Thermal Engineering: Basic and Applied
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Lecture – 53
Fuel of IC Engines

I welcome you all to this session of thermal engineering basic and applied. Today we shall discuss about the fuels of both SI and CI engines. We have seen that in internal combustion engine chemical energy which is stored within the fuel is converted to the internal energy of the gas inside the combustion chamber and then that internal energy of the combustion gases is converted to the mechanical energy which is available at the crankshaft.

So, this energy conversion we have discussed that the chemical energy is converted to internal energy of the gas and that internal energy is converted to mechanical energy and that is available at the crankshaft. Now issue is fuel is needed because our objective is to get some mechanical energy at the crankshaft and to get that energy what we have understood is that we need to supply fuel.

So, if we talk about fuel of internal combustion engines, we shall discuss now the generic aspects of the fuels which is used in both SI and CI engines.

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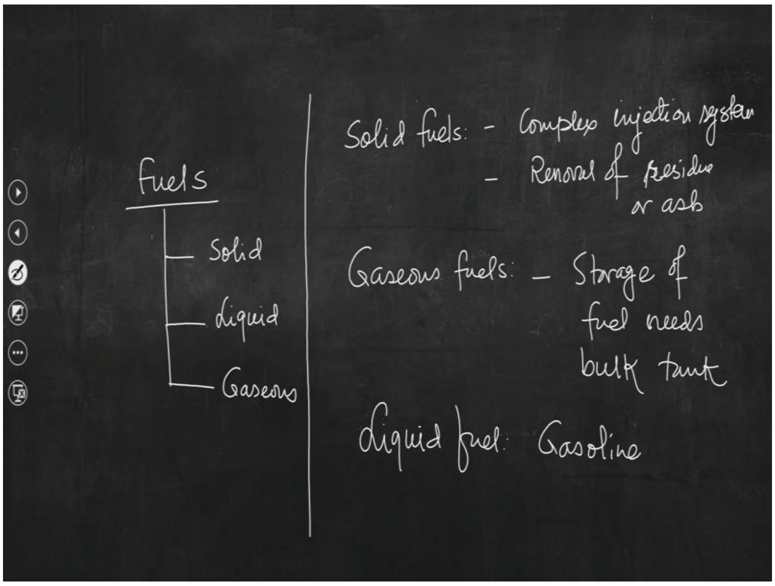

So, this fuels maybe solid, I mean fuels are solid liquid and gaseous fuels. So, internal combustion engine can be operated using solid fuel, can be operated using gaseous fuel, also can be operated using liquid fuels. So, the fuels are classified into three different categories solid liquid and gaseous fuel. So, now issue is if we use solid fuel for the internal combustion engine there are a few issues what are those?

So, use of solid fuel presence of few issues like we need to have complicated injection system and also the removal of solid residue or ash if we are focusing on the solid fuels.

Then if we talk about gaseous fuels most important problem is this storage because we need to have a large tank to store such fuel and this is not only associated with the initial cost but also that to accommodate such a big or large tank is also very difficult. So, for the gaseous fuel issue is problem is associated with this storage of fuel and for that we need storage of fuel needs bulk tanks.

So, but at the same time we also look at the favorable aspects of this particular fuel if we use for the internal combustion engine. So, say for example if we talk about Transportation vehicle. So, accumulating such a big tank in such a vehicle is not so easy because it will consume a large space and that too it will be bulky. So, if we talk about transportation vehicles, so basically over and above the goods engine also need to carry the load of that particular tank but favourable aspects are that if we use gaseous fuel you know that it is providing an important advantage of starting and distribution of the fuel because gaseous fuel is having low inertia. So, it can be easily transported from this storage tank to the combustion chamber it has less inertia.

So, distribution is quite easy but at the same time we also should be careful to make all the fuel line leak free, sometimes gaseous fuel can be liquefied under high pressure. So, why you are talking about gaseous fuel, gaseous fuels are sometimes available in plenty from both natural and even they can be manufactured.

