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Aerospace Propulsion

Liquid Rocket-Pressure Fed System

Lecture 35

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And the last class we had learnt how to calculate the volume required for the propellant or the volume flow rate and then using the burn time the overall volume of the tank right and we had also come up with the equation for the mass of the pressure end.

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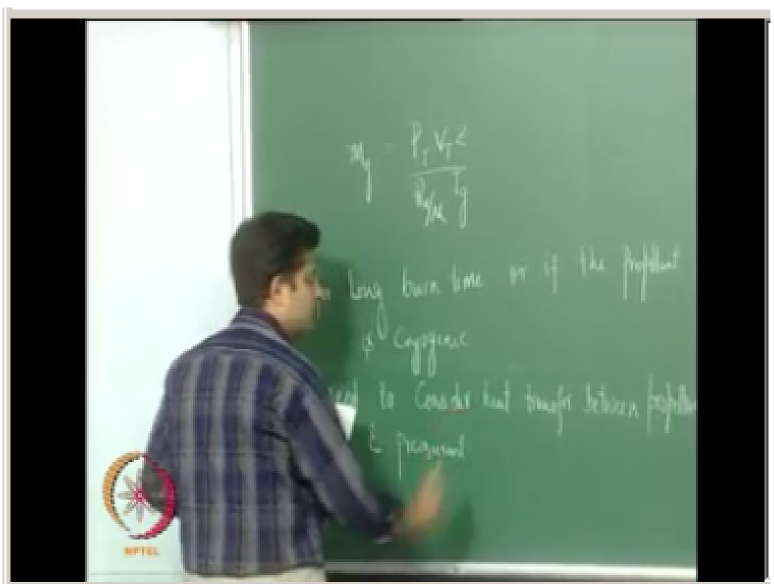

And we said it is equal to okay this is the equation we have come up with and this is valid under cases where in the time of operation is small right if the time of operation is large and also if you have cryogenic propellants right then if the temperature of the pressure and gas and that of the propellant are very different then there will be heat transfer between the gas and the propellant and that needs to be accounted for.

Because if you look at it the propellant will evaporate right and because of its own vapors you might not require so much of the pressure and gas right so we need to take that into account in cases where the time of operation is large or if you have cryogenic propellant so let us look at it now for long burn time if it is cryogenic then there is heat transfer between the propellant and the pressure.

And gas now how do we take that into account one is we should calculate based on the H value right this is a convective heat transfer so we have to calculate the convective heat transfer coefficient and then calculate the overall heat transfer right.

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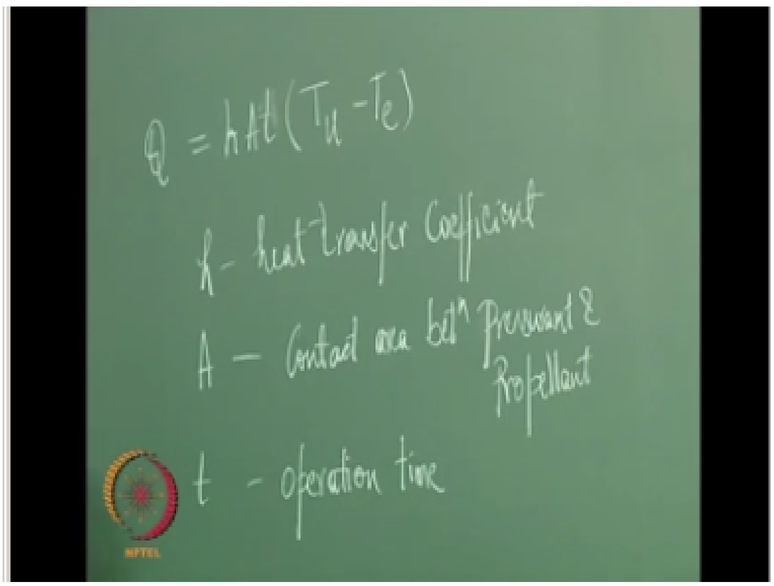

So you will get something like Q is equal to okay where h is the heat transfer coefficient right this is for a case wherein mostly there is a very little flow rate of the pressure and gas right is the contact area between pressure intent so plain okay then t is the operation time and te is repellent temperature and the U is pressure and temperature at the end of expansion now please remember that we are putting the pressure on tat a very high pressure in the gas bottle right.

