Introduction to Explosions and Explosion Safety

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Lecture - 14
Energy Release: Stoichiometry
Equivalence Ratio
And Heat Release in Fuel Rich
And Oxidizer Rich Compounds

Good morning, we will continue with the determination of the energy released form an explosion. Let us do the problem which we posted in the last class.

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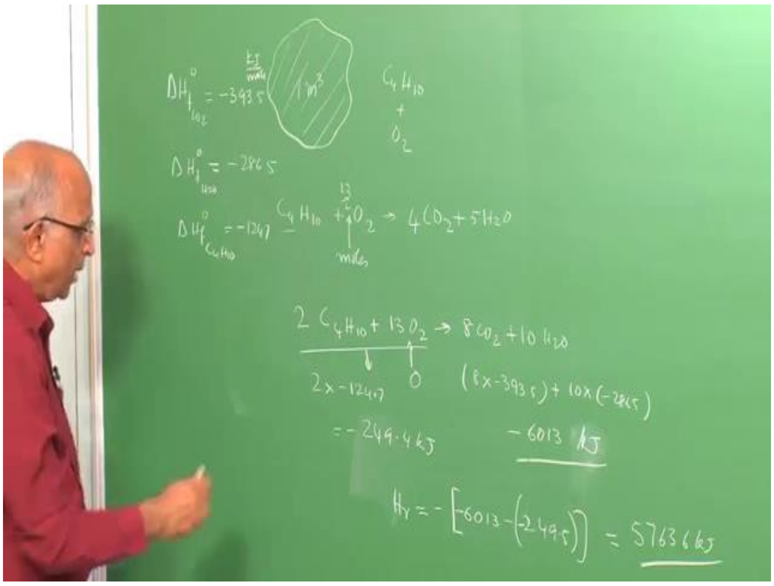

We said that we had a volume of 1 meter cube in which we had a gaseous mixture of butane, butane is c 4 h 10 and also with an oxidizer oxygen. Now, we wish to find out how much energy is released from this volume of the explosive. Explosive is here fuel and oxygen mixed together which can release some energy. We want to determine that energy. To be able to do this we said well I have the fuels c 4 h 10 reacts with oxygen, but we do not know the products of combustion.

You know, if we know the products of combustion and we also know the reactants. We can find out what is the heat of formation of the products. We can find out what is the heat of formation of the reactants and the decrease in the heat of formation is the heat of reaction. Therefore, the first step to do this is we must know what are the products to be able to determine the products, let us for the first exercise assume that the products are going to be c o 2 that means carbon dioxide and water.

We assumed this. In the in the second part may be a little later in this class, we will see how to determine what are the products for the present we just assume this. If we were to assume this we find well I have carbon which is 4 which if it acts with oxygen to form carbon dioxide. I have 4 atoms here well I should get 4 of carbon dioxide. I have 10 atoms of hydrogen therefore, I have h 2 o. Therefore, I should form something like 5 h 2 o.

So, that 4 atoms get balanced here I have 10 atoms getting balanced here and therefore, this is the type of reaction, but then how many atoms of how may molecules of oxygen do I require or how many moles of oxygen do I require, not molecules mind you. That means I have 1 mole reacting with certain moles of oxygen to form 4 moles of carbon dioxide and 5 moles of water. Therefore, if I balance the oxygen atoms.

So, I have 2 over here I have 8 over here and I have 5 over here, totally 13. Therefore, I should have 13 by 2. In other words the reaction should have been c 4 h 10 plus 13 by 2 o 2 gives me this which I can also write as 2 of I multiply totally by 2 I get 2 moles of butane c 4 h 10 plus, I have 13 moles of oxygen which give me. Now, I have 8 moles of carbon dioxide plus 10 moles of water. Now, I need to determine what is the energy see I have been able to write any equation, provided I assume the products were carbon dioxide and water.

Now, I want to determine this I also tell yes yesterday we discussed about heat of formation. We told that the heat of formation of carbon dioxide was equal to minus 393.5 kilo Jule per mole. The heat of formation of water, heat of formation of water at the standard condition, that is the standard heat of formation here also it is standard heat of formation was equal to minus 286.5 kilo Jule per mole and this is for water h 2 as liquid. Heat of formation of the butane c 4 h 10 was equal was equal to 1 minus 124.7. Therefore, now we want to evaluate this is all kilo Jule per mole.

We have 8 moles of carbon dioxide therefore, the heat of formation of the carbon dioxide is 8 into the value here minus 393.5. So, much kilo Jules plus I have 10 moles of water that means 10 into per mole the heat of formation of water is minus 286.5. It is minus 286.5 and this works out to be equal to, if I put it down I have 8 4’s are 32 around and you have 28 therefore, if comes out to be minus 6013 Jule kilo Jules, mind you. This is kilo Jule per mole in to 8 moles 286 kilo Jule per mole into this. This is the heat of formation of the products.

How about the reactants? Well oxygen is a naturally occurring element and we define heat of formation with respect to naturally occurring element. We presume both the products and the products and the reactants are at the same standard condition. Therefore, the heat of formation of oxygen is 0 being a standard being a naturally occurring element at the standard condition. The heat of formation of butane is 2 and butane we had the value as minus 124.7 minus 124.7. This the heat of formation of the 2 moles is 2 into this which is equal to minus 294, I am sorry 248 therefore, 249.4 kilo Jules.

Therefore, what is the heat which is generated in this reaction. Well the heat of formation of the products is minus 6013. The heat of formation of the total reactants over here is equal to minus 249 and therefore, we find that there is a decrease in heat of formation. That means minus 249 to minus 6013 therefore, the heat of reaction in this particular reaction.

I say enthalpy of reaction or heat of reaction is equal to minus of that is the decrease therefore, I put a minus over here 6013 minus 249.2 494 and remind you this is minus therefore, minus over here and minus of minus over here therefore, this is equal to plus 6013 minus 249.5. This comes out to be equal to 5763.6, this is the heat from this particular reaction involving 2 moles of butane and 13 moles of oxygen. Therefore, you know, but how do I determine what is the heat released from 1 meter cube. You know I have to determine how many moles are there in 1 meter cube.

