IC Engines and Gas Turbines
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Lecture – 19
Octane and Cetane numbers Alternative fuels – Methanol, Ethanol, Hydrogen, Natural gas etc.

We will continue our discussion on IC Engine. And today we will discuss about Octane number, Cetane numbers and we will discuss about fuels, I mean an alternative fuels like methanol, ethanol, hydrogen, natural gas etcetera. Before I go to discuss about octane number, cetane number let us first discuss about another one numerical problem that is related to thermochemistry.

So, we have discussed about that what is the you know thermochemistry and the chemical reaction, I mean we have seen that the actually fuel basically falls a fuels are basically family of hydrocarbons so, depending upon the you know number of hydrogen atom and carbon atom, whenever we you know use a particular fuel for the combustion all the carbon we will be converted to carbon dioxide, hydrogen will be converted to H 2 O and there will be they are requires in stoichiometry of oxygen that amount will not, will be good enough to convert all the carbon into carbonate oxide, hydrogen into H 2 O and there should not be in excess oxygen so that, we may get NOx and CO. So, we need to know that what will be the stoichiometric or chemically correct amount of oxygen required to burn a particular fuel, I mean when it is used and in internal combustion engine and that information is obtained from the thermochemistry of the fuels.

So, today we will work out on example to know that what if a particular hydrocarbon is given a generalized formula CxHy then how do we; how can we calculate the amount of oxygen required to burn that fuel to have a, to have an efficient combustion; that means, there should not be there will be required amount of oxygen only there should not be no excess amount of oxygen and to get that amount of oxygen what will be the amount of air required and that will be supplied to the engine and that we will come to know from the problem.

In fact, we have solved one problem while I was discussing about carboration and there we have seen that, what is the air fuel ratio or fuel air ratio, then we have discussed that take an example of a fuel. We have discussed that what will be the amount of oxygen required to burn that fuel and that much amount of oxygen will come from a certain amount of air. So, then we have calculated the fuel air ratio and vice versa.

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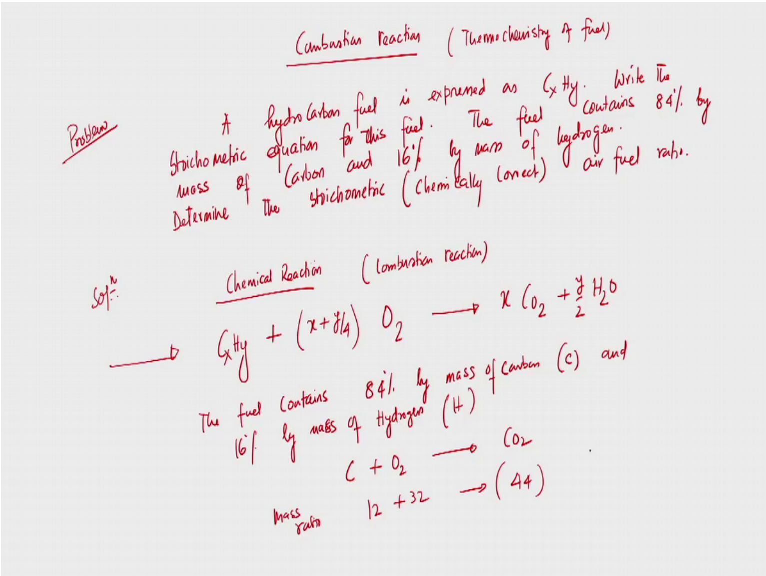

So, today we will work out one example for the thermo chemistry that is combustion reaction; that is combustion reaction. So, basically thermo chemistry of the fuel; of fuel so, we will now write the problem this is very important. So, if a fuel so a hydrocarbon fuel I am writing the problem, a hydrocarbon fuel is expressed is; is expressed as CxHy. Write the stoichiometric equation, stoichiometric equation for this fuel. The fuel it is also given, the fuel contains 84 percent by mass; 84 percent by mass of carbon and 16 percent by mass of hydrogen. Determine the stoichiometric air fuel ratio; determine the stoichiometric or which is sometimes known as chemically correct air fuel ratio.

As I said you, that this will be obtained from the thermo chemistry of the fuel that a hydrocarbon is generalized expression that is CxHy. So, the number of hydrogen atom and number of carbon atoms eventually dictates the amount of oxygen required and if that amount of oxygen is required for the complete combustion or complete burning of the fuel there should not be incomplete combustion. So, to burn that amount of fuel if we require certain amount of oxygen then, what will be the adequate amount of air we need to supply per kg of fuel that information is obtained from the combustion reaction and that is what we have discussed. So, we have to solve this problem.