It is around 350 bar but in the tank the pressure comes down to something like 30to 40 bar so there is an expansion that is happening between 350 and 30 and because of which the temperature will also drop so this temperature accounts for that okay and te is the propellant temperature now if you are using liquid hydrogen or liquid oxygen we need to be especially careful because te can be very low if it is liquid hydrogen it is of the order of 20 Kelvin.

And if it is a liquid oxygen it is of the order of 90kelvin so very low temperatures and because of which the propellant is going to evaporate right therefore we need to find how much is it that it has evaporated and suitably account for it in terms of the pressure end so this is one part of the calculation we have calculated what is the heat flux or what is the heat not heat flux this is heat transferred from the pressure and gas to the propellant right.

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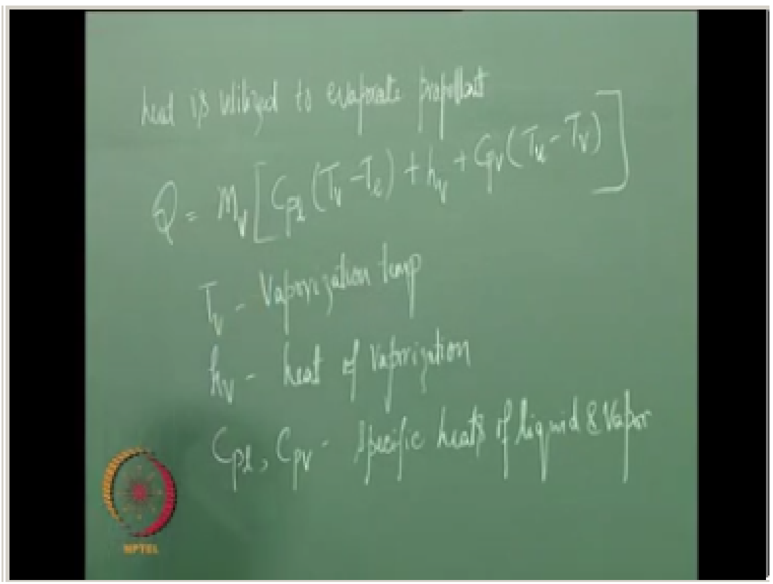

Now the same heat that is absorbed by the propellant causes it to evaporate right the propellant absorbs this heat and evaporates so, so if we have to calculate that so the same queue will be transferred to the propellant and it will lead to its evaporation remember the propellant is a liquid right so it has to change its temperature from its temperature to its boiling point temperature and then there is a constant heat of vaporization.

And then it becomes a vapor and then it has to go towards the temperature of the pressure end right so there are three components okay so this is the liquid phase l corresponds to liquid so this is the TV is vaporization temperature then T is the temperature of the propellant hv is the heat of vaporization then tu is the temperature of the pressure at okay.

So this Cpl and cpv are specific heats of liquid and vapor and MV is the mass of vapor okay so we get if we know all this we can calculate this quantity right so we will know the mass of vapor now if we know the mass of vapor then through the ideal gas relation we can calculate the volume of vapor VIII.

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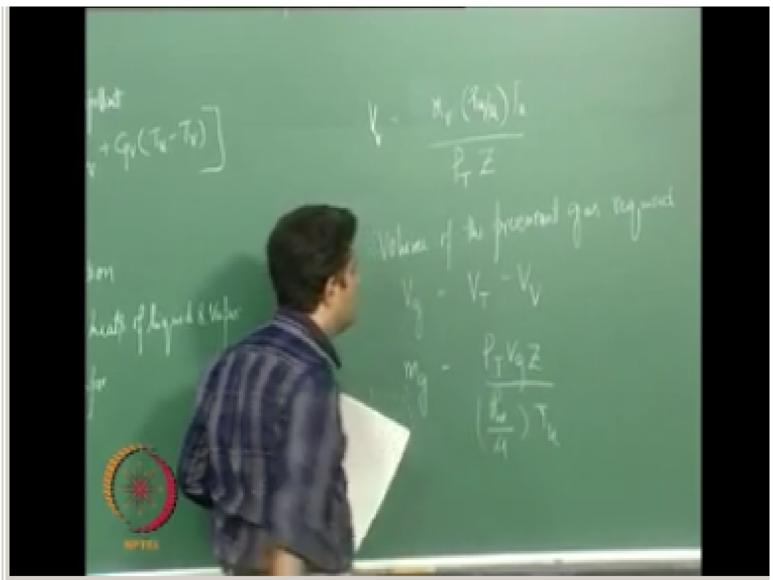

V is equal to okay so we know the volume of paper that is going to be evaporated and based on this value this is the volume of the tank so the volume of the pressure and that is required as VT minus V V right part of the vapor is already given by the propellant itself so you need a smaller volume of the pressure and gas so that is right and based on this we can calculate again the mass of the pressure.

