Turbulent Combustion: Theory and Modelling

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Lecture – 24
Laminar Non-Premixed Flames (cont…)

Welcome back and let us continue the discussion on this internal reacting system. So, we have already discussed the different aspects of the gas turbine engines and then we looked at the chemical rockets and also the ramjet kind of engines in brief.

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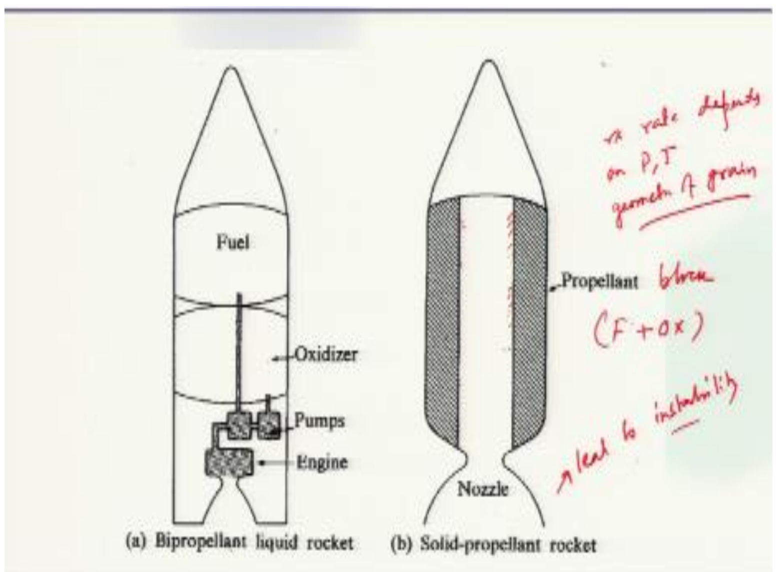

Now, we will continue from here the discussion this is where we stopped: the chemical rockets.

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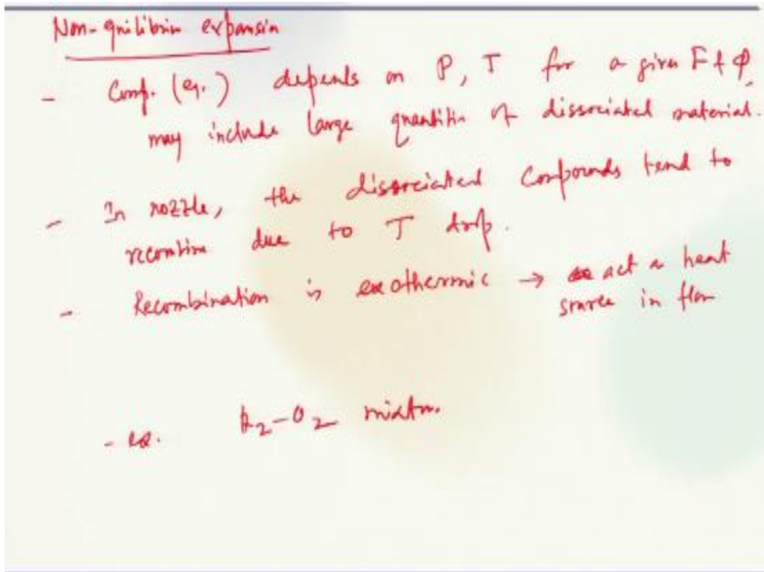

Now, we look at the non equilibrium expansion so, how that impact? So non-equilibrium expansion, so equilibrium composition essentially composition which is equilibrium composition it depends on pressure and temperature for a given fuel and equivalence ratio and also it may be possible that it may include large quantities of quantities of dissociated material. Now when you go to the exhaust nozzle that dissociated compounds tend to recombine because of temperature drop so, in nozzle the dissociated compounds tend to recombine due to temperature drop.

