# Rocket Propulsion

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**Module No. # 01**
**Lecture No. # 20**
**Factors Influencing Choice of Chemical Propellants**

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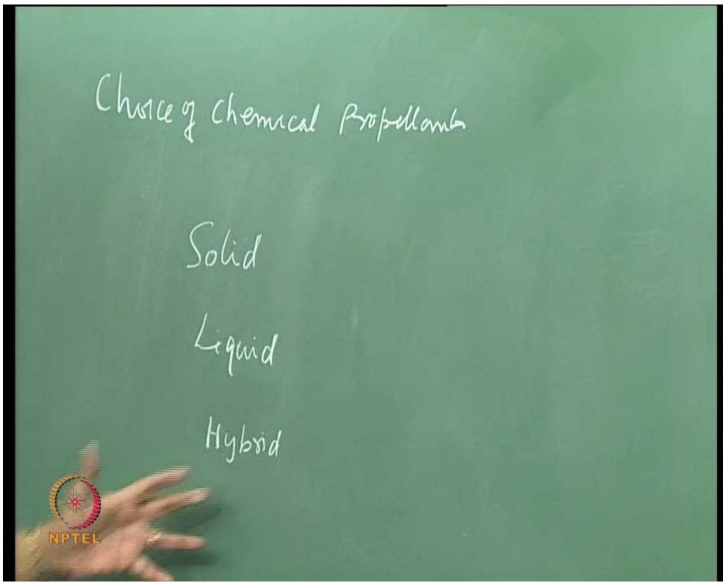


Well, good morning. In today's class, we will complete the choice of chemical propellants. By choice I mean, the criterion what we need to follow. How we say this propellant I can choose because there are so many chemicals. What are the chemicals we use; we will see with respect to solid propellants, we will see with respect to liquid propellants. May be, we will also see any other form of propellants like hybrid and make a judicious choice and then, we will go into details of the propellant used in a solid propellant rocket which we call as a solid propellant rocket. We will look at liquid propellant rockets and the other types of rockets.

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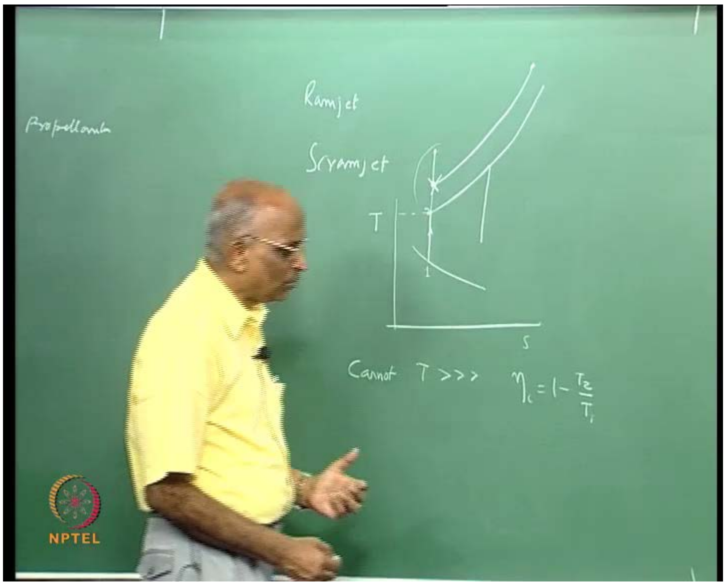


Before I get this, something from the last class which I must clarify. When we consider ramjets, when we consider scramjets, does dissociation play a role like for instance; let us make a diagram of the performance of a scramjet or a ramjet on a T s diagram. What do you do? In the intake I isentropically let us say an ideal condition. I isentropically compress the air from a temperature one to two isentropic compression. Then, what is it I do? I add heat at let us say constant pressure and then, what I do is I expand the gasses again. Let us say constant pressure heat addition could be like this. The pressure line, constant pressure lines are like this and then, I expand the gasses again.

Now, if I were to do this, if I keep on compressing the gasses more and more, what is it? I have a temperature here which is high. I want still further expansion. I go to still further temperature over here, I have still higher compression, I go to still higher temperature over here. In other words, as I go to higher and higher temperature, the air which is getting in will get dissociated and the temperature will be higher and if the temperature is so high that I cannot add any more heat release, I cannot have any engine operating, but the question is if I now say I will still increase my amount of heat addition now, even though the temperature here is higher, I increase the amount of heat addition to still a higher value.

If I increase the heat addition to a very high value, I get intense dissociation and the chemical energy is not really available. Therefore, you do get some bounds. Dissociation plays a role in the choice of the upper bound of temperatures in which some of these engines can operate. Let us keep it in mind. Dissociation is not very peculiar to rockets itself, but to all other forms of engine because as per the rule for a carno engine, I would like to get high temperature to be as high as possible, that is when I get maximum efficiency that is any engine.

If my highest temperature is higher, I get a higher efficiency because the efficiency of a carno engine is equal to 1 minus low temperature divided by the high temperature. If I can make the high temperature to be infinity, I get a very higher value, but to be able to achieve these temperatures, I cannot do so because gas begins to dissociate. That means I will be using my chemical very poorly. If I have to go to a high value of temperature let us keep this in mind.

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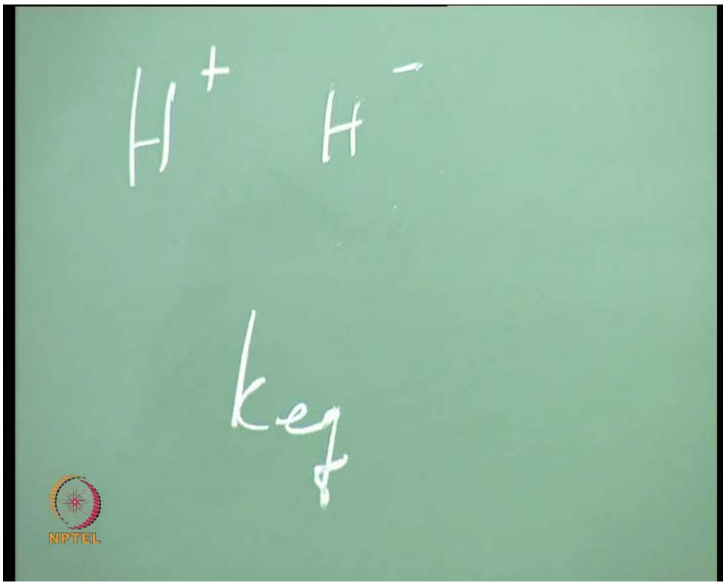


Another point which I also thought I must make is it is not only the species which are getting dissociated, but when I go to high temperatures, I can also get H plus. I can get H minus, I can get the plasma coming over here and I can write the equation to these plasmas using the equilibrium constant and also find out how much of the atoms get into, may be the different forms of excitation. I think these things we must learn to do and maybe we should do it in the project which each one of us will be doing on dissociation.

Having said that, I think let us keep the focus of this class very clear. We want to examine the different choice of chemicals which can be used for solid propellants, liquid propellants and hybrid propellants. What are the things we are done so far?

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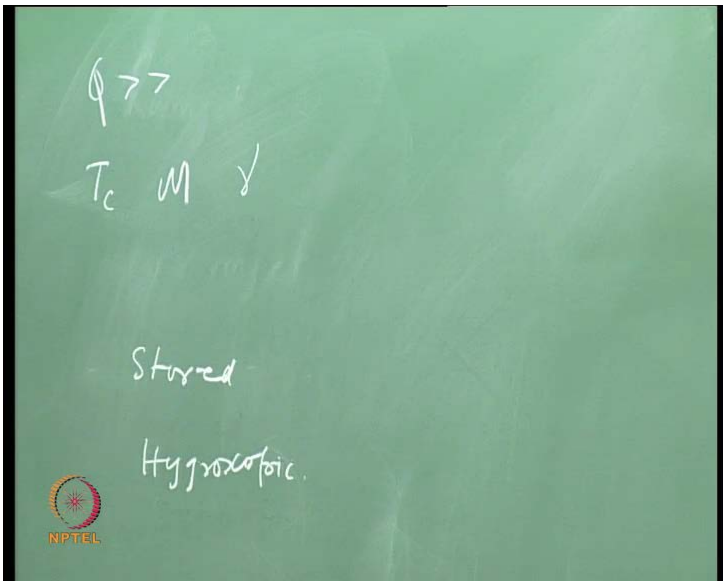


We said well, I would like to get a high value of heat release, I would like to get a high value of temperature, I would like to get a low value of molecular mass. Well, gamma really did not matter much to me.