And required from the same relationship so this will be mg would be okay so in this case if you notice because of the vaporization of the propellant itself the mass of the pressure and required is reduced is this a good thing or a bad thing yes we might be reducing some amount of pressure and gas requirement but overall you are losing some propellant that cannot be pushed into the combustion chamber to pressure to burn it.

So in a sense you are going to get a reduced ISP right this if you can prevent it from happening it will be a better situation right now this is the heat that is transferred from the vapor or the pressure and gas to the propellant so we have used this to calculate the mass of vapor we know the mass of pressure and required right so we can calculate what is the temperature at the end of this using the following relationship.

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So that is we can calculate the mean temperature of the pressure eng that is entering now if we look at the tank volume let us say this is the tank with either fewer Lord oxidizer stored there is pressure and here okay now we accounted for heat transfer from this surface to the pressure end right, right there is also a possibility that heat might be transferred from the walls to the propellant.

And therefore there will be extra vaporization that will happen right and depending on the temperature of the surroundings it might also happen the other way in some cases where an if the temperature of the liquid is higher than the ambient temperature you could have reverse transfer so we have to account for that also and also the case where in the pressure intestates furring heat to the wall right both these things need to be accounted for.

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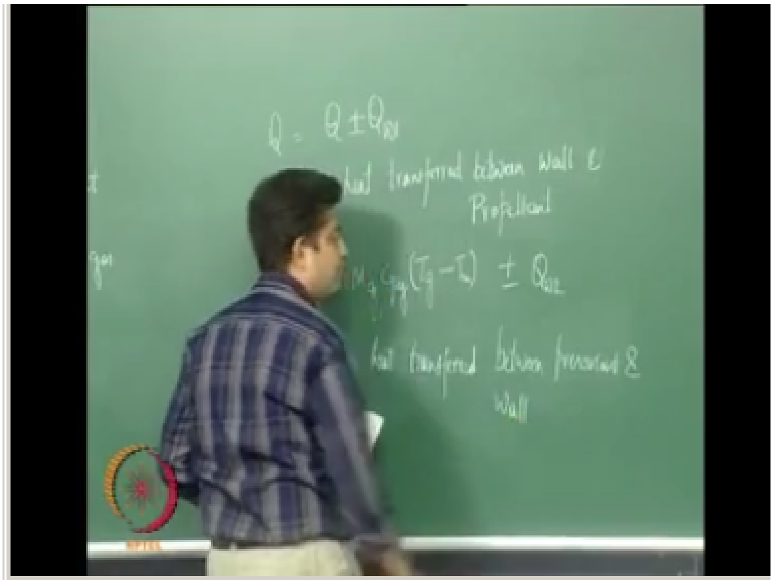

And they can be accounted for in a similar fashion as we have done here only thing is the Q that we had here right Q becomes u will be equal to Q +- Q wall one okay that will be equal to mass of vapor into everything there okay so QR 1 is between wall and propellant and similarly if we are looking at what happens to the pressure and then Q = mg cpg we have included plus or minus to account for the situation when wall is at a higher temperature and the propellant is at a lower temperature.

And also the other case where the propellant is at a higher temperature and the wall is at a lower temperature similarly here two and cue wall 2 is nothing but okay so we have learnt how to calculate the volume and the mass of the pressure and required this is in terms of what is happening in the tack right so if you if you look at what are the processes that are happening on the pressure inside okay we look at it now and we will see how things go there.