So, if we are trying to use gaseous fuel then perhaps we need to make it liquid. So, the gaseous fuels can be liquefied under high pressure but the associated process is highly is costlier. So, it is also not recommended. So, next is the liquid fuel. So, liquid fuel basically we can use gasoline.

So, those are basically obtained from crude petroleum. So, though concerning with the distribution of the liquid fuel is not as easy as the gaseous fuel because it is having inertia, so, we need to have some kind of pumping mechanism to have a proper distribution of the liquid fuel using fuel line and that should be transported to the combustion chamber.

Mostly gasoline is used for the SI engines and this gasoline which is basically a mixture of several hydrocarbon components.

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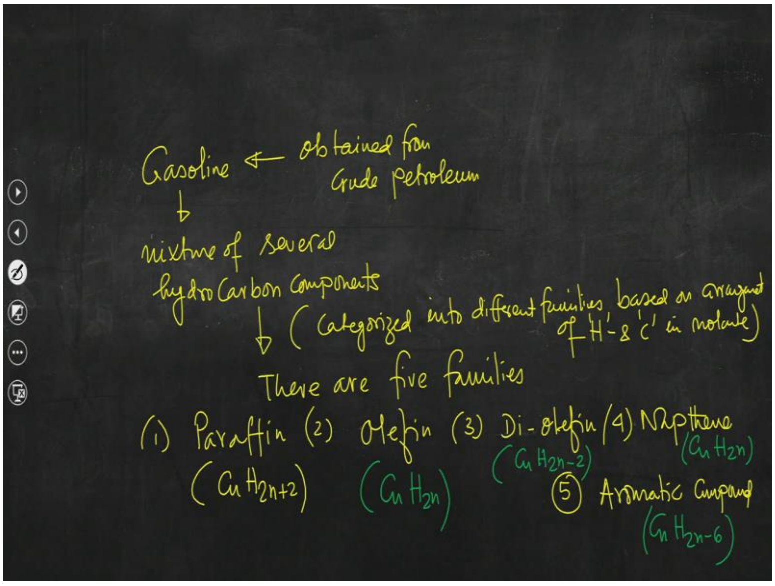

Now it is convenient to categorize them into different families depending on the arrangement of hydrogen and carbon atom in their molecular structure. So, the gasoline which is obtained from crude petroleum and it contains several hydrocarbon components.

So, it is desirable to categorize them into different families based on the arrangement of hydrogen and carbon atom in their molecular structure and there are five such families. So, now these families are very important now to discuss, one is paraffin, number 2 is olefin, number three is diolefin, four is very important napthene and five is aromatic compound.

So, all these are having different chemical structures. So, we need to recall a little bit of chemistry that we have learned in our 10 + 2 course. So, paraffin, the generic chemical formula is C_nH_{2n+2}. So, olefin is C_nH_{2n} diolefin is C_nH_{2n-2}. So, napthene is C_nH_{2n} and aromatic is C_nH_{2n-6}.

So, basically I have tried to write the generic chemical formula of all these families. So, let us briefly discuss about all these five families and which one is suitable for which type of engine.

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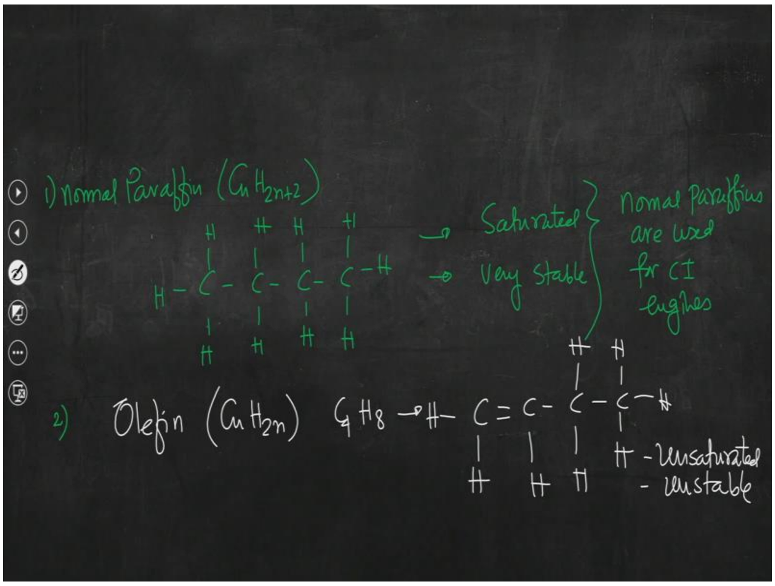