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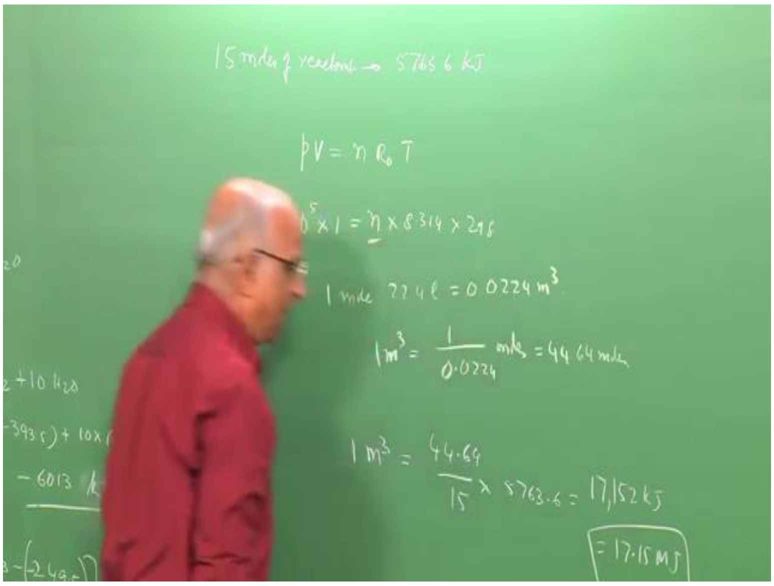

I know that I have 2 moles plus 13 moles, 2 moles of butane plus 13 moles of oxygen. That means I know for 15 moles of reactant what I have the energy which is got from this reaction is 5763. Now, how many moles are there in 1 meter cube. There are two ways of doing had I given the initial pressure of this volume as equal to let us say 1 atmosphere. We also told you know all these things are at the same standard condition, 1 atmosphere and 25 degrees centigrade.

I can now write assuming yes butane and oxygen has perfect gas mixture, mixture of these 2 being a perfect gas. I can write p v pressure into volume is equal to number of moles into universal gas constant r naught into t. Therefore, I can get the number of moles in this mixture the pressure is 10 to the power 5 Pascal 1 atmosphere. I know the volume is 1 meter cube. I know the number of moles I want to calculate in 1 meter cube into r naught the universal gas constant is 8.314 Jules per mole kelvin.

That is why I have so many moles 8.314 T is equal to 273 plus 25 which is 298. This is one way of calculating the value of number of moles. From this equation I calculate or alternatively we also know that 1 mole of any gas as long as it is an ideal gas, at standard temperature and pressure has a volume of 22.4 liters which is equal to 0.0224 meter cube. Therefore, 1 meter cube will contain 1 over 0.0224 number of moles. Either this way I calculate n, n is equal to 10 to the power 5 divided by 8.314 divided by 298 or directly from the volume.

This will come out to be equal to the total number of moles will be 44.64. Therefore, the number of moles of the reactant over here is 44.6. If I have 15 moles of reactant I get so much heat. Therefore, in 1 meter cube of the mixture which contains 44.64 I will have 44.64 divided by 15 in to the energy for 15, which is 5763.6 kilo Jules which is equal to something like 17152 or we can say it is 17.15 omega Jules. This is the way we calculate the energy release provided we assumed here that we are forming carbon dioxide in this. Therefore, for 1 meter cube well I tell myself 17.15 omega Jules of energy are getting liberated.

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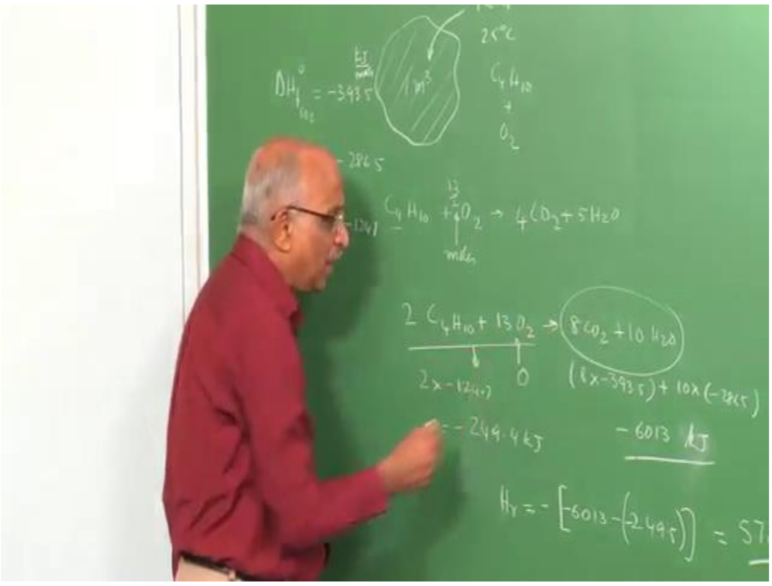

Therefore, I am able to calculate the energies, but my mind you. We have made 2 assumptions, we made an assumption in the products form. Can I not determine the type of products which I will have and if I have to determine this well I need some more definitions.

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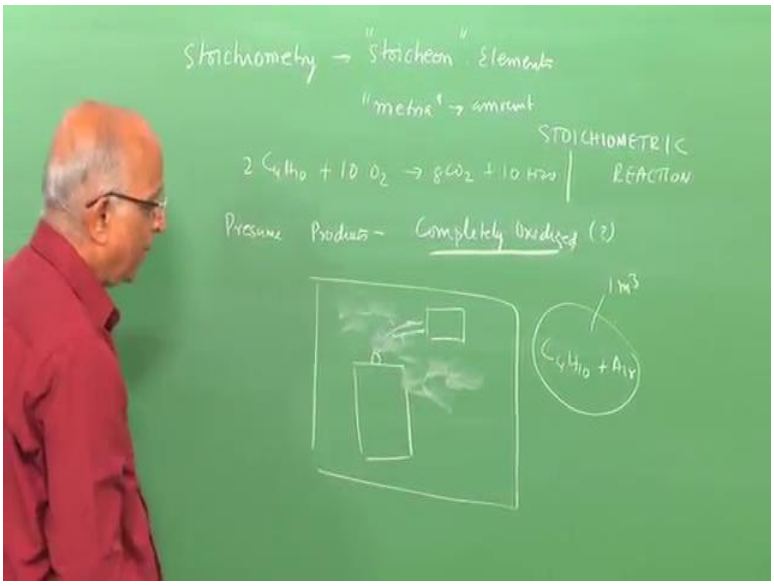

I need to work out with some more inputs that means I need some more data. Therefore, let us see what are the additional definitions what I require. We determine something known as stoichiometry. In any chemical reaction you know when we start learning chemistry with chemical reactions, we define a term known as stoichiometry. What do we mean by stoichiometry, the word comes from the Greek letter stoicheon meaning elements that is stoichio comes form stoicheon, metry comes from the Greek word again meteria, which means amount.

When we say stoichiometry, we mean the proportion of reacting substances. Like in this particular reaction what did we have, we had c 4 h 10 we had 2 moles of c 4 h 10 reacted with 10 moles of oxygen to give me something like c o 2. That is I had something like 8 moles I had 10 moles of water that means m 8 moles of c o 2 10 moles of water.