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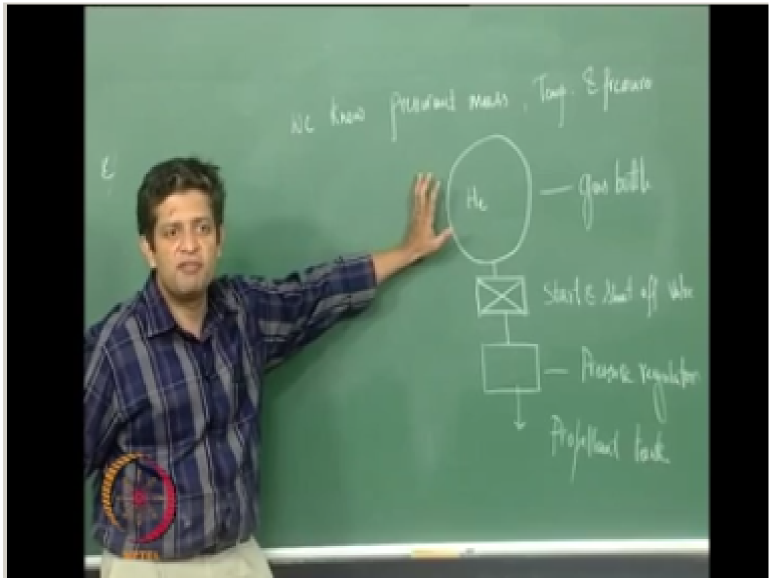

So after all this we know how, how much of mass of pressure and to be delivered and at what temperature and pressure right so fine now if you look at what is happening on the pressure and side pressure inside you have let us say a helium tank right and you have a valve here and then a regulator this is the and here it goes to the propellant tank right now if you look at what is happening inside this gas bottle.

Because you are drawing out gases it was at some pressure very high pressure initially at around 350 bar or you have started to take out mass from this what happens to the pressure inside pressure drops if pressure drops what happens to temperature drops and as a consequence again because this is a constant volume process right you will at the end of the expansion have a lot of cold gas that is of no use right you understand.

The point that if you have gases you will have some amount of gases at the end of the pressurization process that is cooling down very rapidly because it is undergoing expansion and therefore it is pressure also drops because of that right so it is not it is it is not going to be useful because of this let us look at how the pressure drops pressure drops through either if there is no heat transfer of from the wall of the pressure end bottle to the ambient.

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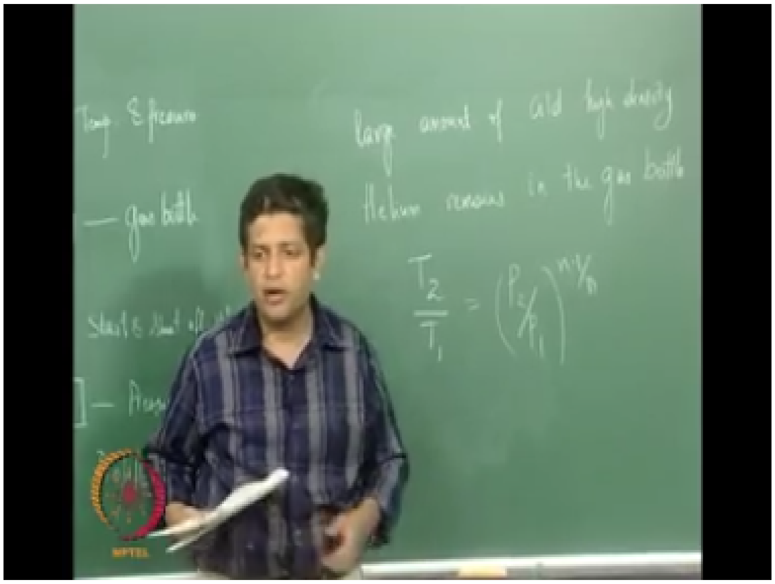

If there is very little heat transfer then it is an isentropic process or otherwise it would be a polytrophic process you and this process is an isentropic or a polytrophic process so you will have a if it is isentropic then it will be γ $n = \gamma$ otherwise n will be lower than γ okay now this means that we have to carry more pressure and gas in order to account for this drop in temperature and therefore drop in the pressure right.

The one way to mitigate it would be to heat it up in some sense if we could heat it up then or if we could maintain the temperature if let us say we maintain the tank at an I in an isothermal condition right then this problem would not be so large but otherwise if we can heat it, it will be better so let us look at that but before we go there we have done all the calculations to find out what is the stored gas requirement let us write that down.