Well, we just looked at this point, but a chemical must be handleable. That means chemical must be being stored. It must not be something which observes moisture from the air is sort of hydroscopic. It is something which must be stable. It must not happen before I start using the chemical. It begins to do something. Therefore, there are other factors in addition to this which also plays a role and which we will be seeing as we studied the different propellants.

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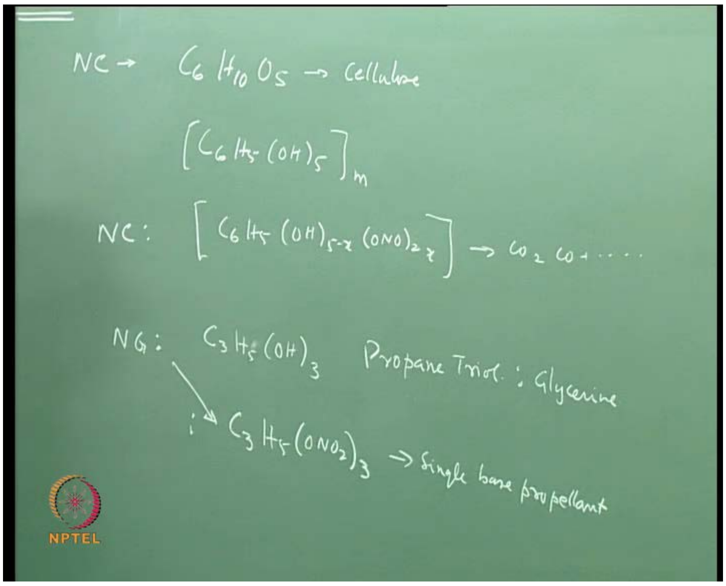


Well, having started this let us get into some details. Solid propellants, we have already seen the different chemicals. Let us start with the chemical with which we started in solids. We said I could use something like nitrocellulose which we said is an explosive. What was the formula for nitrocellulose? We had something like C6H10O5. Is it or is it O10H5? C6H10O5 was cellulose. What I did to the cellulose? It is like paper. This could be written as C6H5OH5 and this comes as a chain, you know like if I have a paper, it is just is a cellulose material. It comes as a material as a chain like this. What I do is for nitro, I substitute point of OH by the nitrate radical. That means I get C6H5. I am left with sum of OH namely, 5 minus x and I put instead of OHONO2X and this is what we call as nitrocellulose.

We talked of this earlier in the class. We told ourselves well, this contains both oxygen and carbon terribly fuel rich, but can still dissociate to form carbon dioxide. May be CO, may be other species could come out over here and this could be used as a propellant. In other words, we could call it as a single base propellant because it is a single explosive which dissociates and does the job. I could have another propellant. The other thing we said is nitroglycerin and we told nitroglycerin is little better than nitrocellulose because nitrocellulose had a very large and negative value of heat of formation. Nitroglycerin was better that way.

What was nitroglycerin? It was derived from propane C3H8. What we take? We take propane, we take 3 of propane, 3 of hydrogen out substitute it by OH namely, an alcohol. We call it as C3H5OH3 which we call as propane triol that is 3 of OH. This is known as combustibly as glycerin. What we do is instead of OH, we substitute it by nitro. That means we have C3H5ONO2 three times and this is what is known as nitroglycerin.

Again in the classes, we found this is slightly oxidizer rich, but it contains OC and H. It can be used by itself. Well, this is also a single base propellant. We call it as a single explosive propellant or a single base propellant just like nitro cellulose which was fuel rich could be used this is slightly oxidizer rich and it could be used, but these are very (( )) used by themselves.

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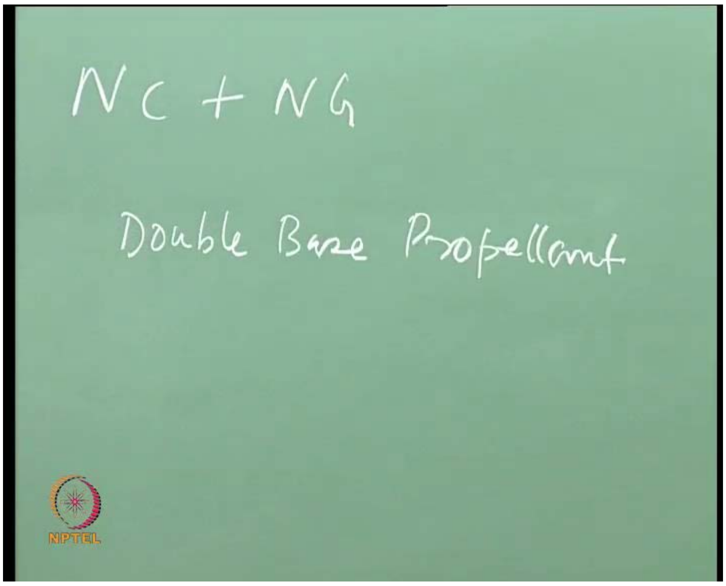


What is done is you mix nitrocellulose and nitroglycerin. That means you have constituents and this is what is known as a double base propellant. Therefore, the first solid propellant what we study would be let us put it down will be a double base propellant which is still used widely.

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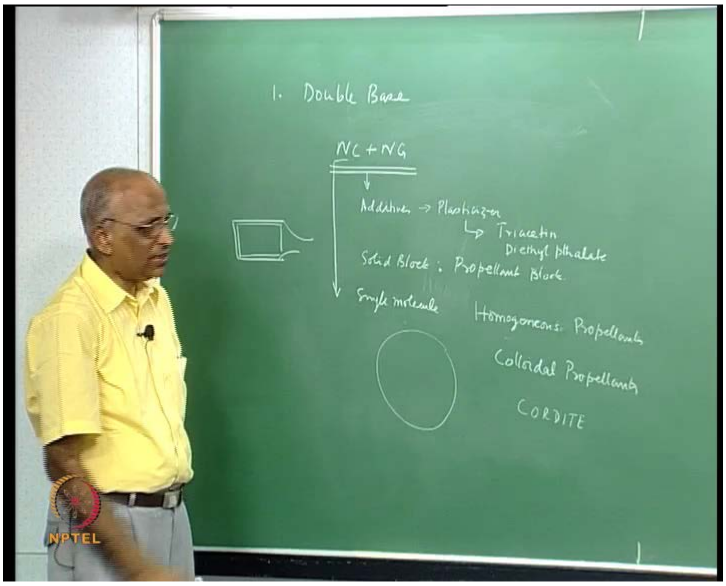


It consists of nitrocellulose and nitroglycerin. Nitrocellulose is fuel rich and nitroglycerin is slightly oxidizer rich and you get much better performance than if these values individually.

How do we make it? Well, we take nitrocellulose. We put nitroglycerin in it, make it as a colloidal solution and add some more additives to it. What are additives? You know whenever we make a propellant; it is just mixing the thing and forming some hard material because we want it as a solid. What do we add? We add some plasticizer, so that it becomes more plastic. We had something which will make it flow because I would like the two to mix together. We had some plasticizer. We took this small part of it, we make it into a liquid, we cure it, make it as a solid block and this solid block what we call as a propellant green or propellant block.