Therefore, the proportion is 10 and 2 over here that is molar ration is 10 is to 2 over here. Therefore, actually strictly stoichiometry just determines the ratio of the proportion of the reacting elements or reacting constituents, but when we use the word stoichiometry, more often they are not what we use is, we presume when we talk of stoichiometry we assume that products which are formed are completely oxidized.

I require to qualify this what do we mean by saying products are completely oxidized. You know in this let us get back to our reaction, we had the reaction 2 c 4 h 10 plus 13 o 2 giving 8 c o 2 and 10 h 2 o. Well the carbon over here reacts with oxygen it forms carbon dioxide, it could have also formed carbon monoxide. May be it could have also not it could have just formed carbon itself, may be it just formed this. If I look at c o 2 c o and this c o is not fully oxidized, it can still get oxidized further to form co 2.

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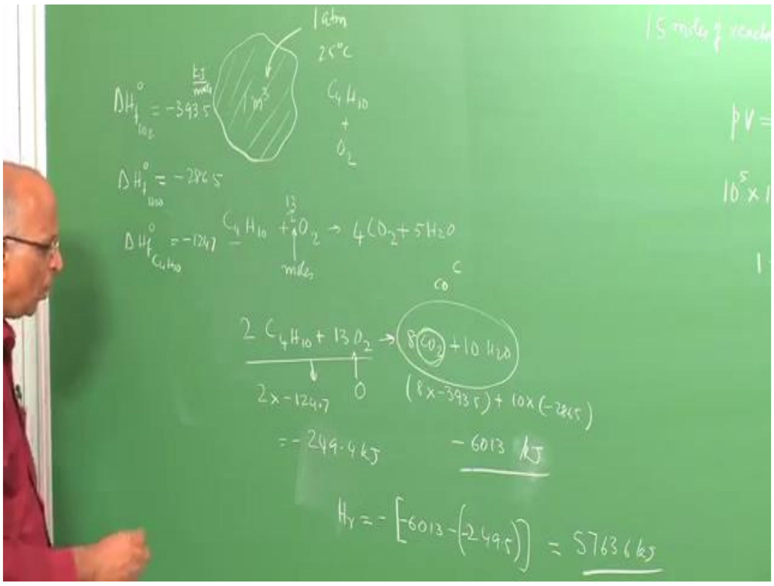

Therefore, we say co 2 is a fully oxidized substance. So, also if I consider water which is formed. Well the hydrogen gets oxidized by oxygen to form water. Well it could still form h 2 o 2 get more oxygen and form hydrogen peroxide, but hydrogen peroxide is oxygen rich it is an oxidizer by itself. Therefore, we say well it is oxidized to form a substance which is neither an oxidizer or a fuel. That is it is fully oxidized to water and when we say fully oxidized substances are what we call as completely oxidized substances.

That means when the products are completely oxidized well the reaction becomes c 4 h 10 plus 10 o 2, what we have written earlier was fully oxidized. This type of reaction is what we call as a stoichiometry reaction. Let me write it again stoichiometry reaction. Therefore, under the assumption that the reactants from fully oxidized products. Well I say completely oxidized products are formed and if I presume completely oxidized products are formed I know that co 2 and h 2 o are formed.

Now, I can calculate the energy which is liberated form 1 meter cube or if I say so many kilograms I can convert this to kilograms and find out the energy release by the explosion of this particular substance, but then you know we still are working with oxygen. You know mind you if there is a spill let us say at home in your kitchen. I have the cooking gas which is essentially butane and maybe I have a pipe line which connects it to the burner at home.

Suppose, there is a leakage of this from the pipe line that is or the cylinder is leaking or your stove is leaking. In the kitchen which has a certain volume, I am able to collect a mixture of in this case I have a mixture of c 4 h 10, which is butane plus air it is not oxygen. You know in in practice whenever a fuel gas leaks and forms a mixture. It is not c 4 h 10 with oxygen, but it is c 4 h 10 with air. Therefore, how do I modify now I want to go further and calculate what is the energy released. Let us say in a volume of 1 meter cube if butane and air are there.

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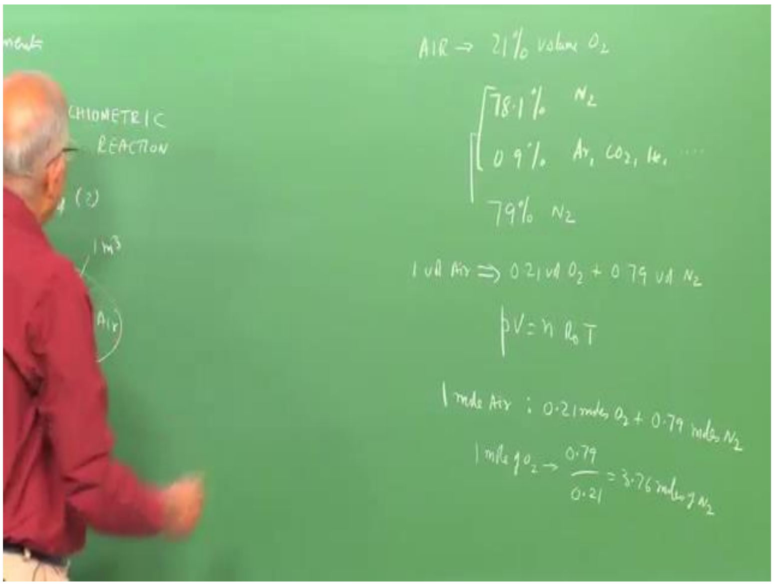

Let us not presume that since I have defined the word stoichiometry, let us say I am looking at a reaction between let us say butane, we will extend it to other substances plus air to form fully oxidized substances namely c o 2 and h 2 o. Therefore, now I need the properties of air to be able to solve this particular problem. Therefore, when I look at air we say we know air perfectly, air consists of 21 percent by volume of oxygen. It also consists something like 78.1 percent of by volume of nitrogen.

It also contains something like 0.9 percent of may be other gases like argon, may be depending on the environment it could contain c o 2. It could contain some helium, it could contain some xenon, argon and all that. These are all may be these gases are not reactive gases they are all inert gases. Therefore, I can combine the nitrogen with the inert gases I can tell well air consists of 21 percent by volume of oxygen and 79 percent by volume of nitrogen.

Therefore, volumetrically 1 volume of air consists of 0.21 volumes of oxygen and the balance 0.7 volumes of nitrogen. Now, we know see I am more interested in moles you know whenever we say we write an equation I say 1 mole so many moles of air or so many moles of carbon dioxide. So, many moles of water is what we are talking of I would like to convert the volume into moles. Again I look at this particular ideal gas equation, I have p v is equal to number of moles universal gas constant which is same for all gases into temperature and may be at any pressure and temperature.

