Rocket Propulsion

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Lecture No. # 21

Low energy liquid propellants and Hybrid propellants

Well good morning. In the last class we were dealing with the liquid propellants and we continue on it. But before continue on it, I would like to clarify that the classification of liquid propellants was distinctly different from the way we classified solid propellants. While we classified solid propellants into something like a double base, composite, mixture of composite, discomposite modified double base un hydra mine propellants.

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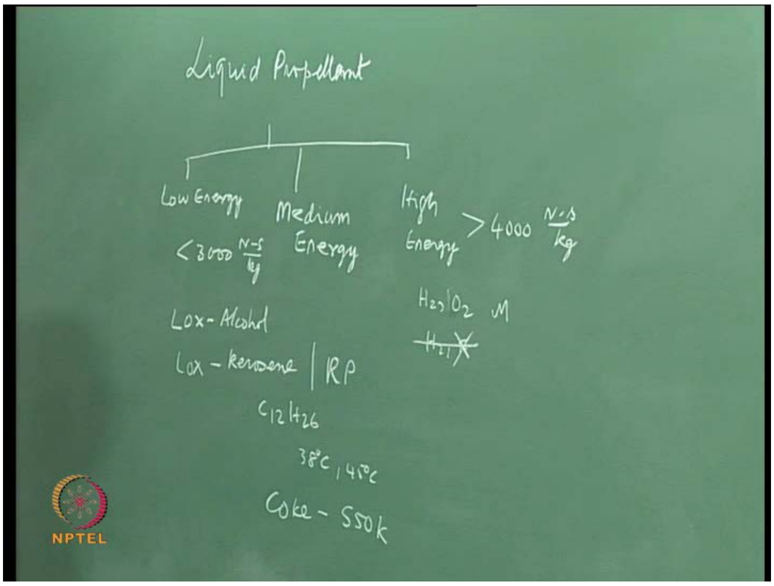

In the case of liquid propellants we had somewhat different classification. We told ourselves the propellant could be a low energy propellant or else it could be something like a medium energy propellant or it could be something like a high energy propellant. In today's class, we continue with this classification and also we will try to see whether any other classification is also possible, so that we cover the entire spectrum of the different liquid fuels and liquid oxidizers, which comprise the liquid propellants. For high energy, we told ourselves well hydrogen and oxygen, which which have the low molecular mass are typically used, not because it has a high energy, but not only high energy but also a low value of the molecular mass of the products.

We also said maybe hydrogen with respect to fluorine will also be a high energy but fluorine being very reactive; this is not really used as a propellant. This was the high energy and we said high energy are those which have specific impulse greater than 4000 Newton second by kilogram right. We then came down to the low energy propellants. We said these are propellants which have specific impulse is less than may be 3000 Newton second by kilogram. And for this we considered, maybe we started with LOX with we said alcohol which was used in the v 2 rocket in 1945, it was developed by the Germans. It was the first flying rocket and therefore, I always take this is an example but alcohol contains oxygen also in addition to hydrocarbon.

Therefore, it is not that energetic. From here went to LOX kerosene. When we looked at kerosene we found well, kerosene was something like an aliphatic compound we said something like c 12 h 26 and it has b since it comes from a petroleum base, it also contains some other constituents it is not a pure chemical as it is. And therefore, while using it we need to be a little careful and we do not use raw kerosene as it because raw kerosene we said has a flash point around thirty eight degrees centigrade or so. And we want it to increase it to something like forty five degree centigrade for which we added additives to this and called the resulting thing as a rocket propellant.

Kerosene is basically referred to as a rocket propellant but we put some additives into kerosene such that the flash point you know, you all would have read about flash point and fire point. Flash point is there where you have some vapour coming but the flame cannot persist whereas, fire point is one where in we have so much of copious vapour such that the even in when you remove the ignition source the fire continues. Therefore, the flash point of kerosene is around 38 we increase it slightly to forty five or higher and also when you heat kerosene in the absence of oxygen it should not form solid like coke and coking temperature. By adding a additives we make sure it is greater than around 550 Kelvin such that you know when you inject something it should not block something if it is heated and all that.

Therefore, basically when we say LOX kerosene we talked in terms of LOX with the rocket propellant. This combination is also referred to as rocket propellant even though kerosene we call as rocket propellant or LOX kerosene as rocket propellant. It is not correct to say a combination because I could use it with different mixture ratios. Well this is one which we studied. Let us see what are the other combinations of oxidizer and fuel which could be the low energy and that is what I start with today. Well, what wid we did we do?

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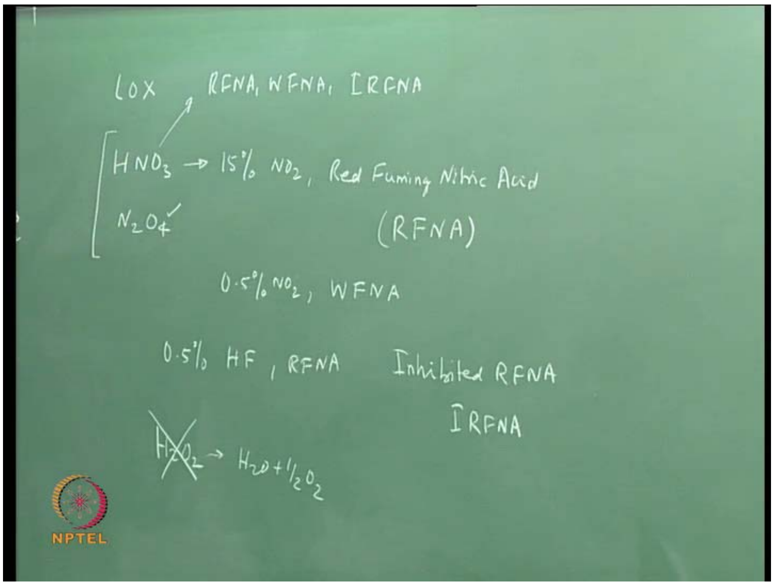

We consider LOX as an oxidizer. Why should LOX alone be an oxidi? Any substance which has excess oxygen could be an oxidizer; maybe we could have HNO 3, nitric acid. And if you see HNO 3 it you have one h and nitrogen any way is inert you have three of oxygen what you need is half H 2 O. That means I still have two of oxygen. Therefore, nitric acid can be used as an oxidizer and it is used as an oxidizer. I could also consider the other substance maybe N 2 O 4 and if you see HNO 3 we saw while we looking at the heat of formation it has something like minus 170 kilo joules per mole was the heat of formation. Whereas, N 2 O 4 had slightly positive heat of formation and we told ourselves for propellant, if the fuel and oxidizer have slight, i have positive or small negative values would be better therefore, N 2 O 4 tends to a better oxidizer compared to nitric acid.

The thing is also appear in to you, you are losing some oxygen to the hydrogen whereas, in the case of N 2 O 4 all the oxygen is available to you. Therefore, N 2 O 4 is also used as an oxidizer. Let us go little deeper because HNO 3 was used extensively and is still used by the defence in some ways. You know when you say HNO 3 well, it can be used but if you can add something like may be fifteen percent of n o two to it; you know you add more n o two to it. That means you add more oxygen to it, it becomes more energetic and therefore, HNO 3 is is is sort of energised by addition of something like fifteen percent n o two and what happens? You know you have fumes of n o two coming the moment you open the lid of the HNO 3 tank and this is known as red fuming nitric acid or rather RFNA.

Otherwise, you have nitric acid you have fifteen percent n o two to it and the moment you add this and you and you sort of want of charge this or you open the can or you open the tank containing n o three; you have these fumes of n o two coming and they are orangish or reddish in colour. We will see some photo graphs of some test firings. You will see some orangish fumes coming and that is because of the excess n o two and this form nitric acid when fifteen percent n o two is added is known as red fuming nitric acid. If you add a smaller content like let say 0.5 percent n o two it still fumes but not in red colour it is known as white fuming nitric acid. Both acids are used in practice as oxidizers. but then this acid is very corrosive. Nitric acid both RFNA, WFNA; red fuming nitric acid and white fuming nitric acid are extremely corrosive and even any vessel you keep, it tends to corrode the vessel. Therefore, what we do is you add something like 0.5 percent of hydro fluoric acid to let say RFNA and this inhabits the corrosive nature of the oxidizer and this is known as inhabited red fuming nitric acid.