Now, what happens, this exothermic recombination reaction may act as a heat source in the flow. So, these are the recombination process, the recombination is exothermic. So, they actually can act as a heat sources inflow. Now, we can see how this dissociation energy is before and after the equilibrium expansion, to take an example of let us say H_2O_2 to mixture and see how that actually affects.

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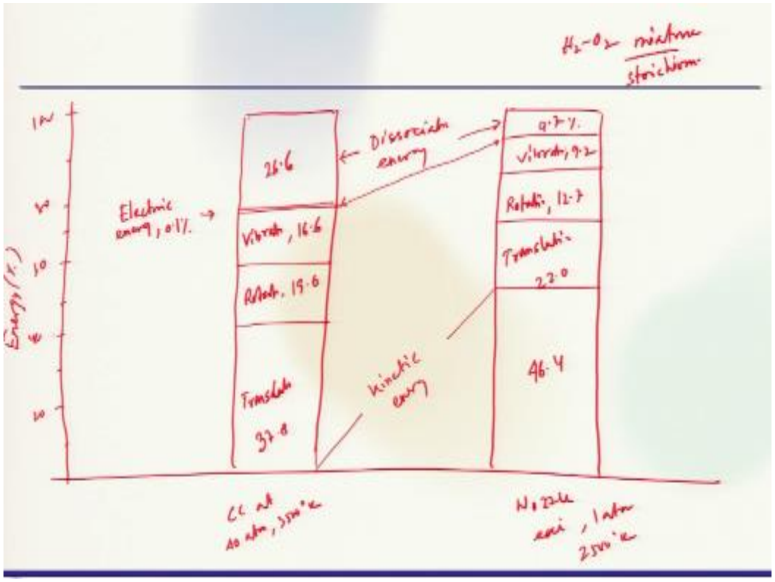

Let’s say, we put a diagram here some axis could be 20, let us say 40, 60, 80, 100. So, this is your energy percentage and we get some let’s say block here and so there will be 1, this could be 1, so this is what it is. So, this is for combustion chamber at 40 atm and 3500 degrees Kelvin. So, this is your electronic energy point 1%. So, this could be 26.6% this is vibrational, so it could be 16.6 rotation, which would be 19 this is primarily translation which is 37.8 roughly like that.

Now, we can look at the nozzle exit and getting blocked like that this is nozzle exit which is 1 atm and 2500 degree kelvin. So, somewhere this is here so this is here this is here, so this is 46.4. This is my translation which is 22, rotation 12.7, vibrations 9.2 and this is 9.7%. So, this guy and here and this guy here this is the dissociation energy and this electronic energy would be here for small percentage and this is the kinetic energy.

So, you can see the differences here, this will illustrate the relative importance of these dissociation energies before and after an equilibrium expansion. So, this H_2O_2 mixture stoichiometric so, this is an H_2O_2 mixture with example and they are in stoichiometric.

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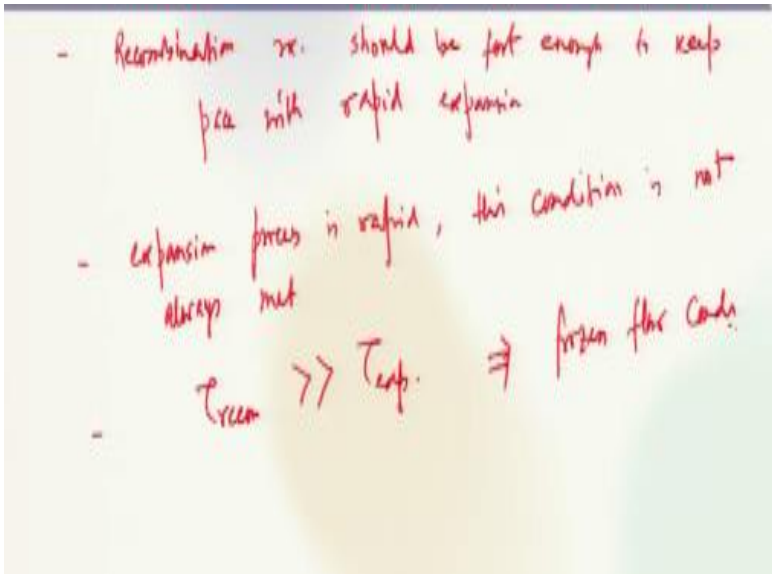