So, this is the problem statement so we have to solve. So now, how can I solve that this is very important. So, we need to write the generalized you know expression rather a chemical reaction for the fuel. So, we will write fast the combustion reaction or chemical reaction; chemical reaction or combustion reaction taking this fuel CxHy this is the most generalized expression that is why I have taken up this example. So, instead of CxHy if the hydrocarbon is given by formula, then it would be much easier. So, CxHy is the fuel so, if I write the combustion reaction the of course, it will be acting with oxygen, then it will produce carbon dioxide plus H_2O and this reaction is basically exothermic reaction. So, it generates huge amount of heat.

So, now we need to know that for the complete combustion; that means, all the carbon atom will be converted to carbon dioxide and all the hydrogen atom will be converted to H 2 O molecule. So, for that how much amount of oxygen required that information be obtained from this reaction and knowing the amount of oxygen, knowing the requirement required amount of oxygen for this particular fuel to have you know complete combustion, we can calculate the amount of air need needs to be supplied for that in your to the engine for the complete combustion.

So, if I like to balance this reaction then probably I can write this is x Co 2 and this is y by 2 H 2 O then, if I would like to obtain all carbon, if all carbon you know convert it to carbon dioxide and all hydrogen convert into H 2 O molecule then, probably the amount of oxygen required it will be x plus y by 4. This is the reaction we need to calculate first the amount of oxygen required, it is given that the fuel contains; the fuel contains 84 percent by mass carbon by mass of carbon and 16 percent by mass of hydrogen right so, H. Then so what I can write that, as I said that all carbon will be converted to carbon dioxide. So, mass ratio if I calculate mass ratio then, 12 plus 32 it is getting 44 that is the molecular weight.

So, what I can see from this reaction. So, if all the carbon is converted to carbon dioxide then, I can see from this reaction that 0.84 you can see that you know; you know 12, I am writing next slide.

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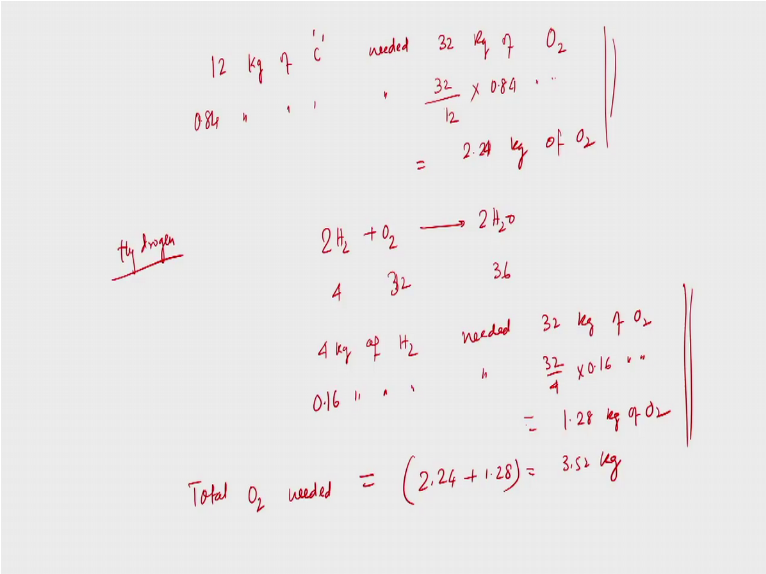

So, we can see from this reaction that 12 kg of carbon needed, how much 32 you know 32 kg of ah; 32 kg of you know oxygen; oxygen then 44 kg of carbon needed 32 by you know 12 into sorry, we require 84 percent by mass so 0.84 kg; 0.84 kg of oxygen. So, this is coming out 2.24 kg of oxygen required if the fuel contains 84 percent that is what I have described that 84 percent by mass of carbon, so that means, for point 84 kg of carbon needed 2.24 kg of oxygen to convert all the carbon atoms into the carbon dioxide.

