Hydrogen Energy: Production, Storage, Transportation and Safety

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Lecture - 60
Use of Hydrogen in Internal Combustion Engines Part - 1

Hello, everyone. So, in this particular module, we will discuss about the Application of Hydrogen in the IC Engines. So, as we know that there has been a lot of talk about this hydrogen applications, and you would have gone through the modules where we discussed about the use in fuel cell and other aspect, but here we will discuss about the IC engines.

So, when we talk about IC engines looks like a very new phenomenon, but just to give a very nice information or you can say a surprising one.

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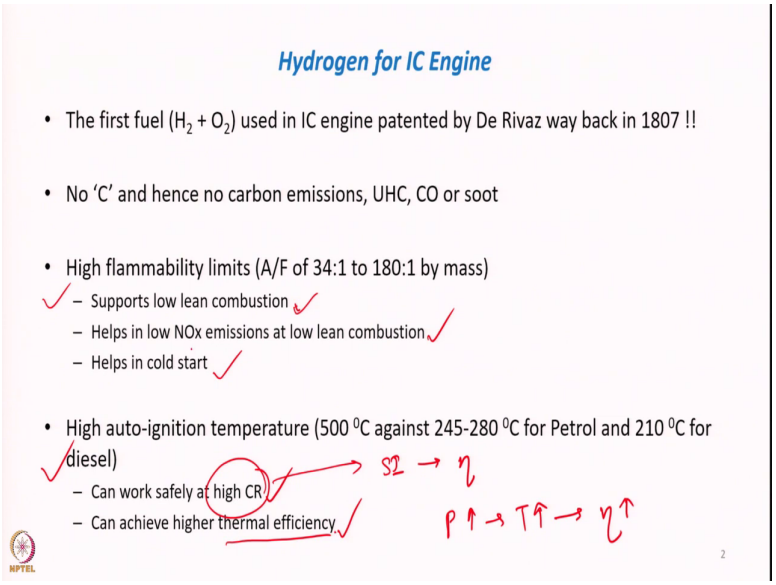

The first fuel that was used in the IC engine way back in 1807, it was actually the hydrogen as a fuel. So, then that was patented by the De Rivaz and one of the major sort of thrust of using hydrogen as a fuel is because it does not have a carbon. Now, CO_2, carbon dioxide emission has been everyone is talking about, but when we talk about the IC engine, there are other emissions that as you know the carbon monoxide, the NOx the SOx and the unburnt hydrocarbon at the black soot or the particulate matter.

So, these are all the issues with respect to the conventional IC engines that we are using. So, but when we have hydrogen we do not have any carbon based molecule in the fuel. So, there would not be a question of unburned hydrocarbon, carbon monoxide or the black soot. So, that is one of the major sort of a benefit of using hydrogen as a fuel in the IC engines.

So, some of the benefits that we look into as a fuel which supports the use in the actual application in the IC engines, it is the high flammable limits, because flammable limits mean. So, just if to understand what does this mean I will not go into much of a details, but yeah as you have sort of know when you have a LPG and then you will see that LPG when you switch OFF, switch ON the knob switch ON the knob it will come out from the burner and then maybe in a second if you are trying to put up a lighter it is not igniting, but you are able to smell it because it has come near to your nose.

But, when after 4 – 5 strikes of a lighter when it ignites the flame does not come to your nose and why so? The fuel is there, the air or oxygen is there near your nose, you are able to smell the fuel, but the ignition temperature which was there at the burner you have given the ignition temperature near the burner why it does not travel to the nose and that is what is the flammable limits explain that.