That means IRFNA. Therefore, you have nitric acid as red fuming nitric acid white fuming nitric acid and an additive hydro fluoric acid h f added to it such that, it does not it is not that corrosive and this is what we known as IRFNA. Therefore, while considering nitric acid let us keep in mind RFNA, red fuming nitric acid; WFNA, white fuming nitric acid and may be modified or inhabited red fuming nitric acid. You could also have inhabited white fuming nitric acid. These are the different forms in which it is used but I say said it was used extensively by difference and in other establishments but now the preferred fuel is N 2 O 4 because this is more energetic considering plus slightly positive heat of formation of N 2 O 4. Well these are about the only oxidizers which are used. People talked in terms of H 2 O 2 being an oxidizer because here also I find there is still excess oxygen over hydrogen H 2 O. I am still left with one o over here but it is a very mild oxidizer and it has a heat of formation which is again terribly negative.

Something like one eighty kilo joule per mole and therefore, it is not an effective oxidizer as it is. In fact H 2 O 2 can directly also dissociate into H 2 O plus half o two and this itself is exothermic and this is used more as a MON propellant as a single in built explosive consisting of oxygen and fuel rather than as an oxidizer.

Therefore, the other two oxidizers which we can think in terms of maybe propellants are HNO 3 and N 2 O 4. Now, let us put the fuels down the these oxidizers will not be as strong as liquid oxygen for the simple reason you are having some little bit of nullifying effect of hydrogen. You are having an inert o here therefore, these are even whenever i use HNO 3 with let say kerosene or N 2 O 4 with kerosene; well it the performance is going to be even poorer than LOX kerosene and therefore, combination of these oxidizers with the fuels what we considered like kerosene will be still be low energy propellants. Let us take look at fuels, other fuels other than kerosene.

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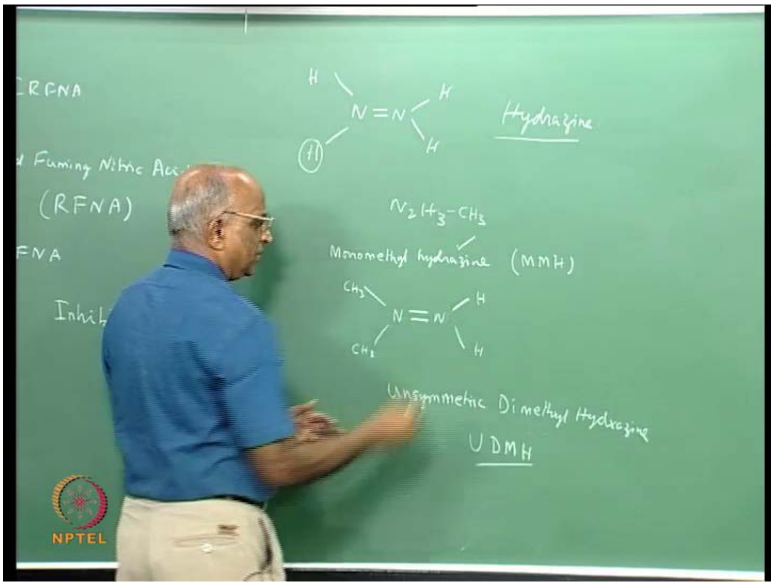

We can talk in terms of what we talked earlier hydrazine, N 2 H 4. We called it as hydrazine. It is a very popular fuel. You know this also had a slightly positive heat of formation and therefore, its itsah its a good fuel as it is. You have lot of hydrogen and therefore, you could have molecular mass of the products could still be light and it could be usable. I can take one of the h over here substituted by a methyl radical. In other words to hydrazine I write this as N 2 H 4, I take one of the h out i have h three left, I substitute it with c h three. In other words I substitute one methyl radical in to the hydrazine and I get what is known as mono methyl hydrazine. While talking of different chemicals you will recall, I said hydrazine is an explosive in the sense it can directly dissociate whereas, mono methyl is also about the same. It has about the same heat of formation around minus plus fifty kilo joule per mole but this has a higher specific heat and it is not as reactive as hydrazine per say and therefore, the preference is to use mono methyl hydrazine rather than raw hydrazine. But hydrazine is also used. Being more reactive we will see to it when we come to the chapter on combustion instability.

Hydrazine tends to be a little unstable compared to mono methyl hydrazine. Well I can keep on evolving and the only other evolving feature around this is, I can have instead of having nitrogen nitrogen have hydrazine hydrogen hydrogen. Instead of taking one hydrogen and substituting it by a methyl radical, on one side unsymmetrically I put one methyl radical here, one mthylel radical here and this is known as unsymmetrically that means the molecule is no longer symmetric. I have something like unsymmetric dimethyl two methyl hydrazine which is known as UDMH. It is not as strong as this because now you are adding little more molecules to it but it is a very powerful fuel. Most of the boosters what we are using in our country we make use of unsymmetrical dimethyl hydrazine.

Therefore, the fuels which we are consider it which we have considered so far are UDMH this is known as mono methyl hydrazine MMH and hydrazine. These are the three fuels which we use and these three fuels can be used with RFNA

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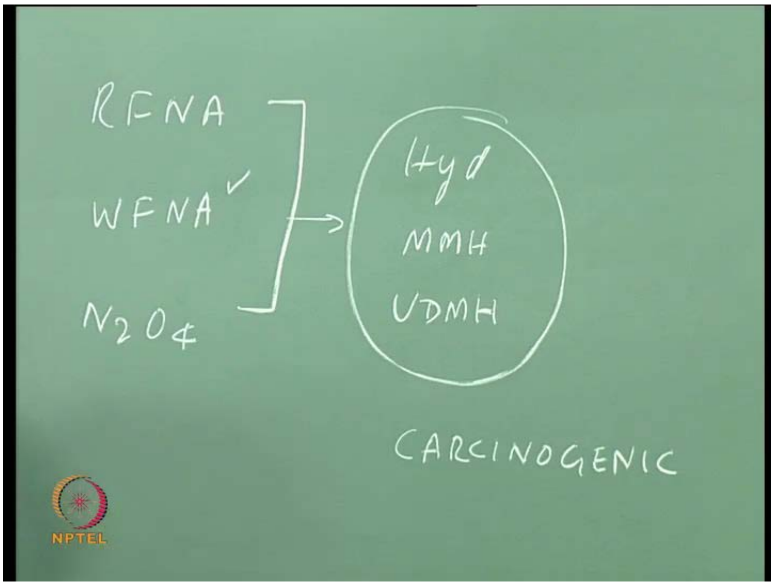

Or with white fuming nitric acid which is quite rare or N 2 O 4. That means i I take these oxidizers, use it with hydrazine or mono methyl hydrazine or UDMH. See, mono methyl hydrazine has a high specific heat, little more expensive compared to UDMH. Therefore, wherever smaller quantities of hydra fuel are required we use mono methyl hydrazine like in upper stage is where I do not want to use so much of fuel. Hydrazine is also used especially in spacecrafts, but as I told you it is little more reactive whereas, UDMH is more widely used for wherever large propellant requirements are there. All these three propellants, all these three fuels are something like can cause cancer and there is a trend in today’s world to get back in and substitute it by kerosene or something, because we say it is carcinogenic. But being rocketry and using small quantities over a period of launches we take adequate precaution and still continue to use these fuels.

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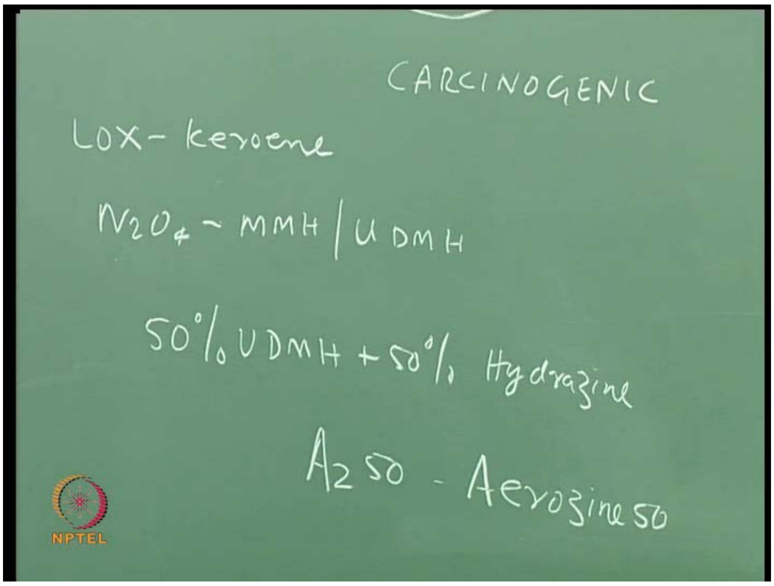

Therefore, now I put the low energy fuels again I said in addition to LOX kerosene, I could have N 2 O 4 with mono methyl hydrazine or with unsymmetrical dimethyl hydrazine either or MMH with N 2 O 4 or UDMH with N 2 O 4. There is also one last fuel which we call as a mixture of fifty percent UDMH plus fifty percent hydrazine. This is known as a z fifty, that means fifty percent of this and fifty percent of this known as a z fifty which is also used with N 2 O 4 this was used in some of the rockets developed in US and therefore, this is known as aerozine fifty. Therefore, now I tell myself well, the low energy propellants could be LOX kerosene, well this is outdated or else when kerosene is substituted or LOX is substituted by HNO 3 and let say HNO 3 in the form of red fuming nitric acid which more energetic, and fuels could be MMH N 2 O 4 or hydrazine. This is one one class of this or UDMH. This is the low energy propellants.