So, long as they are the same, volume pressure is the same temperature is the same, this is universal gas constant. The volume goes as the number of moles and therefore, the moles are proportional to the volume and therefore, I say 1 mole of air contains 0.21 moles of oxygen plus 0.79 moles of nitrogen. Well therefore, may be you know why look at air I already have the equation for oxygen. Can I therefore, say well when I have a reaction involving 1 mole of oxygen the 1 mole of oxygen will carry along with it 0.79 because I am using air.

In air, if I have 1 mole of oxygen the amount of nitrogen or number of moles of nitrogen I have is 0.9 divided by 0.21 which is equal to 3.76 moles of nitrogen. Therefore, if I were to have, a reaction involving air. Well my this equation will get modified because instead of having 10 moles of oxygen, I will also have to carry some amount of nitrogen and let us see what this equation should get modified as. Let us modify this equation now to be able to put air over here. What is it I get I have 2 c 4 h 10 2 moles of butane plus 10 of oxygen.

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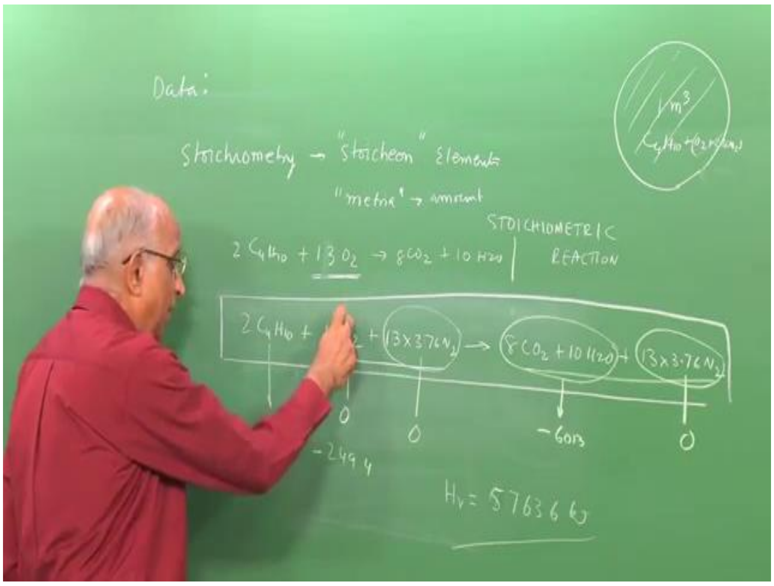

Since, I am having air I am going to get 10 into 3.76 of nitrogen is what is going to form my products. Therefore, now you see I have added nitrogen therefore, this becomes air and the total moles of air are 10 plus 10 into 3.76. That is the total moles of oxygen and nitrogen in the air. This is going to give me, we said well it is a stoichiometric reaction therefore, I form completely oxidized product 8 c o 2 plus 10 h 2 o. He said 10 o 2 here we know let us balance and see, c 4 h 10 what did I have here, I have 13 I have 13.

Therefore, if it was perfectly balanced he should have been 13 over here because I have 8 will take 16 oxygen plus I have 10 26, 26 means 26 of oxygen atoms therefore, 26, 13 into 2 26 over here plus I have 13 over here. Then only I can form 8 co 2 plus 10 h 2 o and nitrogen being inert it gets back into the products as 13 into 3.76 of nitrogen. Now, this is my reaction with air. Now, I want to find out what is the energy liberated, if I have corresponding to the same old problem. If I have instead of 1 meter cube of I have butane plus oxygen in the proportion such that I get stoichiometric or completely oxidized products of combustion.

Instead of oxygen now I add also the amount of that is 3.76 nitrogen for each 1 mole of this I add this. Now, I want to find out what is the energy which is liberated from 1 meter cube. To be able to do the problem again I do the same process. I want to find out what is the heat of formation of the products. Well we have originally when I did problem with oxygen I had 8 carbon dioxide 10 water. Now, I introduce this therefore, these 2 terms remain the same as earlier and what is the value I got for 8 c o 2 plus 10 h 2 o the heat of formation.

That was equal to minus 6013 let us write it out over here minus 6013 and what is the heat of formation of nitrogen at the standard condition. Well we presume that we are finding out the difference when both products and the reactants are at the same standard condition and what is the value for nitrogen. Well it is a naturally occurring element it is 0 over here for oxygen it is 0 as the earlier, it is 0 over here. It is a naturally occurring element, 2 c 4 h 10 if we go back and see the value well it is 2 into minus 124.7 which is equal to minus 249.4.

You know we see that I have exactly the same value for the products. I have the same value for the reactants and therefore, the heat of reaction in this case remains the same as earlier and the value is something like what we had earlier 5763.6. That means whether I burn with air or with oxygen the heat generated in the reaction of the explosive remains the same, but I am interested not in the energy liberated by the reaction, but I want the energy liberated in 1 meter cube of this volume.

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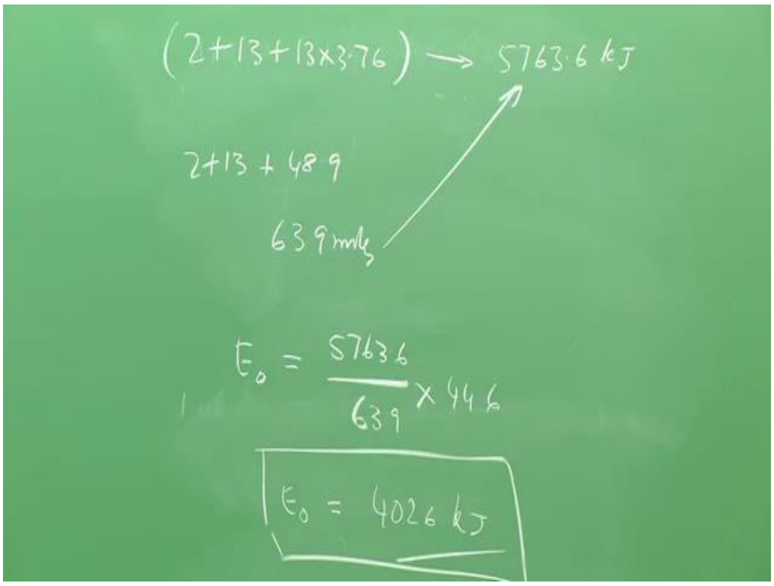

That is where the difference really comes in. Let us now find that value out we get, yes for 1 meter cube we know in 1 meter cube the number of moles are same as earlier. The number of moles of reactant in 1 meter cube is equal to we had 44.6 moles. You will recall we just said yes in 1 mole at standard temperature and pressure has a volume of

22.4 liters and therefore, this is the value. How many moles of the reactant do we have which forms this in this case. Now, we have 2 moles plus 13 moles plus 13 into 3.76 moles therefore, we find 2 plus 13 plus 13 into 3.76 number of moles of the reactant is what gives me the heat release as 5763.6 kilo Jules.