Now, if you have a product to maintain the equilibrium composition while expanding recombination reaction should be fast enough to keep pace with rapid expansion. Now, the expansion processes rapid, so that is why this condition is not always met. Now the limiting case one can have $\tau_{recombination}$ which is greater than the expansion. So this is your exactly frozen flow condition. These things are happening inside the rocket engine. Now, there is a difference between equilibrium and frozen flow and for different propellants so that is there.

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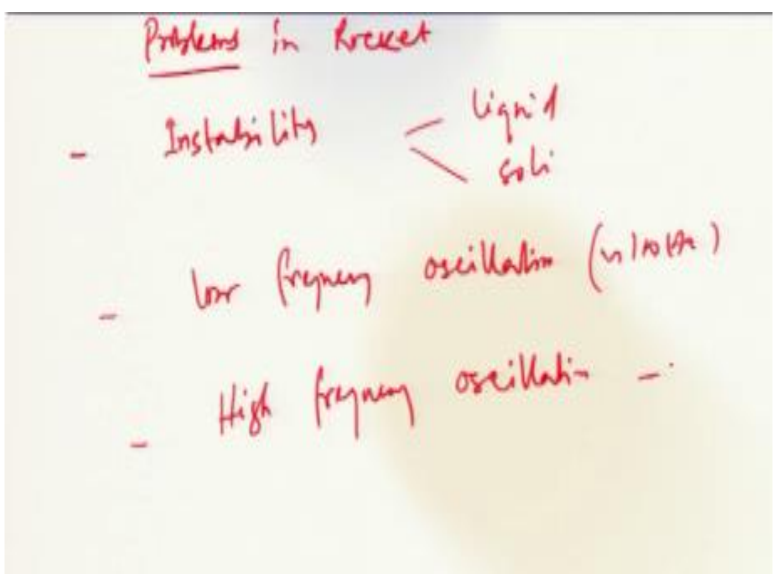

Now, there are some problems in rocket engines. One of the issues is that instability as I mentioned there I mean obviously this exist both in liquid and solid case, but solid case it is more compared to liquid case then you have low frequency oscillations which is roughly 100 Hertz due to the coupling between combustion and the fuel system. Obviously, you will have high frequency oscillations too. This is something called thermostatic or coupling between combustions on the acoustics and flow field something like that.

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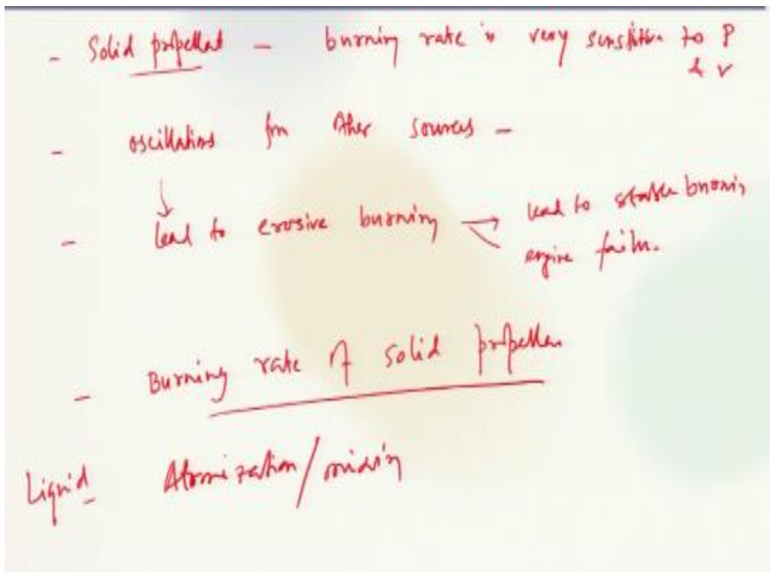

Then you have some things very specific to the solid propellant rockets which is like in solid propellant, burning rate is very sensitive to pressure and velocity. Then you have energy release and propellant velocity or the pressure pattern that causes non-immunity can interact to produce sustainable solution also. So, there could be oscillation from other sources and this comes from that energy release and that coupled with the propellant velocity and all the pressure pattern that develops inside the chamber.