Similarly, if I write the reaction for hydrogen then, twice H 2 O plus O 2 it will be twice H 2 O; that means, 4 it is 32 and we obtain 36. So, from this reaction we can see that 4 kg of hydrogen needed; 4 kg of hydrogen needed you know 4 kg of hydrogen needed, 32 kg of oxygen and then therefore, we can calculate that 1.6 kg of hydrogen will be needing by needed 32 by 4 into 0.16 kg of oxygen that one therefore, it is coming out 1.28 kg of oxygen. So, we have obtained the amount of oxygen required for the conversion of all the carbon atoms and hydrogen atoms into the Co 2 and H 2 O.

There will not be so, what is the amount of oxygen required. So that means, the total oxygen needed; total oxygen needed is two point two 2.24 plus 1.28 that is 3.52 kg. So, we required 3.52 kgs of oxygen for the complete combustion; that means, all the carbon atom will be converted to carbon dioxide, all the hydrogen atom will be converted to H 2 O molecule, there should not be any excess oxygen so that, carbon dioxide again further can react when it may clear it may Co 2 and we may have NOx and c you know carbon monoxide. So, we have identified the amount of oxygen required for the complete combustion.

Now, we need to know that what will be the amount of air required to obtain this amount of oxygen because, we will get oxygen from the air supplied to engine. So, the total air needed because, we know that air you know 1 kg of air; 1 kg of air contains, how much you know kg of oxygen that is very important that you need to know.

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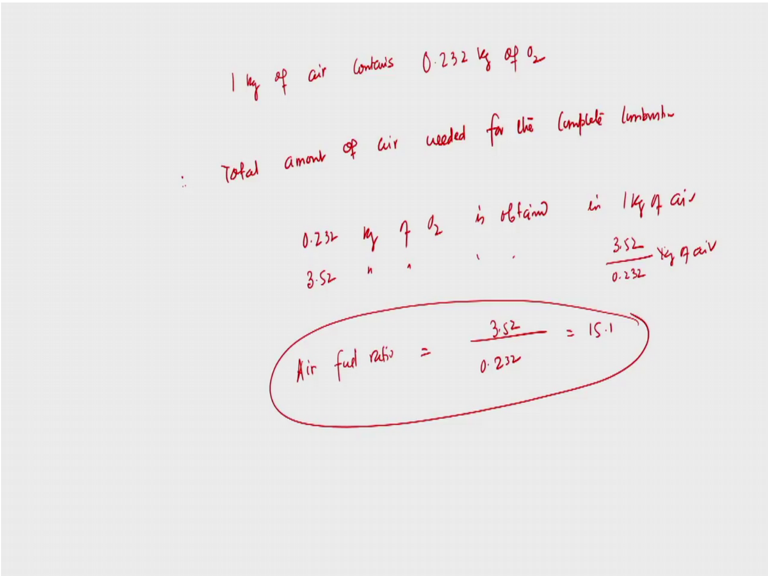

So, that information is very important that what will be the amount of oxygen required for the complete combustion or you know that is stoichiometric air fuel ratio, because without this information we cannot calculate. So, 1 kg of air contains 0.232 kg of oxygen. So, we know that if I supply 1 kg of air then, we will get 0.232 kg of oxygen. So, to obtain because we have calculated the then; that means, therefore, total amount of air needed for the complete combustion will be say 0.23 kg of oxygen available from 1 kg of air.

So, we have calculated that 3.52 kg will be obtained from how much amount of air. So, we can calculate that, I mean 0.232 kg of O 2 is obtained or available in 1 kg of air therefore, we can calculate that 3.52 kg ; 3.52 kg; 3.52 kg of oxygen is obtained from 3.52 by 0.232 kg of air right. So, then we can calculate what will be the air fuel ratio. So, we know that so, this will be the air fuel ratio or fuel air ratio that is very important. So, 3.52 divided by 0.232 is the this is the know; this is known as the so for 1 kg for 1 kg of burning of the fuel we require this kg of oxygen so we can calculate air fuel ratio.

So, air fuel ratio fuel ratio will be 3.52 divided by 0.232 that is near about this will coming like this 15.1. So, we have calculated that you know either the stoichiometric air fuel ratio that is fifteen 15.1 is to 1. So, this is the stoichiometric air fuel ratio that we have calculated. So, we have obtained the amount of oxygen required for the complete combustion and then we have calculated that to obtain that amount of oxygen how much amount of oxygen; how much amount of air need to supply; that means, that means, per kg of burning the amount of oxygen, amount of air is ob required is 15.1. So, the air fuel ratio will be 15.1.