So, if we start with paraffin. So, this is C_nH_{2n+2} and example is say C_4H_{10}. So, what we can say from this particular structure is that valence of all carbon atom is totally utilized. So, this is not unsaturated, this is saturated and this is also stable. So, valance of each carbon atom all are utilized. So, this is saturated because there is no double bond and also very stable, this paraffins are mostly used for this CI engine.

Now we discuss about olefin and this is $C_nH_{2n,}$ example is C_4H_8 and if we look at the molecular structure, this is butane but if we just compare with normal paraffin we can see that there is a double bond. So, it is because of this presence of double bond it is unsaturated and not stable as paraphinase. So, valance of each carbon atom is not fully utilized; so, unsaturated and unstable. So, this is the olefin. All these gasolines are used for both SI and CI engines, but I had written over here that normal paraffins are recommended for CI engine. So, now if we go to the diolefin just to draw the molecular structure.

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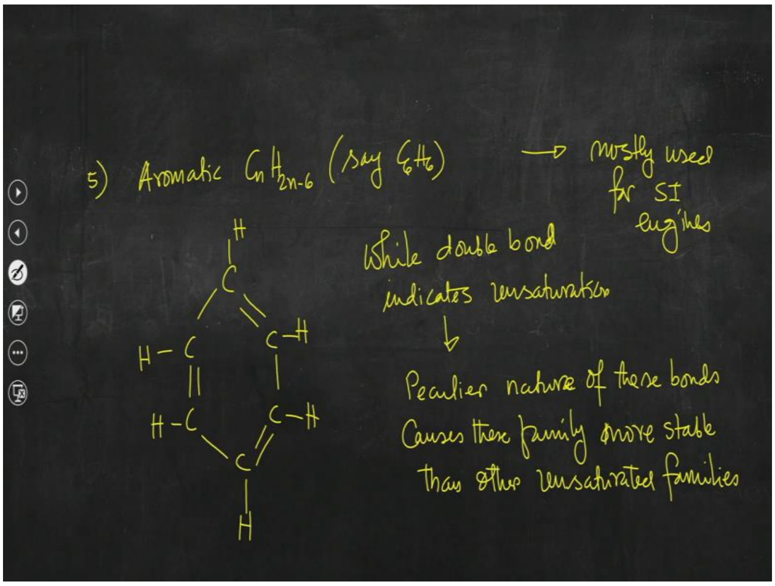

So, this is diolefin what is the chemical formula $C_nH_{2n-2,}$ say C_4H_6, butadiene. So, if we draw their chemical structure, it is essentially having 2 double bonds. So, it is even more unsaturated than olefin and even more unstable. So, this is highly unsaturated and unstable. So, unstable that it may lead to even gun deposit during storage. So, unstable that it does not require any kind of pressure temperature, in the storage tank itself it will dissociate and it leads to gun deposit.

And then four is napthene. So, this is $C_nH_{2n,}$ we can take one example that is C_5H_{10} cyclopentane. So, we will be drawing the molecular structure. So this is ring structure cyclopentane and we cannot see any double bond, valance of each carbon atom is again utilized. So, it is stable as well as saturated. Next is aromatic chemical formula is C_nH_{2n-6} that is Benzene ring.

So, we had studied about this particular ring you know 10 + 2 course. So, this is also ring structure now maybe we can see there are three double bonds. So, we have already discussed about that the presence of double bond leads to unsaturation and makes the compound unstable if that is the case then here we can see there are three double bonds. So, this particular compound or hydrocarbon would be even more unstable and more unsaturated.