Now, these oscillations lead to high rates of erosive burning and that could also for these core lead to erosive burning and that may change the chamber geometry to stable burning or may lead to engine failure. So, this has both aspect it could lead to stable burning and engine failure so, both are possible. Then the problem is the burning rate of solid propellant this is not very controlled.

This is not controlled or not easy to control and in liquid case obviously, one of the issues which is very well known and common is that atomization or mixing. So, these are some of the issues which actually exist even today, and it requires a lot of attention to control these kinds of issues.

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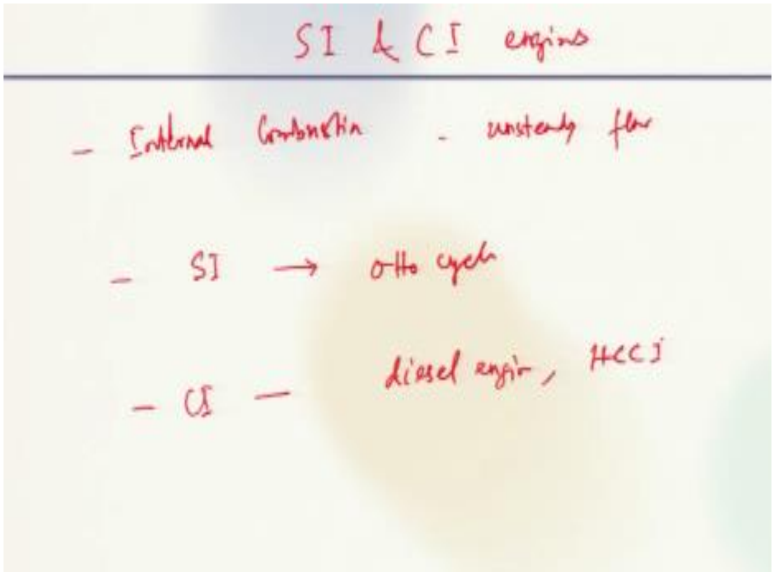

Now, we will move to so, this is our steady flow of pattern of basically the engine which comes under the steady flow conditions. Now in the unsteady there we can look at this is SI and CI engines, which are compression engines and spark engines. So, they are also internal combustion system but unsteady flow. Now SI engine has a cycle which is known as Otto cycle which is or this is basically for your gasoline engine, petrol engines.

And CI engine is basically your compression ignition engine, this is for diesel engine cycle or HCCI in cycles, so they have these things.

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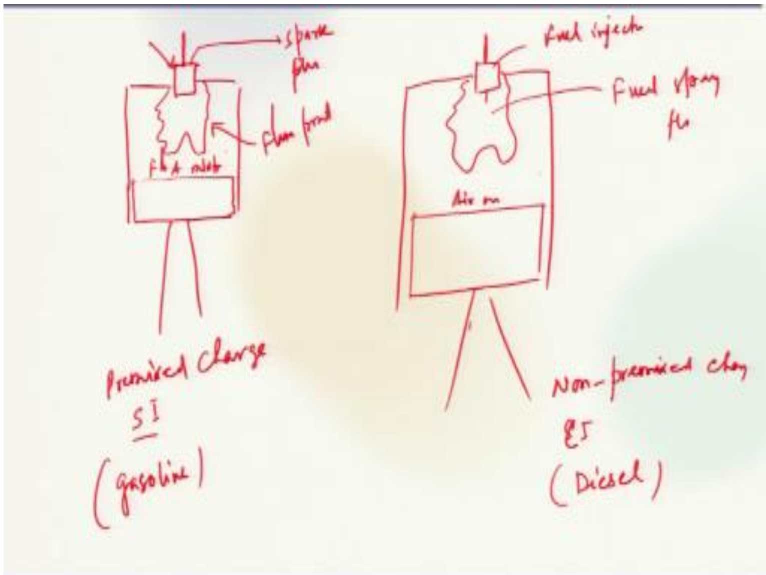