Therefore, if I put this it is 13 into 3.76 the value comes out to be 2 plus 13 plus 13 threes 49. I have 48.9 which is equal to 63.9 moles. Therefore, 63.9 moles gives me this. In the volume what I have I have only 44.6 therefore the energy which is liberated from 1 meter cube is equal to 5763.6 divided by 63.9 into 44.6 which is equal to the value is 4026 kilo Jules. Now, you find yes, there is a difference, the energy liberated with oxygen was quite high of the order of 17.15 mega Jules. Whereas with air the energy release is much higher because why does it happen because of the dilution effect of nitrogen the energy density comes down and the energy release keeps coming down.

Therefore, for a stoichiometric mixture of any cloud, may be a fuel in dire mixture or any other mixture or any other substance we are in a position to calculate the energy release. How do we do that? Well we just let us quickly summarize the method of doing it we calculate for any reaction.

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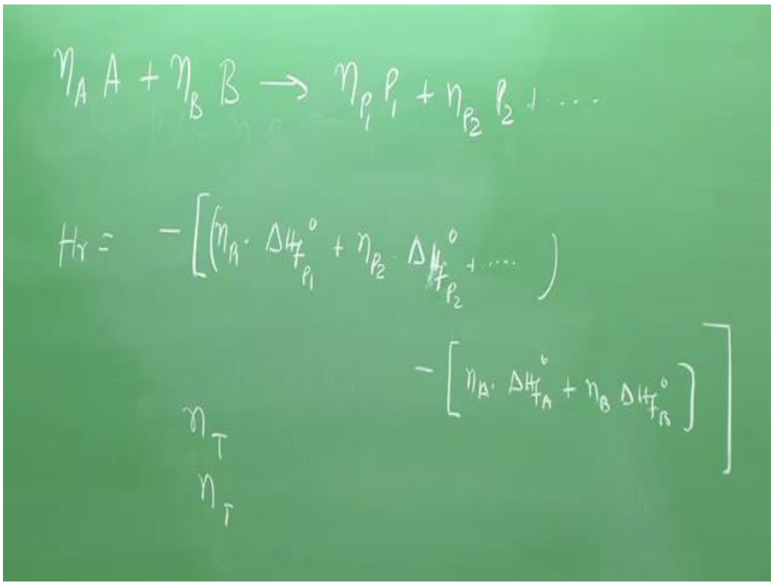

Let us put it as a general form. Well I have may be reactants let us say n moles of reactant A reacting with B moles of may be an oxidant or oxidizing agent B gives me let us say n p moles of product p 1 plus n p 2 moles of product p 2 and so on. Therefore, what is the energy released form this, is equal to minus of n p 1 into the heat of formation at the standard condition for p 1 plus I have n p 2 into heat of formation at the standard condition for p 2 plus so on this is for the product.

I say well these are the products which are formed and what is the reactant minus I have I again put it in bracket n A into heat of formation of A at the standard condition plus n B into standard heat of formation B is the energy of this particular reactions. If I have a particular mass which, corresponds to the total number of moles n or a volume which corresponds to the total number of moles n. Then I know that this energy is liberated from so many moles in this reaction.

Therefore, I calculate for a volume which contains. So, much moles of reactant or a mass which contains this is how we evaluate the energy release form a reaction. Well this is for stoichiometry you know, but in practice there is 1 problem we have. Let us go back and see what is the issue which we could have, when we really have a spill and some gaseous mixture gets formed or if we have something like, let us say we have an explosive like a solid explosive. This solid explosive need not always be in a stoichiometric proportion. It may not always form completely oxidized products of combustion. In this case let us see, what are the other definitions we require, let us first consider the case of may be a mixture with air.

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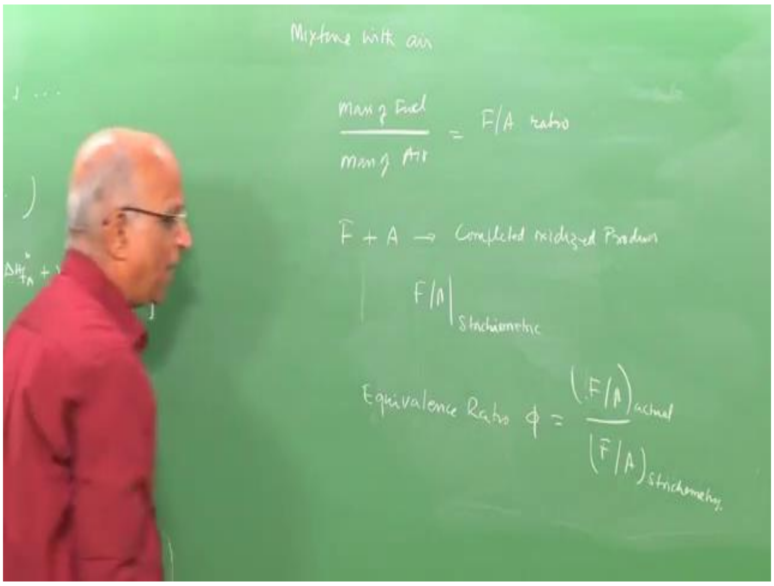

You know when we say mixture, we also talk in terms of mass of fuel divided by mass of oxygen or mass of let us say air because we are considering with air let us mass of fuel divided by mass of air. This we call when it is in the mass ratio we call as fuel to air ratio. You know I could have a fuel reacting with oxygen in any proportion I want. I could also have fuel and oxidizer which gives me completely oxidized products of combustion.

In which case I say this reaction is stoichiometric. Therefore, I can also determine a fuel by air ratio for a stoichiometric reaction and what is the value of this stoichiometric reaction. Well the amount of fuel by air which I say I stoichiometry whereas in practice it could be anything different form stoichiometry because as we told ourselves well it need not always form the completely burnt products. We define something know as equivalence ratio.

Equivalence ratio phi as equal to the actual fuel by air mixture that is by mass divided by let us call it as actual divided by fuel by air mixture for stoichiometry. This is what we call as equivalence ratio phi. Therefore, let us complete, let us determine the value of fuel by air mixture for the previous problem in which we had this stoichiometric conditions. Let us determine this and see what are the variations possible. Let us put down the reaction again, let us calculate this value. Well we had the reaction was c, c 4 h 10 plus 13 of oxygen.

