. In an adiabatic system, either in an open system or in a closed system, there are two adiabatic flame temperatures.

If we make this stoichiometric ratio or stoichiometric equation, and make the system adiabatic, then the temperature attained in any of these cases separately is considered a steady flow process. It will be the maximum, because no heat is allowed to go and stoichiometric mixture is there. The enthalpy is liberated or internal energy will be liberated due to the reaction, which will be contained within system, and it will rise its temperature to the maximum. If we allow the heat to come out, the temperature will drop depending upon how much heat is coming out. Therefore, first restriction is the condition for adiabaticness; another one is the stoichiometric coefficient.

Usually, you will see people code the adiabatic flame temperature for 200 percent. Excess is sometimes used as the maximum adiabatic flame temperature. So, it depends upon different situation. There is no such standard convention. Sometimes, adiabatic flame temperature means the maximum temperature, but to make the concept clear, usually we use maximum adiabatic flame temperature.

Adiabatic flame temperature means any mixture of fuel and oxidizer. If it is same or if it is burnt in an adiabatic system, either in a steady flow process or in a closed system, the temperature which is attained will be the adiabatic flame temperature. The temperature of the flame means the burnt product. This will attain the temperature known as the adiabatic flame temperature. This will be maximum if we give a stoichiometric mixture, because if we give more air, the enthalpy liberated or internal energy liberated per mole will be fixed. Therefore, it will take the proportionate air oxidizer depending upon the stoichiometric equation. So, if we use more mass of air, the temperature will fall, because temperature is the indication of the specific enthalpy or specific internal energy.

Specific internal energy or specific enthalpy will be reduced or the enthalpy or internal energy is liberated, but the mass is more such that it will come to a lower temperature. With excess air, the temperature will be lower. So, the maximum adiabatic flame temperature will be attained when we give a stoichiometric mixture and under adiabatic condition. There are two types of adiabatic flame temperatures: one; adiabatic flame temperature for a steady flow process, another; adiabatic flame temperature for a closed system process. The two will not be same; this will be determined by the change in enthalpy of reaction and this will be determined by the internal energy of reactions. I told you that because of the enthalpy of reaction, the temperature increases since enthalpy has to be made same. Here, H_R has to be made H_P , and since H_P equals H_R . In this case, it has to attain a higher temperature because this is lower than any temperature. Similar is the case for U_R which is equal to U_P .

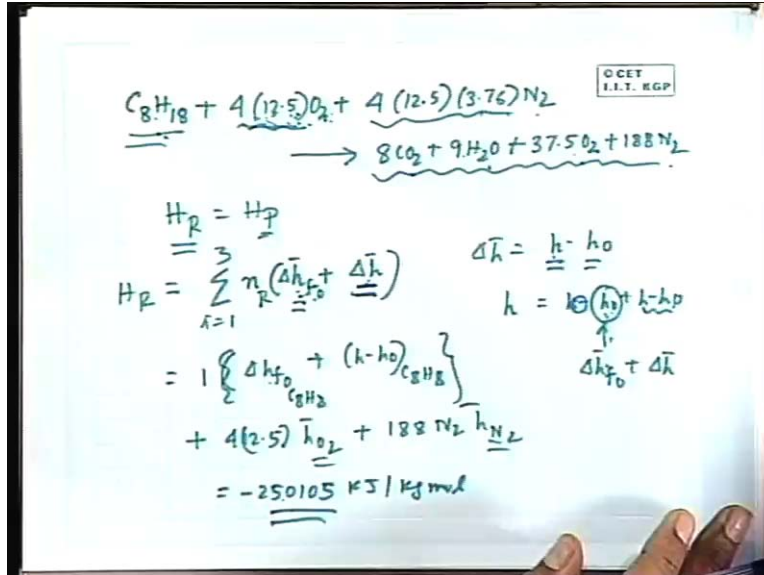
The adiabatic flame temperature is defined with respect to air. Stoichiometric air is defined with respect to [.]. If we use only oxygen, then adiabatic flame temperature will be more, because we use less mass. Until and unless it is spelled out it is very difficult. You will see, some places, they define the adiabatic flame temperature in the oxidizer part only or sometime in adiabatic flame temperature with 200 percent theoretical air. I will just solve the problem like that from a standard book. So, you have to make the basic concept.