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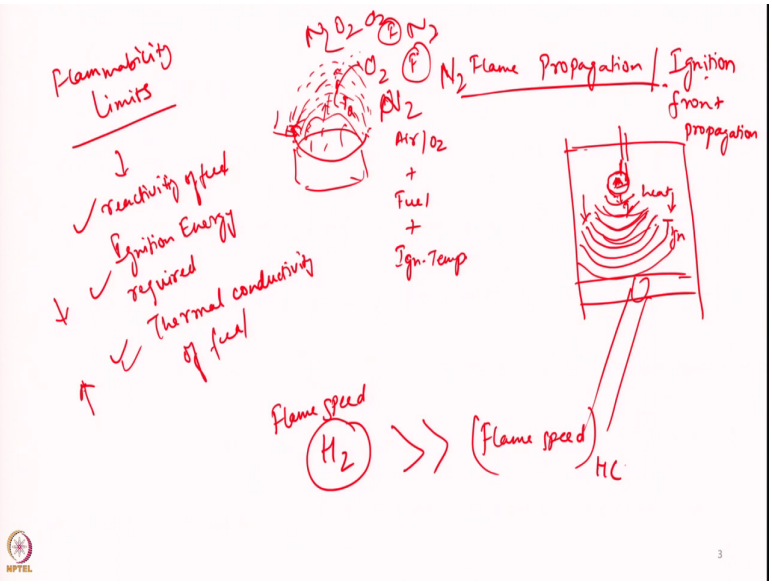

So, if you have any ignition source and you are giving a spark here. So, spark is given here and if there is a flame it will travel or it catches air or oxygen plus it follows fuel and plus it follows the ignition temperatures. So, ignition temperature will be there if this flame goes and

transfers the heat to the nearby molecules of the fuel and oxidizer and there you will see that there is a flame front propagating.

So, flame propagation that we typically known as flame propagation and this is what happens in a IC engine. So, if we see a IC engine, so, let us just draw a quickly about the one type of IC engine that is called the spark ignition. You have a spark plug and there you get a spark here. You get a spark here some fuel in the vicinity it burns and then it transfers heat that q is a heat here.

We transfer the heat and then what happens? This ignition front flame propagation or we can also say it appropriately as ignition front propagation. So, here the property of the fuel and the air mixture and the energy released or the calorific value of the fuel and other aspect it plays a very important role in how fast this flame will propagate or how far the ignition front or you can say how fast the heat is being transferred to the next layer so that the next layer can reach to the ignition temperature.

So, next layer of the fuel oxidizer mixture should reach to the ignition temperature. So, you will get that, but when you have a sort of a gas flame burner the fuel is very low here only few molecules of fuel and then you will have a lot of oxygen, nitrogen, oxygen, nitrogen in the vicinity which will absorb the heat which is being passed from this place to this place. So, you will not see that the all the flame will reach to your nose and, this is what is the flammable limit for an any given fuel.

So, you have a flammability limits. So, reactivity of fuel, ignition energy required, then thermal conductivity of the fuel, all these things plays a very important role and all these things hydrogen is very exceptional compared to any other hydrocarbon. I say that hydrogen or we can say that the flame speed for this hydrogen is very higher than flame speed for any hydrocarbon.

So, any hydrocarbon it is even more than 20 times higher than the any rival hydrocarbon you find any hydrocarbon fuel in that. And, that has a very unique because it has a very high thermal conductivity, it will be able to transfer the heat from this position to this position quickly, thermal conductivity is high. So, temperature is one thing, ignition energy requirement which passes to the next zone apart from the temperature you have to look into the energy also. Temperature may be very high, but the energy contained in this temperature

is in a very small localized zone so that it will not be able to give sufficient energy to break the bonds that is required for any reaction to take place.

So, ignition energy requirement is low. Even though the ignition temperature of hydrogen is high compared to any other hydrocarbon fuel, but the energy requirement for any sort of this reaction will take place is quite low compared to the hydrocarbons. So, and plus the reaction rate is also or the reactivity of the fuel is very high. So, all these things help in the flammability limits.

So, now, when we talk about the flammability limit how does it affect or why it is so good?. So, one of the thing is it supports lean combustion. So, we will shortly discuss about this lean combustion which helps in limiting the NOx emission at low lean combustion. So, it also helps in the cold start.