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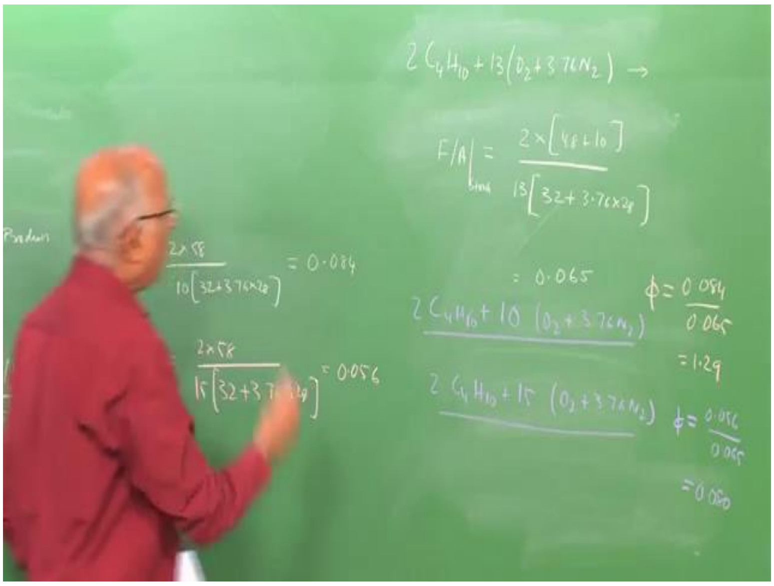

Every mole of oxygen is accompanied by 3.76 moles of nitrogen. Thus this gives me carbon dioxide water and nitrogen. If I where to look at the fuel by air ratio for this particular reaction which gave me stoichiometry products of combustion. The fuel by air ratio is equal to how much is the fuel 2 moles into what is the molecular mass of this. I have 4 into 12 48 plus oxygen plus hydrogen 10 into 1, 10 that is the mass of fuel that means 58 grams per mole is the mass of the butane into 2 is the value of the mass of this, which is reacting with oxygen. What is the mass of air, 13 into o 2 16 2’s are 32 plus I have 3.76 into 28. If I calculate this value it is 58 2’s 116 divided by 13 into 32 plus this value.

The value comes out 0.065. You know in in practice most of the hydro carbon substances. You take methane ethane propane butane or any other substances, the fuel air ratio would be of this order of between 0.06 to 0.07. This is for the case of stoichiometry when you have completely products, but supposing let us say well the substance is such that spillage has happened in that kitchen ideally some amount of butane.

The amount of air in the kitchen is smaller or it is larger. I could have a reaction instead of this reaction let us consider another reaction I put it in a different color chalk. I could have 2 c 4 h 10 it is possible that I have instead of 13 moles, the amount of air with which it mixes is only 10 moles of oxygen plus 3.76 of nitrogen, this is 1 scenario. I could also have the leakage is much smaller and it mixes with the larger amount.

That means I could also have 2 c 4 h 10 plus I could have 15 moles instead of 13 moles of oxygen plus 3.76 of nitrogen. Well this is possible, now in this case well I will have products which are not really stoichiometry. It cannot be oxidized, well in this case I have excess oxygen. Therefore, excess oxygen will anyway give completely form products of combustion, but I will also be left out with this, we will have to do this problem.

Therefore, the question is for this what is the fuel air mixture, let us put the values down I put it on this side. I get fuel air mixture when I have the less amount of air or it is something like fuel rich or let us say oxygen lean both are identical is equal to 2 into 58 divided by 10 into 32 plus 3.76 of 28 in this case. In the second case what is the value I get I get the fuel air mixture actual is equal to 2 into 58 plus now I have 15 into 32 plus 3.76 into 28.

If I calculate this value the first value it comes out to be fuel air mixture 0.084. In the second case it comes out to be equal to 0.056. Therefore, in this particular reaction therefore, what is the value of the equivalence ratio. Well, phi is going to be let us put it over here phi is going to be the value of the actual fuel air mixture 0.084. If the reaction was stoichiometry I should have 13, I should have had 0.065 and therefore, the equivalence ratio is going to be something like 1.29.

In the second case where in I had more of oxygen the value of phi is equal to the value is 0.05 6 divided by 0.06 5 and this value comes out to be equal to 0.08 0. Therefore, what is it we have done let us quickly summarize this before we go to the next part of our problem, that is to evaluate the heat content.

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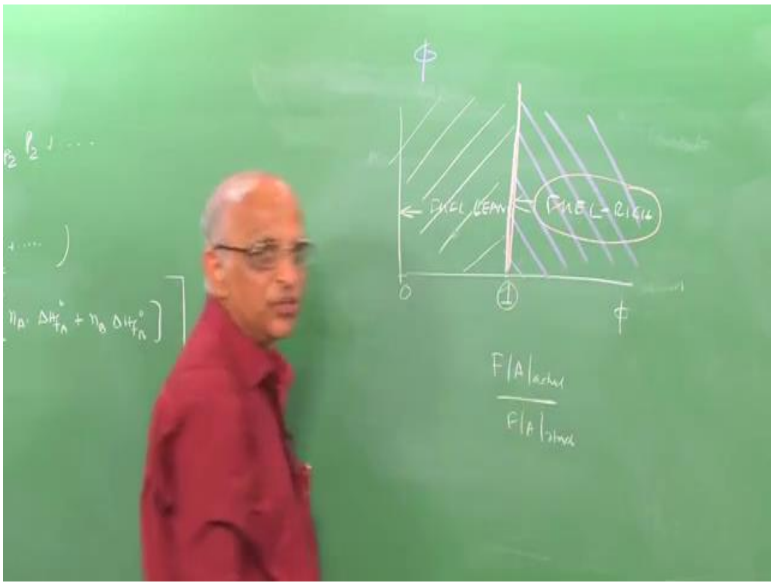

We said well whenever you had this fuel vapor mixing with air what happens is it need not always be in the stoichiometry proportion. That is forming completely oxidized products of combustion. We said well you had an equivalence ratio. I plot the equivalence ratio let us say I draw the equivalence ratio on the axis along this. I tell myself when I have completely burnt products of combustion I call it as stoichiometry. Stoichiometric is fuel by air actual divided by fuel by air stoichiometry.

Well for stoichiometry this becomes stoichiometry the value of phi is 1. If the phi value is less than 1 what does it mean I have less of fuel and therefore, the values between 0 to 1 when the fuel ratio actually is 0, which means I have no fuel at all. I keep on having fuel which is fuel lean or let us say oxidizer rich. If phi is greater than 1 I have more fuel than stoichiometry, well the second part corresponds to a rich mixture that means fuel rich mixture.

Therefore, the region to the right of 1 corresponds to let us say fuel rich and 1 corresponds to stoichiometry and his particular region corresponds to fuel lean. What separates the fuel lean from fuel rich is an optimum which gives me the stoichiometric value. Know in practice this is somewhat important because most of the explosives which we deal with are somewhat fuel rich.

Therefore, we should have some method of calculating the energy release in fuel rich mixtures, but we could also get a fuel vapor mixture which is sort of fuel lean. Therefore, what is do now is how do I now modify whatever we have done for stoichiometric mixture to be able to get the energy release form fuel lean mixtures and fuel rich mixtures.

