**Hydrogen Energy: Production, Storage, Transportation and Safety**
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**Lecture - 61**
**Use of Hydrogen in Internal Combustion Engines Part - 2**

Hello everyone. Yeah so, welcome to the another part of this module and we were discussing about the Use or an Application of Hydrogen in the IC Engine. So, in the last module, we have discussed about the how our engine will work and where these hydrogen finds it suitability.

So, now, we look into the further aspects about its usage and the emission, how its emissions are controlled, which we discussed in the last module.

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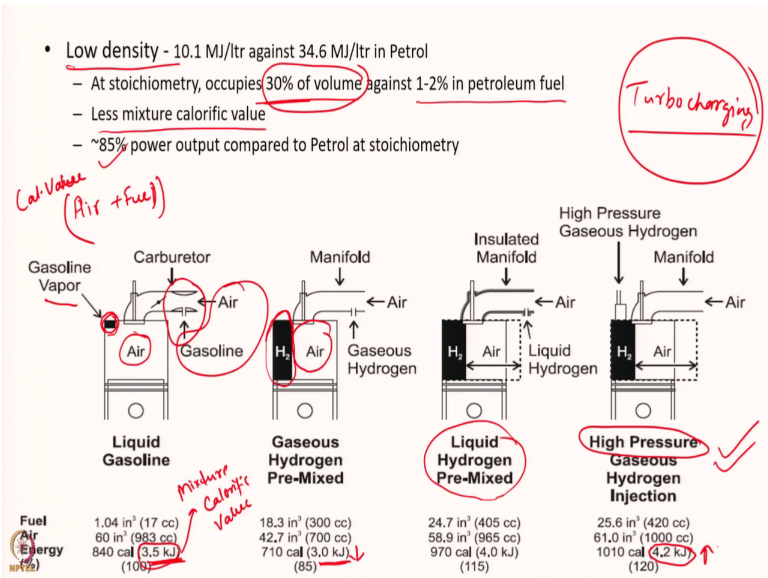


So, now one other aspect that you can say it is a little bit sort of negative is this low density of the fuel. So, as we know hydrogen is a very light gas, even though energy wise its calorific value is quite good, but when we want to burn a fuel in a spark ignition engine, typically we go for stoichiometry.

This stoichiometry means the required amount of oxygen that is enough to burn the fuel, so that there is no unburned fuel left. As well as, we do not want to supply excess air in spark ignition engine otherwise we will be able to supply less fuel. So, in a given size of engine, we have a limitation of supplying the air plus fuel. As we have seen air in the previous things, so air plus fuel both are injected inside the cylinder. So, when both are injected, we are more relevant of the calorific value of our air plus fuel mixture.

So, air plus fuel mixture calorific value. So, this particular calorific value is a little bit lower. And as we look into this example, so our fuel, so we can just have a look here. Like, when we discuss about the petrol in a sort of a 1000 cc engine, the overall calories is around 840 calories or the 3.5 kilo joule.

So, for every power stroke we are able to inject 3.5 kilo joule of energy that is the mixture calorific value. So, this particular thing is called mixture calorific value. And here for petrol it is 3.5 kilo joule. But for the same stoichiometry hydrogen will occupy a more volume.

Here you can see, the gasoline is occupying very small volume not in a liquid form, but in a vapor form because we vaporize petrol and then inject into the engine cylinder. So, because of its higher hydrocarbon, it is a big molecule, but whether it is a big molecule C8H18 or a hydrogen with only two hydrogen atoms both will occupy the same volume.

And that is the fact that the fuel will occupy very less volume. More volume is available for air to inject or the oxygen which will help in the combustion. But here hydrogen being only diatomic gas, we will be left with very less space for the air. And here we see the impact is on the mixture calorific value which comes down to 3 kilo joule compared to 3.5 kilo joule for the petrol air mixture.

So, a liquid hydrogen premix is one of the option, but not so attractive, but one thing is the supplying the high pressure, or what we call as turbo charging. So, turbo charging in the same engine, inject more pressurized air and hydrogen. So, that you can put more fuel into it per cycle. So, in that case we can easily go beyond the 3.5 kilo joules. So, here it is higher. And that is what we have to look for some of the options.

But typically, we will see because of the emissions thing we do not even go to this range. We always prefer to go little lean. Lean means we will supply less fuel for a given stoichiometry mixture requirement and that we will see a little later. But the thing is, it has a low density. At stoichiometry, it occupies around 30 percent of the volume against just 1 to 2 percent in the petroleum fuel, whether it is a petrol diesel or an ethanol or a biodiesel, those kind of fuel.