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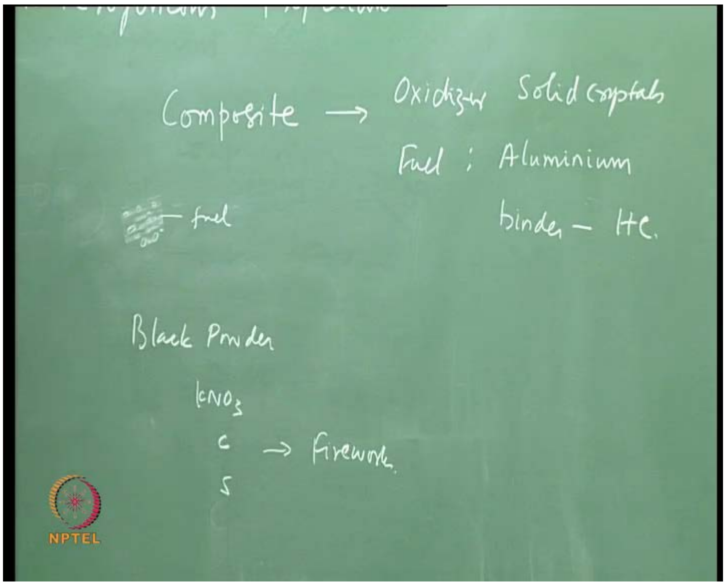


Let me put some names of the plasticizers which are added. You know just to make sure we are in the field. We had plasticizer. We will come back to this plasticizer a little bit. Plasticizers used are something like triacetin. See I do not like these names because some of us do not even know what it means and there is not much point in knowing or something like diethyl phthalate.

What do you mean by a plasticizer? You know something which makes it a little more plastic. That means it makes it little less sensitive to impact. You know something solid. When it is hit, it gets a spark. The plastic sort of observes this, but at the same time, it gives some more consistency to it and therefore, the first propellant we say consists of nitrocellulose and nitroglycerin with a small amount of plasticizer, such that I can make a solid block. This becomes nitrocellulose and nitroglycerin form a single molecule or it is mixed so perfectly that it is homogenous and the double base propellants are also called homogenous propellants.

The mixture is essentially something like a colloid. Colloid means you know you have suspension in liquid and therefore, this is also known as colloidal propellants. The trade name for a double base propellant. Propellant is cordite. We have a factory at Arvinkadu in Nillgiris, which specifically manufactures cordite propellant for use in defense and other purposes. Therefore, we say that the first one is we learnt about nitroglycerin nitrocellulose together.

Individually, these are single base propellants and together they form something known as a double base propellant because you have two bases and we also add some amount of trace quantities of plasticizer and some more additives to make sure that the final product which is formed as a block of solid fuel is something which is workable. I would like to machine, I would like to do something and that is what we will see when we study solid propellant rockets because you know if I want to make something, I want a block, I cannot. I need to have a fixed dimension. I would like to have a rocket in which this goes and I have to machine it. I have to make it length, so that to make it workable. I need to add certain things to it. I cure it and form it as a solid. Therefore, the first propellant we deal with is double base propellant and these are essentially nitrocellulose and nitroglycerin.

Let us go to the next type. There are only four types and out of which the second one what I am going to tell you now is something which is very widely used. Unlike a homogenous propellant, what is there? This is homogenous. That means every where it is exactly same. If I cut it, I cannot find out the difference creations or anything.

The second is what we call as heterogeneous propellant. This is also known as composite as distinct from these double base propellants which are uniformed, which are something like a single molecule or uniform throughout composites are very heterogeneous. What happens is you add oxidizer in a solid form, you add may be aluminum again as a fuel, perhaps not always aluminum and then, you glue it together using some particular fuel.

What do you mean? You know all of us have talked in terms of this black powder when we talked of the course in explosions. What was black powder? We had KNO3 which was ground, we had carbon which was ground and we had sulfur which is ground. We said we mix the three, put gum over it and make it as a paste and use it as something which is an explosive for fireworks.

So, also you take a composite which consists an oxidizer may be some fuel and may be the thing which is bonding together could act as a fuel. Therefore, a composite propellant will consist of an oxidizer which is something like a solid crystal, solid ground crystal. A fuel which could be aluminum. The same fuel could also be the binder which binds the solid crystals and aluminum together or it could be something like a hydrocarbon.

Therefore, as distinct from homogenous propellants or composite propellant consists of an oxidizer or fuel and this fuel could also be the thing which is gluing things together. Let us take some examples and this will become further clear to all of us. Let us see, what the type of oxidizers are we could use in a composite propellant.

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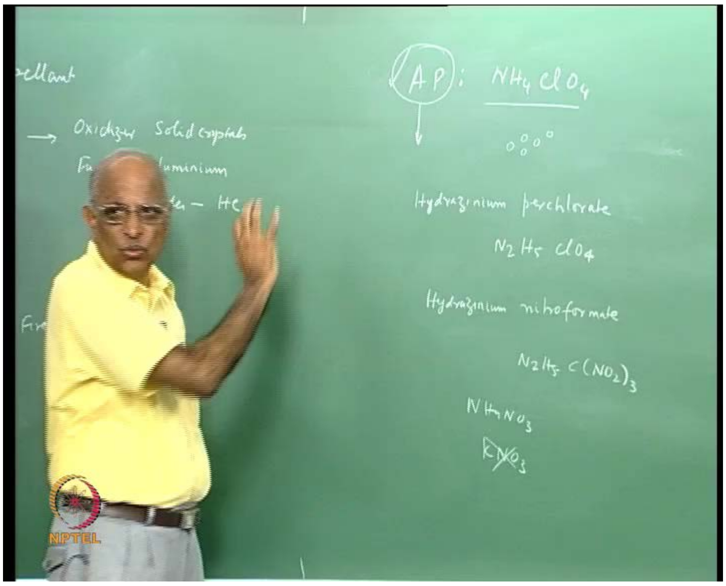


One of the oxidizer which is very widely used is ammonium perchlorate. We call it as AP which is NH4ClO4. Mind you, it consists of hydrogen, but amount of oxygen it contains is so high that it is still in oxidizer, may be NH4ClO4. May be you know this is why very widely used. It dissociates easily and it is not hydroscopic. It can be easily told, can be made as small particles and all that without any problem and that is why ammonium perchlorate is the most preferred choice of oxidizer for solid propellants.

We also have other things. We have still more energetic like hydrazinium perchlorate. Let me get the chemical formula of it correct. Yes, it should contain some hydrazine. That means it should be N2H5ClO4 and another one which is hydrazinium nitroformate and the formula for this will again be hydrazinium N2H5 into CNO2 three times. You know these two things are still something which had been investigated upon, but the only oxidizer which is widely used is still AP as it is we had things like coated AP instead of having the raw AP, such that it is more easily processable. We will come back to that point a little later.

Therefore, we say well, we could have choice of different types of oxidizers, but the oxidizer which is used we could use may be NH4NO3. It also contains, but it is hydroscopic. Not much energy we could in fact use KNO3, but again the k has a larger value of atomic mass and therefore, it is not a preferred fuel. Therefore, whatever be the oxidizer for a composite propellant, ultimately what is being used today is only ammonium perchlorate. These are about oxidizers for composite propellant. Let us take a look at the fuels which are possible and then, we will put that things together and see what is involved in a composite propellant.