This is what I want to do therefore, let us re visit the problem again. See let us quickly summarize though you know because these things are to be kept in mind. We tell ourselves well I talk in terms of a stoichiometric reaction. I talk in terms of a fuel lean mixture I talk in terms of a fuel rich mixture. These are given in terms of the equivalence ratio if the equivalence ratio is greater than 1. Well it is fuel rich if the equivalence ratio is less than 1 it is fuel lean. Let us do the calculations for 1 for fuel lean that is 5 less than 1. Let us do an example for fuel rich which is greater than 1. Let us keep this over here because this is for stoichiometry, let us proceed further let us consider the case, fuel lean mixture that means phi as per this is less than 1.

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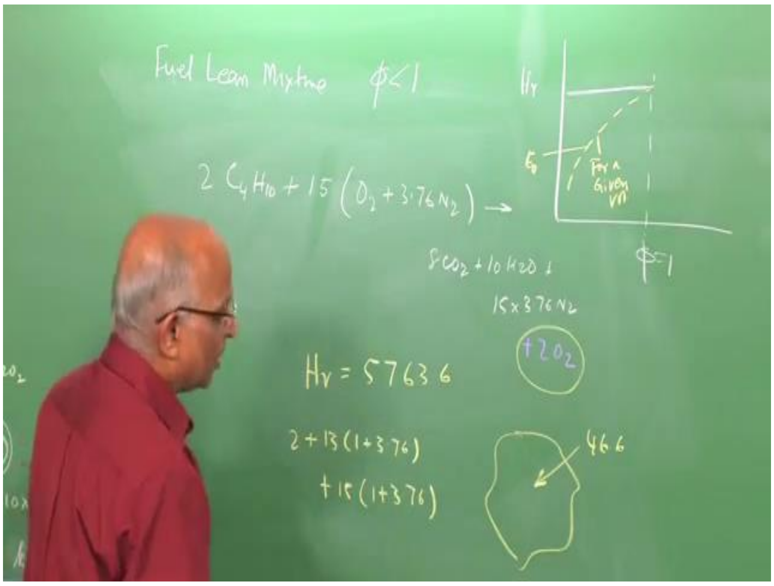

Let us take the same example what I took here. Instead of having this particular reaction where in I have 2 c 4 h 10 plus I had 13 into air is o 2 plus 3.76 nitrogen giving me products. I need to calculate the products. I now say well it is lean therefore, let us presume that the amount of oxygen I have is higher. Let us assume that I have something like 50 amount of oxygen if it is that means I have excess oxygen. Therefore, when I say fuel lean I talk in terms of air being more and what are the products of combustion.

Well I have so much of oxygen, but any way the carbon will get converted to c o 2 the water will get fully oxidized to water here. I also have the balance of 15 into 3.76 of nitrogen which is let it back. Now, is there anything left you know, you balance the equation you find. Well the amount of oxygen what I have what carbon has consumed and hydrogen has consumed is 16 plus 10 26 and the amount of oxygen I have is 30 over here.

That means I am left with 4 of oxygen which is left and therefore, in the products I will also have 2 of oxygen. Well the nitrogen remains the same because it does not participate it is inert. Therefore, now I have the reaction which tells me, well I have in the products in addition to co 2 and h 2 o some oxygen also. Now, what is the energy liberated in this reaction. Well you know we have already seen that the heat of formation of oxygen being a naturally occurring element at standard condition is 0. Well the nitrogen does not play a role it is also 0. Well here also this is 0 we have exactly the same thing 2 c 4 h 10 and 8 c o 2 and 10 h 2 o.

Therefore, the heat of this reaction remains the same as in the case of a stoichiometric reaction and that is equal to 5763.6, but how about the energy release that is the heat of reaction remains the same, but now we find that the number of moles of the reactant have gone up. Previously the number of moles of reactant that means for this reaction the number of moles was 2 plus 13 into 1 plus 3.76. This was our earlier case, this is with oxygen we had air, air 3.76. Now, we have 2 plus 15 into 1 plus 3.76 and therefore, what has happened.

You know, you have excess air therefore, the number of moles in the given volume have gone up. If the number of moles in the given volume are gone up then what is going to happen the mixture is less dense therefore, we tell ourselves this particular energy is released from something like more number of moles. This volume has a fixed number of moles which was 46.6 moles. Therefore, the energy release per unit volume or for 1 meter cube volume or for a given mass will keep coming down as the fuel becomes leaner and leaner.

This is to be expected, let us plot this graphically which I just now told I did not put the numbers drawn because putting the numbers will take some time. We tell ourselves well let us put it down a little better little more with better clarity. Here phi is equal to 1 this is the energy of the reaction. We tell ourselves as long as you have fuel lean that is air rich, the heat of reaction remains the same. But if I want to find out what is the energy liberated for a given volume or for a given mass, what happens is the number of moles in the reaction go off and therefore, for a given number of moles well the amount of heat release comes down.

A given volume, that means we are talking of this is equal to the energy per unit volume or for a given volume. This is heat of the reaction which remain stationary. Now, we want to go ahead and calculate we will do 1 or 2 more examples involving some solid explosives. Such that this concepts get more clear in our mind. Let us do an exercise for the fuel rich condition. Before we revisit the fuel lean condition, fuel rich condition what will happen in fuel rich condition. Let us take another example and let us do this example completely.

Well fuel rich we said, well I do not have something like 13 moles for stoichiometry. May be I will have less let us consider 10 moles which is the example which I considered earlier.

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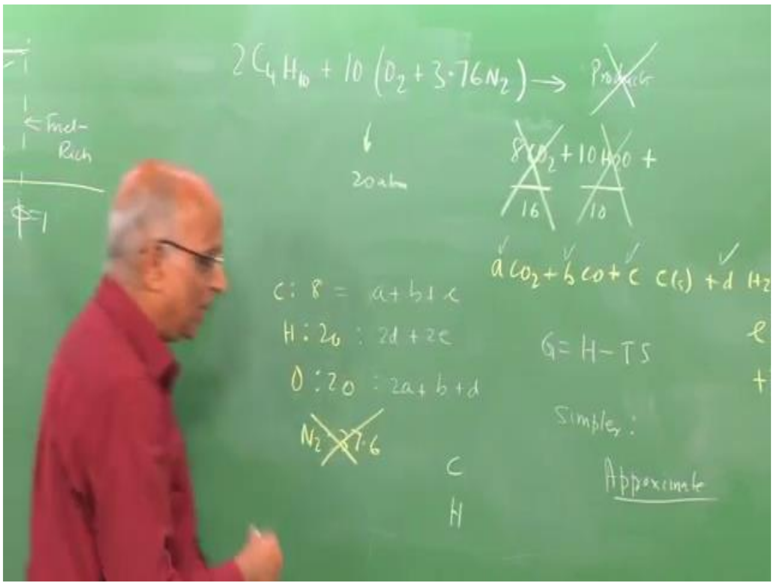

Let us therefore write the equation down 2 c 4 h 10 plus now I have 10 of oxygen, 1 mole of oxygen is in the air is associated with 3.76 moles of nitrogen. Now, I want to write the balance equation. Therefore, what is it I get let us presume like in the earlier cases, I still get let us say 8 c o 2 plus 10 h 2 o plus I get the nitrogen we will put this down a little later. If I were to get carbon dioxide and water that is completely oxidized as in a stoichiometry reaction. I need something like 16 oxygen 16 atoms of oxygen I need something like 10. I need 26 atoms of oxygen and what I have here is just 20 atoms.