Theoretically, an adiabatic flame temperature means, you will have to understand that a fuel is burned with 200 percent theoretical air. Fuel specification is given; what is the temperature at adiabatic condition? Therefore, it is always better to mention adiabatic flame temperature, which means temperature because of burning process under adiabatic conditions. You should remember that it is maximum when you give only the stoichiometric oxygen. Because the minimum amount of another constituent reactant is to be used for complete conversion of the reactant, fuel is not for burning one mole of CH_4 .

The minimum amount of any reactant required is 2. We do not require nitrogen because; we cannot separate oxygen from air. That is why, we have to use nitrogen because, air is the oxidizer which carries oxygen. Nitrogen does not take part in the reaction, but

theoretically speaking, the maximum adiabatic flame temperature will be that which uses only the oxidizer in the stoichiometric proportion. Let me give an example; consider one problem.

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If octane is burnt with 400 percent theoretical air, that mean 4 into 12.5 O₂ plus 4 into 12.5 into 3.76 N₂. The equation 8 CO₂ plus 9 H₂ plus 37.5 O₂, and this will automatically become 188 N₂, is this one and 37.5 is 3 into 12.5; 12.5 will be considered. For this reaction under adiabatic conditions, how to find out the final temperature?

Let us consider an adiabatic condition; it is burnt in a steady flow system. Therefore, H_R is equal to H_P. H_R is equal to sigma number of moles into delta h_f or h_f. Delta h_{f0} plus h_{f0} minus h; that means delta h bar. For the reactants, I is equal to 1, 2, 3. This is the enthalpy of formation, and delta h bar is h minus h, which is nothing but h₀. It is just h, and is written as a technique, because plus a minus a and because these values are coated, that is the only thing. h₀ plus h minus h; this h₀ is the molar enthalpy at standard state. Standard state means, delta enthalpy of formation, and I have told that delta h means change in enthalpy from the standard state to the existing state. Hence, it is written in this way.

Let us consider at initial state given for the gaseous octane which is being burnt with 400 percent theoretical air; let its initial state be given. I am not sure what is the initial temperature given. If you just decompose it, the number of mole is 1. Δh_{f0} ; for this is enthalpy of formation of the compound plus Δh . If the initial state is different from the standard state, h_0 always corresponds to standard state of 25 degree Celsius. Then, I can find this from a table, because these tables are there, where h at different temperatures is computed. So, if I know the initial temperature, I can find it.

Similarly, for oxygen and nitrogen, by knowing the number of moles, I can find this. But, Δh_{f0} for oxygen and nitrogen is 0, because h_0 is 0 by scale. There is no enthalpy of formation, which means that the molar enthalpy at standard state is 0. It is only h minus h_0 plus h . The molar enthalpy of O_2 and nitrogen can be found out for C_8H_{18} plus h minus h_0 plus 4 into 12.5 into H_2O . h is at the existing temperature which I do not know. Similarly, this one is 188 Nitrogen into h Nitrogen, and this depends upon the existing state and we can find out these things.

If the existing state temperature is given; I am just giving a typical value: 105 kilo joule per kg mole. You can write the same thing for the products and the same expansion. You can make the products; where 8 into this thing for CO_2 plus 9 into this thing for H_2O , Δh_{f0} is known enthalpy of formation. (Refer Slide Time: 43:18) Similarly, for O_2 and N_2 , you write this for the products. Only unknown is the enthalpies at the existing state for H_2O , CO_2 and N_2 . You have to guess a temperature; let it be 1000 degree Celsius.