So, with this we have seen that by how we can calculate the required amount of the stoichiometric amount of oxygen or chemically correct amount of oxygen should be supplied for the complete combustion of a fuel having a generalized formula CxHy and probably it will give you a clear picture that, how we can calculate from a combustion reaction that is from a thermo chemistry of a fuel to have a efficient combustion. So, next we would like to discuss about the important aspect is that self ignition characteristics and octane number.

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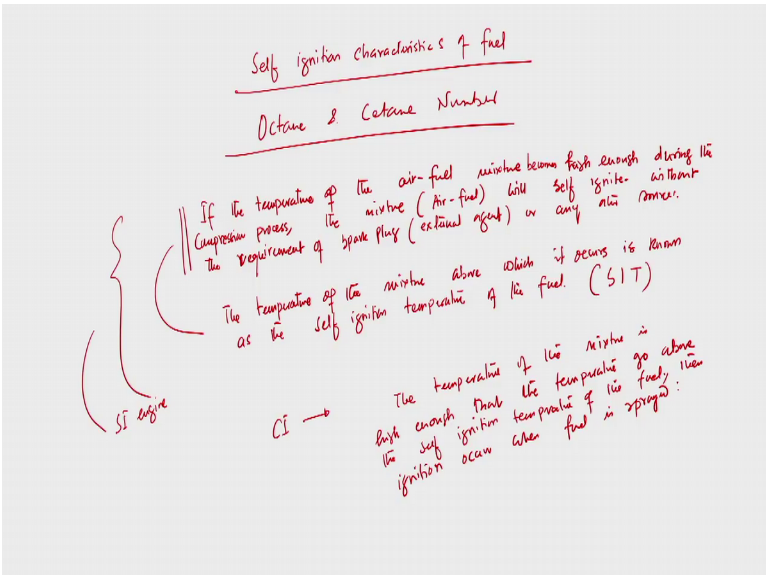

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So, this is very important that self ignition characteristics; self ignition characteristics, characteristics of fuel and from there we will discuss about octane number and cetane number very important. So, what is self ignition characteristics of fuel? So; that means, we have seen that, that in case of a its internal spark ignition engine or I mean even for the compression ignition engine we have seen that, if the temperature of an air fuel mixture is high enough then mixture will self ignite rather I mean in case of a spark ignition engine we require an external agent like spark plug to ignite the fuel, but somehow if we have, if we can raise the temperature of the air fuel mixture that is being supplied through carburetor to a level so that, without it will self ignite rather it will burn without have without needing an external agent like spark plug or source.

So, the temperature above whose this occur is known as self ignition temperature of the fuel. So, what I am telling that, whenever I am using a any particular fuel in a spark ignition engine or in case of a you know I mean, we do not require any spark plug of external agent for the compression ignition engine because compression ignition engine itself in a engine, the you know high pressure and temperature rather high the condition of the air at the end of the compression itself allow the fuel to be self ignite. So, the temperature itself is so high that whenever fuel is spread through a fuel nozzle it the air fuel mixture self ignite.

Now, in case of a spark ignition engine, we supply air fuel mixture through a carburetor then at the and entire mixture is getting compressed during the compression stroke and at the end of the compression stroke we need to switch on the spark plug and the spark plug will ignite whether it will, it will ignite the mixture rather combustion will start from there and we will discuss one day about the combustion in SI and CI engine you will come to know what the combustion start from the zone which is close to the spark plug.

Now, as a now I have said that somehow if I, if we can raise the temperature of the air fuel mixture that is being supplied in the com into the engine cylinder. So, if we can raise the temperature by increasing the compression ratio, but by increasing the compression process to a extent that without having in it the without needing any external agent like spark plug or source the fuel by which are you self ignite. The temperature above which it occurs is known as the self ignition characteristic of the fuel.

So, I am writing that; that I am writing that if the temperature of the air fuel mixture is high enough becomes high enough; if the temperature of the air fuel mixture becomes high enough during the compression stroke; during the compression process, the mixture will mixture that is air fuel mixture will self ignite, will self ignite without without a the requirement of spark plug which is an external agent or any other source or any other source.

So, we have seen that the temperature if we can raise to a level that we do not require any external agent to ignite the fuel and this is very important and the temperature of the temperature of the mixture; the temperature of the mixture rather, the temperature of the mixture above which it occurs is known as the self ignition temperature of the fuel, sometimes it is known as SIT. So that means, the temperature above which it occurs is the self ignition temperature or I mean this is the basic self ignition temperature of the fuel the basic principle of ignition in a compression ignition engine the compression ratio high enough that this is of course, for SI engine. So, this is I am talking about a SI engine; SI engine right.