So, it suffers from less mixture calorific value and typically it suffers with a 85 percent power output compared to the petrol and stoichiometry. And the one of the attractive options is pressurizing or turbo charging, typically what technically we called in the engine literature, turbo charging the engine.

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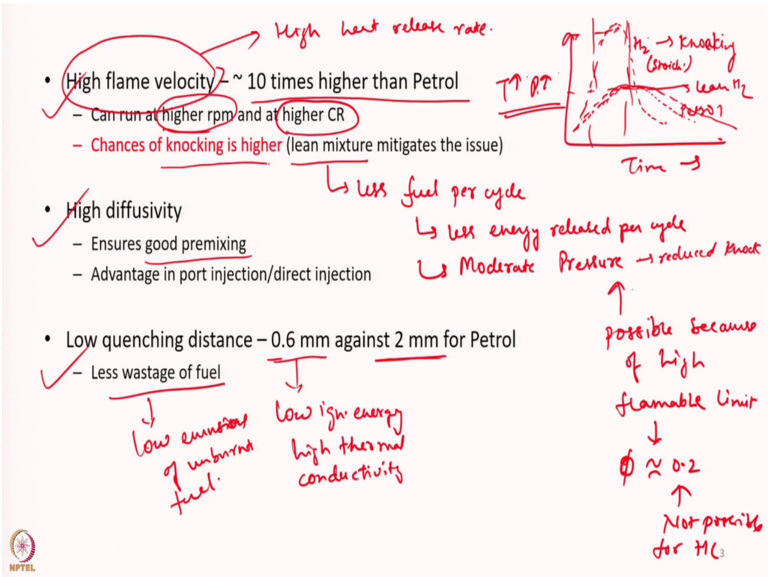


So, now another factor that we have already discussed in the last module was this high flame velocity. So, it is almost 10 times higher than the petrol. So, as we discussed, it will burn in a very small time. And that can help to run our engine at higher rpm. So, we can run at higher rpm, we can go for higher compression ratio, because we do not have to worry about the auto ignition.

Petrol, we do not go for higher compression ratio, because we the chance that it may auto ignite it. It is a hydrocarbon fuel, if you go to a compression ratio of 14, 16 or 18, like a diesel engine, it will also auto ignite. Before you give a spark it will auto ignite, and you do not want that because all the fuel is present in the engine beforehand, and then it will be like a mini blast inside the engine, on what we call as a knocking.

So, but chances of knocking is higher for hydrogen because of this high flame velocity. So, high flame velocity also means high heat release rate. So, if we just plot the time versus pressure rise, if your fuel is burning say this is for petrol, petrol if it is burning like this, there will be a gradual rise in temperature and then all the fuel will burn, then the temperature will come down.

So, this particular peak pressure, say this is for petrol, because it is burning slowly. It is burning little slowly. But when a hydrogen burns, it will quickly burn all the fuel in a very shorter time. So, your high peak pressure for hydrogen will be higher and this high pressure may cause very high impact on your engine piston and engine cylinder wall that gives a knocking phenomena.

You do not want our engine is designed for some peak pressures or you do not want engine to operate at higher pressure, high hydrogen can give. But lean mixture can mitigate the issue. So, this is what lean mixture means, less fuel per cycle. And less fuel per cycle in turn means less energy released per cycle. And this means moderate pressure. I am writing the moderate pressure because pressure needs not be too low, it should be somewhere here.

So, if your hydrogen, this is say, this is stoichiometric and if we do something like this, this will be a say lean hydrogen. So, again, it the pressure will be less, moderate pressure reduced knock chances. So, this is possible. And how it is possible? Possible because of high flammable limits. We can even go for equivalence ratio or phi which is called the air fuel ratio of around 0.2 which is not possible for hydrocarbon based fuel. So, we can go this much low.

So, it will be like if you have a hydrogen at the very light sort of thing or very light concentration in a kitchen, it will ignite. But like LPG will not ignite. It is a little safe. It has to go a little higher concentration to get sort of fire issues or safety issues, but hydrogen is very flammable, a very slight concentration, just 4 percent by volume. 4 percent by volume is enough.