And one can see schematically how these 2 things are different. So, let us say you have a spark plug sitting there which comes through then you can define your combustion chamber like this where you have it piston head and this is the piston movement which happens and this portion is the flame and the other case you can have this is my piston head. So, here this is spark plug, this is my CI engine or gasoline engine, this is a SI engine, this is spark ignition engine, this is compression engine.

So, this would be your gasoline, this is diesel so, this is your premixed charge and this is non-premixed charge and this could be your flame surface. So, that's my flame front, this is spark plug and inside that you have fuel plus air mixture. Here it is your only this is my field stream flame and that's the fuel injector. So, there is a difference you can see inside that there is a fuel and air which is already premixed, they are sitting there and this case it is only air which is compressed so, the working principle is quite different.

And that is why the problems which will arise in each of these case they are also quite different because this particular case in the SI engine or the gasoline engine there is a chance of auto ignition or knocking at something like that because of your fuel air premixed but in the diesel engine, you do not have the possibility of knocking out all these but emission level is quite high.

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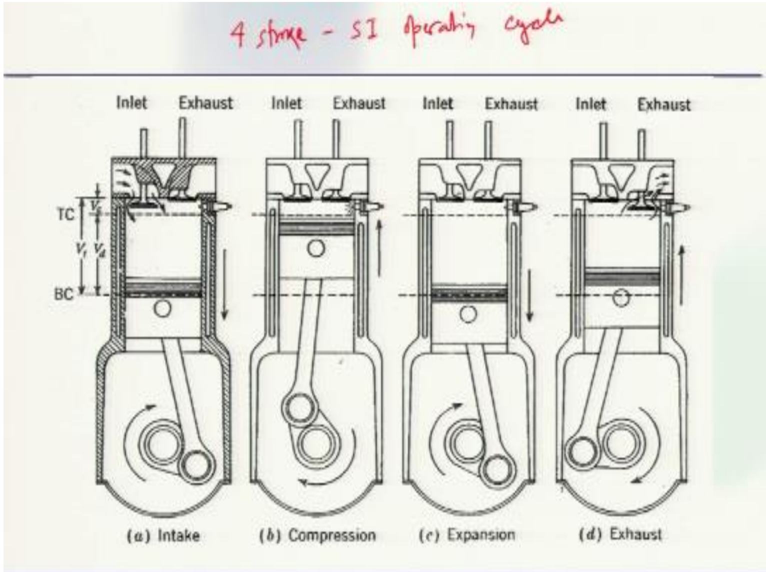

So, one can look at the schematic of this 4 strokes SI engine this is our 4 stroke SI engine operating cycle. Now, first is the intake stroke that means, it comes down so air comes in, this valve opens, air comes in so, the volume increases here I mean basically the rather it is a mixture comes in, then it is compressed and towards the end of this compression you actually ignite that to the spark then when the combustion takes place it actually allows this piston to move down.

So, the expansion takes place and then finally exhaust stroke, these valves open and things go out. So, simple operating principle and this you can typically see in your 4 wheeler car which are on road even today they operate in these kind of cycles, there is a in cylinder combustion which is going on and this happened so quick probably you will not be able to understand how quickly it operates and but you get the acceleration.

Because people only do accelerate by pressing that accelerator but this is what goes on more acceleration that means these revolutions becoming faster it generates the power quickly.