But as I said again for the compression ignition engine, the temperature of the mixture; the temperature of the mixture is; the temperature of the mixture is high enough and high enough that the temperature; that the temperature go above; go above the self ignition temperature go above; the self ignition temperature of the fuel; self ignition temperature of the fuel and then ignition occur when fuel is injected; when fuel is spread through nozzle. So, here the temperature is always have up the self ignition temperature of the fuel. So, it do not require a you know an any external agent for the complete for to reset the combustion that is what you have seen.

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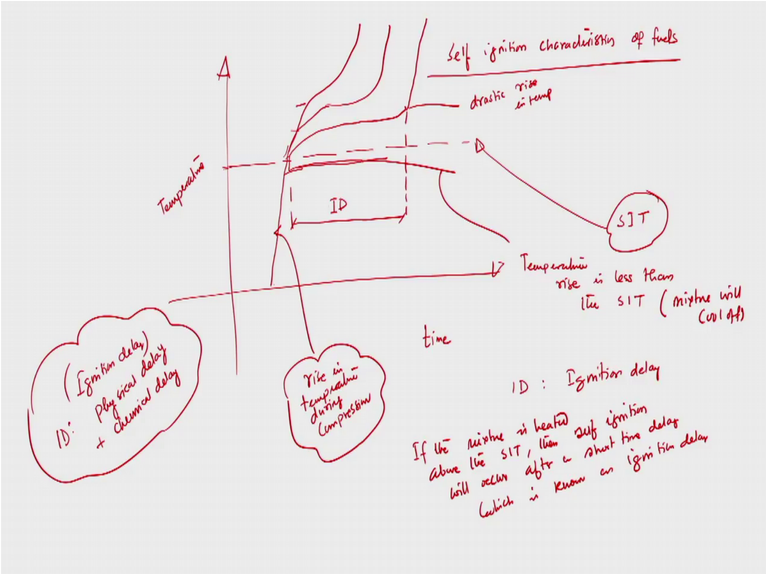

Now, question is if I try to draw the temperature versus time very important now if I try to draw the self ignition characteristics of the fuel so, if I try to draw that self ignition characteristics of fuel, fuels. So, if I try to draw very important that time versus so if I take time along x axis and if I take temperature along y axis then, what I can see from the graph that we will discuss now. So, if I, if we take time as x axis and temperature y axis suppose, if I take a particular fuel so whose self ignition temperature is having a fixed value. So, this is the self ignition temperature of a particular fuel; so, this is the self ignition temperature of the particular fuel that is fixed,

Now, question is if I increase the so, this is the compression process we are increasing the temperature may be we are increasing in such a way that, so we are increasing the temperature. Now, if, now if the you know temperature is so if I draw the you know temperature and temperature is less than the self ignition temperature; if the temperature less than the self ignition temperature so here, temperature rise is less than the self ignition temperature of the fuel. So, here we do not have any self ignition; so, it will be always cooled off I mean mixture will be always you know then the there is you know I mean no self ignition will occur, I mean since the temperature rise during the at the end of the compression at the end of the compression stroke is less than the self ignition temperature.

But so, this is compression heating of course, so this is rise in temperature; rise in temperature during compression stroke during compression stroke. Now if I increase the self ignition temperature and then right this is known as so this is I will tell so, even if I rise the temperature above the self ignition temperature, we can see that immediately after whenever temperature reaches just above the self ignition temperature combustion may not takes place, but entire combustion will require certain amount of time passes there they will be required a finite amount of time for the complete combustion. And then again we can see that, this point is combustion completed and drastic rise in temperature; drastic rise in temperature and so, the moment when the temperature go above the self ignition temperature then, entire combustion is not completed may be fuel fuel by mixture self ignition has already been started during the mixture. Now question is we require certain amount of time for the complete combustion and then only you can see there is a drastic rise in temperature the certain amount of time which is known as ignition delay of the engine

So, this ID which is known as ignition delay of the this is known as ignition delay that mean that; that means, mixture will cool off the mixture will remain, the mixture will cool off when the self ignition temperature is less than temperature rise less than mean SIT that is mixture will cool off, no combustion if the self ignition temperature if the temperature it go beyond the self ignition temperature even then we have we can see from this figure that we require certain amount of time which is known as ignition delay for the complete combustion; that means, the if the mixture is attained to temperature so that means, if the what is ignition delay? If the mixture is heated above the self ignition temperature then, self ignition will occur; self ignition will occur, I mean after a short time delay; after a short time delay which is known as; which is known as ignition delay or ID.