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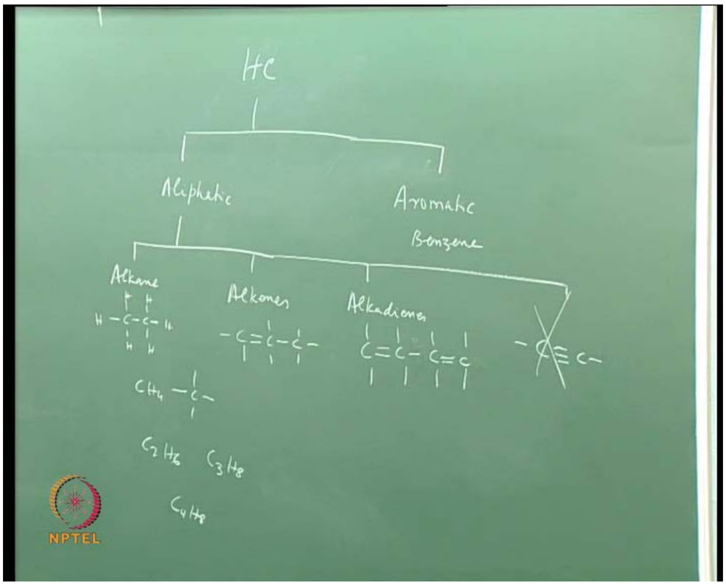


When we say fuel, I also told fuel could be a hydrocarbon fuel. Let us see what the different types of hydrocarbons are and how we use what hydrocarbon.

Let us start the hydrocarbon chain. We know hydrocarbons consist of aliphatic compounds and I think little bit of organic chemistry is always useful. Aeromatic, hydrocarbons aeromatic are those which have a strong smell. Why does the smell come? Because you have the benzene molecule in it whereas, hydro aliphatic compounds are either straight or poly chain compounds. This could be either saturated. We call it as alkenes.

What do you mean by saturated or straight chain compounds? Carbon chains are all straight over here. The second we said is alkenes one double bond, one double bond two in one, one double bond or the third one could be alkadienes which have two double bonds. May be something like. This two double bonds or rather I put a single bond here, I put a double bond here C4, yeah.

Now we could have single chain. We could have one double bond. All single bonds we could have one double bond which we call as alkenes. We could have two double bonds which we call alkadienes. We could also have one triple bond like acetylene C2H4. You know the triple bond is highly unstable acetylene is an explosive. Therefore, we cannot use such compounds. We are trying to find out how we choose a propellant and that is why I am going through this. If you have alkenes, well the example is methane CH4CH4 may be I have C2H6 ethane, C3H8 is propane. Mind you, all these are gasses. I cannot use the gasses anywhere, but there is a trend tendency today to liquefy the gasses like liquid methane, liquid propane and use it. We will come back at the end of this class.

Therefore, we say these are gasses are not so useful. How about butane? Butane is also a gas C4H8. Let us take the butane form of alkanes, alkenes and alkadiene. Let us put it together we said butane.

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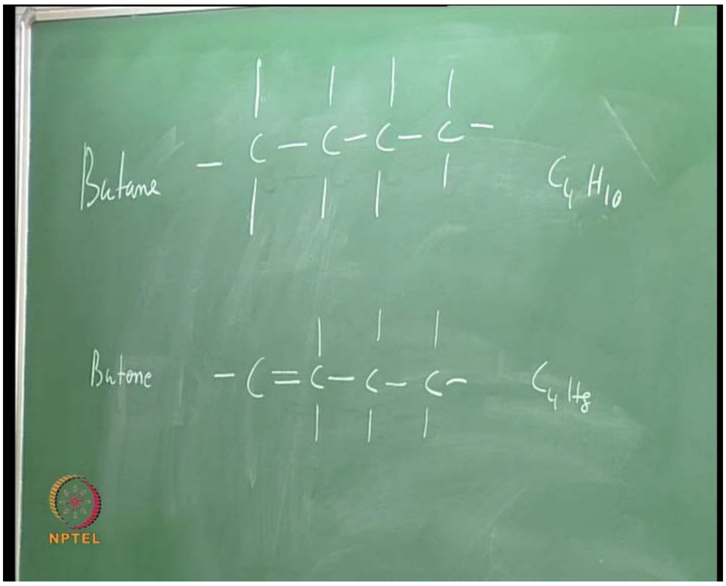


Formula is C4H10 1 2 3 4 5 6 7 8 9 10, formula is C4H10. This is butane. If I were to talk in terms of butane, mind you butane is a gas. Let us go to the next form. Well, I have double bond butane and of course, I will have all the change as it is 1 2 3 4 5 6 7 8 C4H8.

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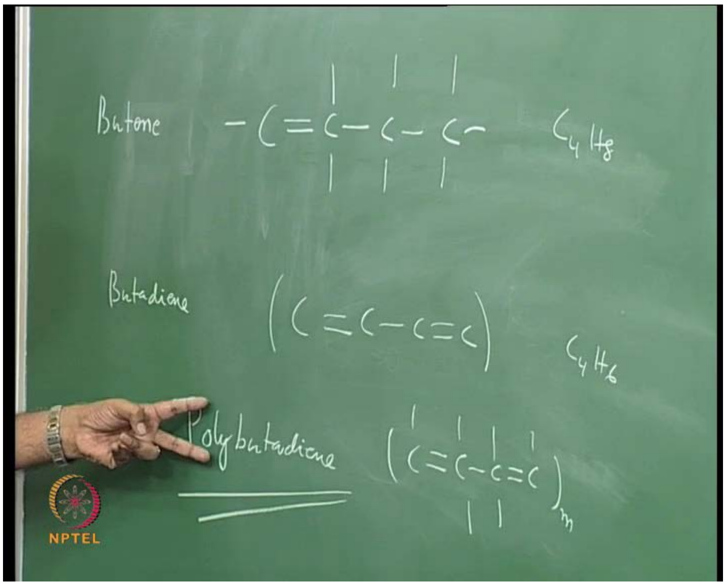


If I now have butadiene with two double bonds, well I have two double bonds and the formula will be C4H6 because I proportionally have decreased to the hydrogen.

Now amongst these all choices of these aliphatic compounds, what we are talking of between alkanes, alkenes and alkadienes? You know this structure is something which you do not lose so much of heat of formation. See another thing which I forgot to tell you was we found that the heat of formation of methane was small negative value. The heat of formation keeps increasing and therefore, very complex substances were not desirable, but alkadiene we do not use much. Therefore, what we use is something like a poly butadiene.

What is poly butadiene? I take a butadiene molecule and I keep on making it into a chain and this is something which is very widely used as a fuel, but poly butadiene is just carbon with may be the hydrogen over here is what I get and to be able to form a good fuel out of poly butadiene, what I do now. I come to the actual fuel which we can use or the binding agent. I want to make it into a good polymer something which has a long chain which can keep the oxidizer particles in it.

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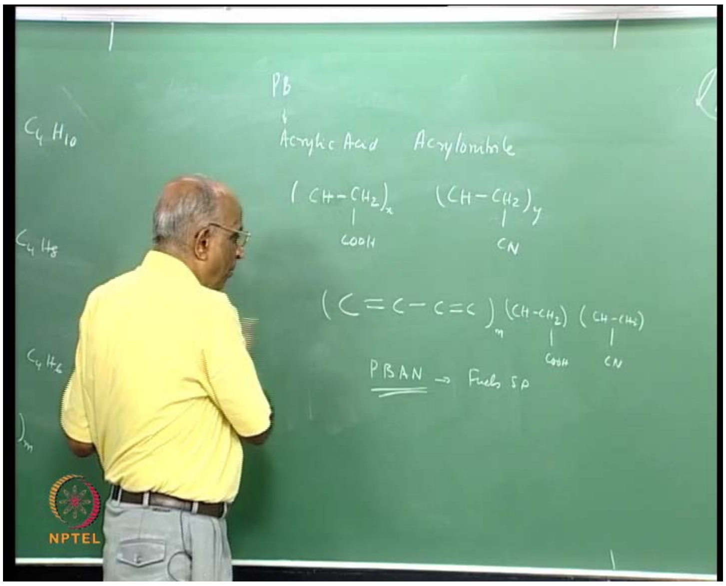


Therefore, I take these poly butadiene whose structure I have just given. May be you know this is something which is a chain or a chain is something which is elastic. It will keep on pulling. I need to make it a little strong, so as that it can hold things together. Therefore, I add something like acrylic acid or else I also may be acrylonitrile.