You give it an ignition temperature ignition energy, initiate the reactions, 4 percent by volume is enough for it to sort of circulate or means like catch the fire and flame will be there. And as you see here, the requirement stoichiometry is around 30 percent, but even at 4 percent it will sustain the combustion. It will ignite. So, that is the one of the positive point. From fair safety point, it is a little sort of a negative property. But yeah from the engine perspective, it is quite good. We can operate.

Another thing it has a very high diffusivity which ensures good premixing. So, it is very good, if you have a good availability of oxygen and fuel near to it. Oxidation of all each and every fuel particle will be good. You will not see a sort of unburnt fuel that we typically get when we are using a liquid fuel like petrol or diesel which has to evaporate, then mix with air.

But here it is a gaseous fuel and it is higher diffusivity in the air is also very high compared to the hydrocarbon based fuel. Another good aspect is the low quenching distance. So, now, how does this low quenching distance makes the difference?

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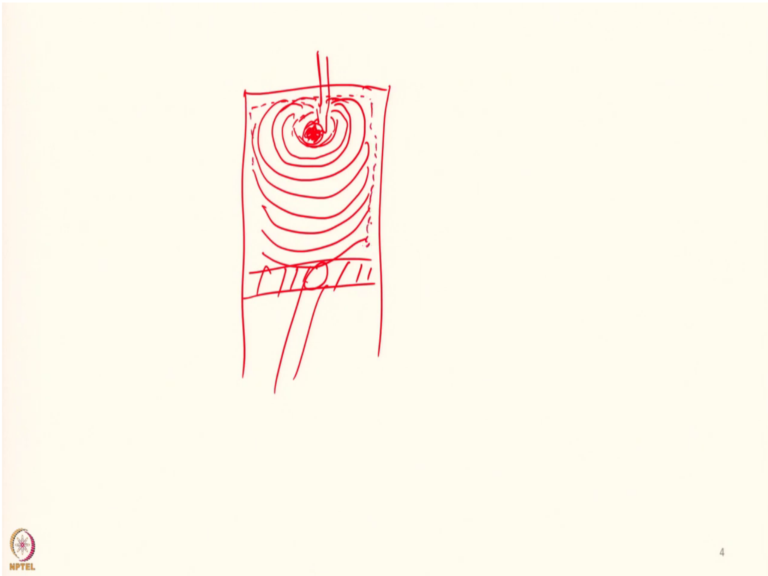

So, now, if we look into again IC engine, so this is your engine cylinder. This is your engine cylinder. And we are again taking the case of a spark ignition engine where you will give a spark. Now, this spark will ignite a small amount of fuel here and this small amount of fuel will burn the other fuel. So, it will go like this flame will follow.

And because the back side there is a less fuel, more and more fuel will burn in the bottom side towards the piston. But there is a zone, just next to the wall.

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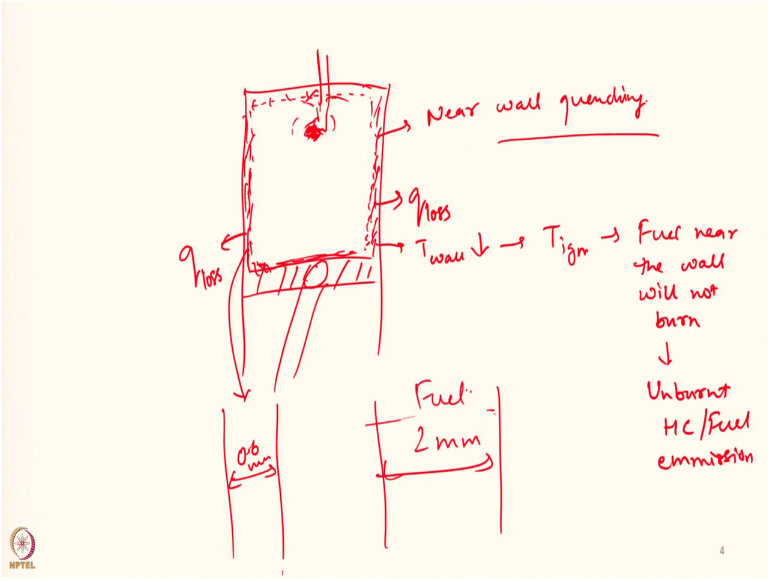


So, just next to the wall where temperature might be low, so near wall quenching. And why this quenching? Because this is a metal wall, so it is undergoing a heat loss. So the temperature of the wall goes down, and if it goes down the ignition temperature, fuel near the wall will not burn. And this is what happens. And in the typically spark ignition engine, in all the petrol engines.