This ignition delay, I am writing this ignition delay or ID it has 2 different parts one is known as physical delay. Physical delay it consist of 2 different parts plus chemical delay. So, this ignition delay the time required to self ignite after reaching the self ignition temperature which is known as ignition delay and this has 2 parts one is physical delay another is chemical delay and as I said you that may be whenever the temperature of the mixture reaches above the self ignition temperature, combustion may start or may initiate, but to complete the combustion you require certain amount of time and then only we can see that the a drastic rise in temperature is an indication of having complete combustion. So, we can see that the time required from initiation of the combustion to complete of the combustion is essentially the ignition delay we can say.

So, I have written the definition that the mixture is heated above the SIT then, self ignition will occur that is fine after a short time delay which is ignition delay, but this ignition delay physically signifies that the time required from the initiation of the combustion to the complete of the combustion and it depends upon several factors and that is why I have written here that the ignition delay can be decomposed into 2 parts, one is physical delay another is chemical delay. Physical delay that is a time delay associated with the you know so many issues; that means, whenever air supplying it will self ignition will occur that is of course, in the context of compression ignition engine.

So, we can not think about having self ignition in case of a spark ignition engine. So, self ignition engine; that means, I mean self ignite, self ignition; that means, compression ignition engine. So, it depends upon the there is total ignition delay as I said you that is a time required between the initiation of the combustion to the complete of the combustion. So, may be we are spraying fuel immediately after reaching the self ignition temperature. So, it will take some time now it will take a finite amount of time to supply the spray because we until and unless we are getting desired spray per time and dissolve fuel in the all the places, we cannot have complete combustion. So, that that is associate associated with the physical delay that is the time required to have a complete spray of the fuel or required amount of fuel that will be spread into the engine through the nozzle and chemical delay it essentially depends upon the chemical characteristics of fuel. Because as I said you that, nozzle is used to fragments the droplet as I have discussed in detail about it in my last lecture one of my last lectures. So, we have seen that we need to decompose you needs to fragments fuel into smaller and smaller droplet.

So, whenever a combustion might start from smaller droplets and it will go to the next and next and that and that essentially depends upon the chemical compositions and chemical characters of the fuel and the that and that is where you require certain amount of time. So, maybe we are, may be whenever we are supplying fuel and the smaller droplet or the first fuel droplet will take part in the combustion then there it will spark plug in the next droplet. So, we require certain amount of time to initiate the complete combustion to complete the combustion in the in the entire domain of the cylinder that is why it is known as chemical delay.

So, physical delay that the time delay associated with the supplying complete amount of fuel with a desired spray pattern in the combustion chamber and chemical delay that is assen essentially associated with the chemical characteristic of the fuel that depends upon which hydrocarbon we are using and may be number of you know ff fluid droplets we are having and may be when one droplet is taking you know combustion is completed it will it percolate to the next droplet like so, so it depends upon the entire you know chemical combustion. So, we have seen that the ID is essentially at small time required that which indicates that the combustion is completed.

Now, question is very important; so, now, if I draw another figure again. So, we can see that very important that if we somehow can this is important. So, the higher the initial temperature rise above the see so from there I can say the I can write that if we increase the higher temperature rise that is which is compression heating that is, the rise of temperature during compression it becomes higher then we can see from the figure that the ignition delay reduces.

So, even though we are using a same fuel we cannot really make it 0 the physical delay and the chemical delay, but physical delay. But chemical delay we can reduce by increasing the temperature initial temperature of the mixture. So, we do not have control over the physical delay because which is associated with the functioning or the or the nozzle itself. So, what we can do we can raising the temperature of initial temperature of the mixture to an extent rather higher the initial temperature of the fuel mixture above SIT lesser will be the ignition delay and this less amount of ignition the less time required will come from the fact that we require lesser amount of the chemical delay is getting reduced.