You know, I think it is necessary to go back in history because when when we go back and see some of the missiles, we still see some other fuels being used two other fuels being used especially at DRDl when when they were making these missiles earlier and s they still continue with it.

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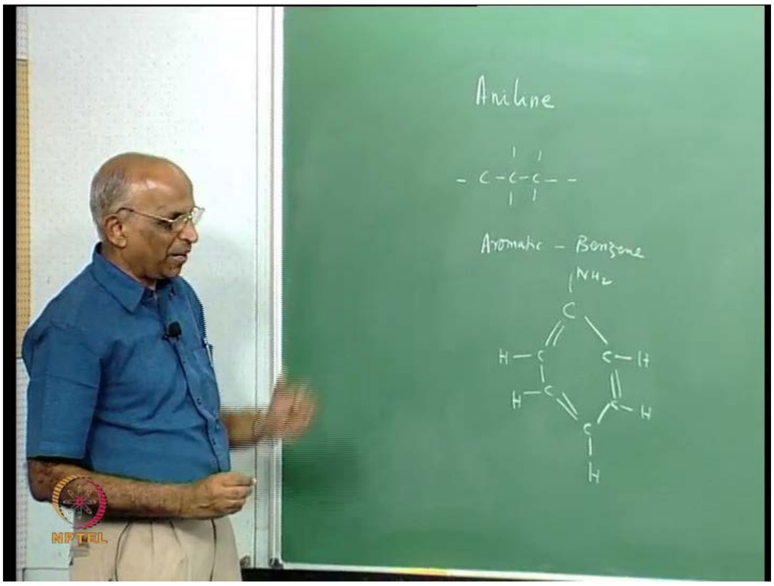

One is known as aniline. See, while all the fuels what we considered where somewhat based on aliphatic like kerosene we say c c all in the straight chain. Aniline is derived from an aromatic compound, aromatic chain which is actually the benzene chain and what is benzene chain? You have c c c c and alternate double bonds 1 2 3 and you have over here 1 2 3 4 5 and 6. What do you do in in in aniline is, you take the benzene chain or you take the benzene, substitute one of the hydrogen by ammine radical NH 2 and this becomes what we call as aniline. Let us keep this in mind because I will come back to something you know this NH 2 over here or we say NH 2 in hydrazine or you say NH 2 in MMH and UDMH is what is an ammine radical and this ammine radical is so unstable or it is so reactive

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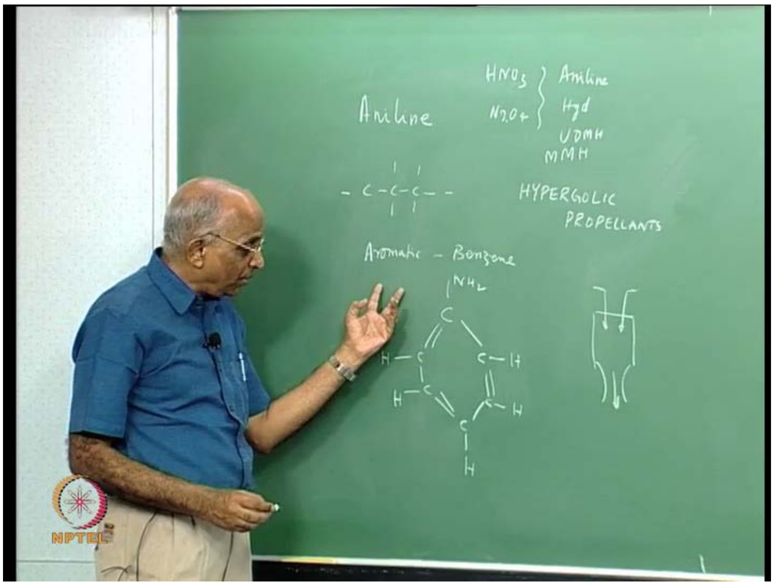

That the moment it comes in contact with let us say HNO 3 or it comes in contact with N 2 O 4; it by itself ignites and reacts and such of the propellants which contain this ammine radical readily react with HNO 3 and N 2 O 4. And such such propellant combinations of N 2 O 4 with anything like aniline may be or with hydrazine or UDMH or MMH will not therefore, require an ignition source.

All what I do is, I put ah fuel, one of these fuels I put one of these oxidizers in to the chamber. Immediately by itself it will ignite and these are known as hypergolic propellants. That why is it hypergolic? the The ammine radical in these fuels readily goes and reacts with the acid or the N 2 O 4 to form hot combustion product. Therefore, the design of the rocket become simple I just have a chamber. All what I need is I have to push this fuel having the ammine radical in it push the oxidizer by itself it burns and it release gas, I do not even need to ignite it. I do not need an auxiliary igniter whereas, if I talk of even hydrogen ah liquid oxygen and kerosene. I need to ignite it because I have to overcome the energy barrier before an ignition reaction chemical reaction can take place therefore, these are all hypergolic propellants

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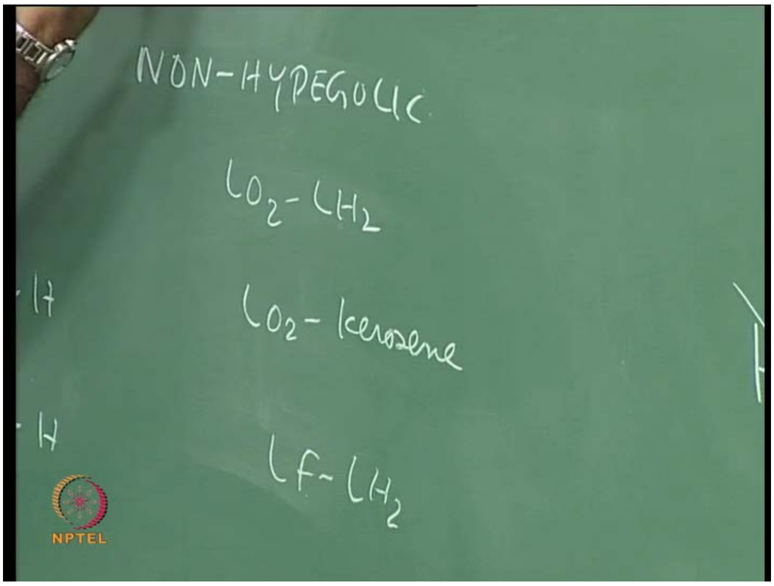

And in we call those which require an an ignition source for initiating reactions or combustion as non-hypergolic. These are liquid oxygen, liquid hydrogen, non-hypergolic, may be liquid oxygen, kerosene.

The only exception is liquid fluorine and liquid hydrogen. Liquid fluorine is so reactive that it will react with anything, with the container it will react. Therefore, it is also it comes in the category of hypergolic but mind you it does not contain an ammine. It comes from the reactivity of fluorine itself. This aniline was extensively used in the seventies and eighties but as a slight improvement over aniline one very last fuel, which I will talk of is known as Xyladiene

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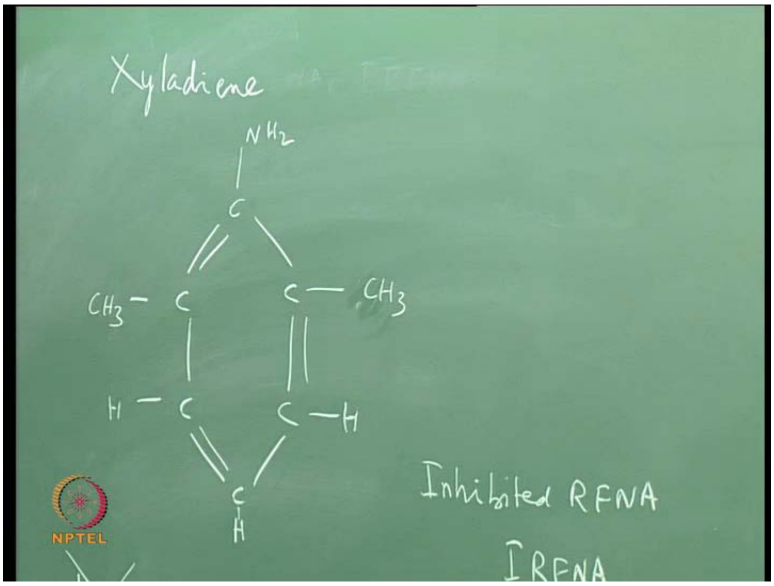

