Fundamentals of Automotive Systems
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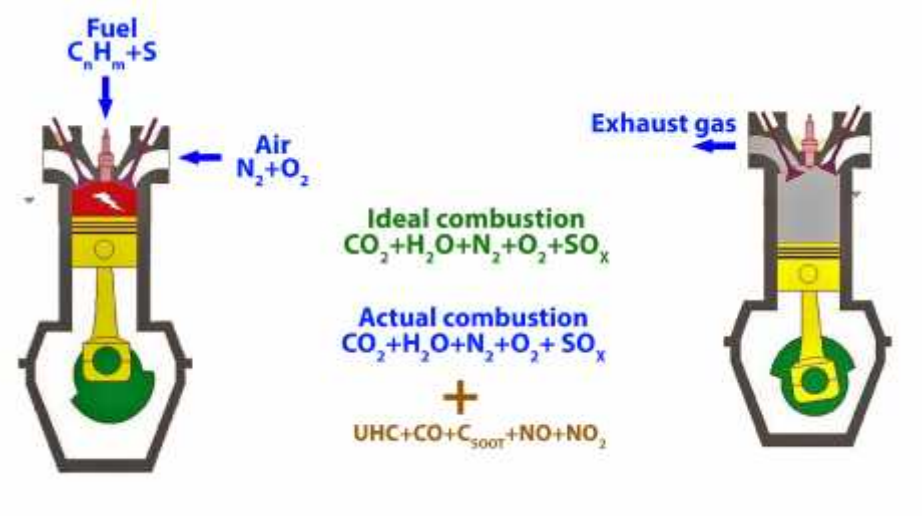
Lecture - 25
Engine Emissions Part 01

Greetings so start let us start get started with today's class. So, we were looking at engine emissions, so broadly emissions from IC engines you know like, can be classified as what are called exhaust emissions that come from the tailpipe, which include all these gases unburned hydrocarbons, Oxides of carbon Oxides of nitrogen, Oxides of Sulphur and also like emissions in the form of particulate matters.

So, in addition to exhaust emissions there are what are called as non-exhaust emissions, which are mainly unburned hydrocarbons that come in into the atmosphere a due to evaporative losses in the fuel tank and other elements like carburetors. And you can also have what is called as crankcase blowback where you know some fuel escapes through the crevices in the piston cylinder assembly between the piston rings oil rings on the cylinder surface okay.



ENGINE EXHAUST EMISSIONS

So that constitutes those constitute non exhaust emissions. So, we are going to look at both categories of emissions and we are going to look at each component of these emissions in today's class and we will also look at what happens in various types of engines like 4 stroke SI and CI engines and also in 2 stroke engines. So, if we look at the ideal combustion process in any

internal combustion engine, we provide fuel which is a hydrocarbon sometimes many times you know Sulphur is present in the fuel.

And we take in air predominantly a mixture of nitrogen and oxygen and when we combust them and when we burn them together in the combustion chamber chemical reactions occur and in the ideal scenario we should get these as the byproducts of combustion that is the exhaust should contain carbon dioxide, water vapor, nitrogen acid is as N_2 any excess oxygen as O_2 and maybe some oxides of Sulphur.

So, that is as close to the ideal process that we can expect. So, in other words, all the hydrogen and carbon in the fuel must be completely oxidized, so that we also avoid other exhaust emissions and also ensure that we are able to retrieve the maximum possible chemical energy from the fuel converted into thermal energy. So, that is the ideal scenario in the real combustion process more often than not, we will get these gases, CO_2,H_2O,N_2,O_2 and oxides of Sulphur.

But in addition, we would also get unburned hydrocarbons, UHC stands for unburned hydro carbons. We will get carbon monoxide CO carbon in the form of particulate matter what is called a soot we may get NO and NO_2, NO and $NO_2$are typically combined and represented as NOX people some people refer to as NOX as a term. So, we are going to get all these additional gases as byproducts of the combustion process in the exhaust.

And these as severe implications on the environment. And in addition to that, we are also going to see what impact they have on the engine perspective, So that is something which we are going to look at so, this is the actual scenario. So let is start looking at what happens in each type of engine and then like we will also discuss each component of this emissions right. So, first starting with emission from SI engines.