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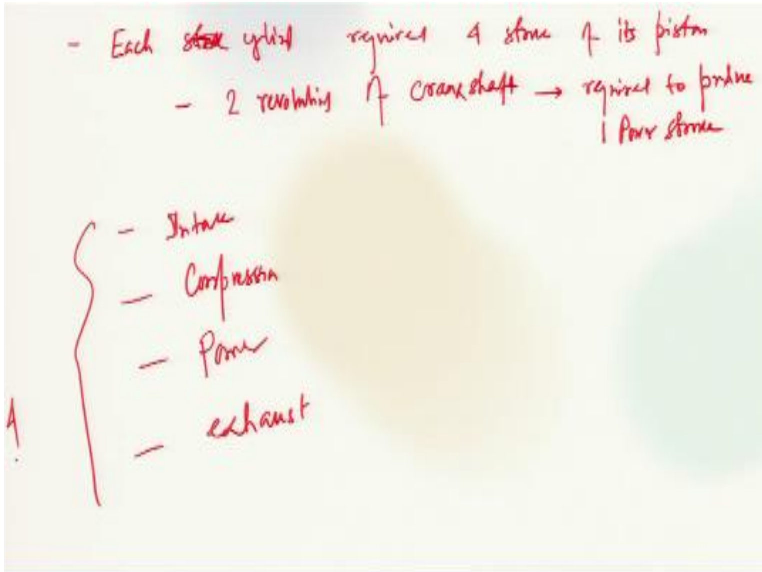

So, most of the reciprocating engines operate on this 4 strokes cycle. So, each stroke essentially or other each cylinder it requires 4 strokes of its piston. So, that means 2 revolutions of the crank shaft. So, that is required to complete the sequence of events which produces one power stroke. So, this is required to produce 1 power stroke. Now, both CI and SI engines use these kind of cycles and as we have seen they are 4 Strokes, 1 is intake, compression, power, and exhaust. So, these are my essentially 4 strokes that is required.

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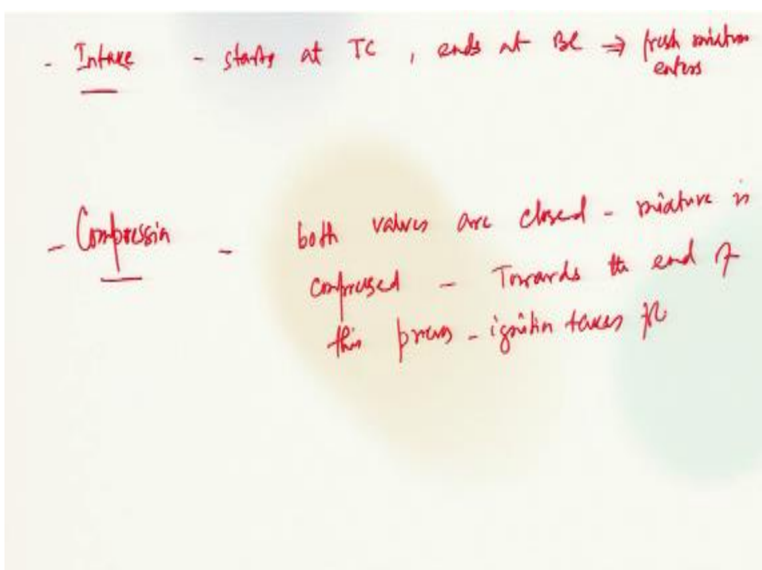

Now, what happens in each stroke actually, if we first take the intake stroke so it starts at top center or top dead center TDC and ends with BDC or BC bottom center so, which allows a fresh mixture into the cylinder so, that means fresh mixture enters there. Now, to increase the mass inducted inlet valve opens shortly before stroke starts and close after it ends. Now, similarly, we can see what happens in the compression stroke.

Now, your both valves are closed at this state and the mixture is now compressed. So, the mixture which is within the cylinder it is now compressed through the piston movement. Now, toward the end of the compression stroke of this process ignition takes place. So, that is the true spark plug. So, that means the compression is immediately initiated and the cylinder pressure increases quickly.