And in xyladiene what do you do is you have the same aromatic structure, you have alternate double bonds, you had NH 2 here this was aniline and you had there balance was all hydrogen over here. you You take two more of the hydrogen atoms may be I remove one of the hydrogen atom substitute it by a methyl radical I remove this substitute it by methyl radical and this is what is known as xyladiene. Again it consists of an ammine radical and therefore, it is hypergolic these two namely aniline and xyladiene are used as liquid fuels for many of the missiles they are low performing very low energetic and therefore, if I were to, sub to, at this point in time just summarize what are the low energy propellants may be in terms of the energetic

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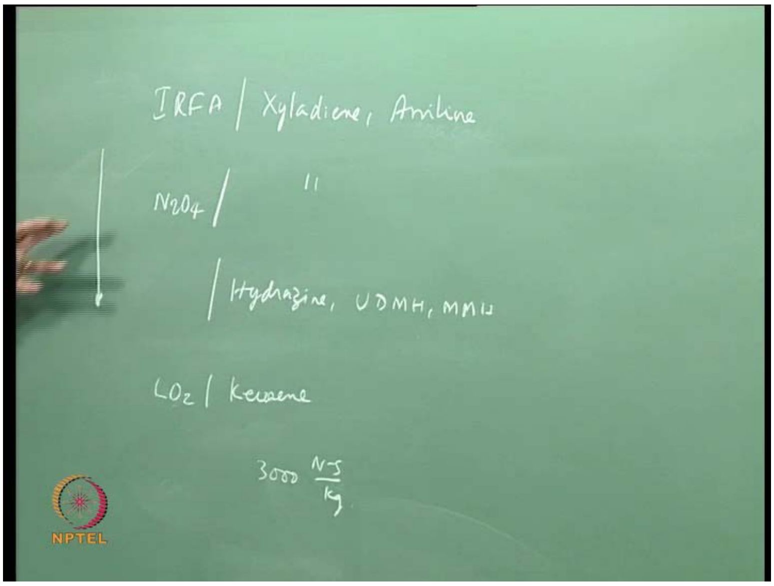

I can say well IRFNA with may be xyladiene or aniline. Then I say may be N 2 O 4 is little better, may be with the same combination, may be N 2 O 4 will be still better with hydrazine, may be with UDMH, may be with MMH unsymmetrical di methyl hydrazine MONo methyl hydrazine and then the last one which we say is may be LOX with kerosene these are the low energy propellants ISP increasing towards this but this ceiling is less than three thousand Newton second by kilogram.

Therefore, these are the low energy propellants and many of these low energy propellants especially those using the nitric acid and N 2 O 4 are hypergolic which means they are much easier to use and that is why we see these fuels being repeatedly used in spite of being carcinogenic is much easier to use and also we find you know it the the system becomes very simple. You do not need an auxiliary igniter, you can whenever you want to you just fire it. Supposing I have a space craft let us say you know in the space craft you just carry a tank. Let us say you carry an N 2 O 4 tank and that is what is done in our INSAT spacecrafts.

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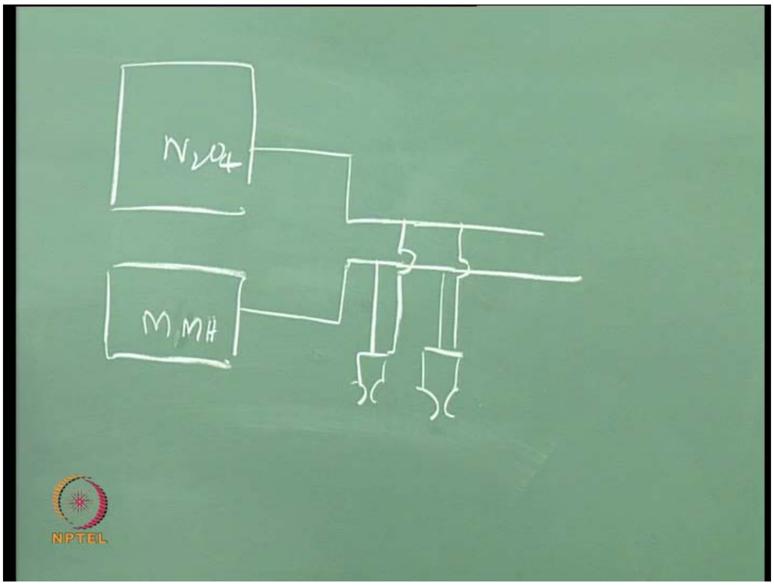

You You have a tank which carries N 2 O 4 another tank. You carry let say MONo methyl hydrazine. Mind you both are low low energy fuels and whenever you want to have some correction may be at the you have a series of rockets which of which are fed from these lines may be, let us say I i have one small rocket over here, maybe I i take the fuel here then again, I have the another rocket over here. i I take more of this and so on. I keep on continuum may be, I have something like twelve rockets and whenever I want to fire it, I just open the line with valve. I admit small quantity and it fires and it will give me an impulse and I can use it very simply. I do not need any other ignition device to be able to fire this and that is the advantage of many of the low energy propellants and of course, kerosene is an improvement over this and kerosene is readily available it is a very cheap fuel again and that is why the majority of the boosters or the vehicles, which require large quantities of fuel make use of liquid oxygen and kerosene. We are still to start with these activities in our country. The only problem is this becomes a semi cryogenic fuel. At this point in time I will slightly divert myself and come back to the medium energy propellants a little later.

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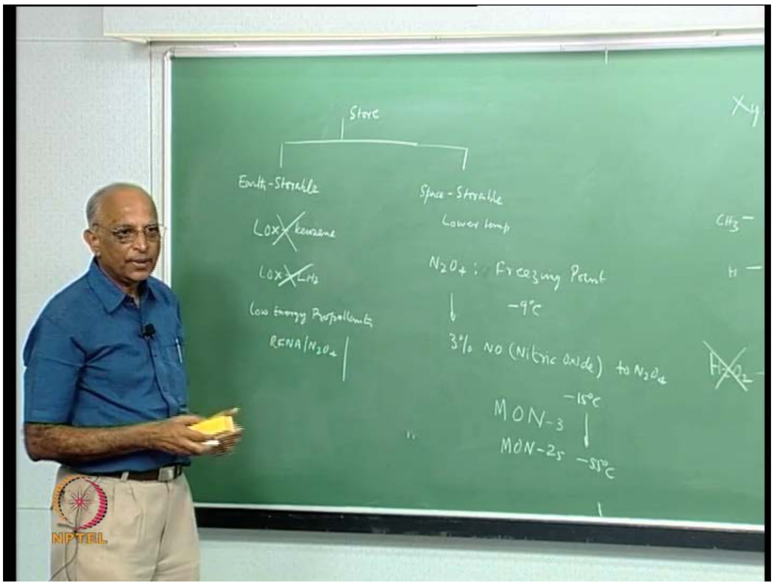

Now that we covered hypergolic, non-hypergolic, we told some are simple. The classification of propellants can also be done be under how you can store the propellants. Why do we say storing is so important? Suppose we have a missile to take off; see missile must be ready at any point in time. That means it the the tank must be always we having the fuel. Therefore, we say as ah propellant could be stored on earth we say earth storable or if I want to fly a space craft and the space craft goes round for twenty years or twenty five years, the propellant must be there in the space craft for that time. That means is must be storable in space, that means space storable immediately when I say earth storable and space storable I say by earth storable something which can be stored on the ground and immediately I can fly.

I say well if I have to have LOX kerosene LOX kerosene I cannot just keep it on ground all the time because LOX has to be kept under refrigerated conditions or insulated conditions. Therefore, this is not even earth storable leave alone space storable. You know similarly, LOX and liquid hydrogen are cryogenic fuels, semi cryogenic and cryogenic fuels these are not earth storable and only most of the low energy propellants, what were the low energy propellants? We have red fuming nitric acid or N 2 O 4 as oxidizer with series of may be hydrazine UDMH MMH were all the low energy propellants. These are all earth storable propellants whereas, if I say space storable; it becomes even worse for me. In space I can get still low, lower temperatures and therefore, not all all these things may not be used. For instance may let us take an example N 2 O 4 as is a very good oxidizer.