Typically what happens is that in spark ignition engines and also like in what to say both 2 stroke and 4 stroke what is going to happen is it a rich mixture rich fuel air mixture would not have would have you know what to say HC and CO since there is insufficient oxygen for complete oxidation okay. So the oxidation process is not complete right, so, if the oxidation process is not

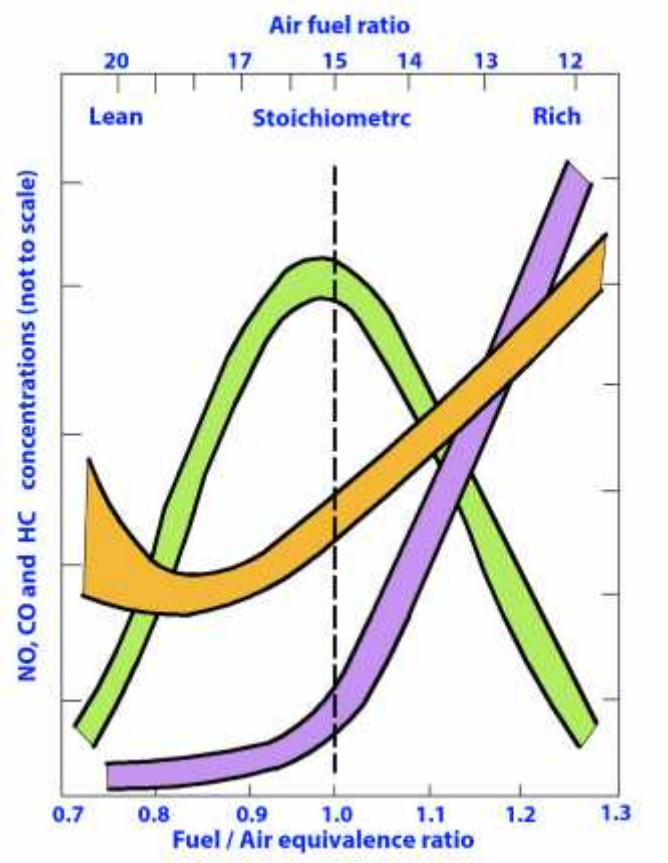
complete you know like, essentially we are going to have this unburned hydrocarbons and oxidation process unburned hydrocarbons and carbon monoxide present in the engine exhaust okay.

And when would this NOX emissions also come into play in fact the oxidation of this one know make so, let me call this solution. So the knock knocks gets form if an oxidation of NOX happens or nitrogen happens you know like at high temperature in the cylinders N_2 will result with O_2 to form this NO and NO_2 So, whenever we have this condition of high temperatures in the cylinder.

We are going to have NOX formation and when would the cylinder temperature be the highest when the fuel air mixture is close to the stoichiometric mixture when we have fuel air mixture to be at the close to the stoichiometric ratio our what to say combustion process is going to be pretty efficient as far as the conversion of chemical energy to thermal energy is concerned and the cylinder temperatures would peak.

So NOX emissions depend on the combustion temperature and hence are the highest at near stoichiometric conditions that is when. Okay so that is when the NOX emissions become the highest of course typically, maximum NOx emission are happens at a slightly lean condition. So, if you compare it, happens at a slightly lean condition because at this condition the cylinder temperature is sufficiently high and there is enough excess oxygen also so, we need oxygen to reactive nitrogen so if you have exactly stoichiometric so there is only enough oxygen to react to the hydrocarbon and oxidize them.

So there would not be any oxygen left. If the fuel air ratio is exactly stoichiometric so slightly lean mixture, so there will be enough heat energy that is released to ensure that the cylinder temperatures are sufficiently high and also there is enough oxygen to react with nitrogen. So, if we take it consider a typical what to say distribution of these gases you know like in a spark ignition engine you know like it looks something like this so, of course this should be stoichiometric okay.



EMISSIONS IN SI ENGINES

So if we plot the fuel air ratio, so, and essentially look at how the emissions get affected in spark ignition engine. So let us consider the equivalence ratio right. So, as we know this side is lean to the right of the what to say the vertical line at 1 it is going to be a rich mixture right. Unsurprisingly in a rich mixture the hydrocarbon content and the carbon monoxide content increase. So hydro carbon and carbon monoxide right.