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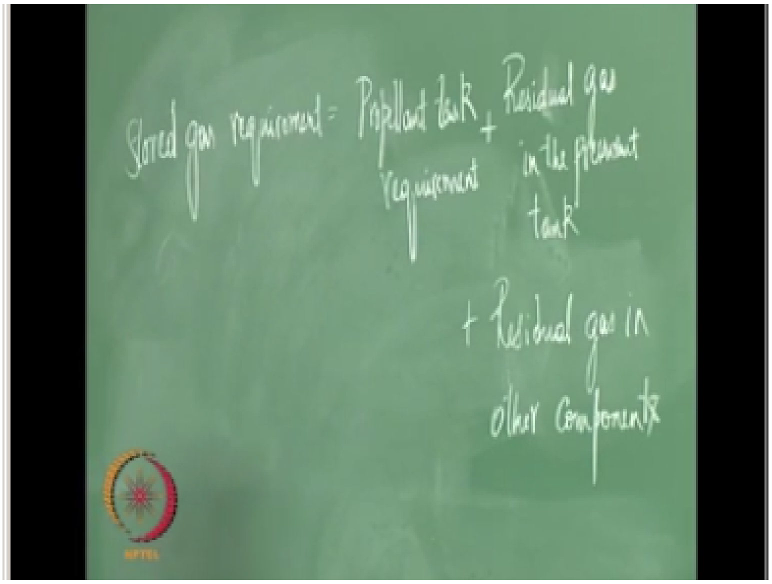

So the stored gas requirement is equal to propellant tank requirement plus residual gas in the pressure and tank Plus residual gases in okay we had calculated this part as mg right fine this is what we discussed right now you will have to have some gas in the pressure and tank that will not be useful and this is if you look at the gas pipeline just like we had propellant trapped in cooling tubes.

And other tubing you will have some gas that will be trapped in the pipeline right so this accounts for that portion now let us look at the water all the possible designs to mitigate this problem of coolant gas temperature falling and therefore you requiring to carry a lot more pressure.

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And one of the designs to overcome this is to have in the helium tank itself a heating this is a heat exchanger okay if you have a heat exchanger here ask the helium cools down if you supply heat to it then the temperature would not drop so much and therefore you will have a lot more of useful pressure okay there is one way of doing it.

But the trouble with this kind of a design is if you look at it you are designing a gas bottle which can withstand very, very high pressures right just doing that itself is a not such an easy job to design something that is leak proof and that stays like that for some time is not easy now you want to have something wherein you will have either a gas or a liquid re circulate or go around that it is not going to be very easy okay.

Then you have you can keep it running and you can keep the temperature such that you can look to maintain the same temperature as you had in the beginning right you are going to have some temperature as soon as you start drawing if you start heating it up the temperature will fall because of expansion and because of heating you can increase it at a rate such that you maintain the same temperature or even.

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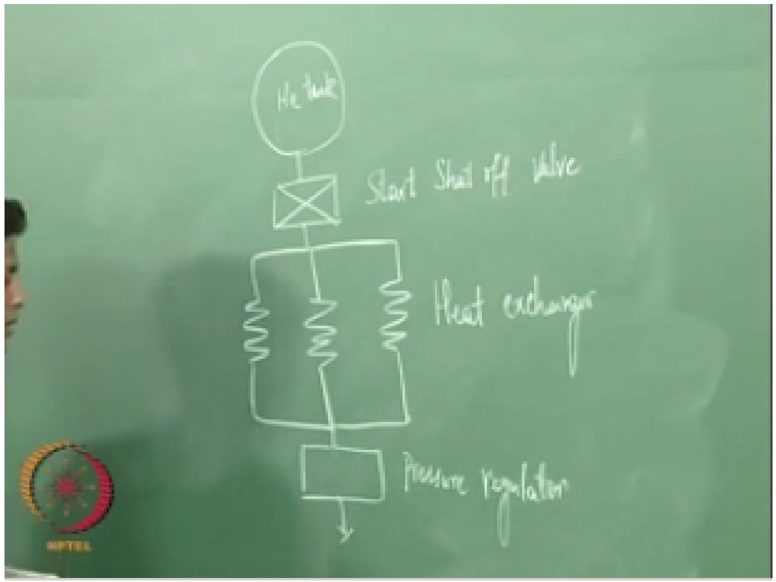

If you increase the temperature it is also better only thing is you need to be careful that your tank is designed in such a way to withstand that kind of pressure the other design that people have come up with this in this design we do not tamper with the tank itself but you in this design you are not really looking at tampering with the helium time capsule but using the concept of heating the gas in another way right.