Find out the enthalpies and equate this for the product and whether it matches the reactants or not by trial error method must be found out.

Conversation between student and professor- not audible (Refer Slide Time: 43:52 min)

It is given by the stoichiometric equation that 400 percent theoretical air means mole four into this. 400 percent means, 4 into 12 point 5. This is four into C_8H_{18} into the moles of oxygen. 400 percent is the theoretical air. One mole requires 12.5 moles of oxygen. 400 percent theoretical air means four times the number of moles which are required for one mole. This is known as stoichiometric coefficient.

Stoichiometric coefficient means, the number of moles required for one mole of reaction. So, 400 percent means the number of moles of oxygen and reactants, but only 12.5 O₂ is reacting, and 3.5 O₂ is as it is. Oxygen is changing its state, for example; the entire Nitrogen, 188 moles of nitrogen is changing its state, only its temperature is increased and it is not taking part in reaction.

Large number of temperature is not for the examination that is only for your understanding.

(Refer Slide Time: 45:37)

$$H_p = 8 \left\{ \Delta h_{f,CO_2} + (h - h_0)_{CO_2} \right\} + 9 \left\{ \Delta h_{f,H_2O} + (h - h_0)_{H_2O} \right\} + 37.5 h_{O_2} + 188 h_{N_2}$$

$H_p = - \text{known}$ $T = 1000^\circ C$
 $k = C_p T$

Let me write what is h_p . 8 into Δh_f for CO₂. Δh_f means at standard state h minus h_0 for CO₂ plus 9 into Δh_f , for H₂O plus h minus h_0 plus 37.5 h_{O_2} . Unnecessarily, I am not going into that h minus, because this will give the same thing; h nitrogen. I assume some temperature. So, this is known as the enthalpy of formation. Standard state enthalpies are known, because standard state means 25 degree Celsius. These depend upon the temperature and are all functions of temperature. I do not know these values, because I have to find out at what temperature this value matches ΔH_R .

ΔH_R is known. I assume some temperature T as 1000 degree Celsius, I find out h . at 1000 degree Celsius, what is the value of h for CO₂, what is the value of h for H₂O, what

is the value of h for O_2 and nitrogen? Find out this and match, but a very clever proposition of this work will be it has gone there. The clever proposition is that; if I tell all gases behave as an ideal gas and take $h = C_p T$ and if the specific heat for all the constituting components given in the products, then it is explicit. Then, you write h as C_p of CO_2 into T . Then you write h as C_p of H_2 into T . Then you can write h_{O_2} as C_p of O_2 into T . You can write h_{N_2} as C_p of N_2 into T and if all the C_p 's are given, then we equate this with H_R which has already been found out; then it is explicit in T and you can find out. But if it is not given as C_p into T then it is a trial error method to find out the adiabatic flame temperature.

Adiabatic flame temperature is different because of two independent things; a fuel has got an adiabatic flame temperature, for example; if you burn octane with this much amount of air and if you make the system adiabatic, this will attain the temperature that will be given by thermodynamics. So, whether the material will attain or not, that is a different issue. Engineers will give different thing, which is why the combustion chamber walls are cooled. Definitely no material till today, so far I know, can sustain a temperature more than 1000 degrees or such because the failure starts beginning 1000 or 1100 degree Celsius. So, immediately heat is removed from the wall.

Actually the temperature attained after combustion is very high in a closed system like an internal combustion engine. Water system is there. So, immediately it takes the heat through the piston and it comes down and there is a rapid expansion. But in gas turbine, combustion chambers are also cooled by air. It cannot be very high, because the highest temperature in a steady flow engine is sustained and extends for a long time so that the value cannot be very high. But for an IC engine, though the peak temperature is very high, it is for a temporary period. This is a different issue; whether the temperature will be sustained or not, but from the view point of thermodynamics, I can tell that this temperature that will be reached.

Thank you.