So, HC and CO content increase in a rich mixture because obviously we are going to have more unburned fuel right and we can see that NOX emission, which is represented by these curves you know like become a maximum slightly lean mixtures, near stoichiometric conditions and that is where they become the maximum. So, this is typically in emissions in 2 stroke, what to say SI engines in addition, question is what happens in 2 stroke SI engine, so this is a general trend in SI engines.

But what do you think would happen in 2 stroke SI engines in compared to the 4 stroke SI engine in 2 stroke SI engines we can immediately see that the process of scavenging would result in more unburned fuel escaping with the exhaust. So if we recall how 2 stroke engines operate, we can recall that the exhaust port is open during the down stroke and during the same phase fresh fuel air mixture is going to come from the crankcase through the transfer port to the combustion chamber.

So, there is a good chance of not only exhaust gas dilution of fresh charge and also fresh charge escaping into the exhaust port. So, due to these reasons, the chances of unburned hydrocarbon being more increase in a 2 stroke engine okay. So in a 2 stroke engine the process of scavenging results in unburned fuel escaping with the exhaust, so that is what happens in a 2 stroke engine. And not only that, please recall that in a 2 stroke engine we add lubricants along with the fuel.

And the lubricating oil has a different chemical composition when compared with the fuel and that is also going to go into the cylinder undergo combustion to varying extents and whatever is left behind is going to be exhausted through the exhaust port okay. So, we have to look at that aspect of the lubricate the lubricants oil or the lubricant fluid that has a higher molecular weight, is also going to undergo incomplete combustion, the combustion chamber that further adds to the hydrocarbon emissions.

So that is what these are 2 important factors that we need to keep in mind when we look at emissions in 2 stroke engines. So, in addition to whatever we have already seen about SI engines 2 stroke SI engines okay. So, now we will come to CI engine shortly but before that let is look at each component 1 by 1 right.

So and then like that will also give us an idea as to which component is going to be important and what type of engines. So let us first look at the first component that we are going to look at is hydrocarbon unburned hydrocarbons okay. So let us abbreviated as HC okay. So, what as we already know, hydrocarbons we can have 2 aspects. So, this is we can have unburned fuel compounds as they are right in the exhaust.

But also like partially reacted compounds right particularly when we have high molecular mass hydrocarbons they can be oxidize partially right they can go to a different chemical structure and still be released along with the exhaust okay so, partially reacted compounds they form when large fuel molecules break up okay due to the heat energy during the combustion process and this is what is called as thermal cracking.

So, thermal cracking is this phenomenal where these larger molecules break down into smaller hydrocarbon molecules and these are also released and what are some limitations with hydrocarbons obviously, they act as irritants for us and odorants okay some are carcinogenic too and hydrocarbons react with atmospheric gases to form photochemical smog. This is once again very harmful right smog is harmful for all living things okay.

So, essentially higher hydrocarbon content can be present in rich mixtures because why because obviously they can they have less oxygen to completely oxidize the fuel particles and unburned hydrocarbons are also present in too leaner a mixture why because they may not have enough fuel to even like sustain the combustion process. So, either too lean as we can observe too lean a mixture would also increase the hydrocarbon content because we essentially cannot sustain the combustion process.

So that is why that is a reason for increasing hydrocarbon content when we go to very lean mixtures, so neither is adequate too rich or too lean right, from an emission hydrocarbons emission perspective. Now let us look at a causes for HC emission. Let me quickly run through them in SI engine you will see that even in CI engines, you know, like many of these causes are going to commit but first let us look at what happens in spark ignition engines.

And what factors are result in significant hydrocarbon emissions okay. So, the first one is due to incomplete combustion obviously. So, the combustion process is not incomplete sorry is not complete okay and there are multiple reasons for this of one is due to improper mixing of fuel and air because of the fuel and air do not mix properly to form a homogeneous mixture we are going to have incomplete combustion right.

So, that is 1 reason second factor is what is called as flame quenching. So, what is mean by the flame quenching the flame gets put out before it can burn all the fuel you know like unburned fuel right so, why does flame quenching happen. So, when the flame gets closer to the wall it can get quenched right and the flame front hits the wall it can get quenched. So that is 1 reason flames also get quenched during expansion of burned gases that result in reduced temperature and pressure right.