Whereas, what I require is 26 therefore, it is it is not likely that 8 c o 2 is getting formed. It is also quite possible that 10 of water is not being formed. Therefore, what could be formed could be something like a moles of c o 2 plus b moles of c o plus may be c moles of carbon itself as a solid plus may be d moles of h 2 o plus, may be e moles of h 2 and so on is what could be formed because there is not sufficient oxygen to form carbon dioxide and water.

Therefore, if I say well my products are going to contain carbon dioxide, carbon monoxide, carbon as suit or carbon in the solid form water, hydrogen and so on. How do I determine the moles a b c d e, when the number of moles of the reactants are given as 2 and 10. Now I tried to do this I tell myself well I can do the carbon balance, hydrogen balance because the number of atoms cannot get lost. That means carbon the number of atoms of carbon in the total left hand side and right side must be the same.

Therefore, I say well carbon on the left hand side is 8, hydrogen on the left hand side is 20 well oxygen on the left hand side is 20, nitrogen on the left hand side is equal to 10 into that is 37.6. Well in the right hand side I will also get nitrogen, but nitrogen if I presume is inert I get on the right hand side 37.6 nitrogen. Therefore, I am really not bothered about this comes on the left hand side and right hand side. Therefore, now I can write 3 equations and the carbon balance equation will now tell me on the right hand side if I were to write the value of 8 is equal to I get is equal to 2 a plus b because 2 into a plus b plus, I have c is carbon balance.

Hydrogen balance is equal to I have 2 d plus 2 e. Oxygen balance if I were to write I get is equal to well carbon balance is c o 2 a c o 2. Therefore, it is just a plus b plus c over here, hydrogen balance is 2 d plus 2 e. Oxygen balance is equal to 2 a plus I have 2 a plus b and plus d. Therefore, what is it, you know I have unknowns this is 1 2 3 4 5 unknowns. I have only 3 equations, there is no way I can determine the moles in the product. Therefore, it becomes difficult for reactions in which the equivalence ratio is greater than 1 or which are fuel rich substances or fuel rich reactions to be able to determine the moles of the product.

I can now determine the product. I have no way of simply balancing it and determine the products. Therefore, I need some more information and 1 way of doing it is, we tell ourselves well I have a reaction taking place. The energy release heats the products to a high temperature. At the value of high temperature the products like co 2 co c h 2 o h are in equilibrium and when things are in equilibrium, well I can use thermo dynamics to calculate the particular ratios here.

That means I say Gibbs free energy is equal to enthalpy minus temperature into entropy. For equilibrium Gibbs free energy is a minimum and therefore, I can use this and calculate, provided I know the temperature, but I do not know the temperature because I do not know the energy release. May be through an iteration process it is still possible for me to calculate this, but the process is rather combursum. May be we will do it towards the end of the course when if and when we get some more time of calculating using chemical equilibrium analysis, but I find yes there is a simpler way of doing it.

That simpler way is somewhat approximate. It is not really rigorous, it is very approximate, but based on my experience I find that this approximate method gives out values of energy release which are quite reasonable and fairly accurate. Therefore, what is it I am going to say, well can I do this approximate analysis, we will just indicate how this approximate analysis is done. You know since I have more number of variables than the number of equations. I tell myself well in my equation. In my reactant I have carbon and hydrogen.

All of us know, well you know charcoal or carbon takes time to burn, it is not as reactive as hydrogen. Hydrogen is a very reactive substances. Therefore, we can tell ourselves well hydrogen first just gets consumed, it is much more reactive. First hydrogen gets consumed and then carbon gets consumed and therefore, we make some assumptions. Let us just list down the assumptions we will do the calculations in the next class. The assumptions which we make are the following. Whenever I have a fuel rich reaction, I tell myself well the nitrogen in the reactant gets back as nitrogen. That means nitrogen is inert it is gets back into products as nitrogen.

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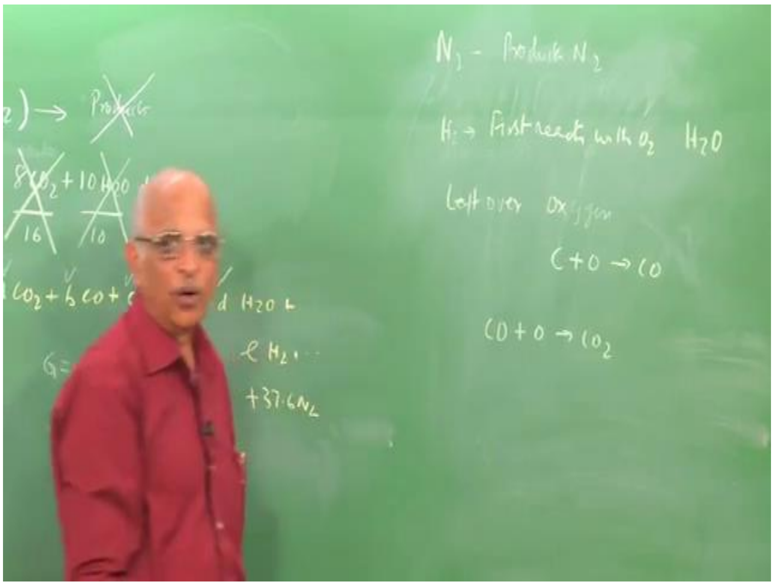

Then if I have in the fuel carbon and hydrogen, hydrogen being more reactive first reacts with oxygen. It tries to consume as much as oxygen as it requires to form water. After forming water, if some oxygen is still left, the left over oxygen goes and reacts with the carbon over here to form carbon monoxide. That means left over oxygen forms reacts with carbon to form carbon monoxide. If oxygen is still left, part of this carbon monoxide reacts with the oxygen which is left over to form co 2. Therefore we have some steps and let us do a model problem in the next class. Then we will be able to find out how fuel rich how the energy can be calculated for fuel rich mixtures.

Well, thank you.