Let us consider the freezing point of N 2 O 4; the freezing point of N 2 O 4 is around minus nine degree centigrade and whenever we have a space craft, when it is not looking at the sun the temperature comes down therefore, I need heaters o keep this warm, but if I were to add something like three per cent of nitric oxide that is n o that means three per cent nitric oxide to N 2 O 4; I can increase the freezing point or make the freezing point instead of being minus nine degree centigrade to something like minus fifteen degree centigrade. Therefore, if I had to make the oxidizer perform in space one of the things to be done is may be I should add some additives like nitric oxide. If I add three per cent, I have a little better and these are known as mixed oxides of nitrogen and since I add three per cent this is known as MON three.

Therefore, all what we do is in the earth storable when I add n two when I have N 2 O 4 as an oxidizer if the same N 2 O 4 has to be used in space for a prolonged period. Then I have to decrease its freezing point, I do that by adding n o two it, if I add three per cent it is known as MON three. If I add something like 25 percent of N O that means, 25 percent of N O, I add, I can decrease the freezing point to something like minus fifty five degree centigrade which is even better. Therefore, in space I can still use may be the other part of it fuel as MMH. But I substitute N 2 O 4 by this and this is the satellite difference between earth storable and space storable propellants; cryogenic and semi cryogenic propellants are those which are neither earth storable or space storable. You can be used in launch vehicle before rocket may be a day before that I ch i i charge the propellants and immediately it takes off.

It cannot be used for missiles, it cannot be used for satellites, it cannot be used for some other purposes like which you want to readily store and use I think these are the different classifications and therefore, what is it we have seen so far we told ourselves well propellants are classified into low energy high energy

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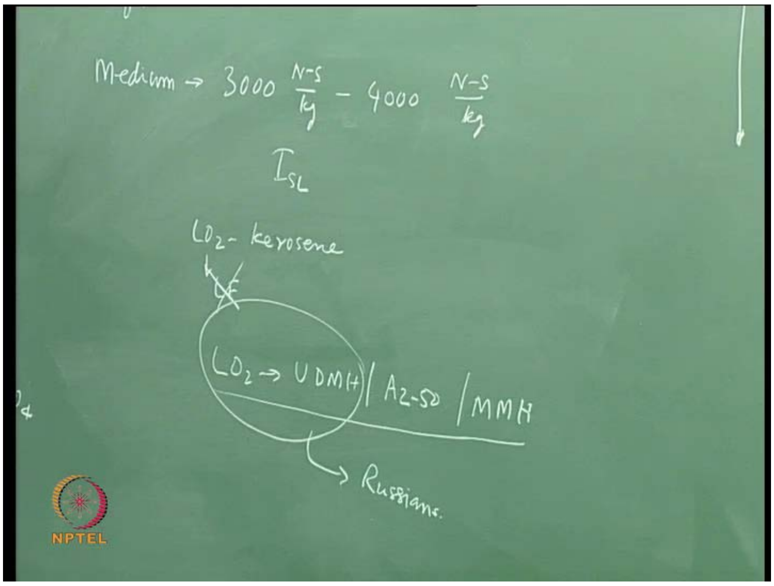

And we have examined these things in between the two. We could also have medium energy propellants which could be in the range of something like 3000 Newton second by kilogram specific impulse to 4000 Newton second by kilogram. Propellants which give specific impulse and what specific impulse? Sea level specific impulse because they form that vacuum specific impulse is much higher and what we evaluate on the ground. Therefore, whenever sea level specific impulse is less than three thousand; I say its low energy, when it is greater than 4000 I say high energy medium energy is this. but there are hardly any good medium energy propellants.

The only things which we can think of is may be instead of having LOX kerosene, if I use instead of LOX, if I use liquid fluorine well, it gives an specific impulse greater than three thousand something like three thousand two hundred it could be a good candidate. but liquid fluorine cannot be used the other is you know, we also told ourselves when I, whenever I have something like RFNA N 2 O 4 these are inferior to LOX because they contain some other elements over here. Therefore, if I can use something like LOX with one of these fuels let let us say UDMH or let us say combination of UDMH and hydrazine, aerozine fifty or let us say with MMH. These become, these give higher performance exceed in three thousand and these are the medium energy propellants but the only one which has been used so far in practice is the combination LOX and UDMH and this has been used by Russians alone.

Therefore, all what we have done with liquid propellants is see we we talked in so many chemicals. Ultimately when it came to usage we just have things which can be counted on finger tips and what are they? Let us now put it down together such that we never forget it

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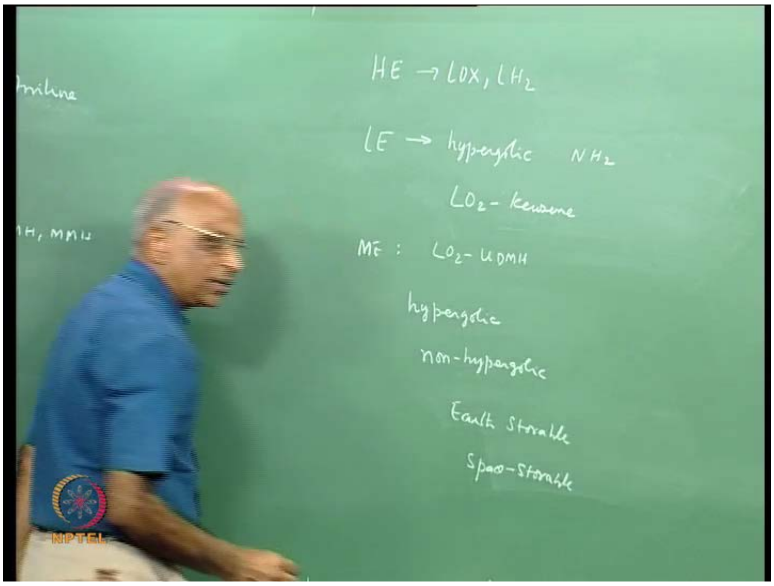

We tell ourselves well high energy propellants are neither storable on earth or in space we call it as it could be LOX liquid oxygen and liquid hydrogen. The low energy propellants are things which are storable many of them are storable in space with little modifications like MON MON three instead of N 2 O 4 or MON 25 instead of N 2 O 4 and these are essentially we said hypergolic. Whenever you have the fuel which contains the ammine radical in it, the low energy also had liquid oxygen and kerosene which is not earth storable neither is it space storable. You have the medium energy propellants which is again semi cryogenic liquid oxygen and UDMH. This is the only propellant which has been used in a rocket so far. Well, these are the classifications according to energy we could classify it into hypergolic or non-hypergolic. Hypergolic are ones which in which the oxidizer and the fuel when they come in contact it automatically burns and that we will consider when we deal with liquid propellant rockets.

Non-hypergolic which need an igniter to get the combustion started in the rockets. The last classification we saw was earth storable liquid propellants and we say it is space storable. The semi cryogenic and cryogenic are neither earth storable nor space storable.

I think this is all about the different liquid propellants what we considered. Let us now quickly go through the last last part of propellants.

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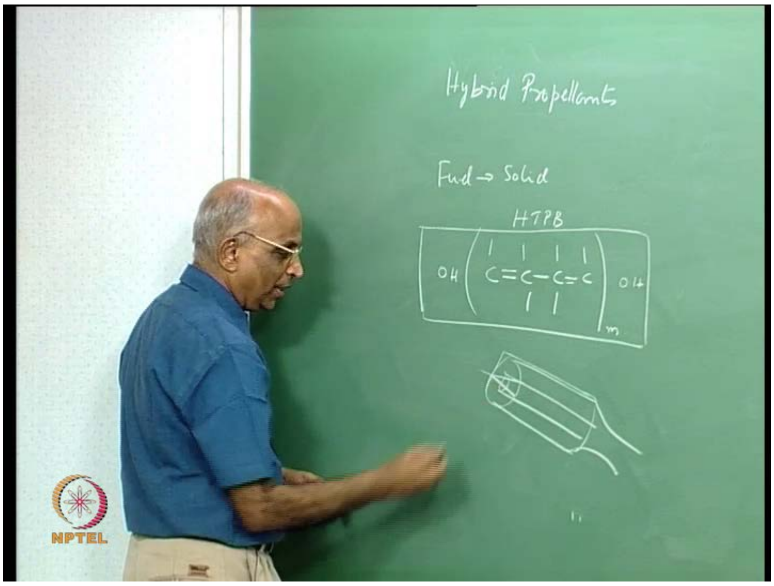

We have considered solid propellants we have considered liquid propellants; let us take a look at what are the things like hybrid propellants before we come and solve one or two small problems. What are the, what do you mean by hybrid propellants? Hybrid propellants are those propellants which are in a mixed face may be the oxidizer could be a solid, fuel could be a solid whereas, the other one could be a gas or a liquid. The the usual practices the fuel of hybrid propellants is in a solid form something like HTPB which we considered. What was HTPB? We told ourselves well it is poly butadiene. You have c cc and c two double bonds what was it? And you had something like six over here, two and two over here. This is what was poly butadiene and it was a chain as it is, may be m over here, may be you use hydroxy terminated poly butadiene. That means I have one OH here, I have one OH here. This could be a fuel for this what? This is the advantage we had with hydroxy terminated poly butadiene? Instead of having something like p band which consisted of acrylic acid acrylo nitrile. That means you had heavier substances, here you have lighter substances and therefore, it is stronger.