So, when the combusted gases expand right. So, the pressure and temperature are going to decrease in the combustion chamber and due to that a flame may get quenched okay. Temperature and another potential reason is contamination with exhaust gases so, because typically there is there may be exhaust gases that may mix with the fresh charge a part of exhaust gases may also remain in the cylinder from the previous cycle and where the concentration of these exhaust gases is high the flame may get quenched.

Because it cannot have enough what to say fresh oxygen right to carry out the combustion process right the fuel air mixture may not be combustible okay. So, incomplete combustion predominantly happens due to these reasons and that increases the level of hydrocarbons in the exhaust. So, what is what can be another reason there are multiple reasons so essentially fuel trapped in piston ring compression oil ring crevices.

So, what happens as we already seen a compression ring or a piston ring provides the seal and an oil ring also install on the piston periphery. So now although like these are carefully manufactured and assembled still we are going to have small crevices right and the fuel air mixture is going to be forced through these crevices and during the compression stroke okay. So, the fuel air mixture may be forced into these crevices okay so at high pressures.

So, now when expansion happens what is going to happen the pressure in the cylinder is going to drop down then there is a pressure difference in the opposite direction is it not okay. So, this fuel unburned fuel air mixture which is which are essentially captured in the crevices may come out because now the pressure is lower in the cylinder. So, during expansion stroke this may come

back into the cylinder okay and this increases the what to say unburned hydrocarbon this can potentially increase. So, this process is what is called as reverse blow-by.

So, if you encounter this term what is reverse blow by you know like essentially, we look at crankcase blow by right unburned hydrocarbons blow past the rings and then into the crankcase and then escape. So, this is like a part of it you know like comes in the reverse direction. First they are forced into crevices but a part of it comes back, so that is why it is called as reverse blowing okay. So that is one reason for hydrocarbon emissions.

So let is go ahead so, another reason for unburned hydrocarbons is leakage past the exhaust valve see here and the exhaust valve can have crevices right. So, fuel air mixture is forced into the crevices around the exhaust valve components exhaust valve seat and so on so exhaust valve so now when the exhaust valve opens this will escape okay and throughout into the exhaust manifold. So, that is why essentially, we have leakage pass the exhaust valve.

So, this fuel air mixture which is stored in the crevices escapes into the exhaust manifold when the exhaust valve is open so, EV in this context means exhaust value. So, that is another reason. So, let is look at more reasons. So, in any engine, there is a significant amount of valve overlap. So, because when the, if you recall the 4 strokes, in a 4 stroke engine, there is always some overlap between the exhaust valve closing and the inlet valve opening and that is going to result in and 2 things.

You know like some exhaust valve polluting the fresh charge and also what is called an exhaust gas dilution and some what to say fuel air mixture escaping also both can happen. So, that is what to say, that happens it can be minimized with careful design, but there may be some components. So, that is why it is called us valve overlap and when will this be more significant at lower RPM, if you recall at lower RPM, there will be more time available for each stroke right.

So, then as far as time interval is concerned each stroke will have more time and consequently the overlap may occur over a larger time interval and that will promote this fresh fuel air mixture escaping into the exhaust what to say manifold right. So, when the inlet valve and exhaust valve

are simultaneously open a part of the fresh fuel air mixture may flow directly into the exhaust okay that is due to valve overlap. So, this is more severe at idling and low speeds due to longer time of valve overlap so, that is another reason.

So, another reason due to higher what to say behind hydrocarbon emissions in the exhaust is due to absorption by wall deposits and lubrication oil. So, see any way on the cylinder you know like we are going to have also other chemicals other components other compounds coming in with the fuel there are going to be other reactions right and we will have wall deposits forming on the cylinder walls and even will have these lubrication oil deposits what will happen is that typically these will absorb the fuel vapor during compression combustion and so on and then later release them okay.

And as the engine keeps on aging, as the age of the engine keeps on increasing what may also happen is that the lubricating oil film may just be may become thick with age and a part of it may get peeled off right with continuing operation and that will also come through the exhaust. So all those will contribute to the hydrocarbon emissions. So all these factors contribute to hydrocarbon emissions in engine exhaust.