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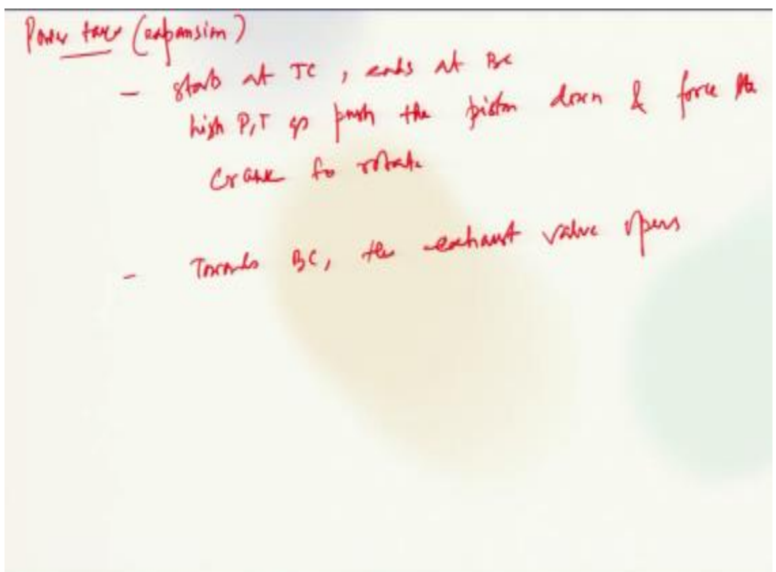

So, then as soon as that happened in the power stroke or expansion stroke so there the piston starts at again top center and ends at bottom center. So, now, since the combustion got initiated inside the cylinder you have high pressure, high temperature gas which will have high P T gas push the piston down and it force the crank to rotate. So, one can think about around 5 times as much work is done on the piston during the power stroke as the piston had to do during compression.

Now the piston approaches towards BC so towards BC the exhaust valve opens and then the exhaust pressure actually drops down to close to the exhaust pressure.

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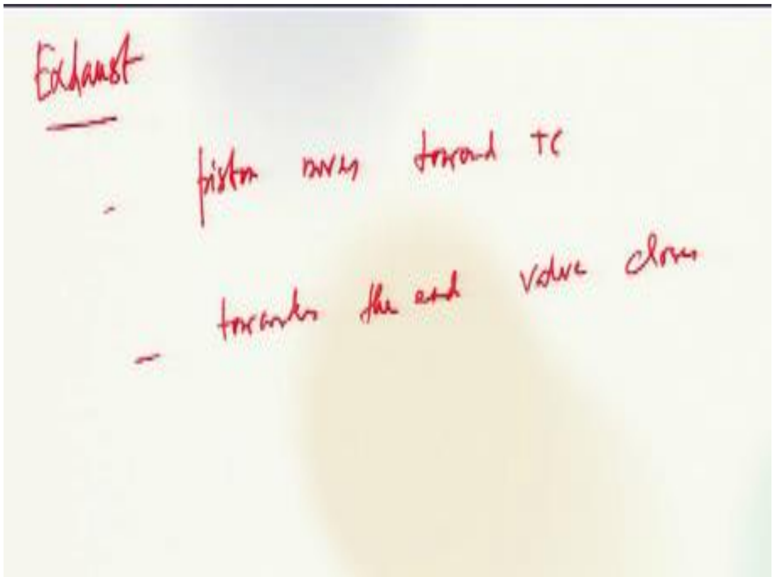

And in the last stroke or the exhaust stroke, since the cylinder is higher than the exhaust pressure so, it allows pushing those gas back towards the top center. So the piston moves towards TC, so as this approaches towards the TC and towards the end that valve closes and the cycle starts again, so this is how one go about it.