Therefore, a typical fuel solid fuel is something like HTPB and what is done is maybe you form a solid something like this may be with a hole in it and then put it in a motocase, maybe attach it to a nozzle and this becomes your solid fuel for the ambient.

Now I need an oxidizer. The oxidizer you you through you inject oxidizer in to it, namely the injector could the oxidizer could be anything what we have considered, and what are the oxidizers, which we have been talking of so far.

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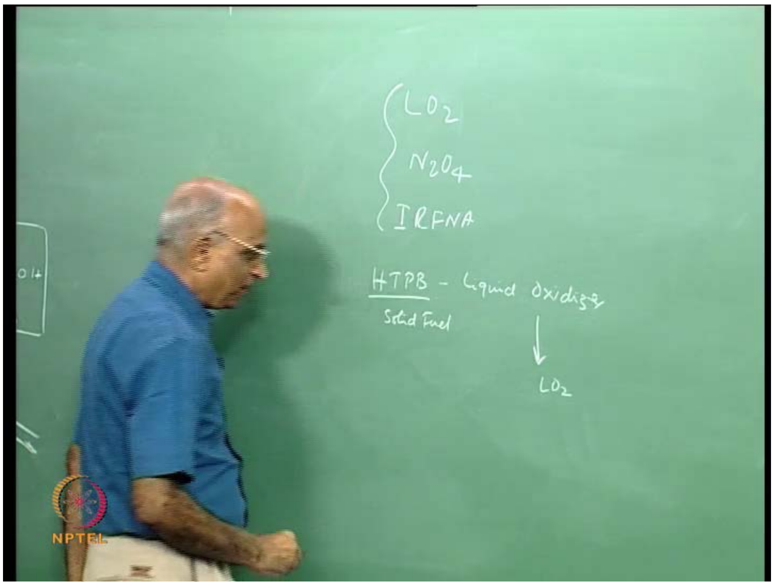

We said oxidizers could be liquid oxygen, could be N 2 O 4 ,could be red fuming nitric acid better still inhabited red fuming nitric acid. Well use one of these things and if I use some of these things and allow the liquid to come in contact with the solid may be it will begin to react, it reacts and then I get the oxidizers of well, these are the hybrid combinations essentially are therefore, HTPB as a solid fuel. And one of these three oxidizers as a liquid oxidizers you know, so far people have not started you never use something like a gaseous oxidizer, because I need large volume to store it and the only hybrid which is used and it is picking up again. There was a time in 80's when there was lot of interest in hybrid rockets but again now a days this are these private companies in US are coming forward and they are trying to make some manned vehicles which will take tourist from ground to space and all that using hybrid rockets. There is some interest again on this. You know, when we talk of liquid oxidizers; well liquid oxygen is powerful enough.

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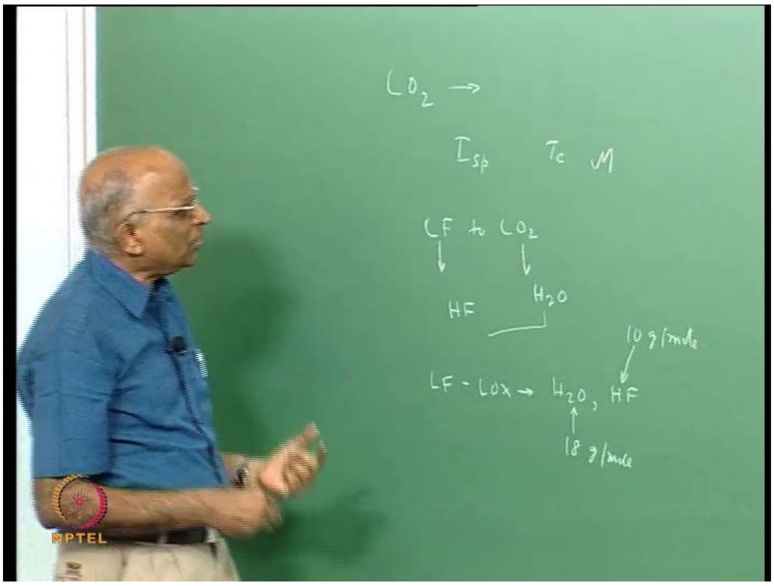

Can I make the value of the specific impulse of let us say liquid oxygen to be higher in some way than by modifying the property of the liquid oxygen itself? Let us tell ourselves well the specific impulse can be increased by either increasing the combustion temperature or reducing the molecular mass of the combustion products. Either you increase the temperature of the combustion products or you reduce the molecular mass of the combustion products. How do I do this is a question. Let us examine the following. Supposing I add liquid fluorine to liquid oxygen; then in that case may be the the fuel in the hybrid propellant let say hydrocarbon originally when liquid oxygen is used gives me water.

Now, when I add some liquid fluorine to liquid oxygen and mind you it is quite easy to add liquid fluorine to liquid oxygen, because the boiling point of liquid fluorine and liquid oxygen are about the same in addition to getting water since I add fluorine, I also get hydrogen fluoride. Therefore, the products of combustion now are with liquid fluorine added to liquid oxygen. I now get in addition to H 2 O, I also get hydrogen fluoride. The molecular mass of water namely H 2 O is 18 - 2 plus 16, 18 grams per mole. The molecular mass of hydrogen fluoride is ten gram per mole. Therefore, you find that the act of adding liquid fluorine to liquid oxygen results in getting more of hydrogen fluoride as I increase the liquid fluorine and oxygen and therefore, the net value of the molecular mass of products which now you get hydrogen fluoride also decreases and therefore, since this decreases, molecular mass decreases I get higher value of specific impulse.

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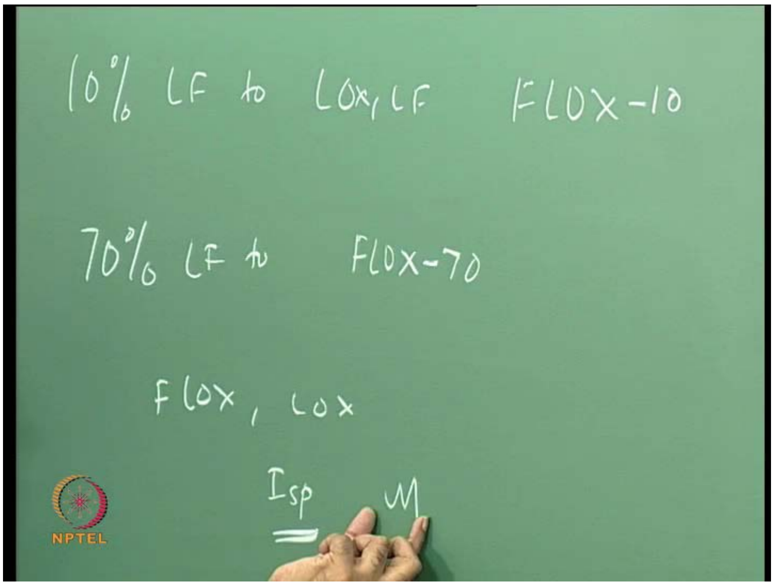

Therefore, what is it you do? May be I add let us say ten percent of liquid fluorine to a mixture of liquid oxygen and liquid fluorine. That means ten percent of liquid fluorine in this particular mixture is known as FLOX fluorine and liquid oxygen. Ten ten percent, if I add something like seventy percent of liquid fluorine to the liquid oxygen mixture then I call it as FLOX 70. Therefore, by using FLOX instead of liquid oxygen LOX; I get much higher specific impulses and therefore, these are considered to be higher energetic substance. The main aim therefore, is by using FLOX instead of liquid oxygen LOX; I get a higher value of specific impulse and the higher value of specific impulse not does not come from the energetics of propellant alone. But by a reduction in the molecular mass of the products which gives me a higher value of specific impulse. Let us keep this in mind that is I can improve the performance of propellants by reducing the molecular mass of the products. These are the all the propellants and we will to summarize the whole thing again let us put the whole thing together.