So, whichever petrol engine you are using you have this major phenomena of wall quenching which leads to unburnt hydrocarbon emissions. So, unburnt hydrocarbon or any fuel. In our case, it is like say hydrogen it will be unburnt, because whatever the fuel is present, near the boundary; near the boundary it will not ignite and it will just come out in your exhaust. And this is one of the major problem which engine scientists are still trying to cope up with.

But what is the benefit with respect to hydrogen is because of its thermal properties, its quenching distance is just 0.6 mm compared to 2 millimeters for petrol. This means, this is because of the low ignition energy and high thermal conductivity, because of these things the amount of fuel that is on the wall, if it is fuel is hydrogen, it will burn more. It is just 0.6 mm of width.

If we enlarge this, which will get burn. But if it is petrol, it will be like 2 mm of distance, whatever the fuel is present here it will not burn. So, that is one of the benefit, it is less wastage of fuel, low emissions of unburnt fuel. So, that is the one of the major benefit when we are trying to use hydrogen as a fuel.

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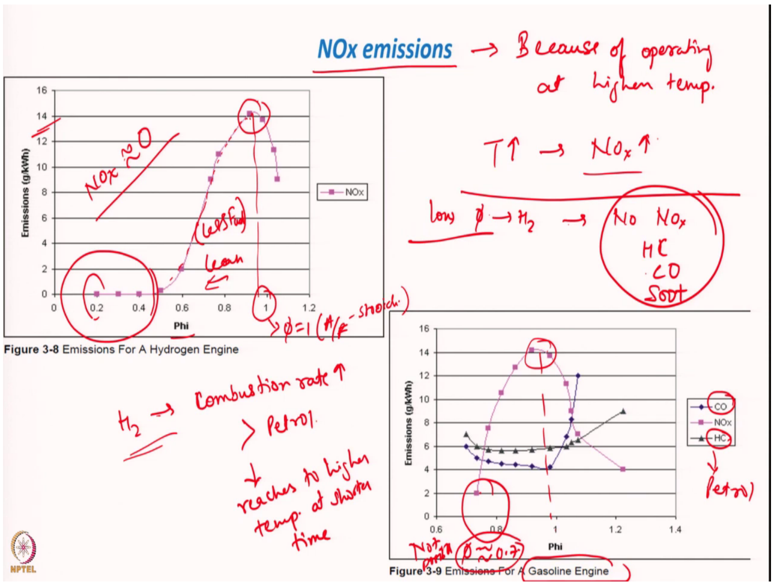


Now, coming to the NOx emission. So, NOx emission is mainly because of operating at higher temperatures. So, if temperature goes high NOx emission will also go high because the NOx emission are preferred at a very high temperature. So, but hydrogen, because the combustion rate is high, combustion rate is high more than that of petrol, so it reaches to higher temperature at shorter time.

So, you may say that if the energy is same, why it is reaching to the higher temperature. Again, we have to go back to this particular thing. Because this higher pressure is achieved, temperature also goes high, because pressure and temperature are linked. So, do not look into temperature is only from the perspective of your energy. Energy release is in very short duration. So, your same amount of energy will try to raise the temperature to higher level. But overall energy release may still be same.

So, that is one of the thing, that with hydrogen you experience typically the higher NOx emission, but here you can see that the NOx emission when we are operating near to the stoichiometry. So, this 1 phi, this means phi is equal to 1, air fuel ratio is stoichiometry. And now this is our lean. Lean condition means less fuel for that.

We can see that the temperature is coming down and the NOx emission is also coming down. So, now if you look into this NOx emission of 14, here for the petrol this also comes near the stoichiometry. But you will not be able to operate the petrol engine beyond sort of phi of around 0.7 it is not possible, not possible for gasoline or a petrol engine.

So, this is example for a petrol engine. It is not possible. But you can even go up to equivalence ratio of 0.2. Means engine will be little lean, less fuel you will inject, power output will be less. But what you are able to achieve is, if you are operating less than 0.5 of the equivalence ratio, you have virtually 0 NOx. and from here you can see that the carbon monoxide and hydrocarbon, it is only for the petrol because it has no emission from the carbon based type of emission.

So, if you are operating at low phi value with hydrogen, means no NOx, no unburnt hydrocarbon, no carbon monoxide and no soot. So, all your major pollutant that was there in any conventional IC engine using the fossil fuel, everything is eliminated. So, that is the sort of a major benefit of using hydrogen in the IC engine as a fuel.