What is acrylic acid? I have CHCH2 giving cargo axial acid CH. This is may be x times. This is what acrylic acid is. Similarly, acrylonitrile is CHCH2. May be y of CN acrylonitrile. What is it? I do have this chain of poly butane. C C C is a polybutane in molecule m at the end of the chain. I put an acrylic acid CHCH2 COOH may be a few of them, then I put something like CHCH2 and I have CNO over here. What does this do? It gives something like a chain. It is not only a chain, but it is able to go in the lateral direction. It gives some rigidity and therefore, I have something which is known as poly butadiene acrylic acid acrylonitrile.

That means, I put the acrylonitrile and acrylic acid together. I call this as PBAN poly butadiene acrylic acid acrylonitrile and this is one of the fuels which are used for solid propellants. You all would have read somewhere. Yes, PBAN is used. PBAN is used in the space shuttle in huge motors. Why it is used? It is possible to make it as a binder and it is possible to have the rubber part of it to have some more hardness and strength and that is how you use the poly butadiene.

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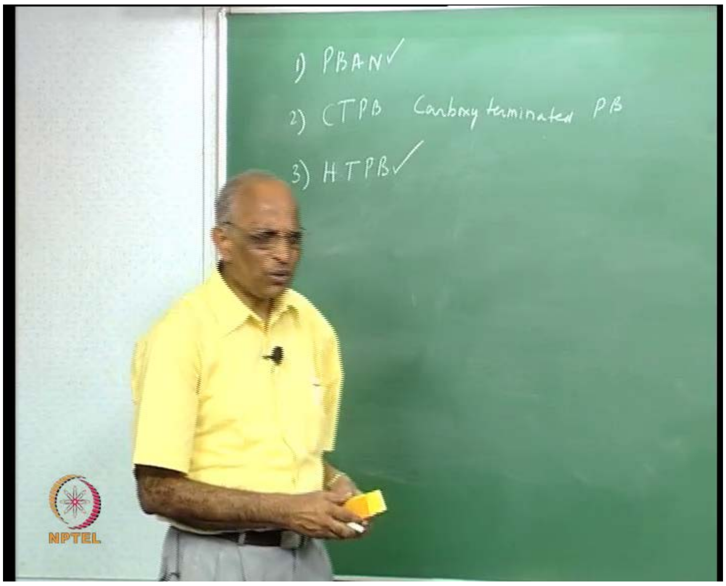


Therefore, we say well the first fuel which I think in terms of using for the solid propellant is poly butadiene acrylic acid acrylonitrile which I call as PBAN. See we know PBAN is something which is sometimes hard. You know I have the cross linking. By all these things, it tends to be hard and second is I have lot of carbon here. You know carbon has a heavy mass and therefore, is it possible to somehow get rid of nitrogen here. Just substitute it by the carboxylic acid namely, the acid part of it. That means, I terminate the poly butadiene with a carboxylic acid type of situation and this is known as CTB CTPB. That means carboxy terminated poly butadiene. That is the second fuel.

There are not many, just some two-three of them. You know all what we have done is we remove the acrylonitrile part of it, keep the carboxyl acid here and stop the chain here. May be it gives little better properties and little more energy than a PBAN propellant, but the choice for major booster today is still PBAN. We see whether some improvements are possible.

The question is why not have a poly butadiene in which I do not terminate it with everything, but I just put something like OH here. I put OH here. In other words, I have hydroxyl radicals which are used at the ends of the chain of this and now, I have the other of poly butadiene C C C again. May be N again something like OH. I keep on terminating at the end of the chain, I put hydroxyl radical and I call it as three hydroxyl terminated poly butadiene.

The advantage of using OH is hydrogen is available. It is much stronger and it is more energetic. Therefore, the most popular propellant today or most popular fuel for propellant is HTPB. The reason being is little more energetic, but for boosters, for large boosters, I still find PBAN continuing to be used. Well, the most popular fuels are PBAN and HTP today and I think we must keep the reasons very clear. Yes, this is more energetic because it contains H compared to C and N or C and are not there anymore, but basically we have the poly butadiene chain which is terminating in these type of chains over here. These are the type of fuels what we use.

In fact, HTBPB is very widely used in the tyre industry and it is also melting like rubbery material which is used in the tyre industry, but for propellants, it is something very much useful. There are one or two exotic chemicals which are being talked of us. Fuels, I think we should get some names of them.

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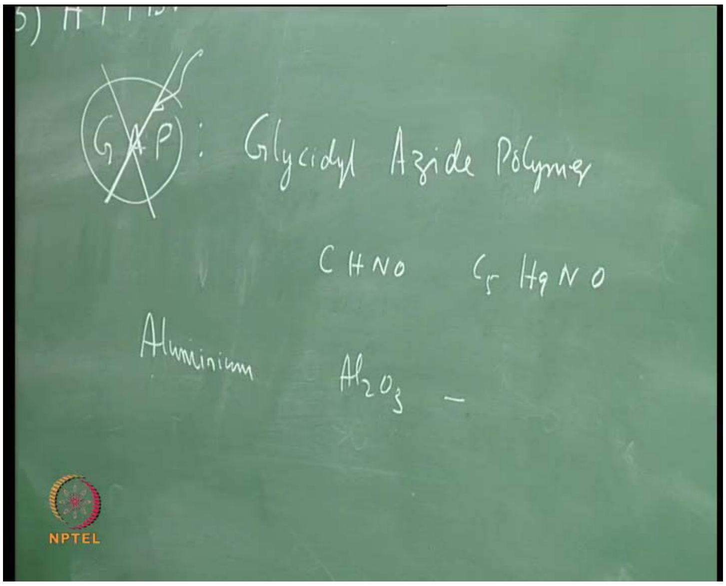


We talked in terms of some fuel which is being talked of. Nowadays, we call it as gap which is known as Glycidyl Azide Polymer and this has a formula something like CHNO. In different proportions, it has been tried something like C5H9, then NO and stuff like that, but I will not get into these molecular formula, but we must keep in mind that GAP contains little more hydrogen than even H2PB. Some results towards is going on using gap as propellant is still not used, but there is some work going on and I think as people who are doing post graduate, we must know what is the current line of research. The current line of research is to increase the energy content. How do you increase the energy content? Have more hydrogen like a hydroxyl terminated poly butadiene.

Therefore, what is it we said well oxidizers for composite propellant could be AP. The fuels could be something like this. Well, we could add aluminum powder. What is the advantage of aluminum powder? It could form Al2O3 in the exhaust product. We said Al2O3 has a very large negative value of heat of formation and I could get the energy from aluminum.

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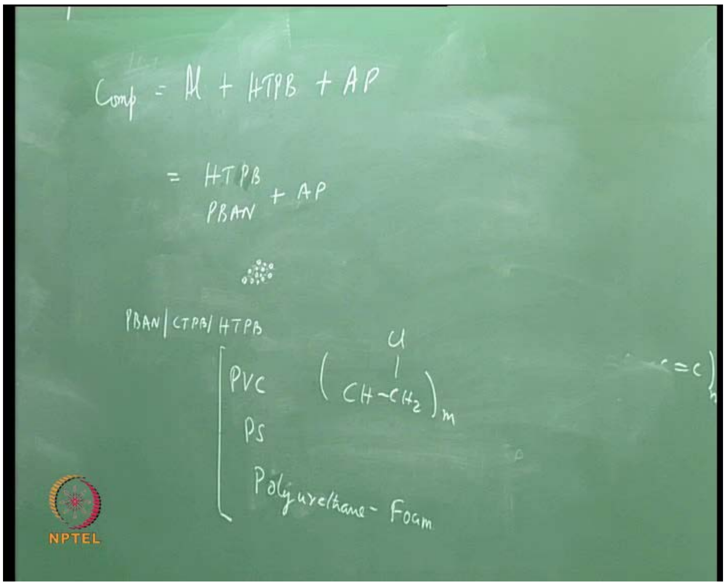


Therefore, a composite propellant basically consists of these three. May be an aluminum powder which we said is a fuel. It could consists of a binder, may be let us take HTPB as a fuel. It is also used for binding aluminum and AP crystals. This is what a composite propellant is.