Here you could even contemplate using a part of the exhaust part of the combustion chamber gases could be blood to have this heat exchanger right there are various other designs that are possible and some of these are discussed in this book by whistle and hang you can take a look at it there is one more design that people have only talked about but hardly ever used one of the problems with all this design.

If you look at it the density of the gas is even if you compress it to something like 350 bar what is the density going to be if you are assuming helium, helium or if you take nitrogen, nitrogen is the same as air density at ambient conditions of nitrogen and air very similar so if you if you are increasing the pressure to 350 bar it is like 350times the density of air is around 350kg per meter cube that this density is very low.

So you need a large volume and therefore the weight of the pressure and tank goes up because if you have a large volume remember the design of the tank it is P D by 2 T so the thickness of the wall goes up and therefore your weight will go up the other way to approach this problem is to use a solid propellant right let us say we were to use a solid propellant then and generate gases which can then pressurize the liquid right.

If you were to do that if you look at the density calculations density of solid propellants is of the order of thousand six hundred two thousand eight hundred right it is already a four-fold increase there but there is a problem that that is one of temperature if you look at the exhaust of solid propellant it will be a very high temperature then such a thing might not be useful here so we need to look at ways to cool the exhaust.

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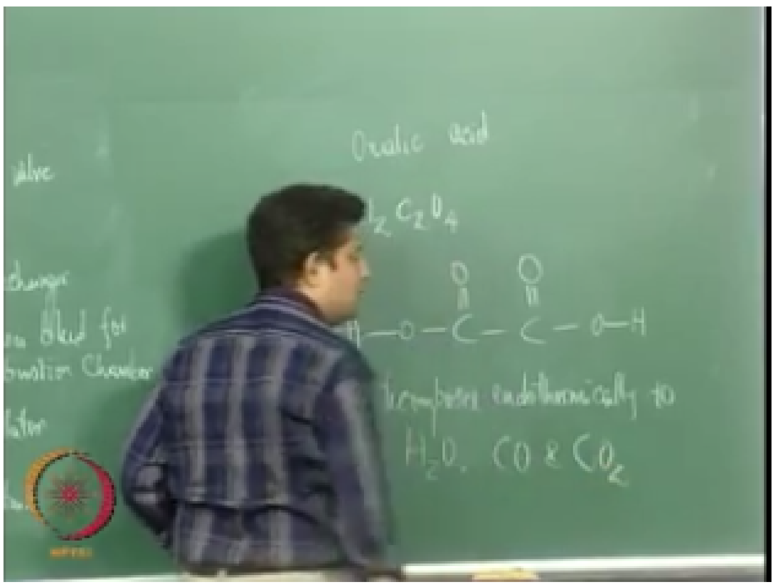

And one of the methods to do that is to use something known as oxalic acid now this oxalic acid is nothing but h2c 204and its chemical structure is like this molecular structure is like this okay now the good thing about oxalic acid is it decomposes upon heating right so if you heat this it is going to decompose to, to water carbon monoxide and carbon dioxide so in a sense if you pass the exhaust gas from a solid propellant over a bed of oxalic acid.

Then you can bring down the temperatures pressure is the only thing that you are interested in right if you look at it pressure is the only thing that you are interested in and if you can bring down the temperatures that is a very good thing to do okay so the final temperatures after and oxalic acid bed is something like 200 degree centigrade is possible.

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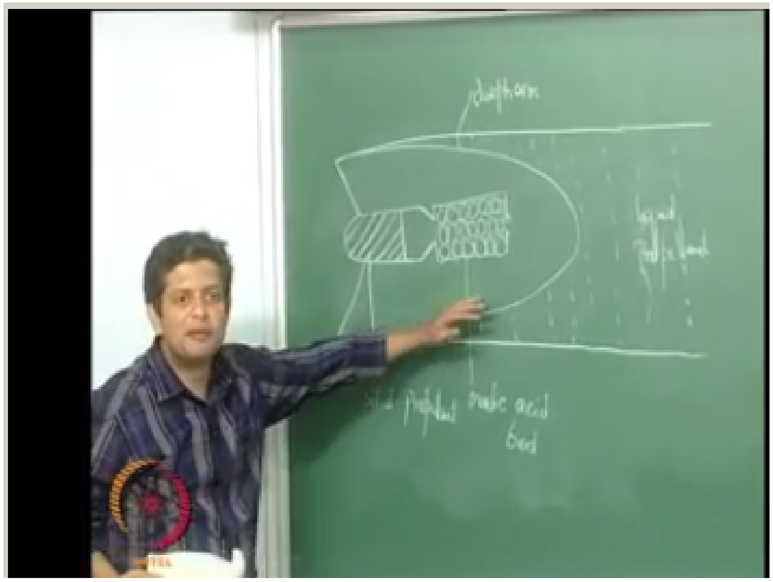