But it is not like this, while double bond indicates unsaturation but peculiar nature of these bonds causes this family more stable than the other unsaturated family. A typical example is benzene and this aromatics are mostly used for the SI engines.

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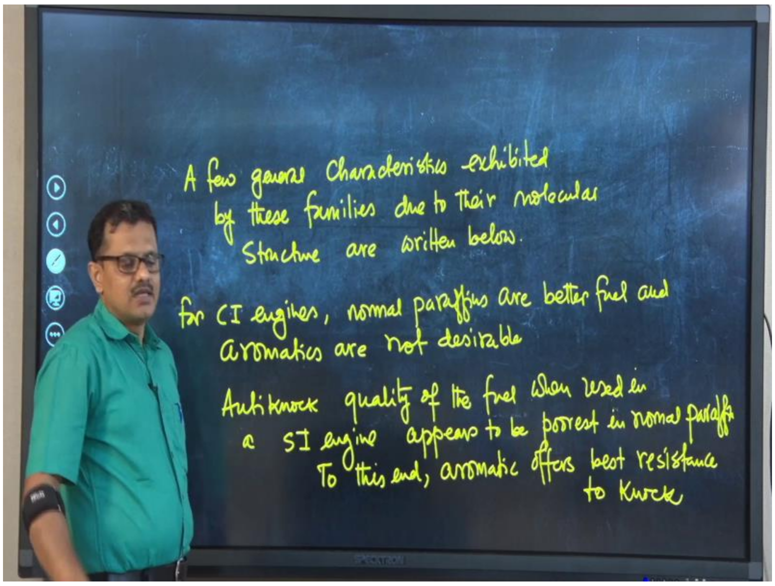

So, we have discussed about five different families paraffin, olefin, diolefin, napthelen and Benzene aromatic, we had taken one example and we had seen that all these hydrocarbons are having you know different characteristic. So, if we would like to write a few general characteristics exhibited by these families are due to their molecular structure.

First of all for CI engine, normal paraffin are better fuel and aromatics are less desirable, why? I had discussed that normal paraffins if we try to recall their molecular structure, we can see this is highly saturated and high stable. So, that is why these are used for CI engines. If we use them for the SI engine, we had seen that we need to have some kind of external agent to ignite it. So, we are not going to utilize this self ignition properties of the fuel instead we are using external agent like spark plug to ignite the fuel and that to SI engines are having low compression ratio.

So, at that compression ratio it is a difficult to have dissociation between the hydrogen and carbon bond, on the other hand for the SI engine if we use some fuel which are having some kind of unsaturation. So, maybe we can easily dissociate them. So, that is why this normal paraffins are much more suited for CI engines which are having normally high compression ratio.

And that to because since there is no unsaturation and so, at that compression ratio it is not going to have any kind of deposition even inside the combustion chamber. Then number 2 is the anti knock quality of the fuel when used in SI engine appears to be poorest in normal paraffin, to this end aromatic offers promising feature. So, to this end aromatic offers best resistance to knock. But since the anti knock quality is not very high for the normal paraffin. So, this is not used for the SI engine because in SI engines antiknock quality is important, to this end aromatic offers the promising aspect.

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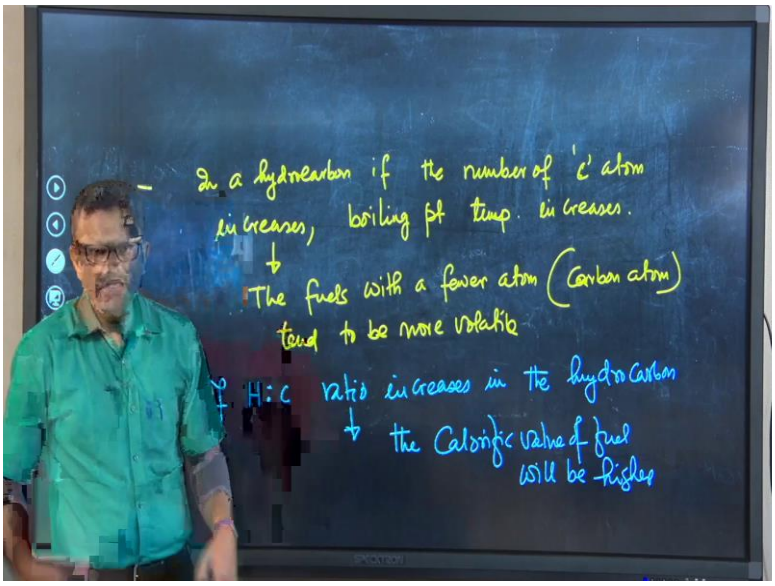