You know it is non-aluminum. It could still consists of HTPB or it could consists of may be CTPB or PBAN plus ammonium perchlorate. These are what are called as composite because ammonium perchlorate comes as crystals, small spheres, or particles and this you burn together using the binder over here. This is a non-AP, non-aluminum propellant. If I still put aluminum powder in it, well I get this particular composite propellant. These are the composite propellant.

So, whenever I talk of composite propellants, I have in mind something like a polymer, I have in mind something like ammonium per chlorate and may be some metals. It may not always have a metal. If you want more energy, I put a metal and in difference very often if I put metal and I see a rocket going up. You know I get lot of high temperature exhaust and that is something which is seeable. Radar can see it and therefore, they try to use either a double base or some other form of propellants which does not have that signature. We will take a look at some of their requirements.

In the past, instead of PBAN or CTPB, see we must be able to distinguish how these things come, may be HTPB. They need use of polyvinyl chloride PVC. What is PVC? It consists of CHCH2 with Cl in a large chain, but these are very low. Nowadays, it is just not used. People tried poly sulphide, people tried foam which is poly urethane. Let us write it out. Poly urethane is just like the foam what you use in your matrix. These have been tried, but these are all very low energy fuels and therefore, it is not used anymore. What is used is an essentially HTPB PBAN and to a certain extent CTBP which is used and these are the different types of composite propellants.

Therefore, we tell ourselves well the second form of propellant is a composite propellant and it consists of a composite of oxidizer particles. May be metal particles like aluminum and a binder or a polymer which connects all of them together.

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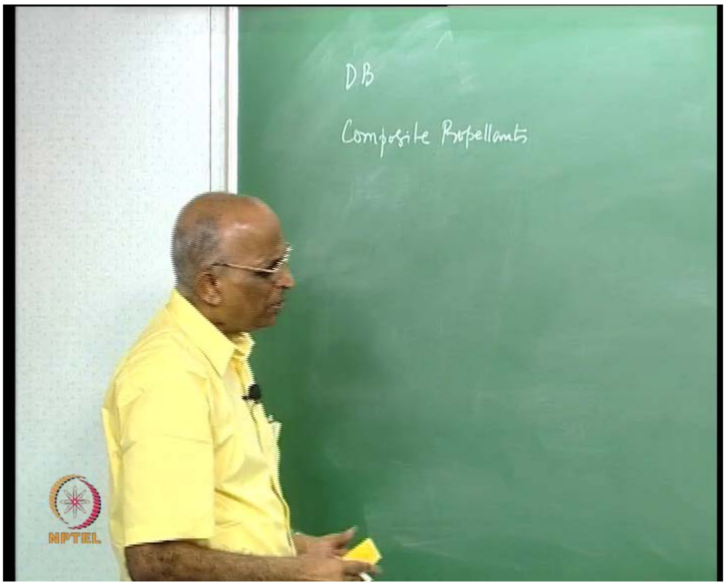

Therefore, we talk in terms of double base propellants. Second, we talk in terms of, but there is something in this you know.

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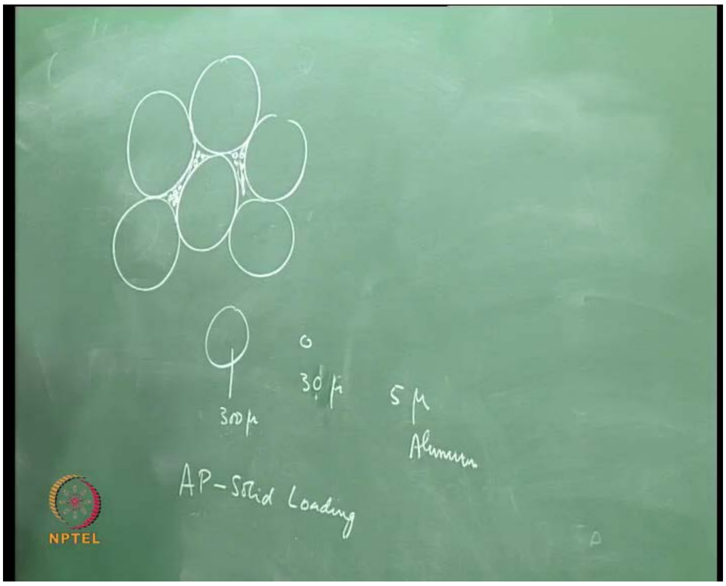


See the problem is I have oxidizer. Let us say, I have spherical oxidizer particles. I have AP like this, like this, like this. If I have a single size of AP, the amount of AP I can put together will be small whereas, if I can have double sizes, let us say I have AP size of let say 3000 microns. Then, if I try to fill with AP and I have binder which binds all these things together, it is going to bind it like this. Here I have polymer, here I have polymer. You know what happens is the amount of AP which I can put in the propellant is small. We call it as AP or solid which is a solid loading in a propellant.

Now, instead of having 3000 micron size, if I make AP of two sizes mainly, I make 3000 micron size and another one I put 3 micron size or let us say 30 micron size. 3 is very small. Then, what is happening is the small particles can be put over here. That means, I can increase loading of AP in the propellant. Therefore, in almost all the propellant composite propellants we use today, we just do not use a single size of AP, but we use by model size typically between 3000 and 30 microns. Why it is used? I want to increase the amount of AP as much as possible and when we use aluminum; aluminium is even smaller size, typically around 5 micron size of aluminum.

Why aluminum? Aluminium is again a solid. I can improve the loading of solid and therefore, I can have a dense propellant as it were and this is all about composite propellants. Well, the other two propellants in solids are derived from these two, we say composite modified double base. We have already seen double base propellant is nitrocellulose and nitroglycerin.

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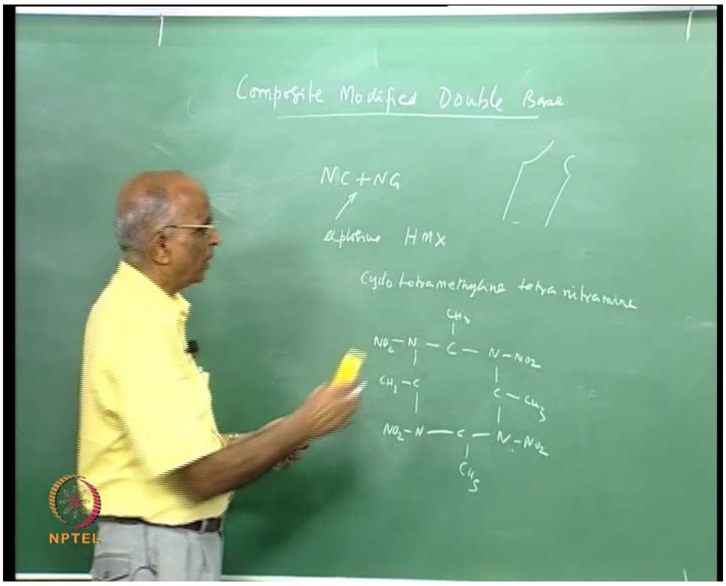


Supposing, I want to increase its energetic, increase the reaction and energy release, that is add oxidizer ammonium perchlorate used in composite to double base propellants and make it more oxidizer rich. I could also add explosive to enhance the energy and the explosive I add is something like an explosive known as HMX. What is an explosive? It consists of fuel and oxidizer together. This HMX consists of something like cyclo tetra methylene tetra nitramine.

You know HMX stands for her majesties explosive because it came from UK and the chain is may be C. You have N here, you have C here, you have N here, you have C at this end, N here, you have C here, N over here and then, you have the methylene radical may be CH3 and you have NNO2. This is just an explosive and I do not think we should spend much time on it. All what you do is you add a HMX to small quantities of this. It becomes composite of a double base and this particular HMX explosive and this is known as composite modified double base propellant.