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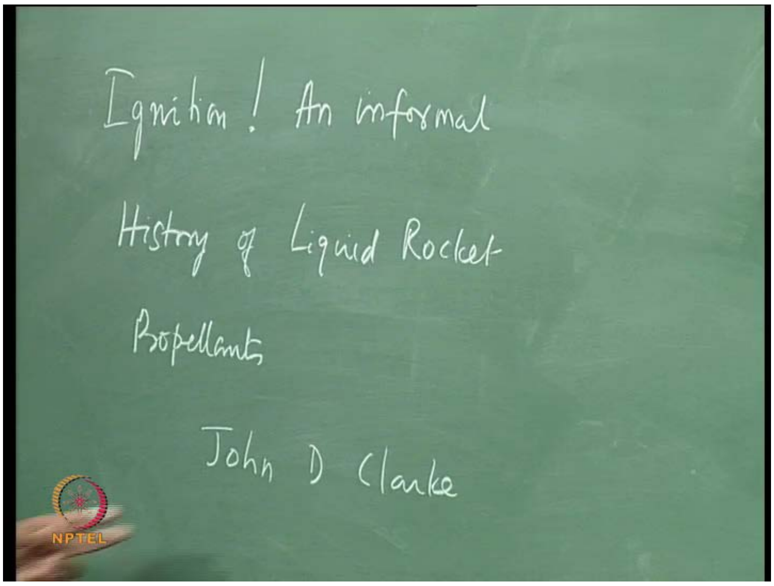

We talk propellants could either be solids could be liquid, could be hybrid. We classified solids into four categories and what were the four categories? We said it could be a double base or a single base, it could be a composite in which case you have crystals of solid dispersed in a solution or dispersed in a material heterogeneously, it could be a combination of composite modified double base. That is double base in composite together or nitrammine liquids we just saw we say space storable, earth storable, hypergolic, non-hypergolic. We said yes low energy, medium energy and high energy and of course, we looked at hybrid propellants. Well, these are the only propellants which are in use today. And when we considered solid rockets, solid propellant rockets, liquid propellants rockets and hybrid propellant rockets we will consider the details of how to make these rockets. What are the factors? There a lot of factors we will be looking at; the chemistry or will we look at the ballistics. There is a lot of things we have to do and that is what we will between from the next class onwards.

I would like to give you one reference which is extremely, which makes extremely interest in reading and that reference is a book called ignition. It is there in our library the name of the book is ignition an informal history of liquid rocket propellants. It is by John Clarke, John D Clarke. Quite an old book though, something like 1962 or so it came out. but it gives a total coverage. It is not only these things we, I am only, not only interested in the performance. See, the liquid propellant or any propellant we must consider like what we said may be storability, may be the ignitability, may be it must not be corrosive.

It must be cheap you know, we have covered all that and he brings it out beautifully like when they were handling these propellants some some acid will get into the fleas ant heat into the system itself.

Therefore, it is not usable what are the defects what are the explosives would could be used and therefore, something which makes an interesting reading. I think this is all about liquid propellants. Let us quickly do something like one or two small problems such that we know how to make may how to solve problems in this particular area of liquid propellants. Let let us do one or two small problems. The first one I choose is extremely simple but illustrative Yes.

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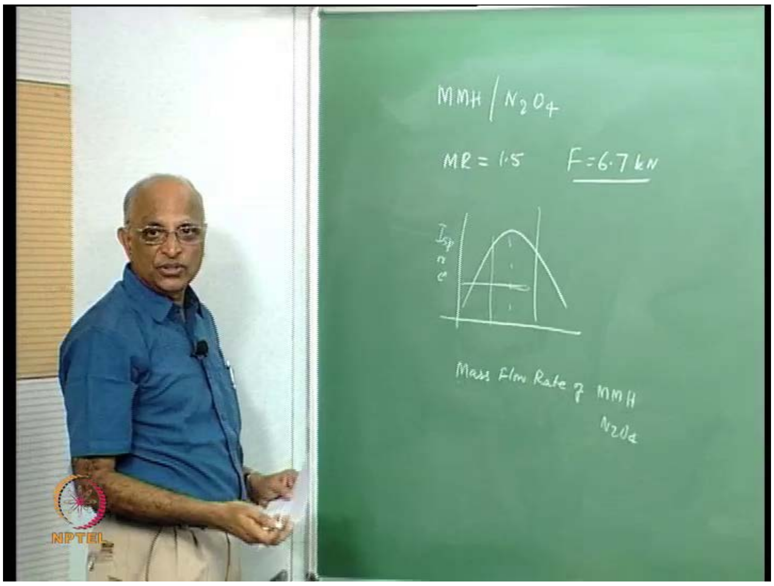

You know supposing I say, I am i'm using a propellant like, let us say MMH and N 2 O 4 as propellants and I say I am going to use it for a mixture ratio of 1.5 that means, the moment I choose a propellant, I also choose a mixture ratio why? Because we told ourselves if I plot I SP or C star, the I SP will be maximum in the fuel rich region and I will choose fuel rich point. Therefore, this is known. Normally even though I say now 1.5, may be here I choose this because for simplicity in doing a problem. Sometimes we will use mixture ratio in which the volume quantities will be the same instead of taking that means the q of their hydrazine, the volume of N 2 O 4 is same such that I just need to develop one tank and the same tank I can use for both the purposes.

Let let us let us start with this problem I say I am going to make a rocket using MMH and N 2 O 4 at a mixture ratio of 1.5; I also I am given one more data. I ii tell myself well the thrust what I require, is 6.7 kilo Newton is the thrust I need. Now I ask a question what must be the mass flow rate of MMH into the chamber? What must be the mass flow rate of N 2 O 4 in the chamber to give me a thrust of 6.7 kilo Newton? Therefore, what I do? The problem is extremely simple. Well a propellant combination is known.

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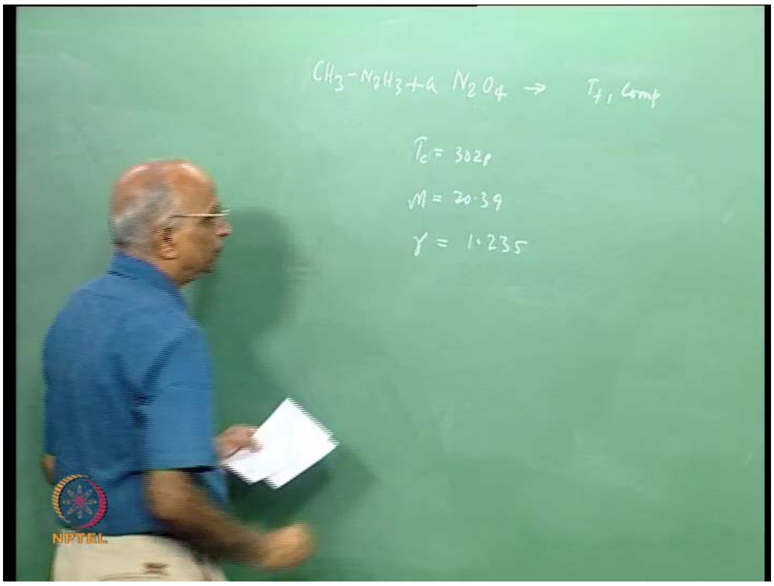

I know the formula for MMH we said it is c h three n two h three. I know the formula for N 2 O 4. I am i'm given the particular mixture ratio mass of this therefore, I know what is the value of this, I can find out the temperature of the products, I can find out the composition of the products using dissociative equilibrium we have covered it or if you want to simpler one assume some products and do the problem. Assume the hydrogen to be much more reactive than carbon and therefore, hydrogen first tries to find out, searches for oxygen, consumes it and only the balance of oxygen is left for carbon to react. The nitrogen in the substance is obtained in the products as N 2. Therefore, the procedure is first we use the hydrogen in the fuel which searches for the oxygen, consumes it, the balance oxygen is now available for carbon to react either fully to carbon dioxide or partially to carbon MON oxide or if even oxygen is not available to carbon and the nitrogen in the fuel or oxidizer is available in the products as n two.

This procedure is quite useful in determining the combustion products for fuel rich mixtures. but it is possible. We must do the detail problem when I do it. I find that the temperature of the flame or temperature of the combustion products is 3028; the molecular mass of the products is equal to 20.39. This was based on dissociative equilibrium and the value of gamma is equal to 1.235. Once I know this, I can get the value of C star.