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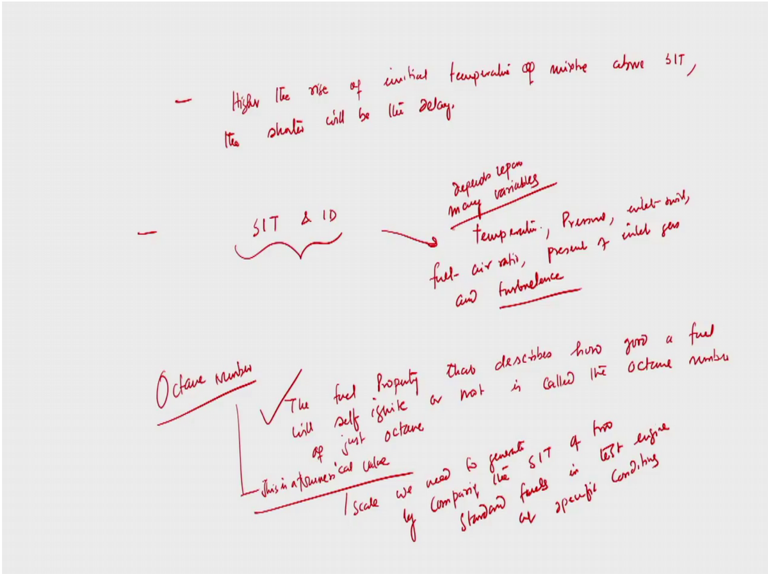

So, from this figure what we can see that, higher the rise; higher the rise in temperature; higher the rise of initial temperature; initial temperature of mixture above self ignition temperature the shorter will be the delay; will be the delay, So that means, by increasing you know by increasing a it depends upon many things air fuel ratio, presence of gasses, density and this see so. and the value of SIT and ID and so higher the initial temperature of the mixture above the SIT the shorter will be the delay and that delay we will take into account the is the short of you know reduce reduction of the ignition delay will essentially come from the reduction due to the reduction of the chemical delay period.

So, now, this self ignition temperature as well as the ignition delay these are this depends upon many things, what are the things? It depends upon temperature pressure; temperature pressure right; temperature pressure many variables it depends upon many variable; depends upon many variables temperature pressure you know inlets valve; inlets valve; inlets valve, then air fuel ratio or fuel air ratio whatever it is fuel air ratio, then presence of inlet gas and finally, turbulence. It is very important we will discuss part effect this turbulence is having in the context of combustion that we will discuss. So, these are the different very well is by which essentially dictates this for self ignition temperature ignition delay of particular fuel.

Now, is very important is that; so, we have seen that you know that in the context of SI engine, the self ignition temperature is very important because it in a SI engine it will not and compression heating when allow the fuel to self ignite. So, you have seen and that is why you require a spark plug. Now we need to know another number another know you know numerical value which is known as octane number. So, what is octane number right.

So, the I am writing the fuel property; the fuel property that describes; that describes how good a fuel will self ignite or not; or not is called the octane number or just octane right. The property that describes how good a fuel will self ignite or not is known as the octane number right. So, this is a numerical value. So, this octane number is basically a numerical value this is a; this is a numerical value this is a numerical value; this is a numerical value and we need to generate. So, thus numerical value and the scale we need to generate by comparing the; by comparing the self ignition temperature of 2 standard fuel; 2 standard fuels in a in a test engine at specific condition.

So, we can experimentally generate a numerical value scale of that where numerical octane number. So, if we know the octane number of 2 standard fuels and then, if you would like to know the octane number of any given fuel then we can take that fuel in doing test in a engine at a specific condition we can generate the scale by how and what will be the what are the 2 standard fuel. So, we have understood that in the context of SI engine, we do not know whether fuel is self ignite or not. In fact, fuel is not self igniting that is why require a spark plug.

Now, what will be, what will be consequence if the fuel self ignite in a SI engine that we will know. So, octane number is basically its numerical value that that describes the how good of will self ignite or not and we need to generate the scale of this number and for that if you need to know the octane number of 2 standard fuels and then if you would like to know octane number of any other fuel then, you have to take that fuel in a test engine at some specific condition knowing the value of the octane number two other fuels.