So, with this, I would sort of try to give you one of the example or like if we say that, it has not, we have not heard about the hydrogen car till recently. The last month only a hydrogen car was, I think from that Toyota. It was sort of released in Indian market.

But that was a sort of a 2005, 2007 itself IC engine based hydrogen fuel based car was already designed and launched. But they are due to various reason, low market penetration, no buyer. It was discontinued after 2007. It never went into the mass production.

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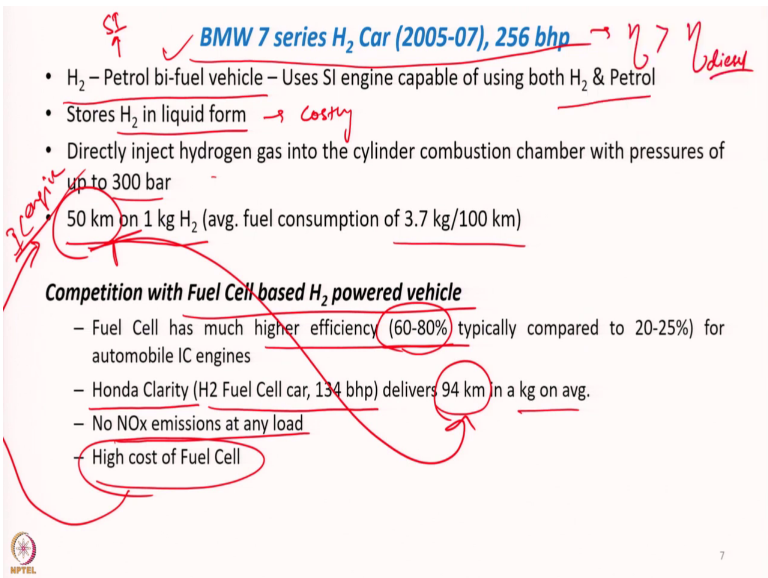


But, yes, this is possible. And one of the major thing was it was very efficient. The efficiency was even higher than the efficiency experienced by the diesel cars. So, typically diesel cars are more fuel efficient, but this hydrogen car was designed to be even more efficient than this thing.

And it was hydrogen petrol bi-fuel vehicle. So, that is the benefit in the spark ignition, because it was a spark ignition. So, if you are run out of the hydrogen, you can switch to petrol and it was capable of using both hydrogen and petrol. It had stored hydrogen in the liquid form, a little costly of air, but yeah.

Directly injecting hydrogen gas into the chamber with a pressure of up to 300 bar. And it was going 50 kilometers on 1 kg hydrogen. So, the average fuel consumption was around 3.7 kg for 100 kilometers. But yeah hydrogen is such a low density gas that even keeping a tank of 8 kgs or 10 kgs of hydrogen in a car, its a challenging thing. So, that was this car did not had a even mileage of around 400 kilometers, less than that. So, that was the issue.

But, when we compare with a fuel cell based hydrogen powered vehicle, that is another thing. For automobile fuel cell based, the example I have taken is from the Honda Clarity. Honda Clarity, the fuel cell has much higher efficiency. So, chemical cells or the electrochemical cell of a fuel cell is not limit limited by your Carnot cycle or second law of thermodynamics. But your IC engine based car is limited.

So, even achieving a 30 percent efficiency in IC engine based car is considered to be very exceptionally good. But easily you can go to 60 to 80 percent, if you are using a fuel cell. So, for a Honda Clarity which was a hydrogen fuel cell car, it delivered around 94 kilometers on an average. And now you compare this was a 50 kilometer. So, 50 kilometers and 90 kilometer, now you compare it is roughly double, double the range.

So, if you have a same full tank, you can go twice the distance, for the same amount of hydrogen, for the same cost of hydrogen. So, also, it has no NOx emission at any load. But to control the NOx emission in your IC engine, you have to design it to run in such a way that temperature remains low.

But the negative side is high cost of the fuel cell compared to the IC engine. IC engines are cheaper, cheaper to make, cheaper to maintain, have higher life, proven technology. We have not seen a fuel cell based vehicle which has run for 15-20 kilometers, but we have engines which has run for even more than 50 years all together.

So, that has been the thing. But yeah, technology is a sort of maturing. We will see how in the future hydrogen economy takes us, whether it will be fuel cell powered or it will be IC engine based power or we do not know whether our automobile will be mostly powered by the electric sort of batteries or through the electric motors.

So, with this note. I would like to thank you. And we will finish this particular module in this mode.

Thank you.