So, in a hydrocarbon if the number of carbon atom increases, boiling point temperature increases. So, from this we can draw a conclusion. So, basically when we will be selecting a particular hydrocarbon for any particular type of engines it is important to recall that if in the molecular structure of that particular hydrocarbon, if the number of carbon atom is more than boiling point temperature will more. If that is the case, then the fuel will be less volatile. So, the fuel with fewer carbon atom tends to be more volatile.

And another important point that I would like to discuss now is if H:C atom ratio increases in the hydrocarbon, then then the calorific value of fuel will be higher. So, the energy content within that hydrocarbon is more. So, as if it is giving an indication that the energy contains within the fuel is more. So, we have talked about several family is as we had mentioned that gasoline is basically a mixture of several hydrocarbon components. And it is it is desirable to categorize them depending on their molecular structure and we could do it. And we had seen that selection of a particular fuel for any particular type of engine is having some arguments and that we had tried to discuss.

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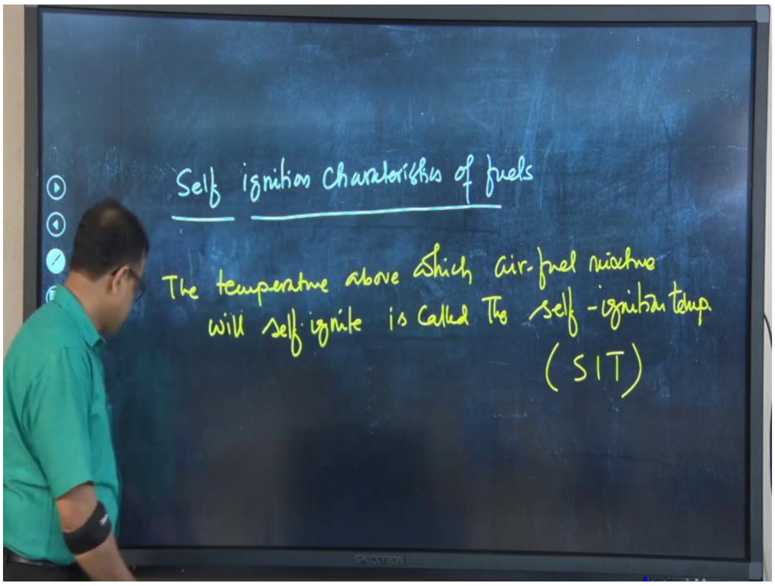

So, now we will discuss about an important point that is self ignition characteristics. So, we had seen that which particular type of hydrocarbon is more suited for this CI engine and which one is much more suited for the SI engine. Now, if you try to recall in one of the previous classes we have discussed that for the SI engine we are going to have an external agent and that is the spark plug. So, at the end of the compression stroke the thermodynamic state of the mixture is not sufficient enough to auto ignite or self ignite and for that we need to have a spark that would be produced by a spark plug and it would be having an electronic circuit.

So, question is if you are going to use any particular type of fuel for SI engine, why not to look at this particular self ignition property of that fuel. So, while selecting a particular type of fuel self ignition property is also equally important and that that is what should be understood. So, try to understand on the other hand for the compression ignition engines.

At the end of the compression stroke, the air is compressed and the pressure, temperature inside the combustion chamber is so high that the moment when fuel is sprayed into the combustion chamber, fuel auto ignite or self ignite. So, from these two we can understand there is a temperature and if the temperature inside the combustion chamber is beyond a threshold value then only fuel will self ignite.