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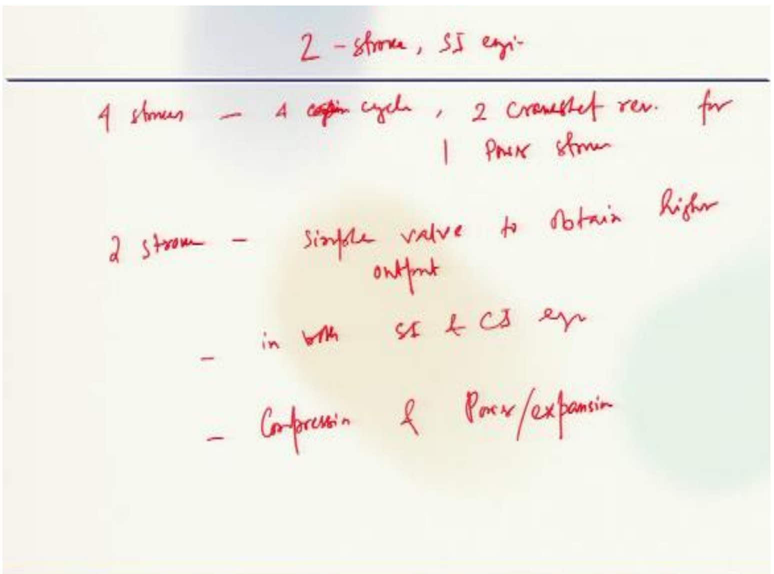

So, now, there could be this is 4 stroke cycle where you have if you go to 2 stroke compared to 4 stroke, 2 stroke SI. So, in 4 stroke you require 4 engine cycles and 2 crane shaft revolution so in 4 strokes requirement was 4 cycles then to crank shaft revolution for 1 power stroke. Now, to obtain higher output for a given engine size is simpler valve designed 2 strokes cycle that uses.

So, 2 stroke has simple value to obtain higher output. So, this is also applicable in both SI and CI engines. So, it has only 2 strokes, 1 is compression stroke and second is the power stroke or expansion stroke.

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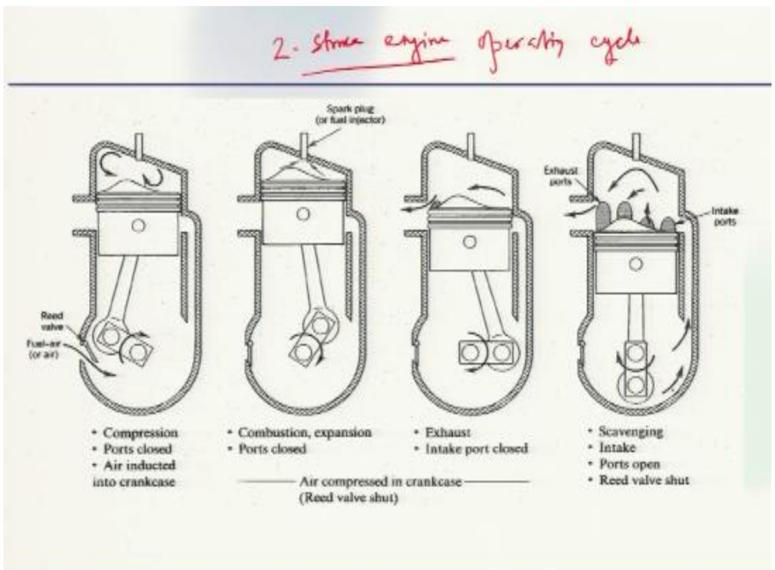

One can see this is a 2 stroke engine operating cycle. So, what happens here, here this is the revolution you require only that this is the compression process. So, it starts by closing the inlet so this inlet is closed and the process starts and the exhaust port opens. Then the compression cylinder contents and draws phase charge into the crankcase as the piston approaches towards the top center and the combustion is also initiated by the spark plug.

And then in these stroke so, this is combustion expansion ports close. So, this is basically in the 2 process where you can see. Now, this is that exhaust or rather the expansion and the power stroke quite similar to that in power cycle. So unless the piston which is the BC when the first exhaust port open and this happens, so essentially it is happening in 2 stroke cycle. We will actually complete the discussion in the subsequent lecture and we will stop here today.