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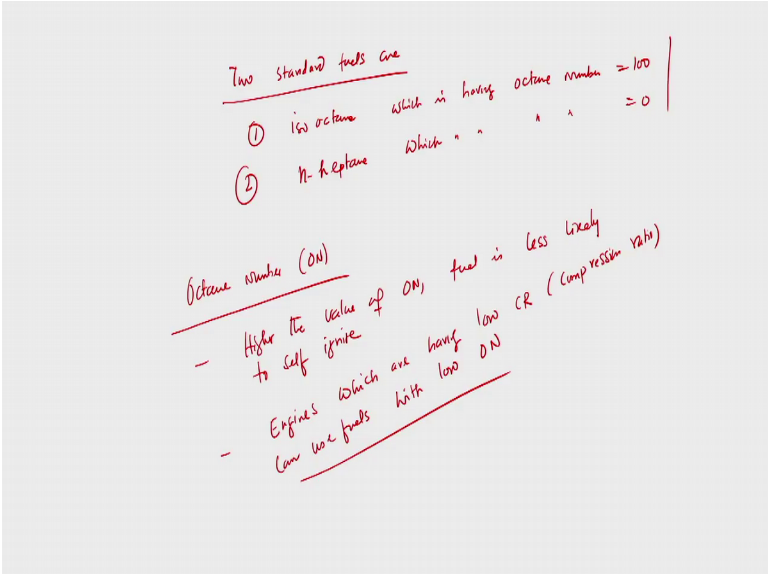

So, this 2 standard fuels are used; 2 standard fuels are very important one is very important is isooctane, I am writing isooctane; which is isooctane which is having octane number is equal to 100, number two n heptanes; n heptane is at the hydrocarbon which is having octane number is equal to 0. So, these are the 2 extreme cases. So, by knowing the octane number of these two fuels we can calculate what will be the you know octane number of any other fuel. So, this is very important that a we can calculate or we can take at that particular fuel in a test engine at specific condition and from there we can calculate. I will give you the you know empirical formula from where we can calculate the octane number of any other fuel knowing the numerical value of these 2 standard fuel of this 2 standard fuels which is having octane number 100 and 0 for isooctane and heptanes.

Now, question is so if the octane number value is high then, octane number value is high that indicates the fuel is self likely to self ignite. So, engines with low compression ratio can be used; can be can use fuel with lower octane number. So, so I am writing this octane number; octane number which is ON. So, higher the value of octane number; higher the value of octane number fuel is less likely to self ignite; likely to self ignite; that means, the fuel which is having higher octane number it is less likely to self ignite. So, if I now from this if I can say that engines which are; engines which are having low compression ratio that is spark ignition engine. So, low compression ratio engine because compression now itself is low so, in those engines we will be using are use can use fuel of with low octane number; with low octane number; low octane number. So, spark ignition engine which are having normally low compression ratio will use low octane number if they use higher octane number fuel it will not it is less likely to self ignite because it will not self ignite.

So, if we use low octane number so, they are they will having tendency to self ignite since we are having low compression ratio compression heating is not so much so; that means, they are have a if you use in an on the top of that high value of octane number then, that their tendency to self ignite will be less. So, if you use low octane number fuel their tendency to self ignite of the fuel. So, even may be although we are having spark plug, but still the compression heating will itself allows the temperature to go close to the octane self ignition temperature. So, that they might have attending it will have half self ignition ok. So, this is about the octane number that that essentially describes that how good of fuel will self ignite or not.

So, today I have discussed about the octane number, we will we have discussed about the we have discussed one problem we have taken one we have solved one problem to know; the you know chemic you know, you know, the what is the amount of oxygen required through the combustion reaction we have seen and we have prob discuss a problem taking a generalized expression of the hydrocarbon CxHy, then we have discussed that that, what is the self ignition characteristics of the fuel and then we have discussed about a few important thing what is ignition delay and by how we can reduce the ignition delay.

And we have discussed that self ignition temperature ignition delay depends upon many variables and one of the important variables is the turbulence we will discuss that aspect while we are discussing about the combustion of; combustion in SI and CI engine, then we have discussed about octane number which is basically numerical value and it is generated from a from a experimental in investigation taking 2 standard fuel which are basically you know isooctane and a which are basically isooctane and n heptane which are having octane number 100 and 0 respectively.

So, if you would like to know the octane number of any other fuel, then we can take that fuel in a particular test engine at some and we were we can carry out experiments at specific condition. And then finally, we have seen that octane number if the value of octane number is higher the fuel will have self tendency to ignite, that is fuel is less likely to self ignite so, naturally the engines which are having low compression ratio; that means, their compression heating is not that much they should not use the octane number fuel of fuel having higher octane number. So, they will try to use fuel with low octane number so, the compression heating may raise the temperature very close to SIT. So, they may start self ignition even without the support of spark ignition spark plug.

So, with this I stop here today and I will continue my discussion in the next class.

Thank you.