Now we can still use some fuel which is used for the CI engine even for the SI engine and vice versa but since we are not going to utilize this self ignition characteristic self ignition properties of the fuel for the SI engines. So, definitely if we introduce a fuel which is used for the CI engine for the SI engine, something will be there and that part will be discussing later when we shall be discussing about the combustion briefly of course.

So, basically we need to know the temperature of the compressed gas whether it is compressed charge that is air fuel mixture or compressed air, if the temperature is above the particular temperature for which ignition will occur. So, the temperature at which ignition will occur is the self ignition temperature of the fuel.

So, pertaining to the selection of the fuel we also need to look at this particular property of the fuel that is we need to know what is the temperature at the end of the compression stroke and if the temperature is good enough to ignite the fuel automatically or we need to introduce spark plug or not. So, now let us briefly write about this particular term. So, what is the self ignition temperature.

So, the temperature above which above which air fuel mixture will self ignite is called this self ignition temperature whether it is SI or CI engine, for the SI engine we supplies air fuel mixture through the intake manifold but for the CI engines we are supplying only air, but at the end of the compression stroke we are supplying fuel.

So, essentially we need to ignite the air fuel mixture not only the pure fuel. So, fuel will ignite but it will ignite the air fuel mixture because it is homogeneous mixture. So, the temperature above which this air fuel mixture will self ignite is the self ignition temperature. Now say if we consider CI engine, if we supply a particular fuel and if we assume that the self ignition temperature of the fuel is so high that the temperature at the end of the compression stroke is not sufficient enough to ignite the fuel, then what will happen combustion will not be completed, we are not going to get enough power. So, it is something not a desirable situation. So, on the other hand we are supplying a particular fuel to the SI engine and if the self ignition temperature of the fuel is so less then maybe before we switch on this spark plug the fuel will self ignite and if that fuel will self ignite then there will be a chaotic rise in pressure inside the combustion chamber and that particular situation will lead to the development of abrupt pressure as well as audible noise and that is the knock.

So, self ignition temperature is equally important for both engines if it is the fuel which is being supplied to the SI engine if that particular fuel is having low self ignition temperature or SIT then the fuel will ignite even before we switch on the spark plug and what will happen that the spark plug switch is on, a main flame front will come from the spark plug area while because of this low self ignition temperature fuel which is there even on the Piston face or other heated surface of the combustion chamber secondary flames will be produced and those secondary Flames will collide with the primary flame front and it will generate huge pressure together with an audible noise and that is not desirable and that is known as knocking. Self ignition temperature is equally important for both the engines CI and SI engine, in particular it is very important for the SI engines now if we try to discuss about this particular property in the context of CI engine in what will happen.

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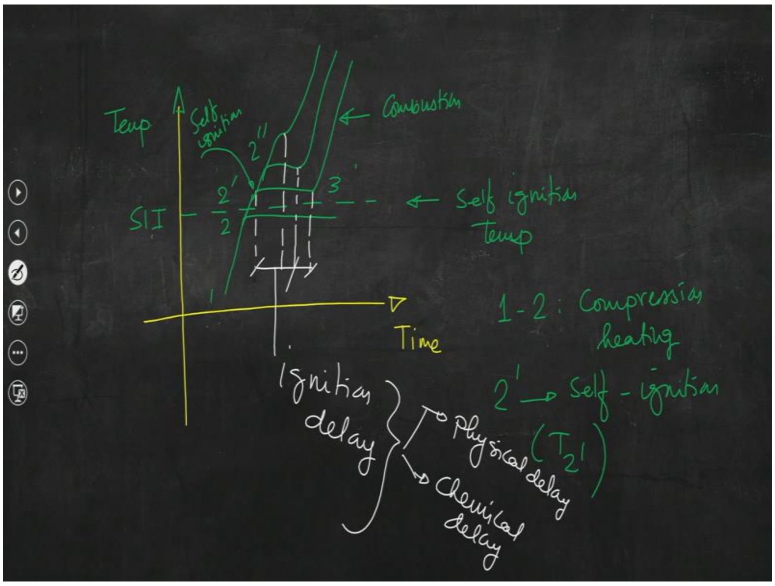

So, we have discussed about the knock which may develop that is nothing but abrupt pressure rise alongside the generation or development of an audible noise. And that may happen if the self ignition temperature of the fuel which is being supplied to SI engine is really less.