So, another fact about this hydrogen is the high auto ignition temperature. So, high auto ignition temperature it is almost around 500 degrees against typically all the hydrocarbons are in the range of around 200 to 300 degree centigrade where it is quite high. So, one thing is it will not be able to auto ignite in the given circumstances of a compression ignition engine or typically the diesel engines that we know.

But, the positive side is it can safely work at higher compression ratio to achieve higher thermal efficiency. So, I will not go into the details of the IC engine, but let me just quickly glance through some aspect of IC engine especially the two major design, the spark ignition and the compression ignition so that you will be able to appreciate some of the facts of a hydrogen being used as a fuel for IC engine.

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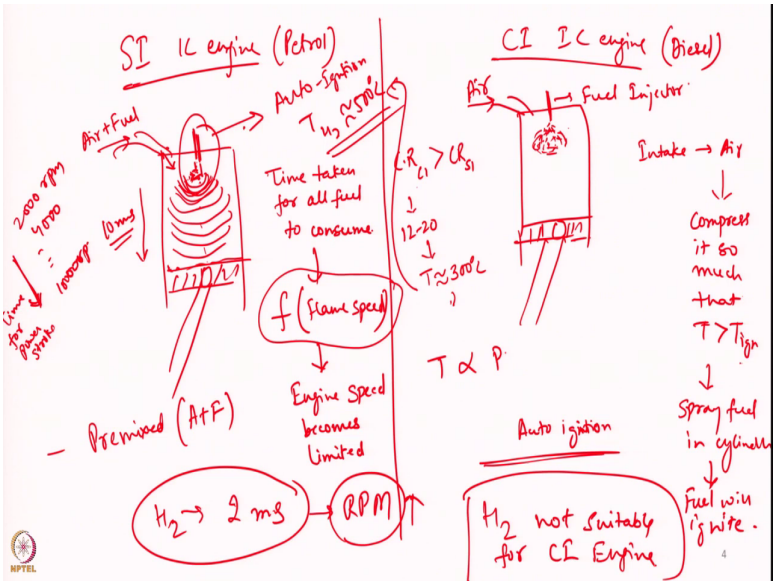

So, when we look into two aspects so, we have this spark ignition IC engine and then we have this compression ignition based IC engine. So, in spark ignition based typically petrol is conventional fuel that we used in compression ignition, diesel is the conventional fuel that is being used here.

So, when we look into the IC engine or spark ignition based IC engine, here we have just like we discussed in the last slide we will have a cylinder and this is the piston and there will be on the top side there will be a spark plug. Spark plug which will give the spark and the flame will propagate. So, what we push here through the inlet we push air plus fuel.

So, air plus fuel we push and that because it is a premixed sort of a combustion premixed of your air and fuel so, it goes into the engine you give a spark the flame will ignite and then flame will propagate through the air fuel mixture because throughout the cylinder you have the air and the fuel everywhere. So, the flame will go there. But, it needs time taken for all fuel to consume and it depends it is function of your flame speed, function of the flame speed and engine speed becomes limited because of the fact.

So, just imagine you have some fuel and whatever the amount of fuel you have injected into the cylinder it will take say 1 or 10 milliseconds to burn completely because this flame will take 10 milliseconds to reach to travel from this top near the spark plug back to this piston or the bottom dead centre which is technically called. So, it will take say 10 milliseconds to burn completely.

So, you have to give 10 milliseconds for the time for your power stroke. So, when you have engine running at 2000 rpm, 4000 or 10000 rpm, your time for power stroke it reduces means you are running the engine very fast, all the four strokes are happening in a very rapid manner. So, as you increase the engine speed or if you are running driving a car or a bike, you give accelerator you will see that the engine rpm is going up.