So let us say you have solid propellant only a converging nozzle is good enough here because you do not want too much of a pressure drop you are not interested in velocity here you are only interested in pressure and then if you have a chamber which has this oxalic acid pellets then the exhaust of this can be connected to the or let me do that also let us say you have this at the head end of the tank right.

Then what you need is something like a diaphragm so here you could have the you need this diaphragm simply because the temperatures are also still quite large even if you have looking at achieving something like 200 degrees centigrade as I talked about at the end of at this point right it is still probably little higher so if you have a diaphragm you could reduce the temperature across the diaphragm and also you do not want and the pressure.

And gases to be interacting directly with the liquid because then it could directly short-circuit and go out of the tank also right then if it pressurizes on this side of the diaphragm then this can expel out the liquid people have compared the all these designs and looked at how much of a saving in terms of weight and other things can you make by using such systems and we will see that in a table here.

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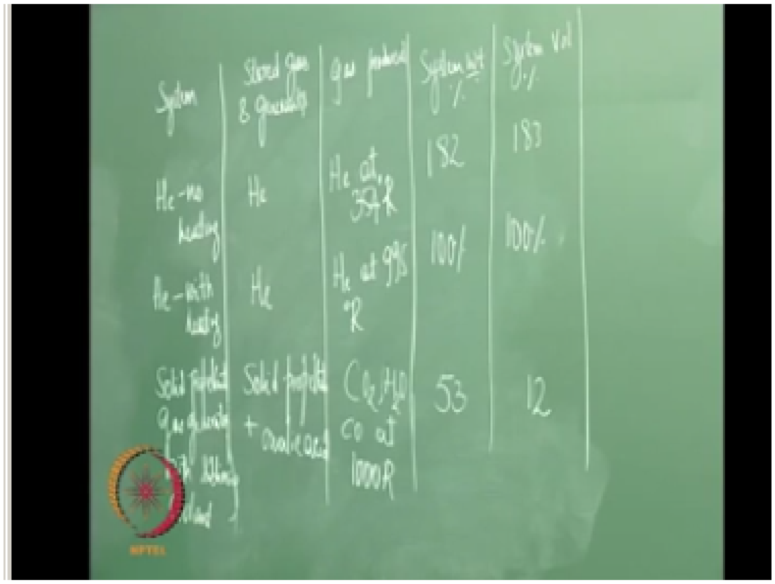

If you have helium with no heating right then the store gas is helium and helium at gas produced is also helium there is another scale of temperature called the ranking scale of temperature so this is in that unit then the weight is 180 2% then volume is 183 % now if we have heating right in the helium gas bottle itself helium is the stored gas and the gas produced is again helium at a higher temperature.

Now and therefore the volume and the system rate reduces essentially because you can now have a smaller tank and therefore the thickness of the tank will also reduce so you can look at it as this being the reference one and all this being comparisons with the reference one then the last thing that we discussed that is solid propellant gas generator with subliming coolant like oxalic acid oxalic acid and you will have co2 h2c who at all this at around thousand Rhine kind.

And this could lead to a phenomenal saving in weight as well as volume okay you look at these numbers these are very, very small compared to this right with the challenge as I said here is you are looking at having here very high temperatures and at the end of it you should have lower temperatures here right and you should be able to have a controlled burning this kind of a system if you have a solid propellant is not amenable to having start.

And stop because you cannot start and stop a solid motor on command you can do it only once but there is no restart possibility so that makes it not so useful but I for example if you have a hybrid motor instead of a solid motor you might have a slightly more complex system but you could have start shut off restart all that possible okay it also means a phenomenal saving in terms of weight and volume okay we will stop here in the next class we will discuss about the turbo pump fed prep system thank you.

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