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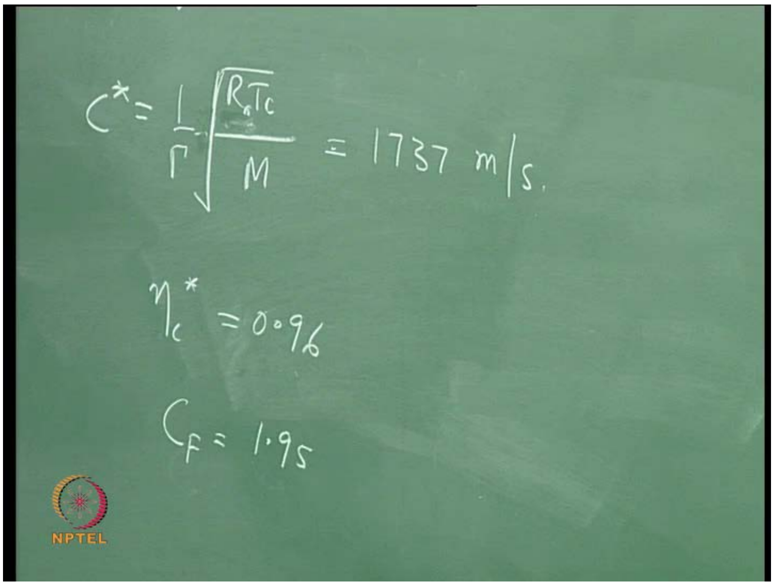

The C star is equal to we told ourselves, is equal to under root r t c by if I in terms of universal r naught by m or rather I take it at the bottom into one over capital gamma. We had capital gamma in terms of under root gamma two over gamma plus one to the power gamma plus 1 divided by 2 gamma minus 1. I substitute the values and the C star will come out to be seventeen thirty seven meters per second. You know, most of these rockets have a C star efficiency we will know how to calculate it when we make, when we study liquid propellant rockets and the absolute value of C star we will assume to be 0.96 for the present since I still do not know how to estimate this. I also say well the thrust coefficient in the nozzle I know for the particular nozzle area ratio, I take the value as equal to let us say 1.95 something which is realizable may be for the particular area ratio, my thrust coefficient is this. Well the data is all available to me.

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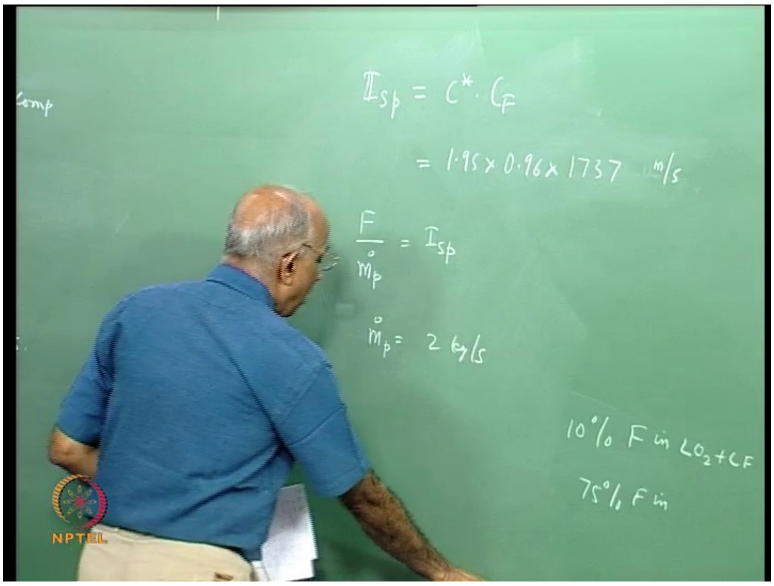

Now I want to calculate the value of specific impulse the value of specific impulse is equal to I SP is equal to we say C star into C F which is equal to C F is 1.95. C star is efficiency is 0.96. The theoretical value is one seven three seven so much meters per second. I want a thrust which we said is something like 6.7 kilo Newtons. Therefore, the the value of thrust divided by the mass flow rate of the fuel and oxidizer total propellant is equal to I SP. From this I get the value of m p dot right. m p dot is equal to thrust divided by specific impulse and that comes out to be something like two kilograms per second.

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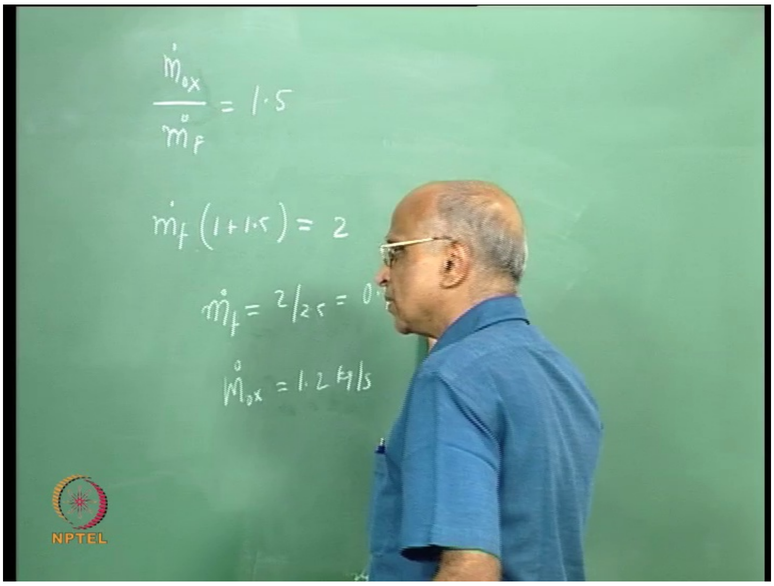

You can do this and now what is the flow rate of oxidizer and flow rate of fuel? You know the mixture ratio is given as 1.5. m dot oxidizer divided by m dot fuel is equal to mixture ratio which is 1.5. Therefore, I know m dot fuel divided by multiplied by one plus 1.5 is a total propellant mass which is equal to two or rather m dot f mass flow rate of fuel is equal to 2 by 2.5 o k and once I know the mass flow rate of fuel I know what is the value of mass flow rate of oxidizer. And this is all what is done. This might be about 0.8 and the total value of m dot oxidizer which is equal to N 2 O 4 is equal to 1.2 k g per second. This is how one solves. It is a extremely extremely simple right. May be some one another problem which we could consider is something. Let us say I have a solid propellant which consists of a, let us say ammonium per chlorate and oxidizer. I will i'll just quickly go through it; we do not need to do it.

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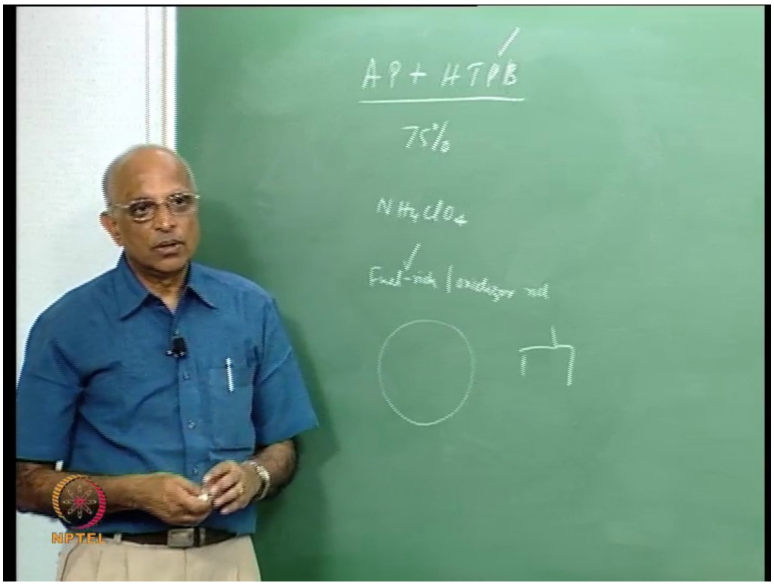

I say I have a propellant which consists of let us say a p plus may be HTPB I say that the solid loading in this propellant is 75 percent. I give you the molecular mass of the HTPB, i I know the molecular mass of A P namely N H 4 c l O 4 and if this is given I want you to find out whether was 75 percent solid loading. That means mass of a p in the total mass of propellant is 75 percent. This is what we called as solid loading. I want to find out whether this propellant is fuel rich or oxidizer rich.

You can do the same thing, I write the equation HTPB, I know the molecular formula, the the molecular mass will be is given to you. Therefore, I can I know the moles of this.

I know the moles of this, I divide this divide it by the total 75 percent. I get the value of the number of moles of HTPB required for a single mole of a p and then from this I can go ahead and find out whether it is oxidizer rich or fuel rich. You will find even this 75 percent solid loading; it will be terribly fuel rich. All propellants tend to be fuel rich. Why did not you all do this problem as a homework problem? Because it is quite simple and actually the the liquid propellants what we use the solid propellants, what we use are quite simple. The solid propellants are made as a solid block and in the next class we will see how to make a solid motor out of this block as it were. Similarly, for the different liquid fuels what are the cycles which we can use such that I can get them to expand and give me some value of get velocity? And similarly, for hybrids this is all about propellants. May be in the next class, we start with solid propellant rockets. Thank you then.