So, whenever engine rpm goes up your time that is available for this combustion or for the power stroke it reduces and there comes this flame speed a very important part. So, if you have a fuel which burns very fast, reactivity is very high, flame speed is very high, rather than 10 milliseconds for hydrogen, hydrogen may burn in just 2 milliseconds.

So, just giving you a number it varies on lot of thing it depends on the lot of other factors, but just keeping all the factors thing comparing with petrol hydrogen will burn it even less than fifth of the time under the similar situation. So, you what you can go is, you can in go for very high rpm.

You can increase the rpm very high to get more and more power because the rpm also decides how much power you are able to draw from the engine because in the given spark ignition engine you do not put too much of a fuel in a given cycle, but you increase the number of cycle per unit time.

And, that is how you get more and more power per unit time or what is joules per second or the power. So, using a hydrogen that becomes a benefit. But, why do you need to have a spark ignition for the given fact that auto ignition temperature. Auto ignition temperature of hydrogen is around 500 degrees centigrade and you need to give a spark to ignite it. Because what happens in a CI engine?

So, now, if we look into the CI engine, the CI engine is just again if we draw a rough sketch of your IC engine in CI engine you do not have a spark plug, but what you have is a fuel injector. So, in your fuel injector your diesel is being spread when the temperature inside the cylinder goes very high and how it goes? Your intake is only air; so, your inlet only air. After intake you compress it; so much that temperature goes beyond the ignition temperature of the fuel.

So, as we know ideal gas law, temperature is a function of your pressure or directly varying as a pressure where you increase the pressure your temperature will go up. So, as your

temperature moves up your will reach to a point. So, you have to go to very high compression ratio.

So, typically the compression ratio for your CI engine is higher than compression ratio for your SI engine. So, typically in the range of around 12 to 20; nowadays 18 to 20 is also there for the high power diesel engines, typically 14 to 16 for most of the diesel engines automobile diesel engines you will see that ok.

So, now this particular aspect that when you are operating at high compression ratio to reach the ignition temperature, in this range you will get to the temperature of around 300 degrees not more than that, but still you would not be able to reach to this temperature of ignition for the hydrogen, but for diesel when you spray the diesel at the end when you reach to the ignition temperature spray fuel in cylinder and then fuel will ignite.

So, what we were able to do through a spark plug in a spark ignition engine that is an automatic. So, that is why it is called the auto ignition of the fuel in a compression ignition cycle. So, you just compress, make the temperature of the whole environment so high that whenever you fuel inject it, it will start burning. So, it will all the fuel will start burning as soon as you inject the fuel.

So, here to control the sort of burning you control the fuel injection rate because as soon as the fuel will come it will try to burn as quickly as possible. So, but hydrogen is not suitable for that, hydrogen not suitable for CI engine because of its high ignition temperature. You can say that keep on increasing the compression ratio we will achieve, but when we increase the compression ratio lot more other things also we have to do. The engine needs to sustain that much of force.

So, typically you will see that a diesel engine is heavier than petrol engine and the reason being it is not because it is producing more power. The reason being you are operating at higher compression ratio. So, you have to design an engine so sturdy that it can sustain that much of amount of high pressure high force.

So, if you further want to increase it to 30 – 35 or so, so that you reach to the ignition temperature of hydrogen you will have to go create sort of a engine or design a engine very heavy. So, that negates the sort of overall requirements, cost and the weight of a vehicle or other things becomes little complicated. So, SI engine is typically suitable for that.

But, what happens to this particular point is that we can increase the compression ratio of a SI engine, so that efficiency gets increased. Why? Because when we increase the pressure our temperature increases and when our temperature increases our thermal efficiency is increasing as per the second law of thermodynamics.

So, this IC engine are thermal engines. They are governed by the second law of thermodynamics and it suggest the higher operating temperature the more will be the thermal efficiency. So, we achieved higher thermal efficiency because of that and now about this NOx emission and all we will discuss it a little bit later.

Thank you.