It is used widely in the defense because they would like to have their missiles which are more energetic than double base propellant or they would like to have properties of the propellant which can be readily formulated. It can withstand some amount of strength because a propellant must also have some strength because it is bonded to the case and it must not get detached from the case or it must not double up cracks and all that. That is why we find composite modified double base propellant. We will call it as CMPB.

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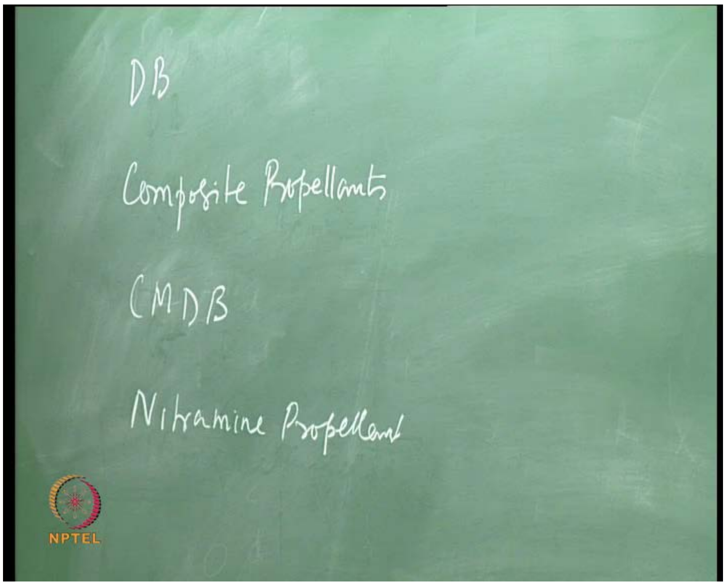


Therefore, the third propellant we say is a mixture of a double base and an explosive. The last type of solid propellant is what we call as nitramine propellant. You know all these propellants have distinct characteristics. You know why? MDB, it will have a burn rate with pressure having something else. We will consider this when we study the solid propellant. We are just trying to take a look at what are the chemicals which constitute the different propellants and what are the different solid propellants what are available.

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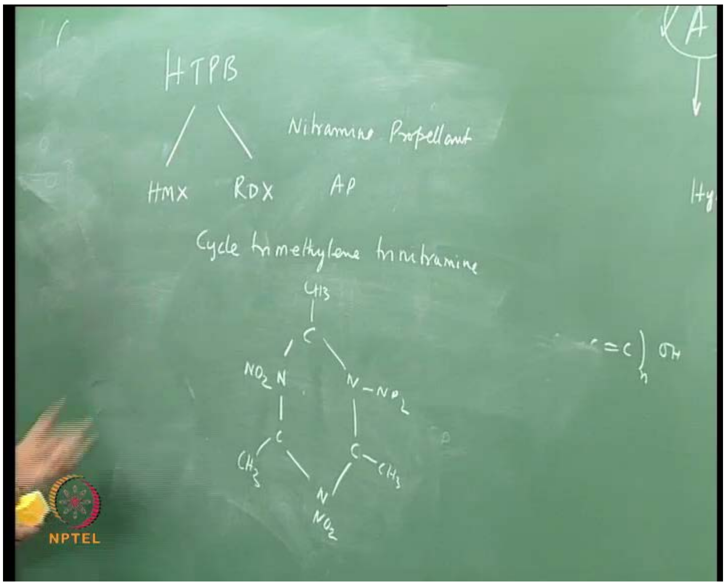


When I say nitramine propellant, we have a binder like HTPB which is a polymer into the polymer, let us say HTPB. You add something like HMX which is an explosive or a slightly less energetic explosive is something which we call as cyclo tri methylene tri nitramine. What is the difference in structure? It is tri therefore, you have CNCNCN going to C, you have CH3, three of them NNO2.

Therefore, you put an explosive into the HTPB binder and that what you get is something which we call as a nitramine propellant. What is the advantage? See HMX is fuel rich, HTPB is fuel rich, therefore what happens is you do not get high temperature, but it is able to generate gas at low temperature and still propel your vehicle. Therefore, any enemy cannot see that a vehicle is going up because he uses radar to see the temperature of the film. Therefore, each one has his own advantages plus the burning rate will change. I will look at it when I consider solid propellant rocket.

In addition to adding HMX, this particular thing is what is known as RDX research and development explosive which cyclo tri methylene nitramine is. You add almost 80 to 85 percent of these explosives. One of these explosives to HTPB and that is what is known as a nitramine propellant. Off late I find AP is also being added to this and this is also called as AP plus HMX or RDX and HTPB is also what constitutes the nitramine propellant.

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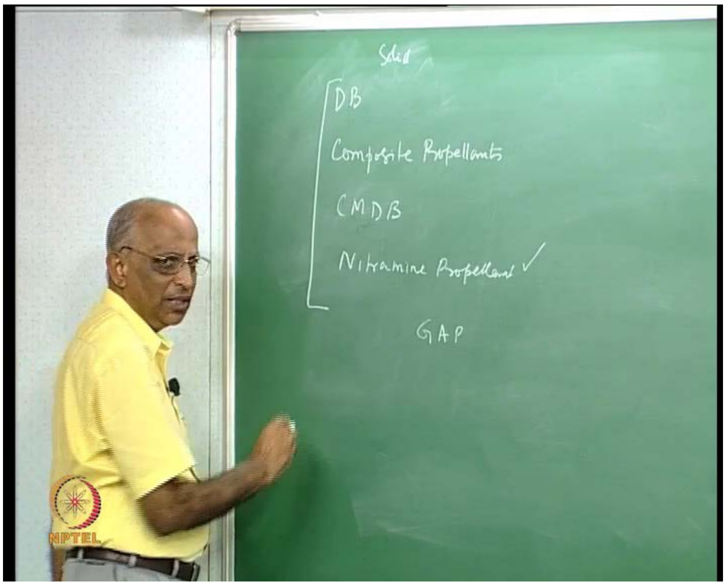


You know actually the research which goes on in the area of propellants is maybe you have something known as glycidyl azide polymer and these things have more hydrogen and something like a fuel like gap. You add HMX RDX and it could not therefore be only HTPB, but glycidyl polymer which could also be used instead of a fuel, I think will not get into some of these things. Glycidyl is again something like a CHNO system.

We will not get into too much of this because our main concentration could be the composites, may be the double base propellants. How they burn and how they are developed. Therefore, we say solid propellants essentially consists of double base composite, composite modified double base and nitramine propellants. We will look at the characteristics when we study the solid propellant rockets.

Having said that, let us go to liquid propellants. They are extremely simple, much simpler than what we talked in terms of solid, solid chemicals and they are classified in a slightly different way. We do not classify them into four such categories.

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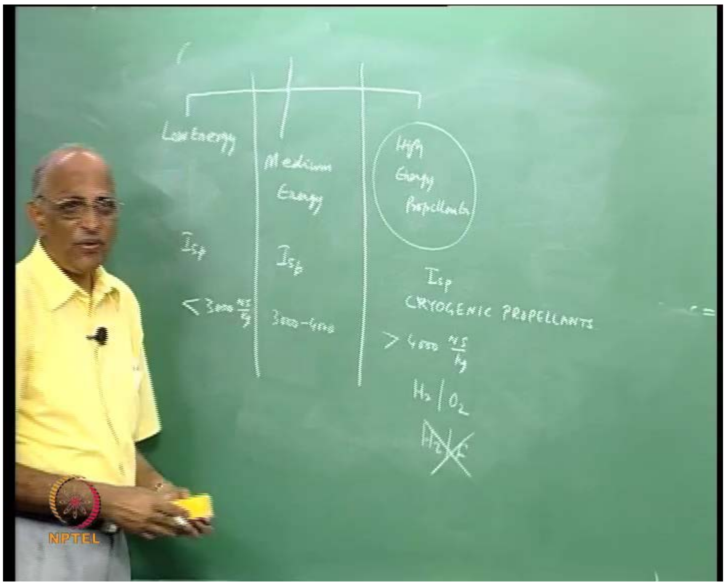


We just say liquid propellants are categorized into three categories. We call it as low energy propellants, medium energy propellants and we call it as high energy propellants.