So, now let us discuss about this particular aspect in the context of CI engines. So, if we plot time say we are using a particular Fuel and for that this is the self ignition temperature. So, I am writing this is SIT. So, temperature versus time in this plane, this is compression heating.

So, suppose you are supplying a particular fuel to the CI engine and this 1 to 2 is the compression heating. Now we can see it is because of this compression heating rise in temperature is so that it is even less than the self ignition temperature.

And fuel will not Auto ignite or self ignite and it will just simply cool off. So, so combustion will not be there, if we use another fuel and if the self ignition properties of that fuel is such that even in the compression heating, temperature will be like. So, this is $2'$ and this is 3.

So, it is because of this compression heating temperature reaches T_2, which is higher than the self ignition temperature. So, it will now self ignite. So, this is self ignition point and then this is combustion, because of this combustion we can say there is abrupt rise in temperature.

So, you know that fuel will self ignite but it will take a fraction of second time to have full combustion or efficient combustion and this period though it is a fraction of a second, it is known as ignition delay. So, this ignition delay has 2 components one is physical delay another one is chemical delay, let me talk about briefly on this particular part.

So, even if the temperature of the fuel or temperature of the air fuel mixture due to compression reaches at T_2, which is above the self ignition temperature of that particular fuel, but combustion will not start exactly at T_2, it will take some time and the time is a fraction of a second and combustion will eventually start at 3 and then rise in temperature.

So, this delay is known as ignition delay and it has 2 components one is physical delay, another is chemical delay. Chemical delay depends on the chemical structure of the fuel I mean mainly fuel chemistry. As we have talked about the number of hydrogen to carbon atom, presence of double bonds.

So, self ignition will start over here, start and we are supplying fuel using a fuel nozzle. So, it is very unlikely that when at the end of the compression stroke that is at T_2, supplying all the fuel into the combustion chamber may take some time depending on the functionality of the nozzle depending on the efficiency of the nozzle. So, nozzle is again a mechanical device. So, it will not be perfect as it is under use. So, it will take certain time to spray the amount of fuel into the combustion chamber.

So, that time is the physical delay. So, it is not very likely that momentarily all the fuel should be supplied into the combustion chamber immediately when self ignition temperature is attained by the fuel. So, it is a physical delay and chemical delay is associated with the kind of chemistry or chemical aspects of the fuel, accounting for these 2 aspects we have this ignition delay.

Now if we can somehow increase the self ignition temperature even little more than say this is 2″ then we can say that self ignition delay is reduced. So, what we can say that higher the rise in temperature of the air, that is the rise in temperature at the end of the compression stroke of the compressed air, the shorter will be the ignition delay.

So, higher is the rise of temperature above the self ignition temperature of the fuel, shorter will be the ignition delay, if sorter is the ignition delay more efficient will be the combustion and that is much more desirable. So, what we have understood is that the self ignition temperature is very important from the perspective of the operation of both SI and CI engines.

For the SI engines this quantity is very important to prevent an undesirable phenomenon which is known as knock and if the knock is severe that will lead to detonation. On the other hand this quantity is equally important to understand the science of combustion for the CI engines because it will give us an insight about the ignition delay, shorter is the ignition delay better is the performance of the engine in terms of the combustion.

So, let me discuss another important or if it is even higher then we can see that the self ignition delay is even getting reduced. So, basically higher the rise in temperature and rise above the self ignition temperature shorter will be the ignition delay.

So, knowing this important property of the fuel we also can introduce 2 important parameters pertaining to the operation of both SI and CI engines of course while selecting a particular type of fuel and preferably rather it is desirable to consider these 2 important parameter while selecting a particular type of fuel for the operation of internal combustion engines.

We shall introduce those parameters along with we shall discuss the physical significance of these parameters in the next class. So, with this I stop here today, thank you