May be by now you all can tell me which will be high energy and low energy. Energy is a misnomer in rocketry because it is not only energy which is important, but a low molecular mass is also important. Therefore, we told ourselves hydrogen oxygen as a low molecular mass, even though the energy may not be high and therefore, when we say high energy propellants, we always mean high I s p propellants, medium I s p propellants and low I s p propellants. Propellants which have sea level I s p less than 3000 Newton second by kilogram are known as low energy propellants, which are between 3000 to 4000 are known as medium energy propellants and those in excess of 4000 Newton second by kilogram are known as high energy propellants.

We immediately tell ourselves, well hydrogen oxygen is by far the best and therefore, the high energy propellants are hydrogen and oxygen. Perhaps hydrogen and chlorine also good. Yes, it is even more energetic, but chlorine is highly reactive and therefore, it was tried in one machine and dropped, but hydrogen and oxygen cannot be used as room temperature gasses. It has to be liquified and they are all very low temperature. Hydrogen at 20 Calvin, oxygen at 80 Calvin being low temperature. We call these propellants high energy propellants as cryogenic because it has to be kept under refrigerated conditions call it as cryogenic propellants.

Therefore, if I want to make a missile, I cannot use a cryogenic propellant because a missile must be ready for launch any time. We cannot wait for a war. Enemy can strike at any time. Therefore, it is not possible. Therefore, these cryogenic propellants are normally used for launch vehicles which you can fill as you want. You can do what you want. You have all the time in the world, but if you want to have something which can go fast may be let us take a look at some of the low energy propellants and then, come back to the medium energy.

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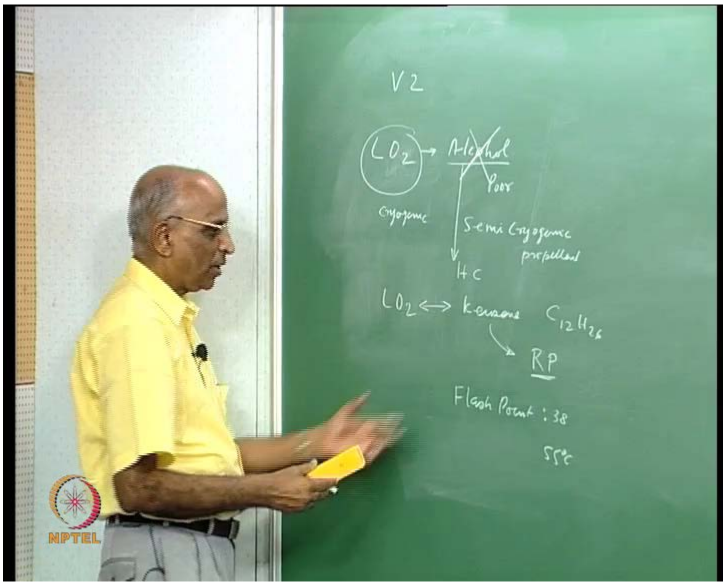


What are low energy? Low energy we said those which have specific impulses less than 3000. Let us put a few of them together. Well, you know all of us had have read of V 2 rocket which was the first rocket ever made and it was by the Germans in around 1945 during the second world war. It use liquid oxygen and alcohol. Alcohol is something like may be some ethyl alcohol and ethane is C2H4 C2H6. May be you remove some of the H and put OH. You have ethyl alcohol, some alcohol at this was done, but it is very poor performing, very low in specific impulse, but liquid oxygen is something which is a cryogenic liquid, alcohol is liquid at room temperature.

Therefore, you have a cryogenic with a room temperature fuel and therefore, this combination will be a semi. It is not totally cryogenic, but a semi-cryogenic propellant alcohol has poor properties. Why does it have poor properties? It contains oxygen also because you have OH. That means it is not a good fuel. Why not use a better fuel like hydrogen carbon? Why not use kerosene? Kerosene has molecular formulas something like $C_{12}H_{26}$ linear chain. No, oxygen. It is a much better fuel and therefore, the present trend is used semi cryogenics consisting of liquid oxygen and kerosene together, but kerosene as it is you know, it has something like it can evaporate quite fast. It is little volatile. You would like to make it suitable for rocket and the kerosene which is slightly modified by additives is what is known as a rocket propellant.

Therefore, kerosene has been extensively used in rockets. It is also known as rocket propellant. It is little different from the pure kerosene. In that I have to put something more. What are the things? Flash point of kerosene is around 38 degrees, but you would like to increase it to something like 55 degrees. Therefore, you put some more additives in it and you increase the flash point. You make sure it does not gel or it does not form sediments and all that. That is known as a rocket propellant. Kerosene is also called as rocket propellant and it is used with liquid oxygen and the values of specific impulse are not very high of the order of 3000 Newton second per kilogram. Therefore, it is one of the low energy propellants.

It has now no longer had alcohol used, but we use liquid oxygen with kerosene. It is a rocket propellant, but unfortunately there are some problems with kerosene. See kerosene is not a pure chemical. You know I go and take petroleum from some, well some petroleum might contain some more (( )), some may contain more paraffin and depending on that the thing changes.

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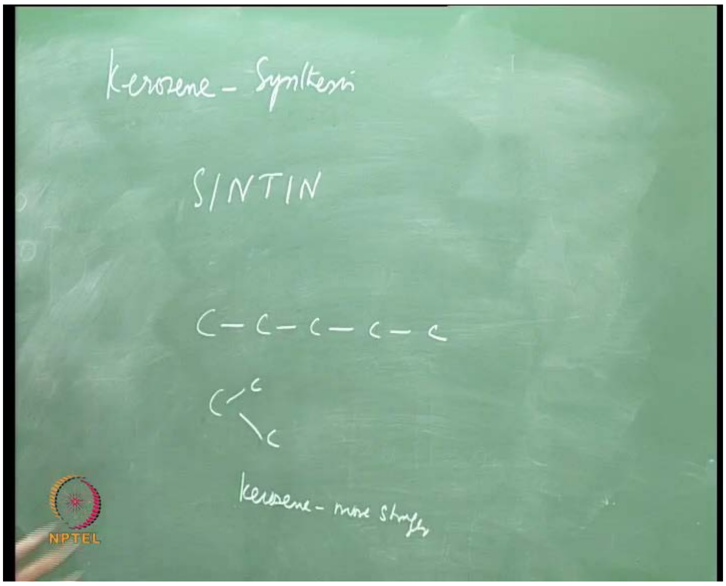


Therefore, people tend to get kerosene to be synthesized to be kerosene in the lamp and the Russians have done it. It is known as SINTIN, but SINTIN is costly. It is made from carbon and hydrogen at high pressure in the lab. It is not very widely used, but it is used by the Russians. What we use is yes, we should have some control on it and we say rocket propellant is something like kerosene, almost kerosene, but with some additives added to it.

You know the work which goes on in these fuels is we tell ourselves, well kerosene might be like this. If I can strain the molecule, if I can make C like this and strain the molecule, I can put some more energy into it. That means I add, I change the bond characteristics, I can make kerosene to be more stronger or to be more even more energetic and work is going on how to put energy through the bonds and all that. We will not consider that, but we will (( )) to say that one of the liquid propellants used is may be liquid oxygen and kerosene.

Maybe there are a few more. I will go through it in the next class, but what I did in today's class is we looked at solid propellant, we classified them into four categories, we started with liquid propellants and we saw the high performance propellants being liquid, oxygen and liquid hydrogen. Then, we were just started in low energy propellants and maybe, we continue with this in the next class. Well, thank you then.